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Real-time Information System for Spreading Rail Passengers across Train Carriages: Agent-based Simulation Study

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Abstract

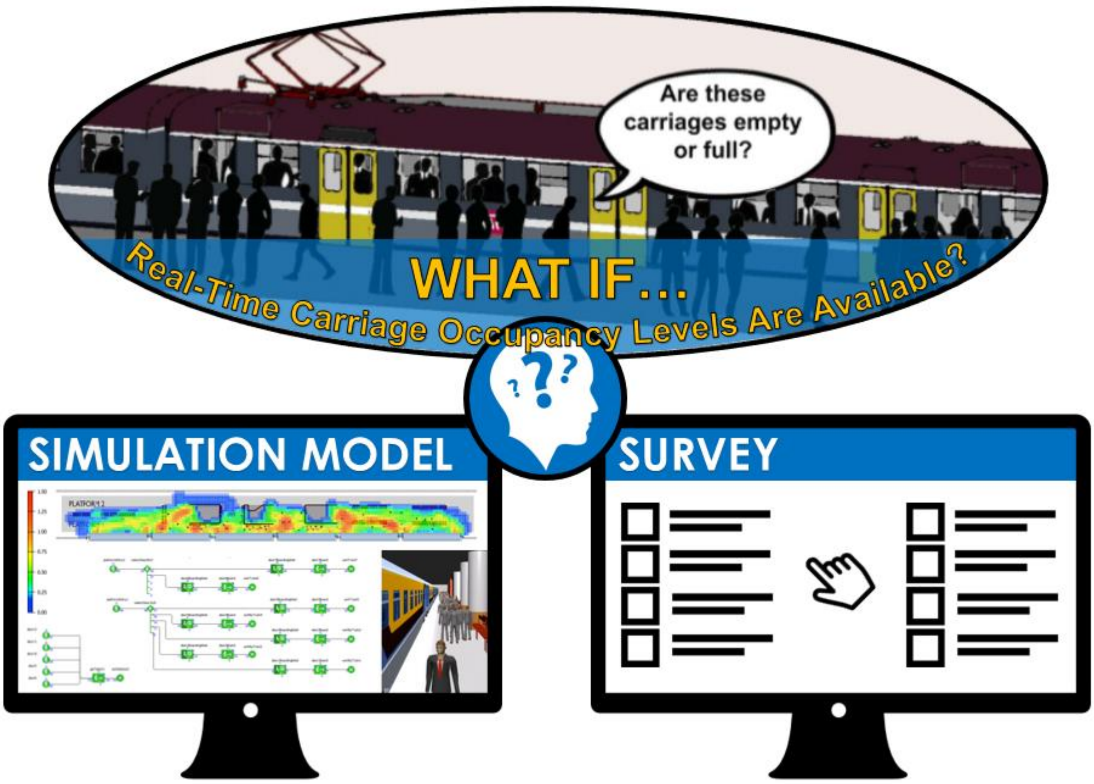
Commuter trains with multiple carriages tend to have varying distribution of passengers. At peak times, this can cause disproportionate occupancy rates of carriages, as well as crowding within the train and along the platform. As a result, passenger satisfaction is negatively affected as indicated by high sectional density and seat unavailability. This study, thus, aims to improve Queensland Rail passenger satisfaction in the boarding, riding, and alighting of trains. This is achieved via an improved passenger information system (PIS) that relays carriage occupancy levels to waiting passengers prior to the arrival of each train. The proposed system influences the passenger decision making process of where to wait along the platform by allowing them to take into account the occupancy rate of each carriage. It also offers a degree of certainty in regard to seat availability and ease of boarding. Passengers will then be capable of distributing themselves among low-occupancy train carriages in advance. An agent-based simulation approach is used to model dynamic behaviours of heterogeneous passengers along a platform as a proof of concept study. The paper develops a conceptual agent-based model that enables us to test various hypothetical scenarios representing different PIS settings as a case study focusing on a train station in Brisbane, Queensland, Australia. The input parameters (passenger volume and boarding/alighting passenger distribution) for the simulation model are prepared based on historical smart card records. The results from the simulation analysis suggest that the carriage occupancy information relay system can improve the distribution of passengers, thus increasing passenger satisfaction levels. Additionally, passenger behaviour data was obtained via an online survey to gain an understanding of passenger perceptions and tolerance of railway crowding within the Brisbane rail network. The survey results are to be used to extend the conceptual simulation model to reflect real-world operations and passenger distributions.

1. Introduction

Crowding within a train and on a platform is a determinant of both the service level for passengers and the level of passenger satisfaction. Thus, overcrowding in the peak hours has been recognised as a serious problem for railway systems in urban areas (Hirsch and Thompson, 2011; Curie, 2010; Hale and Charles, 2009; Qi et al., 2008). It is apparent that the crowding levels differ across individual cars constituting a single train set. According to the transit capacity and quality service manual (TCQSM) (TCRP report 165, 2013), the passenger load imbalance between cars on individual trains ranges from +61% to -33% with respect to the average passenger load per car in the Vancouver SkyTrain, and fluctuates even more (from +156% to -89%) in Toronto's Yonge Street subway. Additionally, the survey conducted by Kim et al. (2014) showed that the loading difference varied from +118% to -90% for the Seoul Metro line 7 in South Korea during the morning peak hours. Kim et al.

(2014) also investigated the underlying reasons why passengers select a specific car of a train on an individual basis. Most (76.6%) passengers have been reported choosing a specific car intentionally. Among them, 69.7% have been reported wanting to minimise the walking distance to exits when they disembark at a destination station, 16.6% sought to minimise the walking distance from the entrance when they board at an origin station, and the remaining 13.5% wanted to pursue comfort while traveling. Wiggenraad (2001) conducted a case study of seven Dutch railway stations to measure dwell time among other parameters, and which components are affected by these parameters. This study noted that passengers tend to concentrate around station entry. However, there has been little research conducted to examine the effects of motivating passengers to distribute themselves by providing carriage occupancy levels to waiting passengers prior to the arrival of each train via passenger information system (PIS). This paper thus seeks to analyse passenger congestion as a function of the passenger load imbalance between cars, boarding and alighting distribution, and the availability of information through PIS as shown in Figure 1. This research focuses on the busiest station of Central in Brisbane, Queensland, Australia as a case study. The adopted approach of this research involves in developing a pedestrian, crowd and railway simulation model for crowd analysis and scenario testing. The approach also includes survey-based study to gain an understanding of passenger perceptions and tolerance of railway crowding within the Brisbane rail network while ultimately aiming to incorporate the survey results into the simulation model.

Figure 1: Modelling and conceptual framework



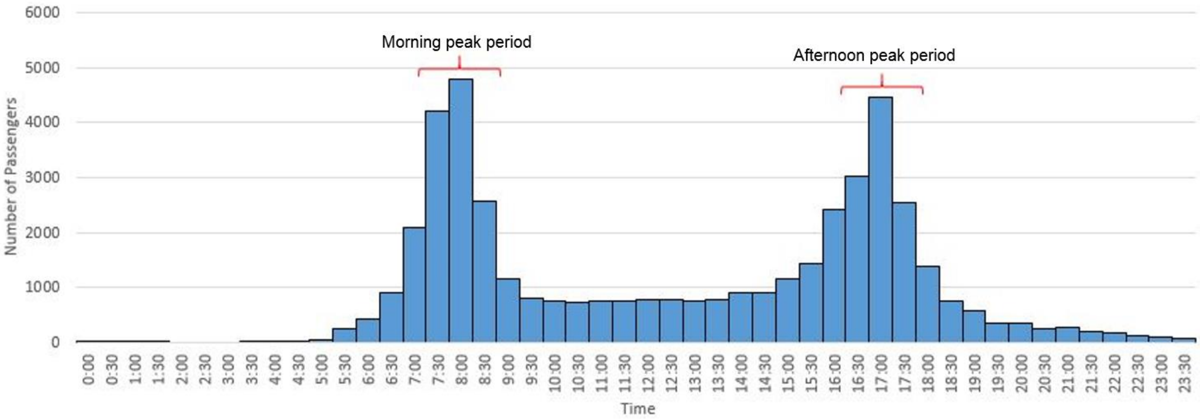
2. Methodology

2.1. Station description and smart card data extraction

Queensland Rail (QR), the railway operator for the State of Queensland, Australia, operates suburban and long-distance passenger services. QR, in partnership with TransLink, the public transport agency of the Department of Transport and Main Roads for the Queensland Government, provides urban and interurban rail and bus services throughout South East

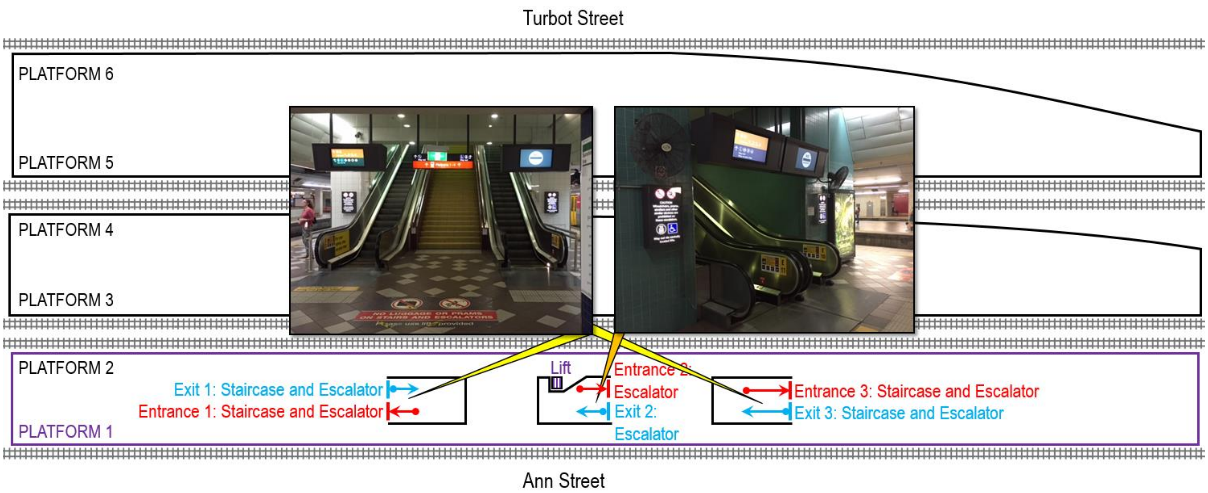
Queensland. The busiest railway station is the Central Station, which serves as a convergence point for 65,000 commuters heading to the central business district (CBD) from the outskirts of Brisbane between 6am and 9pm each weekday. The Central Station consists of 6 platforms (i.e., 3 islands) as shown in Figure 3 and is the meeting point of 12 lines. The station was redeveloped in 2013 to improve customer flow and cater for growing patronage aiming to cater daily for more than 80,000 regular train commuters and visitors to Brisbane City, especially during morning and afternoon peak periods (i.e., 7:00-8:30 a.m. and 4:30pm-6:00pm). To identify the peak periods at the Central Station, a 10-weeday slice of *go* card transaction data recorded between 1st April 2013 and 12th April 2013 was obtained from TransLink (Go Card Smart Card Transaction Data, 2013). The data acquired was used to process and analyse the average number of passengers at each weekday as shown in Figure 2.

Figure 2: Average weekday smart card transactions at the Central Station between 1st April 2013 and 12th April 2013



This study conducts a case study focusing on the Central Station in Brisbane to analyse various hypothetical scenarios representing different PIS settings by constructing an agent-based simulation model. The level of simulation model detail in this paper does not take into account the local interactions among passengers. The scope of the simulation model in this study is limited to the platform 1 at the station. The platform 1 consists of four entrances including one lift on the side of platform 2 as illustrated in Figure 3. The entrances can be accessed via the concourse level.

Figure 3: Central Station layout



2.2. Simulation model construction

To accurately simulate Central Station platform1, the proper modelling software had to be selected. A piece of software, called AnyLogic, was selected as the best option because it provides a very simple way to model the movement of people and train as agents through various processes (Borschev & Filippov,, 2001; Bonabeau, 2002). The software is one of the most widely-used pieces of simulation software by industry and researchers.

A case study of Central Station platform 1 (Figure 4 and Figure 5) in Brisbane, Queensland, Australia was conducted during the afternoon peak hour of 5:00 to 6:00 pm. This context was chosen after an analysis of TransLink smart card transaction data (Figure 2) (Go Card Smart Card Transaction Data, 2013). The project station was chosen for its high current passenger volume and forecasted increase (Queensland Rail Annual and Financial Report 2014-2015). It was assumed that the effects of uneven passenger distribution would be more apparent in this case.

Figure 4: 2D Visualisation of the simulation

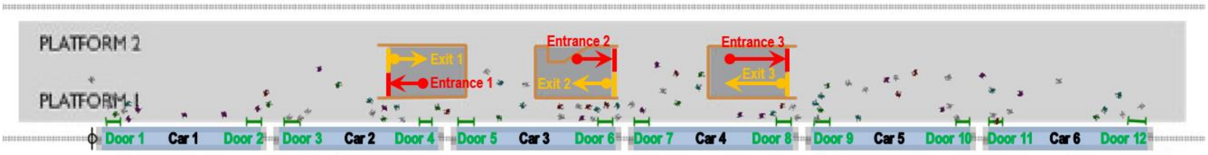


Figure 5: 3D Visualisation of the simulation

The model takes in several parameters and simulates their interactions such that relevant pertinent information can be extracted to represent a real-life scenario. These parameters follow a logic as constructed by the modeller to closely replicate conditions of the project station.

Station parameters make up the spatial setting of the simulation and are unique to the platform (Figure 3, Figure 4 and Figure 5). Extending the model to other platforms and stations would entail acquiring a new set of geometric parameters unique to each platform or station. Station Parameters were measured via direct observation through numerous on-site visits of the platform. Key station geometry parameters were prepared as follows.

- Platform area: 600 m^2
- Waiting area dimensions: 4 x 6 m^2 and 2 x 6 m^2

Passenger parameters shown in Table 1 mainly characterise the passenger agents that behave in the station. Alighting passengers were modelled on a per door basis. Each door's alighting volume was estimated from direct observations made during the afternoon peak hour identified in Figure 2 as uniformly distributed between 4 and 7 passengers per door. Boarding passengers were modelled on a per station entrance basis. Each station entrance's passenger arrival rate was set stochastically at 200 passengers per hour. This is based on the worst case scenario conditions during the afternoon peak hour as limited by the station geometry and train arrival schedule. The decision-making process of each arriving passenger was modelled according to each of the 3 following scenarios.

- Scenario 1: Weighted-distance passenger assignment from platform entrances. The probability of a passenger boarding at a particular door is the proportion of the distance of the door from the station entrance, over the total walking distance of all the doors within the zone.

- Scenario 2: Designated boarding & alighting doors. The passengers can only board at the front door of each car and alight at the rear door of each car, for each of the three zones. Total boarding and alighting volumes were adjusted to be on a per car basis, instead of on a per door basis.
- Scenario 3: Train occupancy-based passenger assignment, where train occupancy is provided before its arrival. The probability of a passenger boarding at a particular door is the proportion of the car's vacancy over the total vacancy of cars being serviced within the zone.

Train parameters (Table 1) similarly characterise train agents and how they behave in a station as a service. Train parameters were available as public information. The train arrival rate followed the actual TransLink schedule of an inter-arrival time of 10 minutes during the afternoon peak hour. The platform was divided into 3 zones according to station geometry. Each zone was chosen according to station entrances and respective train doors that are within reasonable reach of a boarding and alighting passenger.

Table 1: Simulation parameters used

	Parameter	Details
Passenger	Arrival passenger rate / platform entrance	200 passengers / hour
	Alighting passenger rate / train door	30 / min
	Alighting passenger volume / train car	uniform[30,70]
	Pedestrian (passenger) comfort speed	uniform[0.5,1.0] m/s
	Pedestrian (passenger) initial speed	uniform[0.3,0.7] m/s
	Pedestrian (passenger) diameter	uniform[0.4,0.5]m
	Boarding passenger volume / door	uniform[4,7]
	Boarding volume / train door (Scenario 1)	$\left(1 - \frac{X_i}{\sum X}\right) \times P$ $X_i = door\ distance\ to\ closest\ station\ entrance$ $P = boarding\ passenger\ volume$ /door
Train	Inter-arrival time	10 min
	Car dimension	72.4 m x 2.7 m x 3.9 m Length x Width x Height
	Capacity / car	80 passengers / car
	Door width	2 m

2.3. Survey

For this study, an online survey was created in order to understand passenger perceptions and tolerance of railway crowding within the Brisbane rail network while ultimately aiming to incorporate the survey results to agents in the simulation model.

Furthermore, the survey was to gain an insight into passenger behaviour of everyday rail passengers, their evaluation of the current rail network and their decision-making during seat and carriage selection. Survey questions were devised based on factors relevant to measuring customer satisfaction of the proposed solution, these factors were as follows:

- Favoured modes of public transport (bus, ferry, train)
- Purpose and frequency of train travel
- Factors passengers use to assess satisfaction during trips
- Carriage and seat selection decision-making
- Feedback on proposed solution

The survey results are to be used to further develop the conceptual simulation model so that we can measure and control passenger interactions among passengers and between passengers within the Brisbane rail network. In order to achieve this goal, the survey was thus oriented around answering the following key questions:

- Do passengers value crowding?
- How do passengers select carriages currently?
- If given information on carriage occupancy levels, how will passengers move?

The purpose of the first question was to measure the degree and value of crowding as a means to evaluate satisfaction during trips. The purpose of the second and third questions were to obtain specific insight into the role of crowding during carriage selection. Participant responses to these questions ensured a thorough understanding of the effects of crowding within Brisbane.

3. Results

3.1. Simulation analysis

Ten times of replications of the simulation each of length an hour for each scenario are made. In this one hour, 5 trains have arrived and left the station. Each run has a unique seed number for the randomness. It is also important to note that the train has 6 carriages and 12 doors in total, with two doors per carriage (Figure 4).

Four key result values from the simulation model were analysed as shown in Figure 6 and Table 2. These four values are: number of boarding passengers per door (Figure 6-*(a)*), train occupancy level after the train exits the station (Figure 6-*(b)*), passenger waiting time (Figure 6-*(c)*), and train dwell time (Figure 6-*(d)*).

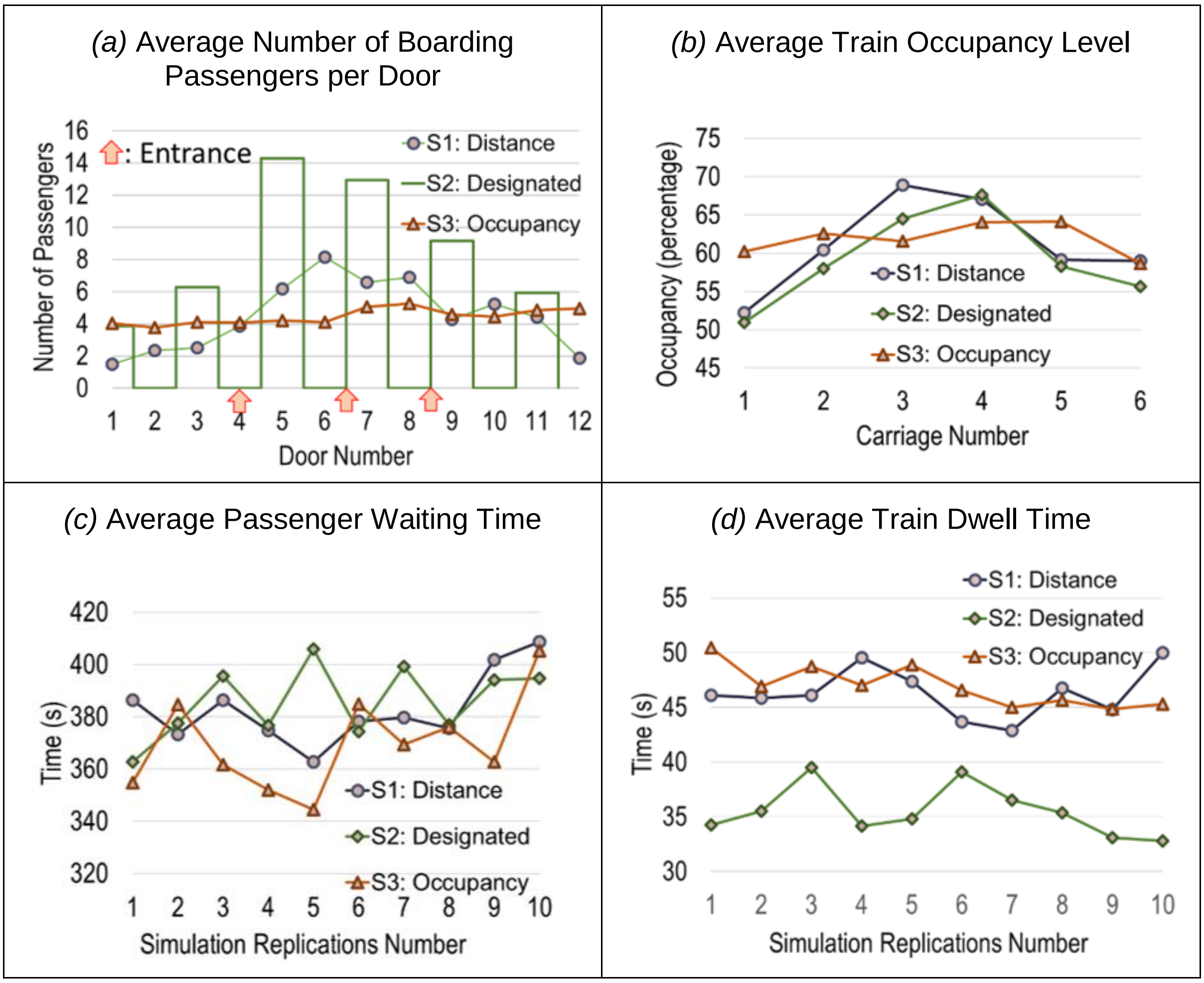
The number of boarding passengers for the first two scenarios where passengers are not given the train occupancy level information follow the same pattern showing that boarding passengers are concentrated around the entrances on the platform. The designated door scenario (i.e., scenario 2) has a higher number of boarding passengers per door compared to the base scenario (i.e., scenario 1: weighted distance) as the number of doors for the boarding passengers in the specific door scenario is halved.

The result of the boarding passengers is also supported when looking at the graph for the train occupancy level (Figure 6-*(b)*). This is the train occupancy level as the train exits the station after the boarding and alighting have been completed. The first two scenarios have train occupancy levels that are higher around the entrances, whereas the train occupancy level in the third scenario is more evenly spread along the train.

When looking at the passenger waiting time (Figure 6-*(c)*), the effects of the changing scenario are difficult to pinpoint since the data is within similar range as shown in Table 2. However, from the graph (Figure 6-*(c)*), it is safe to conclude that if there is any difference in passenger waiting time between the three scenarios, the difference would be within this order of magnitude. More simulation runs are needed to determine a conclusion regarding the passenger waiting time.

The train dwell time graph (Figure 6-*(d)*) between the three scenarios tells a different story. There is a definite decrease of train dwell time when there are designated boarding/alighting doors. On the other hand, the train dwell time for the other two scenarios is quite similar. This may be due to passengers alighting and boarding at the same time when given dedicated doors. In other words, the boarding passengers do not have to wait for the alighting passengers to finish alighting.

Figure 6: Simulation results: *(a)* Average Number of Boarding Passengers per Door, *(b)* Average Train Occupancy Level, *(c)* Average Passenger Waiting Time, and (d) Average Train Dwell Time



NOTE: S1 = Scenario 1: Weighted-distance; S2: Scenario 2: Designated doors; S3: Scenario 3: Occupancy-based.

Table 2: Simulation results

Passenger Assignment Scenario	Average Number of Boarding Passengers per Door				Average Train Occupancy Level (%)			
	Range	Minimum	Maximum	SD	Range	Minimum	Maximum	SD
Scenario 1: Weighted-distance	6.7	1.5	8.1	2.2	16.6	52.3	68.9	2.2
Scenario 2: Designated doors	10.4	3.9	14.3	5.4	16.6	51.0	67.6	5.4
Scenario 3: Occupancy-based	1.5	3.8	5.3	0.5	5.5	58.7	64.2	0.5

Passenger Assignment Scenario	Average Passenger Waiting Time (second)				Average Train Dwell Time (second)			
	Range	Minimum	Maximum	Mean	Range	Minimum	Maximum	Mean
Scenario 1: Weighted-distance	45.9	362.7	408.6	382.7	7.1	42.9	50.0	46.3
Scenario 2: Designated doors	43.2	362.7	405.8	385.8	6.7	32.8	39.5	35.5
Scenario 3: Occupancy-based	60.6	344.6	405.2	369.6	5.6	44.9	50.4	46.9

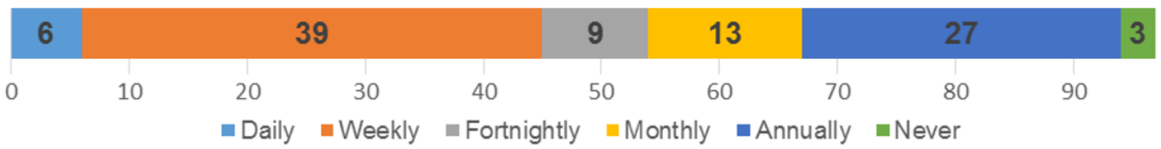
NOTE: SD = standard deviation.

3.2. Survey results and discussion

Following simulation modelling, passenger behaviour data was obtained via an online survey. Passenger behaviour data was gathered from a total of 97 participants whom completed the survey, 90 of which used a concession *go* card. Furthermore, there was a fairly even distribution amongst gender as 43 participants were female whilst 48 were male (with 4 respondents selecting “other” and 2 who did not wish to disclose this information). In terms of age, the majority of respondents were aged 16-21 (80% or 78 participants) with the highest result being a participant in the “76 & over” age group.

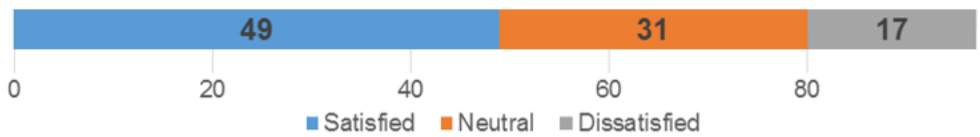
Data provided by the survey indicated how the rail network is utilised by passengers in Brisbane, 34 participants stated that most of their domestic journeys by rail were for leisure purposes whilst 52 participants travel by train for the reason of commuting to and from work. As seen in Figure 7, the frequency of travel clearly shows that majority of participants utilise the train system regularly. However, as there are 30 participants who travel annually or have never travelled via train, this shows that results on passenger behaviour obtained by the survey will not be a representation regular train passengers.

Figure 7: Frequency of travel - how often do you travel by train? (total participants: 97)



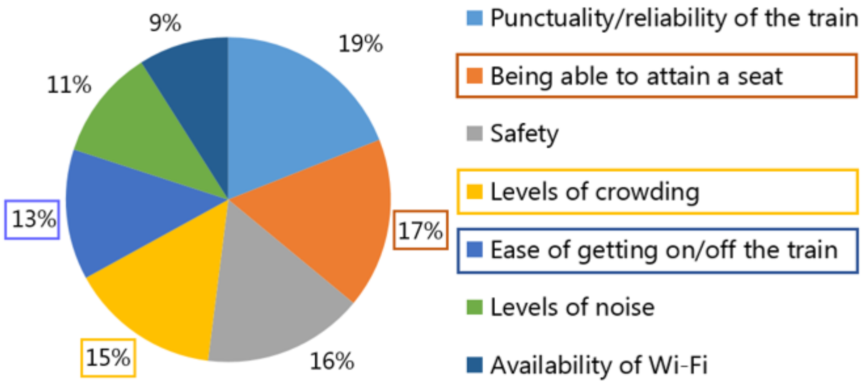
To evaluate the current levels of satisfaction across the three modes of public transport, participants were asked to assess their enjoyment levels based on the options of satisfied, neutral and dissatisfied. As seen in Figure 8 (data specific to trains), the majority (49) of participants were satisfied with the current rail network. However, the proportion of respondents who were neutral or dissatisfied evidently highlights the potential for the current rail system to be improved.

Figure 8: Number of participants satisfied with the current train network - how much do you enjoy travelling on the following modes of public transport (train)?



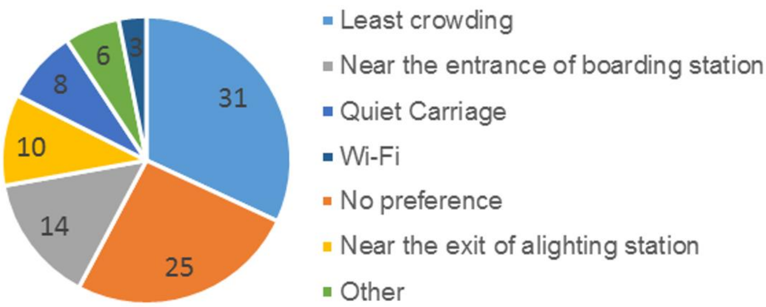
In order to investigate whether people value the issue to begin with, survey participants were asked what the biggest impact on their customer satisfaction was during trips. Participants were asked to rank the suggested options of punctuality/reliability of train, being able to attain a seat, safety, levels of crowding, ease of getting on/off the train, levels of noise, and availability of Wi-Fi in an order of 1 to 7. After aggregating the results as seen in Figure 9, it was seen that being able to attain a seat, levels of crowding and ease of getting on/off the train accounted for 17%, 13% and 15% of the responses respectively. Through evenly distributing passengers along the carriages, there is a higher chance of obtaining a seat. Furthermore, this will also reduce crowding both along the platform and within the carriage, hence making it easier for passengers to alight and board trains. Thus, there is potential to increase the overall customer satisfaction by providing the carriage occupancy level information.

Figure 9: Value of crowding - what has the biggest impact on your overall satisfaction during trips?



To further clarify the importance of crowding as a criterion for assessing satisfaction levels, it was found that the majority of participants (31) select a carriage with the least amounts of crowding, as provided in Figure 10.

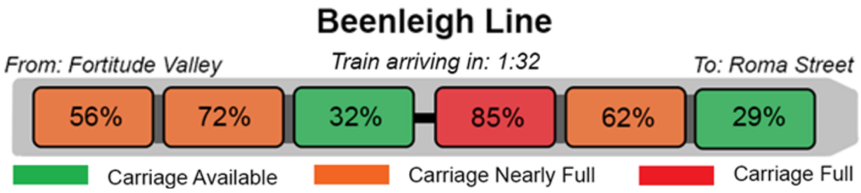
Figure 10: Factors used to consider carriage selection - as you arrive at the station, how do you decide which carriage to board?



3.2.1. Proposed implementation

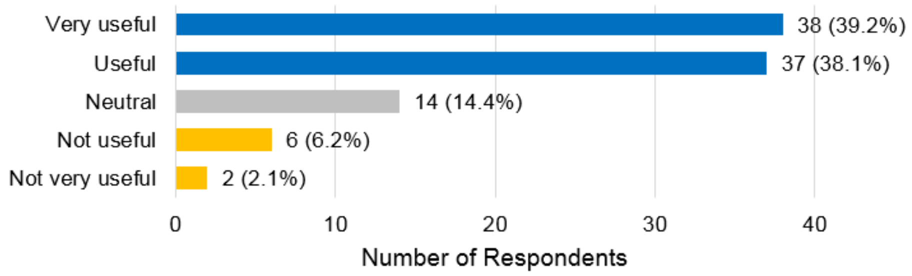
Since the results of the previous questions revealed that crowding is a factor valued among participants in terms of carriage selection. it was important to establish if participants would move accordingly when provided with carriage occupancy level information. Active and potential passenger insight on proposed methodology of internal carriage distribution was seen at the end of the survey. To begin, participants were given an illustration of the type of information that may be provided to passengers as seen in Figure 11. The illustration is to purely provide participants with the type of information provided and is not a representation of the aesthetics design if the methodology is implemented in reality.

Figure 11: Proposed PIS implementation



As seen in Figure 12, more than 77% of participants claimed that the information illustrated in Figure 11 was useful; 14% had a neutral perspective of the information and 8% of the participants did not find the information useful. It can be seen that the distribution of internal carriage occupancy is information that mostly regarded as useful to survey participants. However, whilst the information may be useful to passengers, whether they will use the information to influence their own decision-making is not determined at this point.

Figure 12: Usefulness of the provided occupancy level information



Participants then are asked a series of two questions. The first question asked participant whether they will use the information given in Figure 11 to board a carriage with a lower occupancy rate. The second question asked participants whether they will use the information to re-position themselves along the platform in order to obtain a carriage with lower occupancy rate. The purpose of dividing these two questions is to obtain insight in movement along both the platform and within the carriage. This is because people who use the information to board a carriage with a lower occupancy may not necessarily re-position themselves along the platform prior to the train arrival. There is a chance that passengers might move within the train to obtain a lower occupancy carriage. As seen in Figure 13, when asked whether participants will board a lower occupancy rate carriage, 46.39% of participants answered highly likely; 41.24% answered likely; 9.28% answered neutral, and 1% answered unlikely and 2% answered very unlikely. From the results, it can be seen that most participants are likely to obtain a carriage with a lower occupancy, and as a result, the internal carriage occupancy can be distributed more evenly. Furthermore, this also reduces internal crowding within the carriage. As seen in Figure 14, when asked whether participants will use the information to re-position themselves along the platform 37% answered highly likely, 39% answered likely, 16% answered neutral, 5% answered unlikely and 2% answered very unlikely. From these results, it can be seen that majority of participants are also likely to re-position themselves along the platform prior to the train arriving in order to obtain a carriage with a lower occupancy. As a result, the distribution of passengers along the platform will become more even, thereby reducing crowding along the platform.

Figure 13: Attempt to board a carriage with a lower occupancy rate?

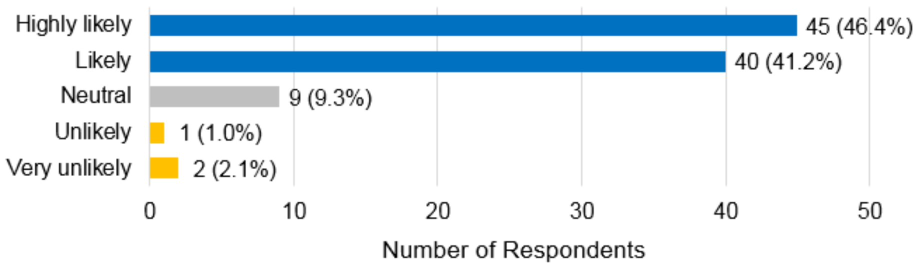
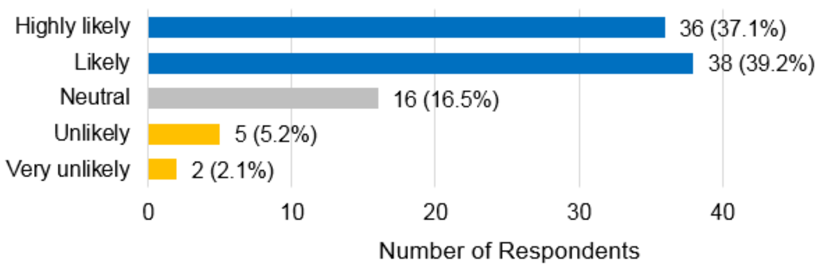


Figure 14: Will you reposition yourself along the platform to board a carriage with a lower occupancy rate?



In order to determine the method in which passengers would like to obtain information, three types of options were suggested in the survey. The suggestion options are through at-platform real-time information display (Figure 15-*(a)*), mobile apps (Figure 15-*(b)*) and public announcement speakers in the stations. Participants were also given the opportunity to suggest methods in the last questions of the survey. Responses included along larger electronic displays along platforms, displays on carriage doors, displays within trains and annotations on platform door. From Figure 16 and response by participants, it can be seen that most people opted for a technology-based implementation of the methodology. It is also seen that TV screens are favoured over mobile applications.

Figure 15: Suggested display options for the proposed PIS: *(a)* at-platform real-time information display and *(b)* mobile app real-time information display

(a) At-platform real-time information display	*(b)* Mobile app real-time information display

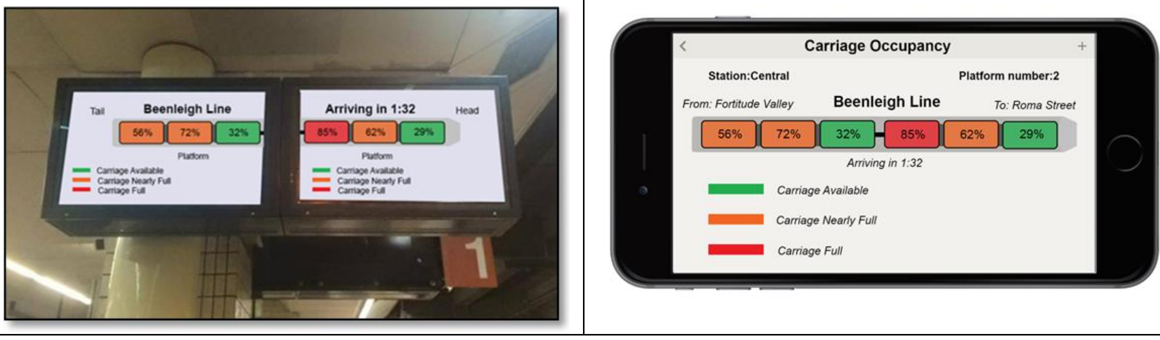
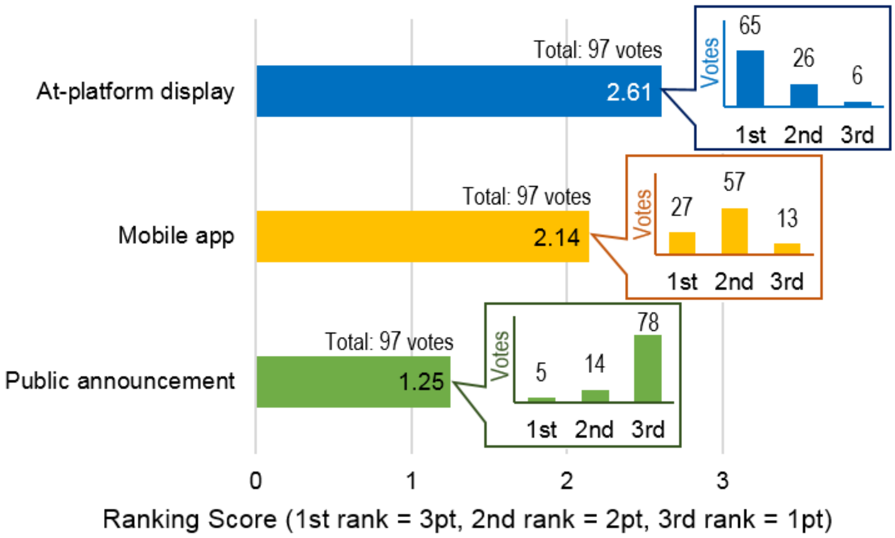


Figure 16: Rank in order from highest to lowest the best way of displaying the information via the proposed PIS



4. Conclusions, Limitations and Future Work

Both the simulation and the survey results show that the implementation of an improved PIS involving carriage occupancy information has potential to lead for passengers to re-distribute themselves more efficiently along the platform to more evenly distribute the passengers on board the carriages. More specifically, the survey showed that passengers would like to obtain a place in a carriage with a low occupancy level, and that if passengers are given carriage occupancy information, they are likely to change their waiting area on the platform based on this information. The conceptual agent-based simulation model was designed to integrate the survey results to agents in the model to test various hypothetical scenarios representing the process of informed decision based on different hypothetical PIS settings.

The results obtained from the simulation model showed that if passengers are given carriage occupancy information and change their waiting area on the platform, then the internal carriage distribution will be more uniformly spread.

However, the current conceptual simulation model cannot take into account the local interactions among passengers which can create substantial delays. In other words, passenger flow performance is to be fully defined as the indicators to measure the interaction between passengers. An ongoing effort will be made to update the conceptual simulation to accurately represent the real world from the perspective of the intended uses of the model such as the feasibility study of the proposed PIS system.

One example of how the solution of using a PIS for carriage occupancy information could be implemented is through the use of beacons. Beacons are devices that can detect the number of electronic devices (for example, mobiles phones) in the vicinity. A beacon could be placed on every train carriage to count the number of passengers on each carriage (based on the number of electronic devices that it counts) and then this occupancy information would be sent to another source such as the television screens on the platform, an announcement over the PA (Public Announcement) system or a mobile application. Passengers could then see this information before the train comes to a stop at their station and wait in areas along the platform where current carriage occupancy is low.

There are many possible areas for further research incorporating both the simulation and the survey. One such area is data collection. Instead of having most survey respondents being concession smart card holders, the survey could be expanded to a more diverse demographic to be more representative of the overall population. Additionally, data collection for the simulation model would be useful. For example, collecting field observations such as the number of boarding and alighting passengers on each train, the passenger waiting times, the type of people (student, worker, elderly) using the station, etc. More research is also needed into the beacon technology to find if this technology is reliable enough for the purpose of carriage occupancy information and if it feasible cost-wise. Finally, further work could be done on the simulation to account for different volume levels of passengers and various decision making time.

5. Acknowledgements

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