The effect of suburban train carriage design upon punctuality, ingress and egress occlusion and passenger comfort.

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ABSTRACT

Many suburban railway systems around the world are experiencing a rapid increase in patronage. While this is a welcome development as an alternative to road congestion, higher passenger densities particularly during peak times of the day have implications upon punctuality, crowding and the passenger perception of comfort.

The authors suggest that station dwell times are a significant factor in service punctuality and are determined by a number of variable factors such as passenger movement through doors, crowding on board, and the carrying of objects, and that these relate directly to the design of the carriage.

The literature (Lau, Harris, Daamen, Bronkhurst et al) generally focuses upon the creation of predictive models around existing vehicle designs with the potential of informing more accurate timetables. There appears to be a paucity of academic research from an industrial design perspective. This paper analyses a variety of carriage designs from around the world to determine what strategies might contribute to a future design of suburban train.

THE AIMS OF THIS PAPER

The primary aim of this paper is to examine the literature surrounding the issues of punctuality where it is affected by accessibility and crowding. The secondary aim is to reveal what current design strategies exist to ameliorate this problem and to what extent they could inform the design of a new suburban train carriage. This paper is divided into three distinct sections;

1. Articulating the problem, how it is currently manifested and measured.
2. A review of the current solutions to reconcile train boarding and crowding problems.
3. An evaluation of the literature that indicates an opportunity to employ a Design methodology to extend and enhance current strategies.

1. ARTICULATING THE PROBLEM

Trains are independent of congested road traffic conditions and therefore have the potential to be faster at delivering passengers into city centres. However increased patronage has led to overcrowding especially at peak times. Overcrowding has an effect upon the length of time the train stops at the station (dwell time), this in turn will have an effect on punctuality. Studies in the value passengers place upon punctuality reveal not only an experiential perception but also a cost. (Kroes et al 2006) conducted a wide-ranging literature review concerning train punctuality from which they drew the following observations;

- Delayed trains mean that passengers may arrive at their end destination late. There are then possible repercussions on connections and appointments, etc.
- Predominant passenger responses to delays are a) acceptance or b) building in a margin in the expected trip time.
- Stated preference experiments conducted amongst passengers rate key issues such as punctual trains and comfort along with ticket price and travel time.

In a specific analysis of suburban Paris trains (Kroes et al 2006), delays were experienced where there was the coexistence of different types of service (i.e. express, freight, intercity) and that train delays occurred more frequently at certain times of the year (winter) and certain times of the week (weekdays).

In the stated preference experiment carried out in the same city (Ibid) the value of passenger comfort was a key variable. Patrons' response to 'not having a seat' was the equivalent of an additional 5 to 14 minutes of travel time, this penalty increasing with the length of the journey. 'Standing in a crowded train' was the equivalent to an increase of 27 minutes of 'disutility'.

Baker, Myers and Murphy (2007) make observations from a British stated preference survey that highlighted overcrowding as a phenomenon that occurs more regularly than unreliability or poor frequency. Over-crowding in this study came down to simply 'not having a seat'.

There are two pertinent repercussions to this particular study ;

1. Passengers place value upon punctuality and general comfort on board the train. Discomfort caused by not having a seat could expand to describe standing fatigue and perhaps anxiety at accessing a door to alight from.

2. If a train is full then boarding and alighting will be slower and less efficient. This affects the dwell time of the train in the station therefore impacting upon the reliability of timetables. This is particularly onerous if the headway between trains is short leaving little time to spare.

1.2 Causes of train ingress and egress occlusion.

There is a wide body of work regarding the dynamics of crowds but less dealing with the specifics of urban trains. Researchers in this latter area (Daamen, Lee and Wiggenraad 2008) describe the critical criteria for ingress and egress occlusion as ;

- Passenger characteristics. Meaning direction of movement, age, gender, physical fitness, luggage, personal discipline.

- Vehicle design. Layout of the interior seating influences dispersal within the carriage.
- Crowding effects (e.g. bunching at vestibules).
- Platform layout determining spatial distribution along platform.

Variable spatial distribution along the platform and the requirement to funnel through evenly spread train doors in a flow counter to those alighting is a feature of an active bottleneck (Hoogendoorn et al 2002). A momentary period of doorway congestion is also exasperated by the following conditions (Ibid):

- Step up or gap.
- Narrow gap with obstacles (other people or luggage etc)
- Where flows from different directions meet.
- Locations where both standing (through) passengers and moving passengers are present.
- Incidents.

In Hoogendoorn et al (2002) there is referred to a minimum distance that people (assuming strangers in this context) are prepared to tolerate between each other and objects. This ‘shy away’ distance has been calculated to be 45cms. Although the exact details of how this distance was determined is not clear. It is also noted that as people move quicker this distance is reduced. Mansel et al (1996) tried to evaluate the relationship between the flow of passengers on the platform with how they flowed into light rail vehicles. Their conclusion to bottleneck issues suggested that planners need to ‘channel’ patrons on the platform side in step with the capacity of the vehicle trackside in order that they cope with crowd surges. Harris and Anderson (2002) identify characteristics of systems with doorway bottlenecks and long dwell times as those where the rolling stock have poorly designed vestibules, with intermediate steps to and from the platform, and multi-directional flows during peak times.

2. CURRENT SOLUTIONS TO AMELIORATE LONG DWELL TIMES

In this section the authors have reviewed current strategies and responses to the extended dwell time and crowding problem. The authors first outline the immediate strategies available to the service provider and then follow with a more extensive analysis of the literature in the area.

2.1 Current immediate options to ameliorate overcrowding;

1. Add an existing carriage to the train. The limiting factor of this solution, determined by the length of the station platforms and rail yard sidings.

2. Increase the number and frequency of the trains. The limit to this solution is determined by the safest gap between trains that can be tolerated. If all the trains stopped at the stations or travelled at the same speed then this would be relatively straightforward. However the headway between trains is determined by a number of factors including the different rolling stock, types of service sharing the line and available resources.

3. Changing seat configurations to open out vestibules. Some operators keep rolling stock seating arrangements to a minimum, running longitudinally along the side of the carriage. Operators can choose to remove seating and open out the standing area (e.g. Connex in Melbourne). The seats themselves can be decreased in size, and the doors widened. However the repercussions of this strategy can engender a negative perception of passenger comfort. Longitudinal seats offer greater capacity for passenger movement than a transverse arrangement (at right angles to the windows) but at the cost of not providing sufficient seating for patrons (Figure 1).

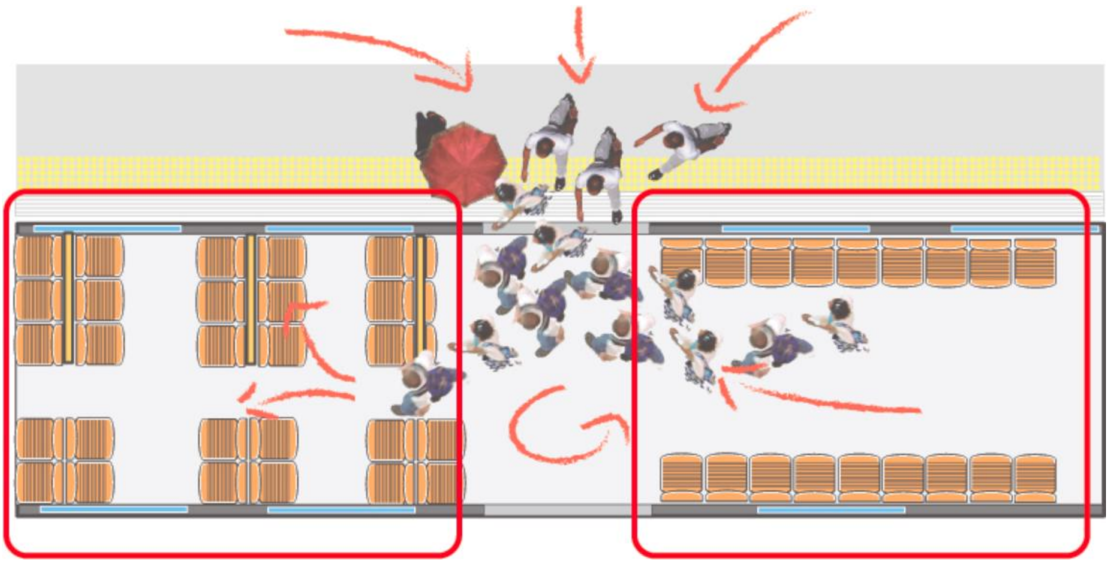


Figure 1.

4. Adding double-decker trains. There is debate within the rail industry concerning the merits of single and double-decker carriages. This will be discussed in more detail later in this paper. Double deckers initially suggest greater passenger capacity. However the primary limiting factor in running a double-decker carriage is the relationship between the 'Loading gauge', which is the outside envelope of the train, and the 'Structural gauge' or minimum clearance to objects around the track such as signals, tunnel walls etc. Some research indicates that for double-decker carriages dwell times increase (Harris 2006) along with passenger accident rates (passenger falls) and diminished disabled access.

5. Track amplification. This is prohibitively expensive, requiring land acquisition with extended service disruption, and the building of new platform infrastructure.

2.2 Literature examining current best practice solutions.

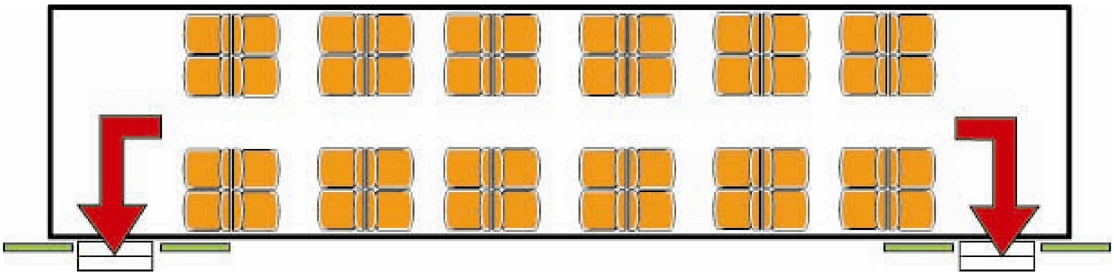
Harris & Anderson (2002) make the claim that for a high frequency service (2 minutes between trains) boarding and alighting times need to be a maximum of 20 seconds. This figure is made up of 60 seconds for run-out / run-in (RORI) 20 seconds for function time (doors opening, passenger movement and doors closing) and a further 20 seconds ‘contingency’.

Faster dwell times are also achieved if the station platform is wide enough to draw away disembarking passengers, a feature of Moscow’s system, which also has very short headways (two minutes). Harris & Anderson (2002) make the observation that automatic train operation is better at keeping time than human controlled systems. Indeed the less ‘slack’ there is in the system the more prevalent automation should be.

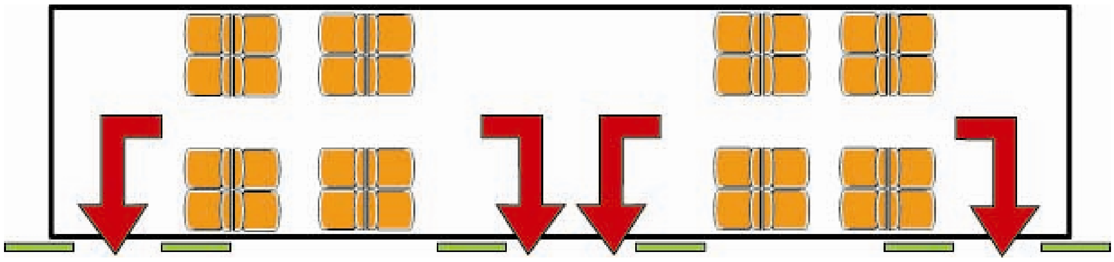
In an attempt to ameliorate passenger bottlenecks networks have attempted the following solutions;

- Wider doors (Mexico City). (1900mm +)
- More doors per carriage (MTRC Hong Kong).
- Fewer seats per carriage (KCRC Hong Kong).
- Separate platforms for boarding and alighting (Sydney, Homebush).
- Graphic floor patterns to encourage efficient behaviour. (Paris, Sydney and New York).
- Bleeper’s for doors (most countries) and military music (Copenhagen).
- More frequent service with short headways (Moscow and Santiago).

Experiments in changing the carriage design to improve or shorten dwell times have been undertaken. Morlok & Nitzberg (2004) describe such tests carried out with New Jersey Transit, Northeast Illinois Commuter Railroad, South Eastern Pennsylvania Transport Authority, New York Metro and North Commuter Railroad. These experiments suggest that a substantial reduction in dwell time can be achieved by using Short Dwell Entranceways (SDE’s), which are in effect wider vestibules with extra opening doors. The original trains on these systems have End Vestibule Entranceways (EVE). This former design has a passenger manually operated door, a stairway of 203.2mm stepping down to alight, and a single lane for the passenger between seats to the door. The SDE’s have automatically powered doors remotely controlled, buffer space around the doors, two lanes (from either side of the central vestibule) between seats and importantly platform level ingress / egress. SDE’s apparently have other benefits; fewer injuries when boarding or alighting (75%) and greater compliance with disability legislation. (Figure 2).



Above:- Diagram of an end vestibule entranceways (EVE) with steps and manual doors (Morlok & Nitzberg 2004).



Above: - Diagram of a short dwell entranceway (SDE) level with platform and automatic doors (Morlok & Nitzberg 2004).

Figure 2.

In Lau (2005) a 'back to the drawing board' theoretical process attempts to determine the optimum layout for the largest capacity design of carriages. This was determined by;

- Seating capacity. The design of the seats and typical requirements for passenger comfort such as width, height, seat back, and pitch of seats. The amount of cushion material that impacts upon legroom and the overall 'footprint' of the seat.
- Standing capacity. Floor space, aisles, door vestibule areas and between carriages.

Lau describes such trade-offs as increasing the number of doors, which reduces the number of seats. It is also noted that where opening doors slide into cavities there is created 'deadlight' areas where there can be no window. Parkinson and Fischer (1996 cited in Lau 2005) make the observation that widening doors is not as effective as having multiple doors. This also reduces seating capacity, but more importantly the wider door soon becomes just a wider single stream of passengers not a two way flow as had been hoped for. Six door carriages (three per side) have a capacity advantage over two doors per side when fully loaded (Ibid). This would appear to be due to the increased standing space in the vestibules as with the Melbourne rolling stock.

Platform configuration i.e. location of bench seating, platform entranceways and shelter, not the train itself contributes to determining those doors with the highest loads. Longitudinal seating (i.e. backs to the window) between two doors at either end of the carriage has a 20% longer dwell time than three sets of doors and a transverse arrangement of seats (Ibid). The speculation is that it takes longer to disembark a train from a position between two widely spaced doors than to maneuver between a three-door carriage in comparable capacity situations. There are examples of modifying platform to door arrangements e.g. one side of the train for alighting and the other for boarding as seen at a number of international airports and network termini (e.g. Homebush in Sydney). This manages flow in single directions but the literature does not reveal the impact upon dwell times.

The design of commuter trains in Tokyo was overhauled in 2000 with the introduction of the Series E231 vehicle. One of its principle specifications was to cope with the huge patronage at peak times. Sato (2000) cites that central to this strategy was a wider body with a longitudinal arrangement of seats. The wider central area catered for standing passengers with some seats folded up when not in use.

Studies in Russia particularly concerning busses have tried to determine the motivations of the passengers when getting onto the vehicle to better predict the filling comfort level and potential future configurations of the vehicle (Regirer and Shapovalov 2003). Not surprisingly the conclusions to such investigations suggest: -

- The rate of boarding is driven by the density of those trying to get on.
- Passenger motivations when entering the vehicle are to occupy the most comfortable positions, often perceived as those areas with the least passenger density.
- Passenger groupings are related to the nature and spread of the stops. There is an inter-relationship between schedule and the distribution of the passengers within the vehicle.

2.3 Double-decker versus single-decker trains.

After service providers have exhausted lengthening trains, or removing seats or increasing the number of trains (if they are able to do so) a popular option within North America and Europe has been the double-decker carriage (Wolf 2005). It has been claimed that two thirds of the world fleet between 2000 and 2004 is made up of double-decker carriages and the trend is set to grow (Ibid). A typical double-decker carriage will take approximately 40% more passengers than a comparative length single-decker carriage. However their dwell times are 0.3 seconds per passenger slower than single-decker rolling stock (Harris and Anderson 2002).

The inclusion of stairs in a double-decker carriage to access seating accommodation inevitably has implications upon universal access. Larger objects; prams, wheel chairs, luggage and bicycles find themselves confined to crowding the door vestibules. This problem is reduced with split-level or tri-level carriages, in which a central level is at platform height containing only a longitudinal arrangement of seats (e.g. Tangara design in Sydney). Where the introduction of double-decker trains will struggle are in countries or systems that have a small loading gauge (i.e. the outer size envelope of the vehicle cannot pass through tunnels and under bridges). The United Kingdom is an example of this although the introduction of double-decker trains was attempted on certain lines as far back as 1948. Ironically it would appear that double-deckers are relatively few where there is high overcrowding and greater standing room is necessary e.g. Japan. There are some very tall double-decker carriages in the United States. Colorado Rail uses a standard carriage with another deck on top (6.03 m). However they serve low platforms and have exterior steps up to the over wheel floor height.

Countries operating some kind of double-decker or split level rolling stock are; Australia, Canada, USA, Finland, France, Hong Kong, Japan, Sweden, Switzerland, India, The Netherlands, Spain and Israel. In the United Sates where there is a requirement of a conductor to validate passenger tickets between stops, a double-decker design has developed with a mezzanine. This enables the conductor to walk along the lower level and reach up and punch/validate tickets of the passengers seated on the mezzanine level. Access to this level is from each end of the carriage by internal staircase. It is highly probable that such an arrangement would create onerous dwell times if the service ran in a suburban environment. These vehicles are in service in Chicago, San Francisco, and Montreal (Agence Métropolitaine de Transport).

2.4 Universal access issues.

Of increasing relevance is the requirement for conformity to disability legislation. The disability rights commission reported (Wilson 2003) an overview of the literature concerning the experiences of disabled people to access public transport in the UK. Of each of the modes discussed the train is perceived as the most difficult to use, principally due to the issue of ingress and egress. London rail is the least accessible mode for disabled passengers in the UK. In the case of underground stations of which the metropolis has 275 stations only 40 do not require the use of steps or escalators (Ibid). On going legislation has been criticized as confusing (Tyler 2002 cited in Wilson 2003) since components of the legislation create exemptions and miss-matches between infrastructure and the vehicles themselves. It has been suggested (Ibid) that minimum standards leave little room for improved development. Instead of dimension based standards services should have performance based standards, e.g. to arrive and leave comfortably and with dignity.

3. CONCLUSION.

The literature and cases reviewed in this paper reveal a complex interlinked relationship of issues attending to the essential problem of doorway occlusion on crowded suburban passenger trains. These issues indicate that most contemporary designs for suburban railway carriages are compromised and have an adverse effect in a number of areas: -

- Difficulties in boarding and alighting trains leads to prolonged dwell times at stations with a corresponding effect upon timetables and punctuality.

- Doorway occlusion (particularly at peak times) negates effective ingress and egress; with repercussions upon accessibility for a wide patronage e.g. disability, pushchairs, luggage etc.

- Crowding and bottlenecking on trains (e.g. bunching in vestibules) can be seen at least in part as the effect of internal carriage and door configuration. Although the literature suggests that the 'blame' can be shared with the platform.

What is also revealing is that there appears to be a paucity of academic research from an industrial design perspective. Indeed Lau (2005) declares "few studies address the design and evaluation of interior and door configurations as a system". Much research measures the extent of the problem but where solutions are suggested they appear to have mixed or as yet untested outcomes. These strategies would include wider doors, more doors per carriage, fewer seats, and audio-visual devices (e.g. painted lines on the ground, and door closing alerts) to prompt desirable passenger behaviour.

Some studies disclose directions for further research. Such as they refer to the need for a better understanding of passenger behaviour, for example; queuing around doors, especially under time pressure, the cultural implications that influence the priority of movement and passenger motivations when entering a carriage. The authors' suggest that the physical designed environment could be a key influencer of these behaviours.

Of course it is recognised that current train manufacturers do have the capability to draw upon a design resource. Breda in Italy uses the prestigious design house Pinafarina. Alstom, one of the largest manufacturers of rolling stock have a highly sophisticated studio based in Paris. However it is suggested that in matters concerning the central theme of this paper, manufacturers are making assumptions on capacity based upon an even spread of passengers, rather than surges in certain areas and empty space in others (Lau 2005). Manufacturers of rolling stock are restricted in their design effectiveness by the commercial imperative and perhaps a limit to their design research resources compared to engineering capability.

A design response to the literature outlined in this paper would seek to address the interface between the essential factors of the platform side of the train and the interior of the carriage i.e.;

Platform characteristics

- Spread of passengers along platform – implied knowledge of the position of doors upon arrival.
- Physical ability – absence of steps into and out of the carriage and wheelchair friendly.
- The carrying of objects, including the accommodation of bicycles.
- Cultural behaviour. A radical design response would inevitably require a change in the prevailing cultural norms.

Carriage characteristics

- Seating arrangements such the orientation, aspect to doorways.
- Aisle and vestibule accommodation for passenger dispersal. A strategy to discourage patrons standing close to the doors and therefore partially blocking the doorway (the ‘sentry’ effect)
- Management of objects and belongings.
- Door location, numbers, dimensions and stepping distance and stepping height.

Although not explored in this paper the authors would point to the benefit of further research into the effect of specific locations upon effective carriage design. For example the track loading and structural gauges determine the maximum dimensions of the carriage accommodation. Data concerning the journey profile of passengers will also provide insights into the requirements of the carriage interior. For example a network in which a relatively low number of long distance passengers travel (i.e. one hour or more) could determine an increase in standing space and a reduction of seating capacity. This sort of analysis was a contributor to the EMU fleet of the newly extended East London Line. Also as referred to in the above list prevailing cultural norms in a specific location might determine the expectation of passengers to stand aside to allow others to alight or not. Further research to better understand these issues will form the basis of the ongoing research activity and inform future carriage design work.

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