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The passenger's influence on dwell times at station platforms: a literature review

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ABSTRACT

Dwell time delays, although small in nature, can accumulate to a large delay over the entire journey of a train. It is, however, difficult to precisely know the amount of time which is required at stations due to the inherent variance in human behaviour. Furthermore, planning practices do not seem to capture the dynamic nature of the dwell time process. The current literature review focusses on the influence that passengers have on the length and variance of dwell times at stations. More specifically, this study focusses on the underlying causes for the distribution of passengers along a platform while waiting for the train to arrive at the station and their behaviour during the boarding and alighting process. As part of this review, two databases were systematically searched, and backwards snowballing techniques were applied. To ensure the quality of the included literature, a systematic quality appraisal was carried out. The findings show that measures related to platform management and changes to train operations have the potential to play a substantial role in reducing the variance in dwell times, as well as improvements in the provision of information to travellers. Such measures also allow for a more solution-oriented approach. However, the actual benefits of such measures need further studying. The findings also show that the distribution of passengers and the behaviour of passengers during the boarding and alighting process are connected and should thus be addressed as a whole rather than separate aspects. The majority of the studies included in this review did, however, not focus on both elements in conjunction. There is thus a need for future studies into the effect of platform management measures where efforts must be made to better understand the impact of measures on both the behaviour and distribution of passengers.

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Introduction

Railway systems consist of a plethora of moving parts that interact with one another. The timetable is the backbone in this system as it is the means of communication

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between the different actors (Goverde, 2005), defining the location and directions of trains at a given point in time, as well as providing passengers with the information on when trains run. A large and growing body of literature has investigated the timetabling process. An important aspect of forming a robust timetable is to include realistic and appropriate times for each process of the journey (Hansen, 2010). One of the processes which influence the train service is the *dwell time* of a train, i.e. the time a train is stationary at a station. Large variations in dwell times reduce the robustness of train operations (van den Heuvel, 2016), and although dwell time delays at a single station might be small, the cumulative dwell time delays over an entire train run can amount to a large portion of the journey time (Christoforou, Chandakas, & Kaparias, 2020). Dwell time planning is, however, mostly based on generalised assumptions (Christoforou et al., 2020; Palmqvist, 2019). Wiggenraad (2001) mentioned that dwell times in the Netherlands were only scheduled for stops at intercity stations, and are the same for peak and off-peak hours, and dwell times at smaller stations are part of the running times. Similar remarks are made by Palmqvist (2019) for the Swedish context.

A static approach to dwell time planning results in actual dwell times exceeding planned dwell times considerably and regularly (Goverde, Hansen, Hooghiemstra, & Lopuhaa, 2001; Hansen, 2010; Nash, Weidmann, Bollinger, Luethi, & Buchmueller, 2006; Nie & Hansen, 2005; Palmqvist, Tomii, & Ochiai, 2020; Wiggenraad, 2001). It is, however, hard to precisely know the amount of time which is required at station stops (Palmqvist, 2019), and delays as a result of dwell times are not well understood since they are poorly recorded (Harris, Mjøsund, & Haugland, 2013), subject to high variability, and hard to predict (Cornet, Buisson, Ramond, Bouvarel, & Rodriguez, 2019). Dwell time itself is stated to consist of two major elements, one being the processes with a fixed length of time and the other being processes with a variable length of time (Seriani, Fernandez, Luangboriboon, & Fujiyama, 2019). Fixed processes are limited by technical features of a train and can be considered to have a relatively fixed time usage. The variable processes include the exchange of passengers and the time which is needed for this process varies due to the inherent variance in behaviour of passengers (Antognoli, Girolami, Ricci, & Rizzetto, 2018). There seems to be somewhat of a consensus about the effect of passengers on dwell times, which is captured within the *passenger flow*. According to a conceptual model of dwell time by Li, Daamen, and Goverde (2016), the passenger flow is influenced by the design of the rolling stock, such as the number of doors and their width, and the number of passengers and their characteristics.

The relationship between the design of rolling stock and dwell times have been studied in a range of settings (Atkins, 2004; Coxon, Bono, & Napper, 2009; Holloway et al., 2015; Su et al., 2019; Thoreau et al., 2016; Tuna, 2008). The relationship between dwell time and onboard passengers and passenger characteristics has received attention in the past as well (Berkovich, Lu, Levine, & Reddy, 2013; Daamen, Lee, & Wiggenraad, 2008; Heinz, 2003; Hirsch & Thompson, 2014; Holloway et al., 2015; Rowe & Tyler, 2012; Sutton & Moncrieff, 2015). Although these lists of previous studies are not exhaustive, they show that there is a sizable body of literature on the effect of rolling stock design and passenger characteristics on dwell times. However, the product life cycle of rolling stock spans multiple decades (Harris, 2005) and extensive changes to platform design and rolling stock, such as wider doors, for example, are not easily made. Furthermore, as Harris and Anderson (2007) state, passenger behaviour is also a potentially influential factor on the benefit of changes to rolling stock and platform design. In addition, Olsson and Haugland (2004) mention that the management of boarding and alighting passengers is a key factor to punctuality in congested areas. This suggests that there is a value to further understand the influence of boarding and alighting passengers on dwell times both before and during the boarding and alighting process in order to define potential measures to reduce the variance in dwell times at stations.

Aim of the study

The starting point of this study is to understand what is happening at station platforms with regards to passenger behaviour and how this affects dwell times. This is done to illustrate which measures have the potential to reduce the variance in dwell times as a result of passenger behaviour. The aim of this study is, therefore, to present the manner in which passengers affect dwell times, both before and during the boarding and alighting process, and the underlying causes hereof. By understanding these underlying causes, an attempt is made to illustrate whether measures besides adaptations to rolling stock have the potential to be effective in reducing the dynamic impact of passengers on dwell times.

Research method

The current study made use of a protocol based on the eight steps to conduct a structured literature review described by Denyer and Pilbeam (2013). These steps are illustrated in Figure 1. The first step of *mapping the field* consists of gaining an understanding of the descriptions of dwell time, for which literature provided by experts was used. The databases used for the literature search are Scopus and Science Direct (searched through the Lund University library search portal). One of the difficulties during the database search was the inconsistent use of terminology by different researchers, meaning that some relevant papers could be missed. The *backwards snowballing method*, as described by Jalali and Wohlin (2012), was applied to the included studies to somewhat mitigate this problem.

The literature search took place in March 2020 and keywords related to *passenger distribution* and *boarding and alighting behaviour* were used to search the databases, these keywords were combined with additional phrases such as *station* and *platform* to narrow down the results. This choice and phrasing of these keywords was based on preliminary findings whilst mapping the field. The time period is limited to publications between

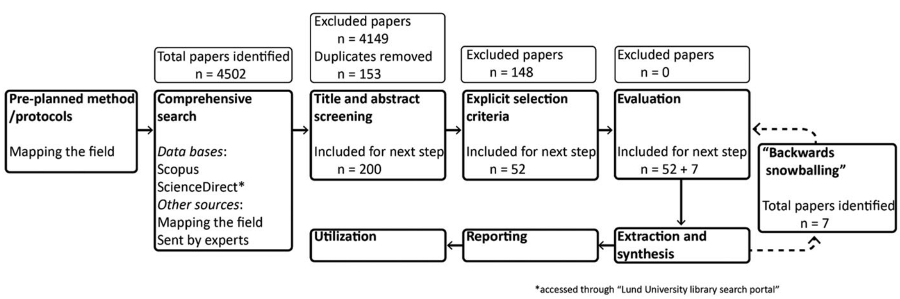

Figure 1. Process of literature review. Adapted from Denyer and Pilbeam (2013).

January 2000 and March 2020. Papers were excluded when the study provided a model without elaborating on passenger characteristics, used fixed boarding and alighting times, focused on busses, or focused on dwell times solely from a timetable perspective. The location where a study took place was added as an additional criterion for studies focussing on passenger flow characteristics. This was done since this study focusses on behaviour in a European context. Walking characteristics and the space maintained between pedestrians are not similar between all cultures, however, North American and European passenger flow characteristics are relatively similar (Daamen, 2004). The studies explicitly focussing on passenger flow characteristics were, therefore, limited to studies from Europe and North America. The *critical appraisal tool for evidence-based librarianship* (Glynn, 2006) was used to evaluate the included papers. It was important to evaluate papers in a structured manner since the literature was not limited to peer-reviewed journal papers. Studies were classified as having either a *good* or *questionable* quality. Studies classified as questionable were re-examined at a later moment before a choice was made to include or exclude these studies.

A total of 59 studies were included in this study. A relatively large number of studies was excluded during full-text screening due to either not being able to access the full-text version of the paper, or the full text not meeting the inclusion criteria. The included studies mostly focus on commuter rail and metro services. These services differ from long-distance trains as they do not offer seat reservation and attract different types of travellers, for example, which can influence the behaviour of passengers. The outcome of the quality assessment shows that the quality of 66% (n=39) of the studies is considered "good", versus 34% (n=20) studies which are "questionable". The latter group was re-examined, and none of these studies was excluded. The main reason for the low-quality score was found to be a lack of detail in the description of the research methods and the inclusion of an ethical approval statement when deemed necessary. The overall quality of the findings was deemed to be sufficient, however.

The following sections describe the behaviour shown by passengers during the boarding and alighting process and how this has an impact on dwell times. This is followed by a section on the underlying causes of the distribution of passengers on station platforms and how this affects dwell times, and a section on potential measures.

Boarding and alighting behaviour

One of the more visible ways in which passenger behaviour influences dwell time duration happens when a passenger tries to board a train while the boarding process is near completion. Passengers who run to catch the train may resort to *door holding/forcing* (Karekla & Tyler, 2012). Coxon and Bono (2010) mention several reasons for door holding such as passengers trying to "squeeze" into an already full train and passengers on-board hold doors for late-arriving passengers. Harris (2015), studying station stop delays in Oslo, Munich, and London, states that dwell times can be extended by 1–13 s when passengers hold the doors of the train open. Dwell times are further extended when the closing procedure has to be reinitiated (Harris et al., 2013; Harris, Risan, & Schrader, 2014b). *Excessive service* by staff members such as helping passengers with reduced mobility board (Coxon & Bono, 2010) or holding the doors for late-arriving passengers, although be it with the best intentions, extends dwell times as well (Harris, 2015).

Observations in Oslo show the mean delay due to excessive passenger service is 25 s. Door holding is more present when late-arriving passengers can see the train doors (Hyun, Ko, & Robinson, 2016), and during rush hours. Lindfeldt (2017) interviewed train conductors in Stockholm and found that door holding occurs at as much as 60% of the stops during rush hour. This indicates that door holding can be considered as a serious issue during peak hours and that, although only a limited number of passengers is involved, the impact on dwell times is large.

The other situations in which passenger behaviour influences the duration of dwell times occur when a group of passengers is already waiting on the platform when the train arrives, also known as *clustered boarding*. Li et al. (2016), in their conceptual model of dwell time, state that boarding and alighting rates are influenced by the number of passengers. Harris and Anderson (2007) mention that passenger movement rates are typically in the range of 1 passenger per door per second. However, the researchers also state that this is situation-specific. A study by Harris (2005) revealed that the relationship between the number of passengers and dwell times is not linear, however. Harris, Graham, Anderson, and Li (2014a) state that the range of alighting rates is as large as 0.4 and 2.6 passengers per second and boarding rates between 0.3 and 2.1 passengers per second. Observations made in Switzerland by Gysin (2018) show that the relationship between passenger numbers and dwell time can even differ between platforms at a single station, serviced by the same type of trains. In addition, Fernández, Valencia, and Seriani (2015) and Thoreau et al. (2016) mention that passenger movement rates even change during the boarding and alighting process itself. Harris (2005) provides three possible reasons for the difference in boarding and alighting rates. The first reason is that later alighting passengers have to move through the interior of the train. Secondly, congestion on the railway platform itself introduces variance in process times. The third reason stated for the changes in movement rates is the interaction between boarding and alighting passengers. This interaction is a result of opposing passenger flows.

Harris et al. (2014a) state that a situation in which the flow of boarding and alighting passengers is of equal size results in most interactions (i.e. overlap) and thus the longest dwell times. Overlap indicates situations in which boarding and alighting at a single door occurs at the same time resulting in reduced passenger movement (Seriani, de Ana Rodríguez, & Holloway, 2016c). Findings by Seriani et al. (2019) on the relationship between the ratio of passengers and dwell time contrast the statement made by Harris et al. (2014a), however. In their study, the researcher found that the total boarding and alighting time with a balanced ratio was 40.8 s, versus 41.9 s when the majority of passengers were alighting and 49.6 s when the majority of passengers were boarding. This shows the impact of a skewed ratio in passenger flows, which is most prominent when the majority of passengers board a train.

The interactions between boarding and alighting passengers occur in the area in front of the train door known as the *platform train interface* (de Ana Rodríguez, Seriani, & Holloway, 2015; Holloway et al., 2015; Seriani, Fujiyama, & de Ana Rodríguez, 2016b). The term is sometimes abbreviated as PTI, however, the full term will be used in the remainder of this paper for clarity. The platform train interface can be depicted as a semi-circular area, on the platform in front of the train doors. Two phenomena can be observed within the platform train interface which helps to explain why a skewed ratio results in longer dwell times, the queuing behaviour of passengers on the platform and the formation of boarding and alighting lanes.

Formation of queues and lanes

There is a relationship between the formation of queues on a station platform and the formation of lanes during the boarding and alighting process. Queuing behaviour influences boarding and alighting times when passengers on the platform crowd in front of doors and block the flow of alighting passengers. Most queues are formed inside and around the platform train interface area (Seriani, Fujiyama, & Holloway, 2016a). Dell'Asin and Hool (2018), studying the formation of queues near train doors in Switzerland, found that queues tend to grow parallel to the edge of the platform rather than perpendicular. Seriani and Fujiyama (2019a), observing behaviour at two stations of the London Underground, found that most people position themselves in the middle of the platform, respecting the platform edge and leaving space for circulation. This suggests that waiting passengers position themselves in such a way that the circulation on the platform is not severely affected.

The location of these queues with respect to the train doors is affected by the awareness of the location of the train doors before the train halts. de Ana Rodríguez et al. (2015), and Seriani and Fujiyama (2019a) studied the effect of platform edge doors (which provide an indication of where the train doors will be) in London. The researchers observed that passengers queued next to the platform edge doors, instead of clustering inside the platform train interface area.

Another factor which influences the formation of queues is the ratio between boarding and alighting passengers. In their study on queuing behaviour in London, Seriani et al. (2016a) observed that passengers tend to wait more in front of the doors when the amount of boarding passengers is substantially larger compared to the number of alighting passengers, as illustrated in Figure 2a. In comparison, when the ratio is skewed towards alighting passengers queues are formed next to the train doors as shown in Figure 2b, and situations in which the ratio is neutral show mixed queuing behaviour.

The position and shape of these queues has a strong influence on the formation of boarding and alighting lanes. Lanes inside the platform train interface area are formed during the boarding and alighting process by passengers following the person in front of them. Seriani and Fujiyama (2019b) mention that wider doors result in the formation of multiple alighting lanes, speeding up the alighting process. The formation of lanes is, however, strongly related to the available space on the platform and the "pressure" of passengers waiting to board (Harris et al., 2014b; Seriani et al., 2016b). When the platform train interface area becomes crowded, there is less space for alighting lanes to be formed as shown in Figure 2a (Seriani et al., 2016a; Seriani et al., 2019). In addition to a

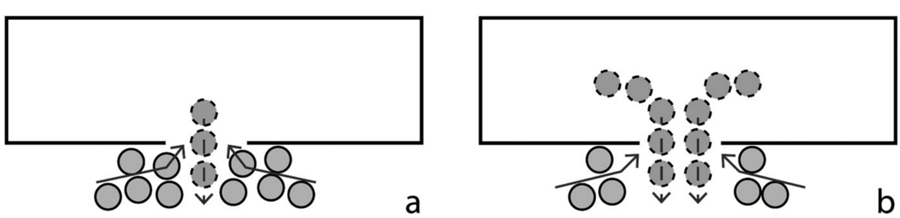

Figure 2. The effect of the ratio between boarding and alighting on queuing behaviour and the formation of lanes. Source: adapted from Seriani et al. (2016a).

crowded platform train interface area, passengers further reduce the space for lanes when "leaning in" to look for gaps in the flow of alighting passengers, reducing the usable door width (Heinz, 2003; Harris et al., 2014b).

An explanation as to why a larger number of boarding passengers influences the queueing behaviour and formation of lanes can be found in the stress levels. The willingness to wait in an orderly fashion changes when stress levels are higher (i.e. a crowded situation). When the number of passengers waiting to board is high, passengers tend to be less respectful when boarding a train (Heinz, 2003), and strive to acquire a seat as soon as possible (Hirsch & Thompson, 2014). This behaviour is also described by Seriani et al. (2016a) who found that boarding starts before alighting is finished when there is a high number of boarding passengers, whereas passengers wait for the alighting process to finish when the number of boarding passengers is low.

Distribution of passengers

So far, it has become clear that the behaviour of passengers during the boarding and alighting process relates to the number of passengers boarding through a specific door. This suggests that adding more doors can mitigate the issues of overlap due to a high number of passengers boarding through a door. A study on the dwell times of commuter trains in Stockholm and Tokyo by Palmqvist et al. (2020) provides somewhat of an illustration of how additional doors seem to be beneficial with regards to dwell times. The study indicated that dwell times were remarkably similar between both cities, even though the passenger load in Tokyo is higher than in Stockholm. One explanation could be the intended capacity per door. Trains in Tokyo are fitted with four doors per carriage, meaning an intended capacity of 38 passengers per door, whereas the trains studied in Stockholm are fitted with two doors, with an intended capacity of 67 passengers per door. Although no clear statements were made on the actual number of boarding passengers per door for each train, the difference in intended door capacity indicates a potential benefit of fewer passengers using a single door. However, the intended capacity is not always the way passengers use the available doors and situations where a large group of passengers boards through a limited number of doors occur.

Fox, Oliveira, Kirkwood, and Cain (2017) use the term *concentrated boarding* to address the phenomenon of a relatively large number of passengers boarding through a limited number of doors. Building on the observations made by Fox et al. (2017), Oliveira, Fox, Birrell, and Cain (2019) revealed the negative effect of concentrated boarding on dwell times. The researchers compared three trains with a similar number of boarding passengers. They found that it took 75 s to complete the boarding process for the train which showed the highest degree of concentrated boarding, compared to 23 and 45 s for the other two trains. Although the study population was rather small, their findings do indicate that concentrated boarding has a large impact on the duration of dwell times.

The number of passengers boarding through a certain door is closely related to the distribution of passengers waiting on the station platform. Dell'Asin and Hool (2018) state that passengers are likely to use the door which is nearest to their waiting position. In addition, Heinz (2003) states that passengers who wait by a crowded door will only change doors when the walking distance is less than 10 metres. This suggests that the position on the platform defines the door used for boarding. The rationale for passengers on where to position themselves is influenced by their origin- and their destination-station (Fang, Fujiyama, & Wong, 2019) and will, therefore, be described in this manner in the next two sections.

Origin-based distribution of passengers

Origin-based distribution is influenced by the situation and layout at the station where a journey starts, the origin. Davidich, Geiss, Mayer, Pfaffinger, and Royer (2013) studied the waiting positions of passengers on two stations in Germany. Their findings show that waiting passengers try to stay out of the flow of circulating passengers by standing near already present obstacles, such as pillars, and services such as ticket machines and kiosks. Nash et al. (2006) observed the passengers distribution at several stations in the Zurich area and found that objects such as waiting rooms and the available roof coverage influence passenger distribution as well. The latter is relevant in the case of bad weather when people look for shelter. Similar behaviour was observed by Bosina, Meeder, Weidmann, and Britschgi (2015) at two stations in the same area. The researchers also mention the influence of time on the waiting position of passengers, where the waiting position is dependent on the time between arriving at the platform and the departure of the train. Circulation reduces closer to the departure time of the train as passengers prefer to wait closer to the platform entrance instead of finding a comfortable waiting position. Wu, Ph, and Ma (2013), Fox et al. (2017), and Fang et al. (2019) observed similar behaviour, where passengers who arrive close to the departure time tend to board at the nearest door. Rüger (2018) hypothesised that this behaviour is a possible result of passengers worrying about missing the train as well as passengers wanting to minimise their walking distance on the station platform.

Findings by Fox et al. (2017) at Oxford Station contrast the notion that the circulation of passengers is time-dependent. Their study found that 25% of passengers boarded less than 24 metres away from the entrance point to the platform, regardless of the time between arriving on the platform and the departure of the train. The relation between the platform access points and passenger distribution is observed in multiple other countries as well, such as Canada (Krstanoski, 2014), the Netherlands (van den Heuvel, 2016; Wiggenraad, 2001), Korea (Lee, Yoo, Kim, & Chung, 2018), and Sweden (Peftitsi, Jenelius, & Cats, 2020). Fox et al. (2017) hypothesised that passengers prefer to stand at a more central position, such as platform entrances when there is a larger variance in train stopping positions. Passengers chose a central location in these cases since the likelihood of the train halting near them is believed to be greater, reducing the fear of not being able to board.

Destination-based distribution of passengers

Destination-based distribution is influenced by the situation at the station where a journey ends, the destination. Observations by Fang et al. (2019) in London found clusters of boarding passengers near doors that are closest to the exit at the destination stations of a large number of travellers. Similar behaviour was found by Zheng (2018), who studied the movements of transferring passengers, showing that most alighting passengers used carriages which were near to the locations of exits. Experience with the surrounding area of a station influences the choice of which carriage to board as well. Bosina, Meeder, and Weidmann (2017) studied the relationship between train carriages and exit locations based on passenger flows in Switzerland. Their observations showed that, when a specific area can only be reached through a certain exit, the passengers using this exit alighted from the train carriages nearest to the location of this exit. A similar effect of the surrounding area of a station is shown in a study focusing on Amsterdam central station. Van Den Heuvel and Hoogenraad (2014) used smartcard data to understand the relationship between the train stopping position and the use of exits. Their findings show that many passengers make use of a single exit location, even though the trains do not always stop near this exit. One of the possible reasons mentioned for this behaviour is that most of the connecting transport modes are located near this exit. This is in line with statements made by Nash et al. (2006) and Rüger (2018) on the effect of exits which are orientated towards specific services on the distribution of passengers. These findings suggest that passengers deliberate chose which carriage to board, based on prior experience.

Kim, Kwon, Wu, and Sohn (2014) surveyed passengers to understand their choice of waiting positions on a platform in Korea. A large majority of the respondents (77%) stated that they, indeed, deliberately choose their waiting position. Most respondents stated they try to minimise the walking distance at their destination. Jusuf, Nemec, and Zahradnik (2017) found similar results in Austria, where a survey revealed that 59% of the respondents base their waiting position on the location of the exit at their destination. A study by Pritchard (2018) in the UK further highlights the influence of the location of exists of the choices made by passengers. Participants in the study were shown three carriages and their respective crowding levels, as well as the location of the entrance and exit locations on the platforms. Participants were then asked which carriage they favoured most. The results show that the carriage furthest away from the exit was almost always the least desired, even if it was the least crowded. Similar findings with regards to the effectiveness of information on onboard crowding levels were found in a study in Stockholm by Zhang, Jenelius, and Kottenhoff (2017). Their findings indicate a shift of boarding passengers from the first, most crowded, carriage to the second, less crowded, carriage. However, their findings indicate that there was no significant shift of passengers to the last, and least crowded, carriage during their study period.

These findings indicate that onboard crowding does not influence the distribution of passengers in the same way as it does for route choices, where passengers adapt their travel behaviour to avoid crowded carriages (see for example the studies by Raveau, Guo, Muñoz, and Wilson (2014) and Kim, Hong, Ko, and Kim (2015)). Pritchard (2018) hypothesises that the choice of passengers on where to position themselves on a platform is influenced by prior experience of queues at platform exits, suggesting that experienced travellers position themselves in such a way that they experience the least amount of hindrance at their destination. Zhang et al. (2017) hypothesised that similar factors such as minimising walking distance and door-to-travel time have a stronger effect on the choice of carriage than onboard crowding has. These hypotheses are in line with the findings by Kim et al. (2014) and Jusuf et al. (2017).

Findings by Christoforou et al. (2017), who surveyed travellers in Paris, contrast the notion that the exit positions influence passenger distribution on platforms, however. Their survey revealed that 69% of the respondents chose their waiting position on an explicit rationale. Surprisingly, although 81% of passengers were aware of the location of the exit at their destination, the reasoning behind their choice is stated to be mostly based on meeting a friend, or on increasing on-board comfort. An online survey by Ahn, Kim, Bekti, and Cheng (2016) found similar reasons as to why passengers chose a certain train carriage. Their results are, however, not representative of experienced train travellers due to a large number of respondents who stated that they rarely travel by train.

Measures to reduce the impact of passenger behaviour on dwell times

The findings so far on the effect of passengers on dwell times indicate that the variance in the behaviour of passengers induces variance in the duration of dwell times. This relates to late-arriving passengers, queueing behaviour and the formation of lanes, as well as the degree of concentrated boarding at stations. Several different kinds of measures which help to mitigate the impact of passengers on the variance in dwell times have been tried in the past. These measures are aimed at reducing the amount of concentrated boarding, reducing the interaction between boarding and alighting passengers, or reducing the chance of late-arriving passengers through platform management or railway operations. Measures to reduce the total number of passengers boarding a specific train seem less efficient. Although Preston, Pritchard, and Waterson (2017) showed a willingness of passengers change to a later train when informed about high on-board crowding levels, such behaviour is strongly dependent on the type of passengers. Commuters who must adhere to a strict schedule are less likely to be able or willing to make such a change in travel times. The findings so far also highlight that adaptations to rolling stock design without additional measures seem to be less effective. Even though a study by Seriani and Fujiyama (2019b), for example, mentions that wider doors result in the formation of multiple alighting lanes, this benefit is reduced when queues are formed in front of the doors, reducing the useable door width.

Platform management

Platform management measures have the potential to reduce the degree of concentrated boarding and change the behaviour of passengers during the boarding and alighting process. Concentrated boarding, for example, is found to be a result of passengers either arriving shortly before the train arrives, being unaware of where the train will halt or the layout at their destination station. Platform markings can help to inform passengers on where the train will halt, and when combined with messages indicating passengers should spread out, can help to reduce concentrated boarding. There is, however, no evidence as to which degree these measures decrease the level of concentrated boarding (Oliveira et al., 2019). Providing information on on-board crowding levels has a potential to spread out passengers, depending on the layout of the destination station and motives of passengers. Perkins, Ryan, and Siebers (2015) modelled, among other things, the effect of such an onboard crowding information system. The researchers assumed that such a strategy will result in less concentrated boarding. The average boarding and alighting time was reduced by 7.3% as a result. However, as described before, the studies by Pritchard (2018) and Zhang et al. (2017) show that other factors such as the layout of a station and walking distances have a strong influence on the actual willingness to make use of certain carriages, even when presented with crowding information.

The use of platform markings, or a more drastic measure such as platform edge doors, indicating where the train will halt also have the potential to reduce overlap between flows of boarding and alighting passengers. Passengers are more likely to queue next to the door when an indication of where the train door will be is present on the platform (de Ana Rodríguez et al., 2015; Seriani & Fujiyama, 2019a). de Ana Rodríguez et al. (2015) found that boarding and alighting times significantly improved when queueing behaviour was more organised, and fewer clusters were present in front of the doors.

The effect of platform markings can be strengthened when a "keep out zone" is added, which helps to organise the formation of alighting lanes. These measures do not always work as intended, however. Research by Seriani and Fernandez (2015) found that participants formed a boarding lane through the middle of the "keep out zone" instead of allowing more space for alighting passengers. The researchers mentioned that there was no clear explanation for this behaviour, but they hypothesised that the message was not clear for the participants.

Furthermore, anecdotal evidence by Barron, Canavan, Anderson, and Cohen (2018), suggests that queues are formed perpendicular to the platform edge when platform screen doors are present. The formation of queues perpendicular to the platform edge reduces the available space for circulation on the platform. No effects on passenger flows are mentioned by the authors, however. It is also important to mention that the effect of "keep out zones" depends on more than the behaviour of boarding passengers. High onboard crowding levels can mitigate the benefits of these measures (Rowe & Tyler, 2012), indicating that it is not "one size fits all" solution. Furthermore, such measures can be difficult to implement when there is a large variety of train compositions and stopping positions.

Platform management measures can also help to reduce the congestion on a platform. A study by Muñoz, Soza-Parra, Didier, and Silva (2018) on the use of gates on a platform to reduce counter flows of passengers in Santiago (Chile) showed several improvements. One of the main results highlighted is the reorganisation of passengers on board the train, meaning they are closer to their exit location. This in combination with a reduction in counter flows meant passengers would clear the platform quicker, reducing the exit times and increasing service reliability.

Train operations

Measures which are based on train operations are a more active approach to try and mitigate the impact of passengers on dwell times. Adapting the stopping position of a train based on the spread of passengers has the potential to be beneficial in situations where, for example, platform markings are difficult to implement. A simulation study by Sohn (2013) and field study by van den Heuvel (2016) showed the potential benefits of such measures in reducing concentrated boarding. The latter study showed a mean decrease in the duration of dwell times of 30 s and a 50% decrease in the variance of dwell times when the stopping position was adapted to the passenger distribution. The effect was, however, smaller when the number of passengers waiting to board was relatively low. There must, however, be sufficient additional space on a platform to allow the train to stop at an optimal position for this type of measure to work (Sohn, 2013).

Another measure related to the operation of trains is to provide passengers with information about seat locations and reservations. A study by Farnsworth, Kirkwood, Court, Shehab, and Tinworth (2017) showed a potential reduction of 44% in dwell times when all passengers are informed about a seat location. In their study, the researchers modelled boarding and alighting sequences with different degrees of knowledge about seat locations for the passengers. The findings indicate a benefit of seat reservation on dwell times since passengers optimise their boarding strategy. Seat reservation is, however, not always possible or desired, in the case of metro services for example, and such a measure thus depends on the type of service.

Measures such as platform management and adaptations to the stopping position of trains do, however, not help to reduce the likelihood of passengers arriving near the tail end of the boarding process. Providing clear information ahead of time and at multiple locations will help to reduce the amount of incidental late-arriving passengers who are not known with the departure times and locations. A study by Oliveira et al. (2017) highlights the importance of information provision. Participants in their study mentioned that if the information on the departure platforms is only present on a central screen, they tend to group around this area. When information is subsequently provided shortly before the departure time of a train, passengers have limited time to make their way to the correct platform. Passengers are further impeded when the station is congested.

Station congestion is, among other things, a result of the timetable. Simulation studies by Rindsfüser and Klügl (2007) and Ahn, Kowada, Tsukaguchi, and Vandebona (2017) show how trains with high passenger loads arriving in short succession or at the same time result in congested railway platforms. Although these results are best viewed in a descriptive manner, the studies indicate that arriving passengers cannot vacate the platform before the next train arrives. This results in growing congestion on the platform, making it more difficult departing for passengers to reach their train on time. Timetable adjustments aimed to reduce congestion inside the station can thus further help reduce the risk of passengers arriving near the tail end of the boarding process when stations are busy.

Summary

This study set out to illustrate how the behaviour of passengers influences dwell times. Dwell time is stated to consist of both fixed and variable time elements. The fixed time element consists of the technical processes and was not part of this review. The variable time element is made up of the passenger exchange, and as the name suggests, it is assumed that this process induces variance in the duration of dwell times. The current study, therefore, focussed on how the behaviour of passengers on station platforms both before the train arrives and during the boarding and alighting process affects dwell times, and the underlying causes of hereof. This is done to illustrate which type of measures have the potential to be effective in reducing the impact of passengers on dwell times.

Behaviour of passengers

The way the exchange of passengers affects dwell times can be split into two categories. These two categories are late-arriving passengers and passengers boarding in a cluster, as illustrated in Figure 3. Late arriving passengers elongate dwell times due to door holding or extensive passenger service by railway staff which hold the train to allow these passengers to board. The likelihood that passengers arrive near the tail end of the boarding processed is increased when the passenger flow in stations is reduced and when information on departure times and platforms is provided shortly before the train arrives and at a limited number of places.

Clustered boarding illustrates how the behaviour of passengers in a group affects dwell times. As illustrated in Figure 3, the time it takes for a cluster of passengers to complete the alighting and boarding process is defined by an accumulation of several factors. This accumulation defines the actual flow of passengers through a single train door. The flow of passengers varies during the boarding and alighting process because of the interaction between passengers. Passenger flows slow down when there is a higher degree of interaction. The degree of interaction is governed by the formation of lanes, where organised lanes result in less interaction between passengers. The way lanes can be formed is defined by the usable door width. This is not always the physical width of a train door, however, since the usable width is governed by the shape and the position of queues

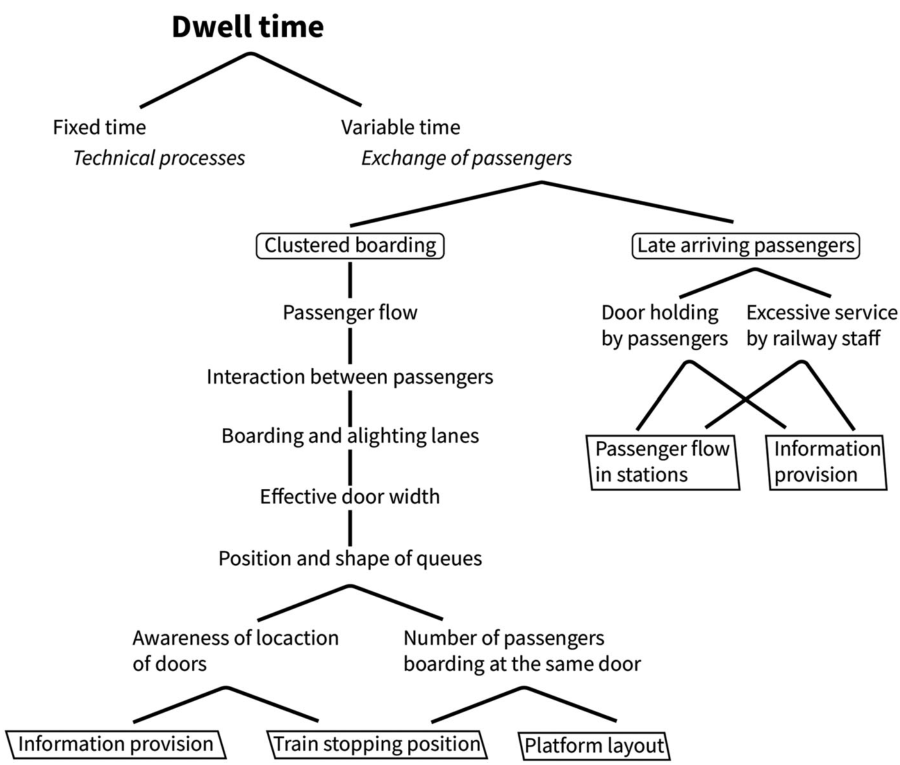

Figure 3. Hierarchy of passenger influences within dwell time.

inside the platform train interface area. When passengers queue in front of the doors, the ability to form lanes is reduced and the degree of interaction increases due to the funnel formed by passengers on the platform. This illustrates the importance of organising the position and shapes of queues in the platform train interface area when attempting to reduce the duration and variance in dwell times. The position and shape of the queue of waiting passengers can be considered as the foundation of the eventual passenger flow rates during clustered boarding.

Two factors are found to influence the position and shape of queues of in and around the platform train interface area. As depicted in Figure 3, these two factors are the awareness of passengers on where the train will halt and the number of passengers who board at the same door. A larger number of passengers queueing up around the same door increases stress levels within this group, and passengers start to bunch up in front of the door. Crowding of the platform train interface is less present when passengers are aware of the location of the doors when the train halts. Passengers, in this case, tend to wait to the side of the door, leaving more space for alighting lanes. The distribution of passengers is affected by the platform layout, both at the origin and destination station, and the stopping position of the train. Experienced passengers position themselves based on the layout of their destination station, reducing the distance between the train and their exit. Passengers who base their waiting position on their origin station either stand near objects or the platform entrance. The latter is more present close to the departure time of the train, and when there is a large variance in where trains halt at the station.

Impact on dwell times

How the previously mentioned aspects of the boarding and alighting process affect the duration of dwell times is illustrated in Table 1. Depending on the situation, late-arriving passengers can extend dwell times by 1 s, up to 25 s. This indicates that, even though these situations include a limited number of passengers, the effect on dwell times is relatively large. A skewed ratio between boarding and alighting passengers elongates dwell times depending on which way the ratio is skewed. The largest increase in dwell time can be found when the majority of passengers is boarding, this is line with previous statements on the queueing behaviour. When a large number of passengers is waiting to board through the same door, the interaction between passengers increases. This helps to explain why concentrated boarding has a relatively large effect on both the duration and variance of dwell times.

Table 1. Overview of effects on dwell time.

	Effect on dwell times		
	Change	Base	Study
Door holding	+1s to 13s	Not mentioned	Harris (2015)
Excessive service	+25s		
Majority of passengers boarding	+8.8s	40.8	Seriani et al. (2019)
Majority of passengers alighting	+1.1s		
Concentrated boarding	+30s to 52s	45s & 23s	Oliveira et al. (2019)

Measures

Measures to reduce the impact of passengers on dwell times should focus on several aspects. First, the measures should be aimed to organise the queueing behaviour and the formation of lanes, reducing the interaction between boarding and alighting passengers. Secondly, measures should aim to reduce the degree of concentrated boarding since this helps to reduce stress while boarding. Thirdly, measures should aim to mitigate the risk of passengers arriving near the tail end of the boarding process.

The findings in the current study indicate that adaptations to rolling stock design, such as the addition of doors or making use of wider doors fail to capture the dynamics of the behaviour of passengers and the way they interact during the boarding and alighting process. Additional doors result in fewer passengers boarding per door and allow for passengers to be spread out more evenly, in theory. However, when there is a high degree of concentrated boarding due to the layout of the platform, or inexperience of travellers, the additional doors will not be used in an optimal way. As for wider train doors, the potential benefits of the additional width is mitigated when passengers crowd the platform train interface area, reducing the usable width of the door. In additions to this, it is difficult to generalise how passengers and rolling stock interact due to individual characteristics of both passengers and stations. It is, therefore, difficult to adapt the design of rolling stock in such a way that it solves the issue of variance in dwell times at all stations.

This leads to the notion that platform management and changes to train operations can play a substantial role in reducing the variance in dwell time. These types of measures focus on the underlying causes of the variance in dwell times, rather than focussing on the outcome, which is more the case with changes to rolling stock. Furthermore, platform management can be implemented in a way where it is less costly than adaptations to rolling stock and provide more adjustability over time. This adjustability of platform management allows measures to be adapted to the situational context of a specific station such as the location of entrances and the main cause for variance in dwell times and measures can be adjusted if the situation changes over time. Some examples of such measures and the effect on dwell times are shown in Table 2.

A key with most of these measures is the provision of information through platform management. Information such as indicators of where the train will halt can help to reduce the number of passengers opting for a central waiting position due to unfamiliarity with the train service. Such markings also help to organise the formation of queues and lanes since passengers tend to queue to the side of such markings, rather than in front of the train door. Indicators of where the doors will be can combined with additional

Table 2. Effects of measures on dwell times.

	Effect on dwell times		
	Change	Base	Study
Keep out zone to organise queues and aid the formation of lanes	−22s	44.4s	Seriani and Fernandez (2015)
Adaptation to passenger distribution on platforms	−5s	70s	Perkins et al. (2015)
Adaptations to the stopping position of trains	−30s*	144s	van den Heuvel (2016)
Seat reservation	−80s**	180s	Farnsworth et al. (2017)

*this effect was only present during peak hours
**this reduction occurs when 100% of the passengers have knowledge about seat locations versus 0%

markings such as the use of a "keep out zone" to strengthen this effect. Information on the platform and time of departure at multiple locations is beneficial in reducing the risk that passengers arriving late due to unfamiliarity with the train service, not knowing where to go, and subsequently having to rush through a station to be able to board their desired train. This can further be strengthened by adaptations to the timetable where the arrival times of trains with high passenger loads are better synchronised to reduce congestion inside stations due to high passenger numbers and maintain a sufficient flow of passengers through stations. Measures such as the use of gates to reduce the counter flow of passengers or seat reservation on trains are not always possible or desired, but show to be beneficial in cases where the station or service requires or allows such a measure.

Concluding remarks

To conclude, the current study reinforces the notion that the behaviour of passengers can have a large impact on dwell time duration and variance at stations. The study highlights:

- the importance of organising the behaviour of passengers to reduce their impact on dwell times
- the importance to view both passenger distribution and passenger behaviour during the boarding and alighting process in combination with each other
- that platform management can play a substantial role in reducing the variance and duration of dwell times compared to changes to rolling stock design as these measures target the underlying causes and can be adapted to local circumstances.

The effects of platform management measures on dwell times, and the generalizability hereof, remain to be a point of discussion, however. Not only due to a lack of knowledge on the actual benefits of platform management measures, and the effects with respect to different types of train services, but also how these effects are studied and reported. The majority of the studies described in the current study focussed on behaviour found on metro and commuter rail services. The behaviour of passenger, such as their waiting position, can be different for long-distance rail services where, for example, seat reservation is more common. Furthermore, a majority of the studies focussed on measures which either target the boarding and alighting behaviour, or a change in passenger distribution. The current study shows there is a clear relationship between the behaviour of passengers and the degree of concentrated boarding. Future studies should, therefore, focus on increasing the understanding of platform management in different situations. In addition, future studies need to view changes in both passenger behaviour and distribution in conjunction, rather than as separate elements. And lastly, the studies found in this review mentioned the changes to the mean dwell times but did not always mention the changes in the variance of dwell times. The changes in the variance should be included in future studies when describing the effects of measures since changes in the variance of process times are just as important as the changes in the mean values.

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