Analysing passengers' behaviours when boarding trains to improve rail infrastructure and technology

Luis CR Oliveira [1], Catherine Fox [1], Stewart Birrell [1], Rebecca Cain [2]
[1] WMG, University of Warwick, Coventry, CV4 7AL, United Kingdom
[2] Design School, Loughborough University, LE11 3TU, United Kingdom

Abstract. Concentrated boarding describes the phenomenon when rail passengers congregate in certain areas of the platform and board the train carriages that stop near these areas. This influences the distribution of passengers throughout the carriages, which can negatively affect passenger comfort, safety at the platform-train interface, efficiency of the rail network, and the reputation of rail travel as a whole. This project aimed to determine whether concentrated boarding occurs in stations in the UK in order to understand its relevance for future rolling stock, infrastructure design and its associated manufacturing research. Video recording technology was used to observe the movements of passengers in Oxford Station and data was collected for nine individual trains. By reviewing the recordings, the number of passengers boarding through each door of the trains was determined, and the boarding distribution along the length of the platform was plotted. Several reasons for noted trends are offered, and potential solutions proposed. The use of real time information could be invaluable to minimise concentrated boarding, as it would allow passengers to make informed decisions as to where they could board trains to have a better journey experience. These findings indicate the relevance of a human-centred design process, particularly the user research stages, in the process of defining priorities for manufacturing and engineering.

Keywords. Station design, Railways, UX, passenger behaviour, platform-train interface

1. Introduction

Railway transportation is one of the most popular methods of transport in the United Kingdom, allowing large numbers of passengers to travel in an efficient and cost-effective way. There has been substantial growth in the importance of rail travel, reflected in the number of passenger journeys across the UK. One government report shows almost continuous growth in recent years, as figures indicate that train operating companies are providing more than double the number of journeys by rail in comparison to two decades ago [1]. Transporting such high volumes of passengers provides its own challenges; overcrowding on trains and platforms can often be observed, and is a common complaint from 20% of passengers in the UK [2]. With passenger numbers growing faster than the increase in service capacity [3], this can have a further impact on the safety of passengers and staff, user experience and on the finances of the operators.

British rail transport is observing an increase in demand in recent years [4,5], and the extra demand can negatively affect how passengers perceive the quality of the service. With a fast growing number of passengers in diverse countries, platform congestion is common during peak times [6]. The amount of time a train remains stationary at a station, also known as 'dwell time', is fundamental for the effectiveness of the rail system. This time increases if large numbers of passengers are queuing to board, which will have negative operational implications [7].

A contributing factor to the perceived overcrowding in the railway sector is concentrated boarding. This phenomenon occurs when passengers congregate at access points to station platforms, such as at the ticket barriers, or near staircases, meaning that a high proportion of passengers board using the same doors. This can lead to some carriages being crowded whilst others remain relatively empty, and lead to a negative customer experience. It could also cause safety concerns at the platform-train interface, as large crowds boarding through one door can cause individuals to trip or slip whilst climbing aboard the train [8]. Another disadvantage of concentrated boarding is the potential financial impact on the train operating companies. Train operators are required to pay compensation to the infrastructure operator and to other train operators to make up for 'lost minutes' caused by unpunctual services [9].

For years, the manufacturing research community have been attempting to track human motion to improve the interaction with work environments [10]. This article intends to extend this concept with the application of ergonomics to a broader scenario, encompassing passenger interactions with transport infrastructure and technology. Evidence from this paper shows that the principles of human factors can be applied to improve the design of stations and optimise the flow, efficiency and passengers' wellbeing whilst in transit.

2. Literature review

2.1. Concentrated boarding

The boarding and alighting process had been subject of several studies, generally in a laboratory setting [11]. Such research has attempted to quantify the number of passengers passing through doors in a given time, and proposed layout modifications for both the platform and trains [12,13]. Usually, the objective is to understand the impact of boarding and alighting on the dwell time, calculating how long it takes for all passengers leave or board the train [14].

Canadian studies have indicated that there was a high distribution of passengers waiting for the light rail trains next to the location of the only platform access point [15]. One study on the Toronto metro system also indicated that the position of the station's entrances determines the boarding pattern, with the highest proportion of passengers boarding the first carriage nearest to the station's only transfer and entrance point on all the trains studied [16]. A study carried out in several railway stations in the Netherlands observed that the station infrastructure does appear to cause a concentration in the areas where people board trains [7]. Another study held at eleven Dutch railway stations observed "clear concentrations of waiting and boarding passengers around platform accesses", although no specific figures were provided [17].

One extensive research project in Seoul, Korea, interviewed 340 passengers to understand their preferences for metro carriages. The majority of participants (76.6%) said that "their motivation was to minimize the walking distance to an exit when they disembarked, 16.6% reported that they sought to minimize the distance from the entrance when they boarded at an origin station, and the remaining 13.5% reported that they wanted to pursue comfort while traveling" [18]. In Switzerland, one study also showed that passengers tend to minimise walking distances at the destination [19]. Similarly, a study in Vienna, Austria, asked metro passengers why they board through certain doors, and found they have the tendency to board the carriage to optimise the exit process at the destination, and the crowdedness of the carriage was ranked in second place determining the choice of boarding position [20].

2.2. Initiatives to reduce concentrated boarding

After understanding the reasons for concentrated boarding in Austria, one study proposed a system to counteract the concentrated boarding by measuring train occupancy via the weight of the carriage then communicating that to the next station [20]. A display in red or green would show on the platform which wagons were less crowded, with the intention to make passengers move to the locations near less crowded carriages. One study with commuter trains in London, UK, also suggested a passenger information screen to optimise the "platform utilisation and the distribution of passengers, providing information so that passengers know where to wait on the platform for different length trains" [21].

A different approach was proposed by researchers working at the Schiphol Airport station in Amsterdam, Netherlands. Instead of expecting passengers to move to other points on the platform, they tested the adjustment of the train stopping position, which was changed by 50 metres further forward. This simple measure decreased station dwell times by 30s during rush hour, and the average station dwell time decreased from 144 to 112s [6]. However, this method does not reduce the crowdedness of specific areas of the platform, and merely facilitates these passengers boarding less busy carriages instead.

Researchers in the UK asked passengers of the Gatwick Express (London, UK) if they would alter their choice of train or move along the platform if they had information about crowding via a website, a smartphone app or at the station. Passengers were found to prefer the carriage closest to the exit at the destination station, but non-commuting business travellers expressed a willingness to walk further in order to find an available seat [22,23].

A possible way of reducing crowding on platforms, and therefore concentrated boarding, is through the use of visual markings on the platform which direct passengers to spread out along the full length of the platform. This system is frequently employed on both mainline rail and metro systems (Figure 1). However, there is no evidence to confirm if these markings substantially decrease the levels of concentrated boarding.

Figure 1 - Platform markings at Coventry railway station, UK

Research with passengers of long distance trains found out that the boarding process usually results in a rather negative experience, and that passengers want to have a seat [24]. On these trains, where the ability to find a seat may be more valuable than on the metro and commuter services, measures can leverage the need for a seat to motivate a more even distribution of passengers throughout the train. Smartphones can be effective sources of information to provide real-time pre-trip information [25,26]. Navigation and wayfinding information can be given directly to passengers informing where to stand in order to locate the available seats [27]. Projects [28] have proposed showing a diagram of free and reserved seats on phones, so passengers will be able to see the occupancy level of individual carriages and check where seats are available, therefore having the information about the optimum place on the platform to wait for the train.

2.3. User experience research

The design, development and introduction of technological systems in the market should be based on comprehensive user research to increase the chances of acceptance [29,30]. Understanding user behaviours is fundamental to map possible challenges and address these in the early phases of development. In transport studies, journey maps have been used to illustrate the problematic points of interaction for bus [31] and rail passengers [24,32]. A recent government report indicated the need to increase the public transport user experience as one of the solutions to promote efficient and sustainable transport systems that meet the needs of travellers in the UK [33].

2.4. Research gap

Aside from one short paper [34], no published research was found regarding actual observation of train boarding patterns at mainline railway stations in the United Kingdom. The present study was designed to establish whether concentrated boarding is prevalent in these stations. By proving or disproving this theory and evaluating its effects, it was hoped that potential solutions might be considered by railway companies, which would be beneficial to both passengers and the companies. This project has been undertaken as part of the CLoSeR Project, which is a multi-partner project set to develop systems which will improve diverse areas of rail travel. By better understanding the causes of concentrated boarding, the project will be better equipped to design, manufacture and tailor systems to reduce these negative effects and potentially improve the experience of rail travel for passengers.

3. Methods

3.1. Observation

Otherwise known as the bird's eye technique, this style of data collection allows researchers to gather information without direct interference with those being observed [35]. Another method used in several studies of passenger behaviour is video recording. Obtaining recordings allows large quantities of data to be analysed extensively and, when mounted discreetly, cameras are capable of avoiding the 'observer effect' [36]. Unobtrusive observation seemed to be the most appropriate data collection technique in the context of studying concentrated boarding, as it enables large numbers of people to be studied in public spaces. The observation of passengers boarding public transport and their behaviours has been subject of previous studies, but usually focusing on the ergonomics aspects of boarding, finding seats and alighting [37], or the on-board activities performed by passengers [38].

3.2. Location

Data was collected on-site at Oxford Station (Park End St, Oxfordshire, OX11HS, UK). After initial contact with the station manager to explain the project, a preparatory investigation was carried out at Oxford Station. Prior to the visit, the timetables for each platform had been reviewed in order to see which was the busiest, and would therefore provide the most data. Whilst on-site, it was observed that there were several locations along the platform where cameras could be positioned easily by placing them on top of platform furniture, such as signage and vending machines. Several short test shots were performed to determine which angles would be preferred to record as large an area of platform edge as possible without obstructions. These preparatory recordings, along with observations during the first visit, indicated the positions of the cameras, so that during actual data collection there would be overlap between the areas covered by the cameras to ensure no doors would be missed. Eight digital point-and-shot cameras, mounted on small tripods, were placed in strategic places along the length of the platform, such as can be seen in Figure 2.

Figure 2 – Camera used during this study

3.3. Recordings

Data was collected on Platform 3 of Oxford Station on the 18th November 2016 to determine crowd behaviours when passengers board trains. Whilst at Oxford Station, a platform plan was produced as a rough sketch, so that the positions of specific features, such as platform furniture, entrances, staircases and structural members could be reproduced graphically as illustrated in Figure 3 below. Cameras A and B were affixed to a drainpipe using adhesive tape. Cameras C, D and E were placed on top of a timetable board. Cameras F, G and H were placed on top of a vending machine. Each camera was set to record continuously from approximately 3:00 pm. As the cameras would automatically turn off after one hour of continuous recording, they were all reset at an appropriate time so that data from trains around this time would not be affected. The eight cameras were unable to watch the whole platform, meaning that for the longer trains some carriages stopped beyond the areas covered by the cameras. Passengers boarding these carriages were counted individually or recorded using cameras on mobile phones by two of the authors positioned at both ends of the platform.

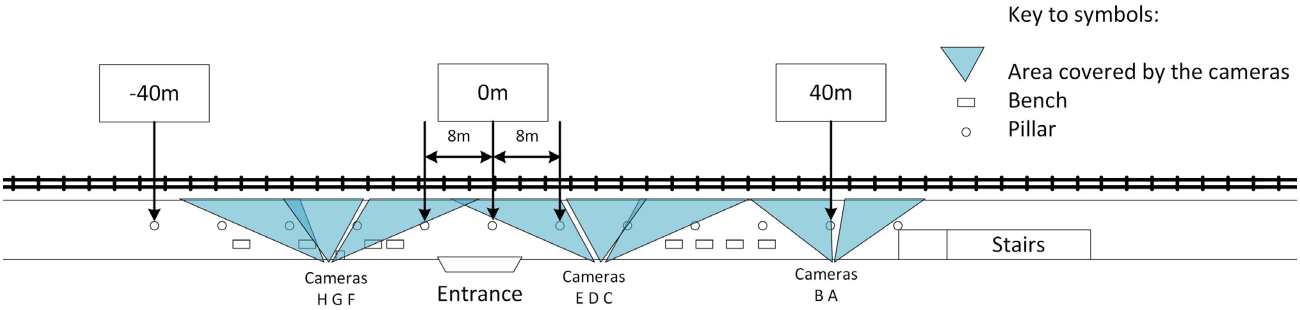

Figure 3 – Platform diagram and positioning of the video cameras

3.4. Ethics

As the project involved the observation of members of the public without their prior knowledge or consent, our use of unobtrusive observation brought about ethical concerns such as the observation of vulnerable groups of people. It was very important to preserve the anonymity of any groups taking part in the data collection, and to only collect data in situations where people would ordinarily be observed in a public place, and where they would normally expect CCTV cameras to be in operation. Whilst collecting data, four A4 posters were displayed to inform participants of the video recording and uses for the data. One poster was placed immediately below cameras A and B, attached on the drainpipe with self-adhesive pads. One poster was displayed on the wall below cameras C, D and E, and two posters were placed one on each side of the vending machine (for cameras F, G and H). It was agreed that the researchers would cease filming if any individual raised serious concerns or was uncomfortable with being filmed (which was not the case). This work had been approved by the Biomedical & Scientific Research Ethics Committee from the University of Warwick.

3.5. Data

Data was recorded from nine individual train departures from Great Western Railway (GWR) and Cross Country services, which stopped at Platform 3 from 15:07 to 16:31 (Table 1). Reviewing the videos allowed the numbers of passengers boarding through each door to be counted, and other factors which might have affected the boarding process (such as the loading of bikes or the buffet cart, and the boarding of less mobile passengers) were observed. The data for each train was recorded in a Microsoft Excel spreadsheet, giving a total of 581 passengers boarding the trains. The recordings were also used to determine the number and type of carriages in every train, and the distance along the platform that the front of each train came to a halt in relation to the entrance. Stopping positions considered 0m as the pillar directly in front of the entrance (Figure 3), with the right hand end of the platform (towards the rear of the train) defined as positive values, and the left hand end of the platform (towards the front of the train) defined as negative values.

Table 1 – Details of the trains studied at Oxford Station

Train No.	Time	Origin	Destination	Operating Company	Model of train/ Carriages	No. Passengers boarding	No. Doors	Approximate stopping position (m)
1	15:07	Oxford	Ealing Broadway	GWR	BR Class 165	33	10	-22
2	15:16	Manchester	Bournemouth	Cross Country	BR Class 220	17	8	-38
3	15:31	Worcester	London Paddington	GWR	BR Class 165	102	10	-20
4	15:37	Banbury	Ealing Broadway	GWR	BR Class 165	69	8	-19
5	15:43	Glasgow	Southampton Central	Cross Country	BR Class 220	20	10	-34
6	16:01	Oxford	London Paddington	GWR	BR Class 180	114	8	-24
7	16:07	Oxford	Ealing Broadway	GWR	BR Class 165	53	12	-27
8	16:16	Manchester	Bournemouth	Cross Country	BR Class 220	55	8	-21
9	16:31	Worcester	London Paddington	GWR	Intercity 125	119	14	-54

4. Results

As can be seen on Figure 4, our results indicate that there is evidence of concentrated boarding. The first example shows that almost 60% of the 102 passengers boarded this train within 16 m either side of the main entrance, comprising the two first coaches. Fewer than 10% of passengers boarding the back two carriages (to the right on the image). The second example adds evidence of the concentrated boarding, although the last coach was first class. Other particularly problematic service was number 9, the longest train observed. This was an Intercity 125 high-speed train, with one locomotive at each end, and two coaches for the first class and buffet towards the front of the train, which stopped near the access to the platform. The next available standard class door was used by 38 passengers (32% of passengers boarding). This train composition clearly affected the overall distribution of passengers, with most passengers boarding immediately in front of cameras E, D and C. This service was at a peak time.

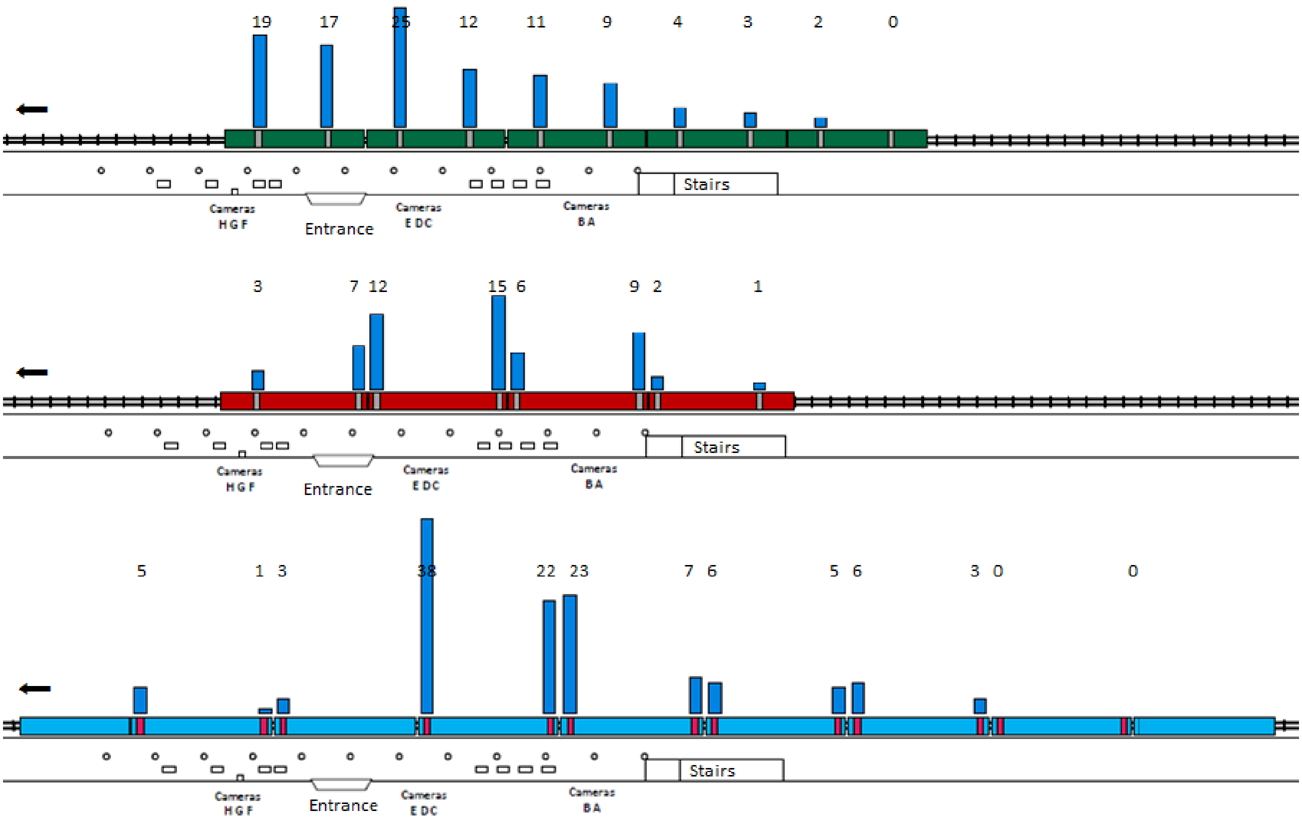

Figure 4. Train 3 (top), 8 (middle) and 9 (bottom) as examples of the number of passengers boarding through each door

Figure 4 exemplifies the number of passengers boarding through the doors of three trains, in context with the train and the station layout. However, since as almost every train had a different layout or stopped in a different place, it was difficult to group any of the data with respect to the 'door number'. To combat these problems, the platform was later split into 8m blocks, so that the exact distances along the platform where passengers boarded could be visualised more easily using bar charts (Figure 5). The distances of each door were determined and the data grouped into intervals along the platform, with 0m taken as the pillar in front of the main access to the platform.

Table 2 presents the number of passengers boarding the observed trains by their positions on the platform. The advantage of grouping the results as distances is that it makes the data easier to describe, and therefore the evidence of concentrated boarding made clearer. The different train layouts meant that in some 8m blocks, several doors in close proximity contributed to a high concentration of passengers, thus affecting the trend of the data. By grouping the data into larger 16m blocks, this effect can be reduced, and the overall trend restored more easily (Figure 6).

Table 2 – Number of passengers per train and per 8-metre position on the platform (0 being the platform access, positive values to the right and negative values to the left)

	-40--32	-32--24	-24--16	-16--8	-8-0	0-8	8-16	16-24	24-32	32-40	40-48	48-56	56-64	64-72	72-80	80-88	88-96	96-104	104-112	Total
Train 1				2	9		7	6		7		2								33
Train 2	3			2			7			4			1							17
Train 3				19	17		25	12		11		9		4	3		2	0		102
Train 4				7	12		31	5		5		6		1	2					69
Train 5	0			6			5	3			4			1			0			19
Train 6						48			32			14	6			14				114
Train 7			2	7		10		8		12	14									53
Train 8				3		7	12		21			11			1					55
Train 9	5			4				38			45			13		11			3	119
Total	**8**	**0**	**2**	**50**	**38**	**65**	**87**	**72**	**53**	**39**	**63**	**42**	**7**	**19**	**6**	**25**	**2**	**0**	**3**	**581**

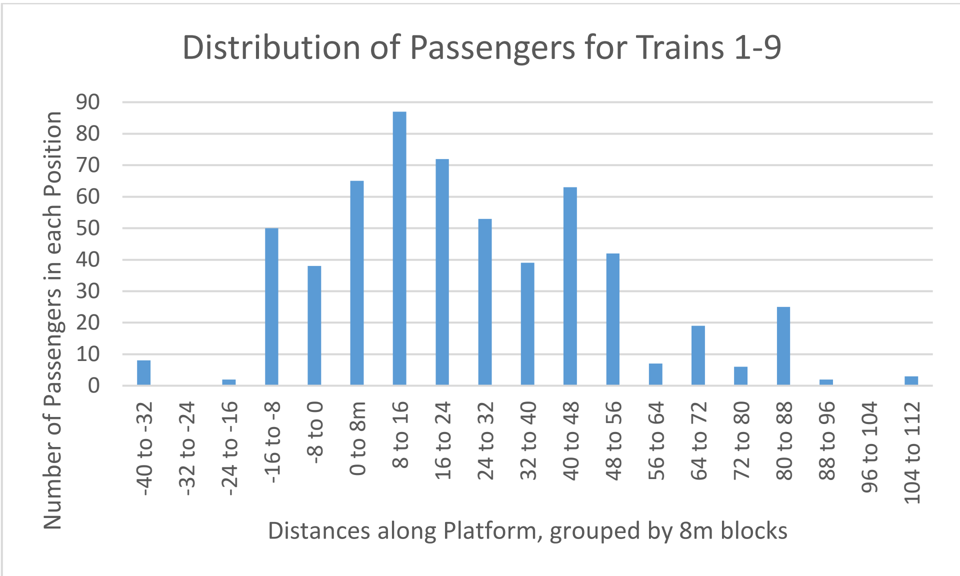

Figure 5 – Distribution of all passengers along the platform by distance (8m blocks).

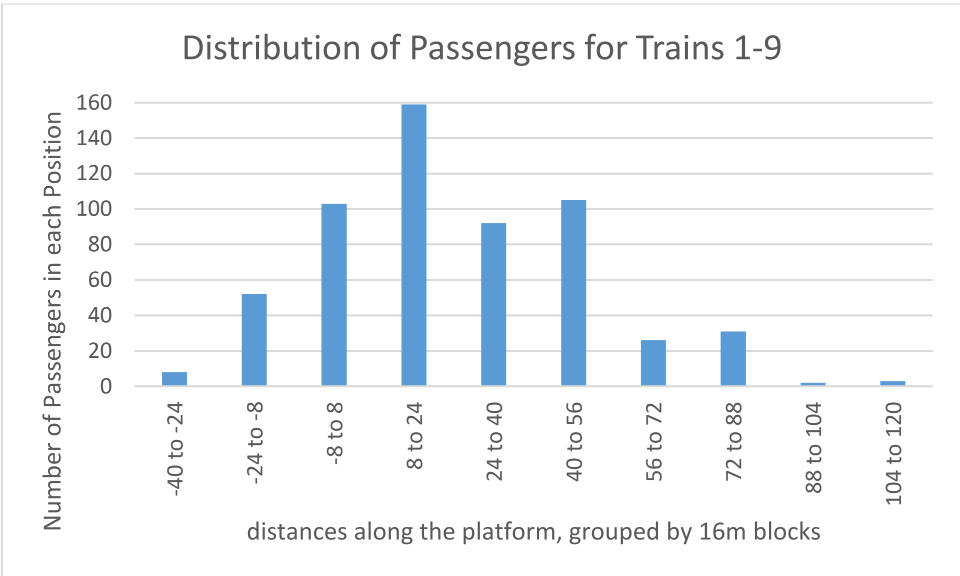

Figure 6 – Distribution of all passengers along the platform by distance (16m blocks).

Figure 5 presents the distribution of passengers for all the trains studied, agregated by the distance to the main access to the platform. The most common position for passengers to board the train is between 8 and 16m to the right of the entrance. As can be seen on Figure 6, over 50% of all passengers studied boarded the train in an area of less than 24m to either side of the main entrance, with this percentage decreasing towards the extremities of the platform.

4.1. Dwell time

Figure 7 shows the duration of the dwell time with a breakdown of time used by each activity whilst the train remained stopped at the station. As soon as the train came to a halt, we timed how long it took to open the doors, passengers to alight (if any) and board the train, the idle time (when the train remained stationary with doors open but no passenger alighting or boarding) and the time taken to close the doors and start to move. Train 9, which had the most prominent concentrated boarding, also had the longest dwell time. Even with no passengers alighting, it took 75 seconds for 38 passengers to board through the busiest door. For comparison, trains 3 and 6, with more than 100 passengers boarding, managed to have all passengers on board on much shorter times (23 and 45 seconds respectively) (Table 3). The issue of concentrated boarding was particularly problematic for train 9 because of the design of the train. The Intercity 125 has narrow doors, allowing only one passenger through at a time. Furthermore, these doors have to be manually closed. Station staff are required to walk the length of the platform checking if the doors are secured before departure, resulting in long 'closing doors' time. The total time this train was stationary was 3 minutes and 27 seconds. Trains 1, 3, 4 and 6 had longer 'idle' time because they arrived at the station with time to spare (of those, trains 1 and 6 originated from Oxford).

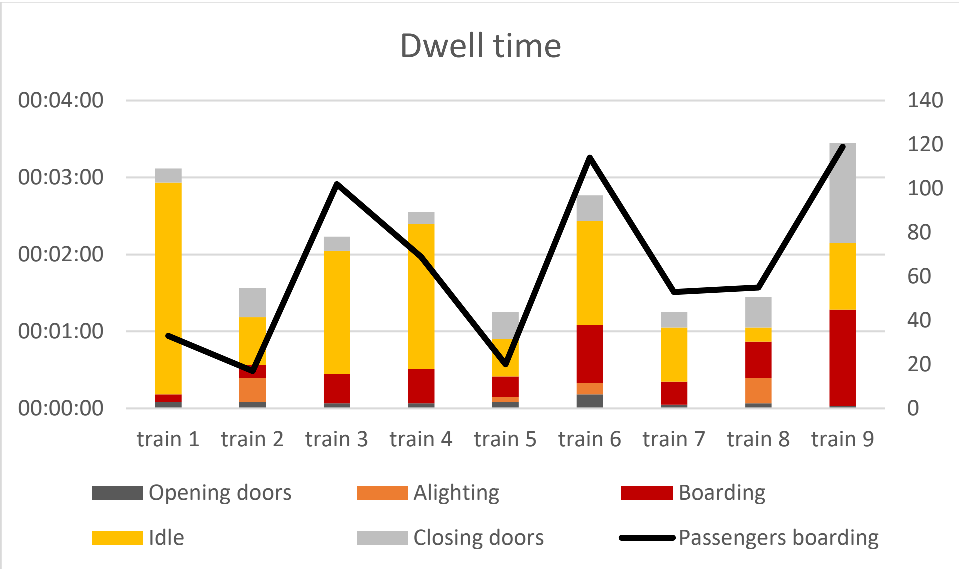

Figure 7 – Breakdown of time (minutes) used per train whilst stopped at the platform, and number of passengers boarding (secondary axis)

Table 3 – Breakdown of time used per train whilst stopped at the platform, and passenger boarding

	train 1	**train 2**	**train 3**	**train 4**	**train 5**	**train 6**	**train 7**	**train 8**	**train 9**
Opening doors	00:00:05	00:00:05	00:00:04	00:00:04	00:00:05	00:00:11	00:00:03	00:00:04	00:00:02
Alighting	00:00:00	00:00:19	00:00:00	00:00:00	00:00:04	00:00:09	00:00:00	00:00:20	00:00:00
Boarding	00:00:06	00:00:10	00:00:23	00:00:27	00:00:16	00:00:45	00:00:18	00:00:28	00:01:15
Idle	00:02:45	00:00:37	00:01:36	00:01:53	00:00:29	00:01:21	00:00:42	00:00:11	00:00:52
Closing doors	00:00:11	00:00:23	00:00:11	00:00:09	00:00:21	00:00:20	00:00:12	00:00:24	00:01:18
Dwell time	00:03:07	00:01:34	00:02:14	00:02:33	00:01:15	00:02:46	00:01:15	00:01:27	00:03:27
Passengers boarding	33	17	102	69	20	114	53	55	119

4.2. Heatmaps

Heatmaps were also produced in order to display the data in the context of the station infrastructure. Best known for plotting eye-tracking data on a multi-coloured map, they can also be used to analyse movements of pedestrians [30]. Figure 8 summarises the areas where most of the trains stopped. It can be seen that most trains stop with the front of the train within 24m of the entrance of the platform. Only one train stopped beyond the 40m reference point, by the first pillar, which limits the canopy area. Consequently, the back carriages are usually beyond the stairs, which is an area without the canopy.

Figure 9 shows the most popular areas for the boarding of trains. Passengers tend to use the doors in front of the entrance, 16m to the left and 48m to the right. This image indicates that passengers have a tendency of using only 64 metres of platform 3.

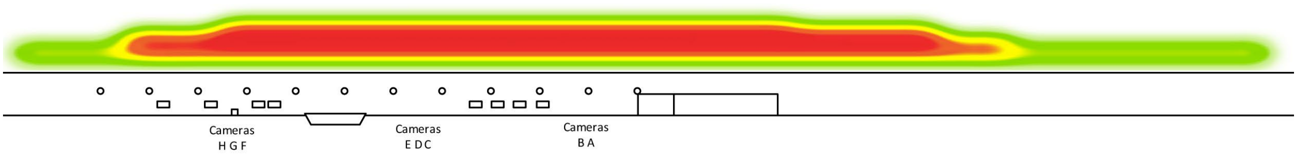

Figure 8 – Heatmap displaying the most frequent positions in which the trains stopped

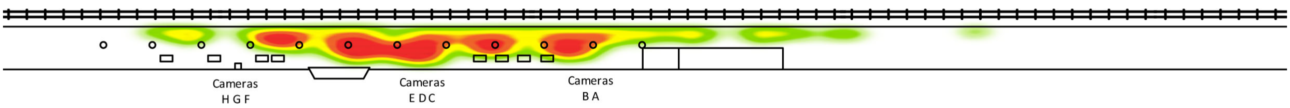

Figure 9 – Heatmap displaying the most frequent positions in which passengers boarded the trains

5. Discussion

By studying the distances along the platform at which people board, evidence of concentrated boarding can be found. Over 50% of all passengers studied boarded the train in an area between 24m to the left and 24m to the right of the main access to the platform. It was observed that on certain occasions, a large number of passengers gathered in front of specific doors, for example the fourth coach of train 9. The compounding conditions of the approaching rush hour, and the first class coaches arriving at the most populous area of the platform meant that 38 passengers (32%) boarded through the first available door. This number is above what was considered the 'worst case scenario', as suggested by Harris [14].

Several explanations could be provided for why concentrated boarding occurred at Oxford Station. Some of these decisions could be made on a conscious level, with the passenger choosing a carriage for a reason. Passengers may have a reservation for a specific seat, or be thinking ahead in the attempt of optimising the exit at the destination [18]. Previous studies show that passengers who travel frequently choose a particular carriage of the train based on the layout of the station where they will be disembarking [21,23]. In order to leave the destination station fastest, passengers choose to board the carriage that will likely come to a halt closest to the destination station exit. This may provide some explanation as to why the distribution of passengers is slightly skewed towards the front end of the platform for trains 3, 6 and 9, which are GWR services and all terminate at London Paddington Station. It is likely that the majority of passengers travelling from Oxford will be disembarking at London Paddington, which is a terminus station. Therefore, some experienced passengers prefer to board at the front of these trains, which will arrive closest to the ticket barriers and main exit. Conversely, trains 2, 5 and 8 do not demonstrate concentrated boarding very clearly. The distributions found on Cross Country services are less skewed towards the front end of the platform in comparison to GWR services. As these are all Cross Country services, this can be attributed to the destinations of the services. Table 1 shows that the final destinations of Cross Country trains are not terminus stations, therefore their exits are unlikely to be towards one end of the train.

Other explanations for concentrated boarding could be subconscious, with the passenger naturally drawn to the door by which they board, perhaps influenced by the environment around them. Station infrastructure and platform furniture seems to influence where people stand while waiting for the train. The length of the canopy and the position of the stairs limited the area where the majority of passengers stood at this specific platform. Another reason for this is the fact that that the trains studied were of differing lengths, and stopped at different positions. Consequently, the central portion of the platform would be expected to have highest chances of being provided with a door. Passengers with little experience of boarding trains at a new station may not be aware of where the train is likely to stop at the station. Therefore, passengers would congregate in the central area to have better chances of having a door in front of them in comparison with the extremities of the platform. It is also possible to relate to the tendency for passengers to seek convenience, and their unwillingness to walk unnecessarily. As they enter the station, they may wish to rest their legs, and so endeavour to stop walking as soon as they deem appropriate. When the train pulls into the station, the passengers will then board the train at the doors closest to them [39].

Another factor influencing the decision of where to board is the positioning of the first class carriages. The first class area was at the front of trains 5, 8 and 9, causing passengers who were waiting at the left of the main entrance to have to enter a carriage further back in the train. Passengers were then seen boarding through the closest available door.

It was observed that passengers who arrive at the station later than the train are more likely to board the train at the nearest point. This is a logical concept as, in this circumstance, travellers will put catching the train as a priority, and will consider their further comfort once they are safely on board [16]. The likelihood of concentrated boarding would decrease as the platform gets particularly crowded, forcing people to make full use of the entire length of the platform, or causing people to choose other doors if they observe long queues to board the train through the door where they stand.

5.1. Strategies

From the data presented here, a few strategies can be suggested in the attempt to minimise the prevalence of concentrated boarding. These options encompass changes to the design of station infrastructure and train coaches [8], changes to train stop position, and the use of new technology. Width of doors, size of gap, height of steps and the presence of vestibules create conflicts during boarding, which ultimately affect the dwell time [40]. However, improvements on these aspects are expensive and time consuming [41], yet unlikely to interfere with the distribution of passengers through different carriages.

Changes can be made to the station infrastructure in order to reduce the prevalence of concentrated boarding. One option would be to make changes to the exact layout of the station, such as having entrances, ticket barriers, stairs and other elements such as furniture, vending machines and waiting rooms more spread out along the length of the platform. Since passengers tend to board a carriage to minimise the walking distance at the destination [18], improving platform access in the final station will also minimise the problem of concentrated boarding at the originating station.

The stopping position of trains is proven to improve the dwell times, and therefore can be a strategy used to manage the boarding process at busy stations [6]. Our results demonstrated inconsistency on where trains stopped, sometimes increasing the concentrated boarding. Drivers could dynamically use the stopping position to make passengers use specific doors according to the existing scenarios in given stations. To implement this strategy, train drivers would have to know the historical or, ideally, current concentration of passengers on the next calling platforms. A method could be for the train to stop with the less busy coaches to appear in front of the busiest areas of the station.

In recent years, real time information has become much more widely used in public transport systems [42], and is a frequent demand from passengers [43]. Smartphones can be used as platform for delivering information and motivating users to change behaviours [44]. Technology can be employed in order to indicate where the train will come to a halt in the station, so passengers would know the area of the platform covered by the train. Options for sharing this data with rail travellers include through mobile technology applications, or via display boards installed on the platform [45]. This information could also convey information about the location of first class carriages and where each coach will stop [27]. That way, passengers with a reserved seat would know where to stand, and it could improve the experience of boarding [24]. Technology could also be used to provide real time information on seat availability throughout the train, allowing passengers without a reservation to make informed decisions as to where to position themselves on the platform. Simulations indicate that there is potential for technology to optimise the boarding process and the knowledge of the location of free seats can foster a more even distribution of passengers on board of trains [46]. Whilst knowledge of exits at the destination is an influencing factor for commuters who travel on the same routes on a daily basis, it may not determine the behaviour of leisure or business travellers [23]. Hence, less experienced travellers can be supported more effectively with technology in their attempt to find seats and have a more comfortable journey.

Heatmaps similar to Figure 8 and Figure 9 provide context for the distribution of passengers boarding, together with the position of where the trains stop in the station. These proved to be useful for summarising the overall findings of the data collection, and are clear for people to understand the busy areas via a simple colour scheme. Different versions of these heatmaps could be produced for trains throughout the day. These could be displayed on platform signage to demonstrate the observed boarding distributions to passengers, in order to encourage them to take action to distribute themselves more evenly, to avoid the discomfort of crowding on the platform and on the train.

There is a potential disadvantage for this technology to become too popular: as if everyone uses it, concentrated boarding could become worse under certain situations. For example, if the real time information showed one carriage to be particularly empty, then passengers could crowd this area, and thus merely changing the location of concentrated boarding. It would have the advantage of generally preventing crowding within trains, however, as passengers would be able to check the availability of seats throughout the train, and therefore seek these out whilst on board.

5.2. Limitations and future work

The range of data from Oxford Station collected during this research was limited, as it covered only around two hours due to the digital cameras having limited battery life and memory space. This meant that the boarding process could be recorded and analysed for only nine trains. Thus, data could be affected by the time and day at which it was collected. This research also only considered one location. It is understood that passengers from different areas of the country and stations with diverse layouts might display differing traits.

This study used manual counting of each passenger boarding through each door, which proved to be a time consuming task. There are other systems capable of counting passenger flow through doors using cameras or infrared sensors, or measuring occupancy via the weight of the carriage [47]. However, since these sensors are located on the train, and that the train stopping position varies, they may not provide a true picture of the position on the platform where the passengers congregate. A more accurate measurement of concentrated boarding should combine door access counting with the location of that door relative to the platform.

Future research could observe a larger number of boarding processes for longer periods. Cameras should be connected to the mains for power supply and to hard drives for video storage, which would allow for much longer uninterrupted recordings. In addition, more stations and more platforms could be studied. It would provide a larger dataset to allow comparisons between platform designs and indicate trends in terms of train types, train operating companies, destinations and times of the day. That way, results would have more confidence and could potentially be generalised. Research could also evaluate in more detail and for longer periods how the concentrated boarding affects dwell time. By highlighting the time that trains have to wait for passengers to board, especially during the morning and evening peak times, it could provide a broader picture of the effect of concentrated boarding on the efficiency of the rail system as a whole.

Not knowing where trains stop may explain passengers' behaviours, but this information is not wholly clear from this study. Further research could make use of qualitative data to understand why passengers stand at particular places, via a range of methods such as interviews or self-report cultural probes [48]. Passenger could share their reasons for choosing specific areas of the platform and other details, for example destinations and their (lack of) familiarity with the current station or destination. By hearing from passengers themselves, it will be possible to assess more closely their reasons for choosing a place to wait for the train. It will also help understand the experience of passengers boarding through different doors, and provide a better picture of how they feel, similarly to studies mapping the passenger experience [24]. Future work could analyse, as well as train destination, the next stop and/or time to next stop. Passengers travelling on short distance services may regard seating as less important than those who will travel for long, and passengers disembarking at a terminus station may have their own reasons for preferring coaches towards the front of the train [22]. Another final recommendation for future research involves the implementation and evaluation of technology designed to counteract concentrated boarding. Studies could be carried out to establish the level of engagement that installing these systems would receive from the public. In addition, real-world assessment of the efficiency of these systems could be implemented, in order to evaluate their impact and the possible benefits of technology to reduce concentrated boarding.

6. Conclusion

This study, focusing on mainline rail, demonstrated the existence of concentrated boarding, the fact that passengers congregate at specific areas of the platform and tend to board through the doors closest to the platform access. This paper proposed different options that might help to reduce the incidence of concentrated boarding. Some of these solutions involve infrastructure changes, which would be costly and would require a certain level of engagement from stakeholders and the public to be successful. One promising option considered was the use of real time information in order to communicate to the public where the train will stop, the occupancy level of each carriage and the location of free seats. If this information is constantly updated and is consistently accurate, it could provide a clear motive for passengers to act to reduce concentrated boarding.

Observing user behaviours proved to be an invaluable research method to inform the design of rail systems. Manufacturing research can provide modern techniques to facilitate data collection for mapping human movements [49]. Automated passenger tracking and counting systems could be mounted on the station ceiling to provide this data [50]. Human-centred manufacturing techniques had been used to improve work environments using diverse types of motion capture [51]. The research community in Robotics and Computer-Integrated Manufacturing can provide the additional tools needed to define the re-design actions needed to improve the layout of rail stations.

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