WCTR 2013 RIO

SELECTED PROCEEDINGS

N INNOVATIVE APPROACH TO METROPOLITAN TRAIN CARRIAGE INTERIOR CONFIGURATION; TO IMPROVE BOARDING, ALIGHTING,DWELL TIME STABILITY AND PASSENGER EXPERIENCE.

MR. SELBY COXON, MONASH UNIVERSITY, MELBOURNE, VICTORIA 3145, AUSTRALIA
DR. MAJID SARVI, MONASH UNIVERSITY, MELBOURNE, VICTORIA 3145, AUSTRALIA
DR.ROBBIE NAPPER, MONASH UNIVERSITY, MELBOURNE, VICTORIA 3145, AUSTRALIA
ASSOCIATE PROFESSOR ARTHUR DE BONO . MONASH UNIVERSITY, ELBOURNE,ICTORIA 3145,AUSTRALIA.

This is an abridged version of the paper presented at the conference. The full version is being submitted elsewhere. Details on the full paper can be obtained from the author.

ISBN: 978-85-285-0232-9

13th World Conference on Transport Research
www.wctr2013rio.com
15-18 JULY 2013
Rio de Janeiro, Brazil
unicast

AN INNOVATIVE APPROACH TO METROPOLITAN TRAIN CARRIAGE INTERIOR CONFIGURATION; TO IMPROVE BOARDING, ALIGHTING, DWELL TIME STABILITY AND PASSENGER EXPERIENCE.

Mr. Selby Coxon [1], Monash University, Melbourne, Victoria 3145, Australia.
Dr. Majid Sarvi [2], Monash University, Melbourne, Victoria 3145, Australia.
Dr. Robbie Napper [3], Monash University, Melbourne, Victoria 3145, Australia.
Associate Professor Arthur De Bono [4]. Monash University, Melbourne, Victoria 3145, Australia.

Email for correspondence: selby.coxon@monash.edu.au

Submission for track:
A3: Rail Transport (SIG13)

ABSTRACT

Suburban rail operators in Australia, as in many other countries, are facing considerable challenges in the rapid growth of patronage. Higher passenger densities particularly during peak times of the day have implications upon train punctuality, crowding, accessibility and passenger comfort. There are a number of alternative strategies available to transport operating companies; ticket pricing policy, increasing services, lengthening platforms and track amplification. Some research (Lau, Daamen et al) suggests that the design of the train carriage interior has a significant influence upon accessibility and passenger dispersal once on-board. This paper describes research into the re-configuration of metro carriage interiors for the Melbourne rail network that seeks to ameliorate problems of doorway occlusion and passenger dispersal with the aim of stabilising dwell times and improving passenger experience.

The data for this study was drawn from the Melbourne suburban rail network due to its particular challenges in accommodating both a metro (short trip) system with a lengthy outer suburban network on tracks shared with regional and freight services. The research methodology embraced two strategies; An Industrial Design studio methodology that combined the collation of factual evidence to inform an empirical design activity consisting of drawings and models. The study then embraced computational simulations to determine the efficacy of a developed design concept.

The result of the this process was a design that embraced flexible seating; extra doors that operated only during peak periods without sacrificing seating and strategies that

manipulated passenger flow. Subsequent computational modelling of this concept indicated that these innovations can improve dwell time stability and passenger dispersal for the Melbourne rail network. The work also demonstrates to a wider audience that it is possible to explore the design of carriage interiors to improve network performance as an alternative to current costly operating strategies.

1. BACKGROUND

Rail is an important contributor to the movement of people and goods in many of the world's large cities. In 1863 when the first underground railway in the world opened in London, only 10% of the worlds population lived in cities. Now in the early 21st century over 50% of the world's population live in a city (Burdett, Sudjec et al 2009). Suburban, metro and subway systems are very efficient in terms of the number of people moved relative to land use. The city of Tokyo for example is 2.1 million square kilometres in area with a population of over 35 million inhabitants, 80% of whom use the subway. This is the highest level of patronage anywhere in the world with some 2930 million-passenger journeys (2009 figures) per year (Ibid).

The appeal of suburban commuter rail to city planners is in its peak hour carrying capacity (Costa B and Costa F 2010). This capacity is determined by the size of the carriages, number of carriages per train and the maximum number of trains circulating through the network. Compared to bus only cities, commuter rail networks have a 400% (per capita) higher public transport patronage. Putting aside the enormous initial cost of building the infrastructure, commuter rail is seen as a significant improvement in the transportation of people in cities (Litman 2005).

However, rail networks in many cities in the world can struggle to be punctual. The most significant variable in the journey of a train is the time it will take standing at each station. This 'dwell time' is at the mercy of the duration it takes passengers to board, alight and disperse within the train carriage or along the platform. At peak periods dwell times can become extended as passengers jostle to board or alight. It is general practice that timetables have built in 'recovery' time and attempt to predict extensions of dwell time during peak periods. However, with sudden spikes in increased patronage the predictability of dwell times becomes more difficult. Extended dwell times reduce the headways between services, therefore effecting network capacity, ultimately impacting upon an operator's revenue and contributing to poor passenger perceptions of the mode.

1.2 Predicting dwell time

Dwell time predictability is important in the creation of service timetables. To this end operators subdivide the dwell time to better understand where problems lie. Current timetable orthodoxy determines dwell times by mathematical means. While there are variations to the formula, they all in essence treat boarding and alighting as a linear period of time multiplied by a coefficient representative of how much passengers have been

slowed down by the proximity of other passengers, width of the doors and if they are carrying belongings. Figure 1 below, shows an example of a dwell time formula used in calculating dwell times on Comeng trains in Melbourne in 2008 (Aguirre 2008).

$$\textbf{Dwell time} = C + (f1 * A) + (f2 * B) + (f3 * TS^{3} * B)$$

Where: -

C = Constant for the Door Cycle Sequence (5 seconds including opening and closing).
A = Number of alighting passengers.
B = Number of boarding passengers.
TS = Number of through standees.
f_1 = Alighting friction coefficient based upon a number of parameters such as door width. 1160mm (Melbourne Comeng doors). Coefficient of friction 0.984.
f_2 = Boarding friction coefficient.
f_3 = Through standees constant friction coefficient equal to $6.2 * 10^{-4}$

Figure 1. Dwell time calculation formula (Aguirre 2008)

So taking for example a single trailer car on the Melbourne network with three doors. If each of the doors is occluded by 15 passengers in each vestibule and a total of 15 passengers wish to alight and 15 people board then the dwell time would be calculated as follows.

$$\begin{aligned} \text{Dwell time} &= 5 \text{ secs} + (0.984 * 15) + (0.984 * 15) + (6.2 * 10^{-4} * 23 * 15) \\ &= 5 + 14.76 + 14.76 + 0.214 \\ &= 35 \text{ seconds.} \end{aligned}$$

Embodied within the coefficient (0.984) in figure 1, are data relating to a wide range of empirical studies. Transport operating companies (TOC's) choose what level of detail they wish to build into the coefficient. In the example above the coefficient of friction (f_1 and f_2) were based on studies of Dutch passengers (Wiggenraad 2001) even though the above outcomes were applied to Australian patrons. It has been argued (Harris and Anderson 2004) that the data is robust for a wide range of international applications. There is a temptation to simplify and create an average set of results. While building coefficient figures might simplify determining dwell times, they also mask the intricate composition of the causes of extended dwells. Studies show that there is a wide range of qualitative variables impacting upon passenger behaviour while boarding and alighting (Daamen et al 2008). The literature reveals that dwell times are determined by a list of qualitative factors such as the prevailing culture of the passengers, their age, relative athleticism, the gap between the platform and the train, the level of the occlusion at the door and their motivations once within the train to finding a seat. These human factor variables are difficult to determine quantitatively and they relate strongly to the interface between the passenger and carriage.

Figure 2 below, encapsulates as a flow chart each of the 'factors' that affect the ability of the passenger to board or alight from a train. These factors are in themselves small when concerned with the individual, but when expanded to embrace multiple passengers and crowds the impact upon dwell time becomes much more significant.

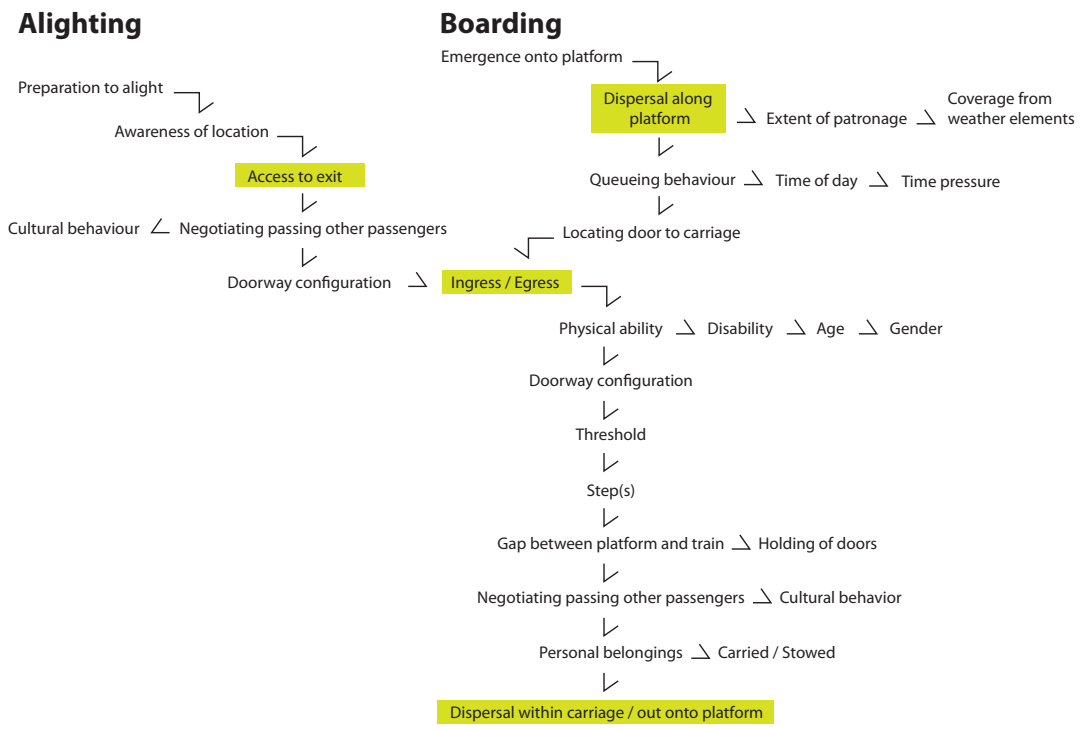

Figure 2. A cascade down flow chart of all the factors involved in dwell times.

1.3 Crowding

After a period of stagnation and decline from the 1950s, the latter part of the 20th century witnessed extensive growth in rail patronage (Stone 2009) in many of the worlds largest cities and very much so in Melbourne - 43% from 2005-2010, (Currie 2010). An increase in employment in the central business districts, congested streets, petrol prices and competition for land for parking has drawn people back to the railway. Higher passenger densities particularly during peak times of the day have implications upon crowding and with that the passenger perception of comfort and customer satisfaction (Baker, Myers and Murphy 2007). High patronage leads to doorway occlusion, extended exchanges of boarding and alighting passengers and thus a lengthening the train dwell time. A number of reports (Australian Bureau of Statistics 2008, Currie 2010) have highlighted overcrowding as a key issue to be addressed.

Rolling stock manufacturers and operators determine expected passenger load capacities for their trains during the design process, however, the actual number of passengers that can board a train can be determined by a passengers willingness and ability to physically

squeeze into a carriage. As many stations are not staffed and many trains are driver-only operated, there is no real means of preventing people from boarding. Hence, it is difficult to prevent overcrowding.

There are a number of methods by which crowding is quantitatively measured. Within Australia each of the five capital city TOCs (Melbourne, Sydney, Brisbane, Adelaide and Perth) have differing definitions of crowding. These range from calculating the number of people standing per square metre, the percentage of passengers in excess of a predetermined capacity, the percentage relationship between seating and standing patrons and the length of time passengers are required to stand.

Despite variations in Melbourne's rolling stock the maximum capacity for each peak service is deemed the same for all trains i.e. 133 passengers per carriage, 798 for a six-car set and 399 for a three-car set. Passenger numbers above 798 are in excess of the load capacity and are therefore deemed to be crowded. Under this method, a count is undertaken twice a year or after significant timetable changes, measuring how many passengers are travelling in the weekday peak hours, Figure 3. Counting is carried out strategic points in the network often where loads will be perceived as the greatest just before the city centre and at significant interchanges.

Figure 3. Manual train passenger load counting. Richmond station Melbourne September 2011.

Crowding as described in the literature (Hirsh 2011) and as evidenced by the Metro Loading Standards Survey correlates with trains falling behind schedule as passengers struggle to board and alight. Punctuality is a measure of performance that the TOCs take seriously as franchise contracts carry punitive clauses for failure to meet timetable expectations.

1.4 Punctuality

The contribution of lateness and cancellations to overcrowding can be severe with trains following a cancelled service usually the most severely overcrowded. 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 the specific analysis of suburban Paris trains (Ibid) delays were experienced where there was the coexistence of different types of service (i.e. express, freight, intercity) a similar issue in Melbourne and that train delays occurred more frequently at certain times of the year (winter) and certain times of the week (weekdays).

2. CURRENT METHODS TO ADDRESS THE PROBLEM

As discussed in the background introduction to the problem, passenger loading data are used by TOC's to determine patronage spikes and signal adjustments in their service provision. These adjustments come down in economic terms to either increasing capacity or reducing demand. Increasing capacity can take various forms; -

- Increase the number of services.
- Increase the length of the trains / platforms.
- Track amplification.
- Re-configure the interior of the rolling stock.

The alternative 'quick-fix' is to reduce or spread patronage. 'Demand side' economic theories reduce overcrowding through the use of price. For example by increasing peak fares, so called 'pricing-off'; or creating incentives to travel very early such as free travel

before a certain hour. Increasing fare price has been shown in model predictions to reduce peak hour loads much more than early bird discounting (Douglas 2011). However, petrol price volatility has also been shown to negate this effect (Currie 2010). Economic measures to reduce demand can be counter productive since they negatively effect revenue streams.

2.1 Increase the number of services.

Network capacity is driven by the frequency of services that can be operated along the line. Bringing services closer together is feasible if the TOC has enough rolling stock and dwell times remain consistent. Networks such as Melbourne have further complexity in that lines are shared with express train services, regional and freight services. Keeping trains a safe distance apart is the role of sophisticated automatic signaling. It has been argued that service capacity improvements could be made in Melbourne by improvements in signaling (Mees 2007).

Harris and Anderson (2002) make the claim that a high frequency service would be in the range of 2 minutes between trains. This figure is made up of 60 seconds for run-out (slowing down), run-in (speeding up), a dwell time of 20 seconds (passenger movement) plus a further 20 seconds for 'function time' (doors opening, and closing) and a further 20 seconds contingency. Harris and Anderson (ibid) also 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.

The Melbourne Metro Load Standards Survey of May 2011 reveals that at some cordon stations during peak as many as 18 services are running. This reveals a headway of 1 minute 39 seconds. At other points in the Melbourne network, for example where lines converge from the eastern suburbs, headways of two minutes are achieved from 8.30am to 9.00am. From 5.00pm through to 5.30pm the results are the same. The northern corridor reveals the same approximate 2 minute headways at both peaks in the day. This data does not include the imposition of regional V-Line and freight trains coming into the city from outlying towns running on the same lines. The evidence of this data set compared with the literature would appear to suggest that the Melbourne network is at capacity, at least during peak periods, and there is little capacity improvement to be gained by increasing the number of services.

2.2 Increase the length of the trains / platforms

The length of trains today are controlled by the length of platforms created decades ago. In cities with long established infrastructure and old stations the opportunity to undertake costly modifications to platforms is limited. Since it is difficult to extend trains by the addition of carriages, then many TOC's have taken the opportunity to go taller and increase carriage capacity. Double decker carriages are a popular option within North America and Europe (Wolf 2005). It has been claimed that two thirds of the world fleet between 2000 and 2004 was 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 is in countries or systems that have a short height loading gauge (i.e. the outer size envelope of the vehicle cannot pass through tunnels and under bridges).

Platform configuration including the arrangement and design of entranceways and exits, the location of bench seating, and shelter, not the train itself, contributes to doors with higher loads (Ruger and Tuna 2008). Shorter dwell times are also achieved if the station platform is wide enough to draw away disembarking passengers, a feature of Moscow's system.

2.3 Track amplification

The most expensive, most difficult option and the one slowest to affect change available to TOC's is to increase the number of lines. Extending a network or adding tracks requires many years of planning. Despite the benefits offered by a city's extensive rail network many metropolitan authorities invested heavily in road infrastructure (Kenworthy and Laube 2001) in the second half of the twentieth century to the neglect or abandonment of rail (Stone 2009). Census data show that for the journey to work for the thirty years between 1976 and 2006 Melbourne experienced the largest proportional decline in the use of public transport of any Australian city (Mees et al 2007). Melbourne now with the highest population growth rate in Australia also has the fastest decline in journeys to work by car (ibid). It is impossible to react to demand through network amplification at the speed of change experienced in patronage. Track amplification as a response to train crowding therefore represents the most difficult to implement and long term of the strategies available to the TOC.

2.4 Re-configure the interior of the rolling stock.

Rolling stock interior design can provide some respite to crowding by the manipulation of seat numbers, their positions, and the location of hand-holds. Suburban trains typically have a life span of thirty years. They might be refurbished after fifteen years but it is clear that while they are an enormous investment modifying the interior represents a low cost option in comparison to those already discussed in this paper.

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 impacting upon legroom and the overall 'footprint' of the seat.

- Standing capacity and the amount of personal space anticipated to be reasonable.

- Overall floor space, aisles, door vestibule areas and usable space between carriages.

There are currently two fundamental arrangements of seats. The first is longitudinal, running along the windows facing toward the centre of the carriage. This arrangement is the choice of train designers when the track gauge is at Standard or narrower (i.e. same or less than 1435mm inside rail to inside rail). This arrangement is also commonly referred to as 'metro style seating'. On networks of traditionally high patronage the wider central floor space makes passenger flow quicker and unobstructed (Ruger and Tuna 2008).

The second arrangement is transverse, typically this composition of seating is used in wider (broad gauges, greater than 1435mm) carriages and regional and intercity trains. Evidence suggests (Ibid) that passengers favour sitting in the direction of travel or at second best backwards but seldom sideways. Transverse seating is used for services covering longer trips where the tolerance for a low level of discomfort is less than short inner city journeys. As transverse seating narrows the gangway between doors it is also an arrangement that is the least effective at encouraging passenger flow on frequent stop services.

The Melbourne network has the advantage of a broad gauge at 1600mm, and can therefore accommodate a mixture of transverse and longitudinal seating in it's fleet. The extent of the network also means that in many ways the services need to perform as both metro and to some extent a regional service. Australian urban land use has been typically sprawling with low population densities leading to extensive commuter distances for a metropolitan service. Journeys from the outer reaches of the Melbourne rail system can take more than an hour.

Experiments in refurbishing the carriage interior to improve or shorten dwell times have been undertaken by a wide number of networks. Morlok and Nitzberg (2004) describe such modifications undertaken 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).

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.

A critical factor in the design of seating arrangements is how they will effect passenger dispersal. Studies in Russia (Regirer and Shapovalov 2003) particularly concerning buses have tried to determine the motivations of the passengers when boarding the vehicle to better predict the filling comfort level and potential future configurations of the vehicle. The conclusions to such investigations suggest that the rate of boarding is driven by the crowd 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; and that there is an inter-relationship between schedule and the distribution of the passengers within the vehicle. Passengers move deeper into the vehicle if their journey is longer and they don't anticipate needing access to the door to soon after boarding.

More recent studies in Australia carried out as part of research for the RailCRC Hirsch and Thompson (2011) reveal that a range of behaviours are prevalent amongst passengers determining their onboard behaviour. Of significant priority to passengers was the procurement of a seat, followed by the creation of personal space by a variety of means including the use of carried items and personal behaviour, and the willingness to disengage with fellow passengers. There is a 'premium' during periods of crowdedness for obtaining a window seat where this disengagement can be best achieved by looking out of the window (ibid).

While obtaining a seat might represent the ideal comfort condition and primary motivation of a passenger there are a number of circumstances in which passengers prefer to stand. These conditions revealed in the Hirsch and Thompson (2011) study are: -

- The cleanliness / hygiene of either those one might have to sit next to or of the seat itself (food spillage for example).
- Entrapment from the doors. During peak loads crowding in the vestibules and with it the corresponding occlusion of doors is exacerbated by an unwillingness of passengers to move further into the carriage.
- Ventilation. During summer when carriage air-conditioning struggles to maintain performance, passengers express a preference for standing next to doors so that they might take some fresh air at each stop.
- Behaviour of fellow passengers is also cited as a deterrent to sit close or next to someone who might represent a threat, or create physiological discomfort or anxiety.

The Melbourne network runs a majority of rolling stock with transverse seating often three seats together on one side of the aisle and two seats opposite. The three seat arrangement is particularly troublesome since the middle seat is the least attractive to take during crowded times since it means an awkward ingress and egress without hand holds, close

proximity to strangers and narrow sitting space. The result is that even in crowded peak periods seating goes wasted or occupied by bags, with only the confident, agile and particularly tired prepared to struggle for the seat.

2.5 Making changes to existing interiors – the Melbourne experience

From 2004 to 2010 the French TOC Connex held the franchise for Melbourne's suburban train network. Melbourne has 15 lines, 830kms of track and 212 stations. The train fleet consists of approximately 357 three-car sets or close to 179 full length six carriage trains. The Melbourne network carries 680,000 passengers each weekday (Victoria Department of Transport website, accessed 23rd October 2010).

Melbourne has five different types of rolling stock with differing door positions and seating arrangements. The track is broad gauge (1600mm) therefore affording a wide internal layout that can accommodate a 3 + 2 transverse seating layout. However just under half the rolling stock runs a 2+2 transverse seating arrangement, including all the newer carriages. All trains carry some longitudinal seating adjacent to end vestibules.

The nature of the Melbourne network dictates that multiple services from outer suburbs are funneled into the central business district into a section of the line known as the 'City Loop'. During peak periods and short headways any extension to dwell time as commuters board and alight can have major consequences upon the timetable. This is especially true of dispatching empty trains at the end of the service back out into the system in a timely manner.

In 2008 Connex in collaboration with industry consultants sought to determine what could be done about extended dwell times. The Comeng model of train, which is the most common in the fleet (187 three car units), was used as the benchmark. This design of carriage has been in service since 1982 and was last refurbished between 2000-2003. The total passenger capacity of this model is 399, including standees with 289 seated across a three car set consisting of two motor-cars (less seating due to drivers cab) and one trailer car.

The study considered four interior arrangements of the carriages. In each case there was a reduction in seating capacity and a corresponding increase in standing room. The researchers used a standard dwell time calculation model to determine the resulting benefit of each layout (see figure 1). Not unexpectedly these calculations revealed that the layout with the largest number of seats removed offered the best improvements in dwell time.

In addition to the raw mathematics of the analysis, Connex also investigated methods that might encourage passengers to move more deeply into the carriage between doors. Existing Comeng trains only provide handrails in the vestibule area. These are limited to above the door and along the edge of the draught screen. This positioning encouraged passengers to occlude the door in the 'sentry position', if they could not readily move into

the carriage to locate a seat. Handles are located on top of the seats but they accommodate only one passenger at a time. This contrasts with a vertical pole that might provide stability for individuals standing adjacent to each other. As already observed the 3+2 layout also suffers from the 'abandoned middle seat issue'. Even in trains with high loads and numerous standing passengers the central seat may remain unoccupied (Hirsch et al 2011).

The Melbourne study carried out by Connex concluded that longitudinal handrails suspended under the carriage ceiling would draw passengers away from the doors and further into the carriage. It was also proposed that more longitudinal seating adjacent to the vestibule would improve passenger flow. The extent to which the TOC is prepared to remove seats is a significant political and public relations issue. Since there is a correlation between seating and comfort (Baker et al 2007) TOC's are reluctant to be perceived by the general public through the media as reducing passenger comfort on-board their trains. More standing passengers also has one other implication; in order to mitigate the risk of injury to passengers in the event of an accident, trains are obliged to reduce their operating speed creating consequences for network capacity.

These examples reveal a complex interlinked relationship of issues attending to the essential research problem of crowding and extended dwell times. What is also revealing is that there is 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". A design response would therefore 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 factors: -

- Spread of passengers along the platform – implied knowledge of the position of doors upon arrival.
- Accessibility – 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 possibly require potential change in the prevailing cultural norms.

Carriage factors: -

- Seating arrangements such as orientation and aspect to doorways. Aisle and vestibule accommodation for passenger dispersal.
- A design strategy to discourage patrons from standing close to the doors and therefore partially blocking the doorway (the 'sentry' effect). Doorway occlusion particularly at peak times negates effective ingress and egress; with repercussions upon accessibility for a wide patronage e.g. disability, pram, luggage etc.
- The management of objects and belongings.

- Door location, their numbers and dimensions, gap distance and gap height.

The literature also reveals the restrictions (the legacy of old station infrastructure), and contradictions that TOC's are faced with. Melbourne has a particular extra dimension to its problems in that the network functions as a quasi-regional train system. The same service is obliged to perform like a metro system with short trips and frequent stops in the city centre. Few other systems in the world face this dilemma of population growth while using multiple types of rolling stock on the same lines.

While there are a finite number of passengers that could ever fit into a rail carriage, what is clear is that not all the interior design options have been exhausted and that through the following studio research it might be found that advances in interior layout could compliment wider strategies currently employed or under consideration.

3. DESIGNING AN ALTERNATIVE CARRIAGE INTERIOR

The previous sections of this paper have described the scale of the problem and the parameters within which a design response is to be made. In this section the redesign of the carriage interior layout is addressed. Visualization through sketching is the primary means of articulating ideas in Industrial Design. To determine door and seating geometry across the length of the carriage and for the sake of clarity a scale plan view projection is used. The plan view (based upon a cross-section at floor height and to a width that matches Melbourne's broad gauge width. The plan has then been overlaid with a grid drawn up with $0.25m^2$ squares, a dimension determined by standing and seat pan spatial areas

The plan view is the simplest and quickest way to map out concept options. The goal of each sketch layout is to address the basic aims of the research in determining how passengers might enter and exit the space and be accommodated within the carriage. To assist assessment of the relative merits of each layout some quantifiable measures are applied as follows;

- Capacity per carriage. As close to or better than current capacity i.e 133 passengers.

- The number, position and dimensions of any door proposals. This is more difficult to evaluate through sketches alone. Unlike a finite number of seats the flow of passengers through a door is open to variation of number their speed and physical stature.

- Passenger dispersal. This is more qualitative and relies much more upon an intuitive response. Sketch layouts explore the creation of visual mechanisms that, in part due to prevailing cultures and instinctive behaviours, encourage passengers away from doors and to move further into the carriage.

3.1 Sketch studies

The first sketch studies wrestle with the opposing dilemma of managing transverse seating with longitudinal seating. The former is seen as more comfortable for longer journeys (> 20 minutes), but slower to alight and disperse, while longitudinal seating is less comfortable over longer distances but quicker to board, alight and disperse.

As has already been observed in the literature review, experiments in interior layout carried out in both Melbourne and Stockholm compromise the seating arrangements by locating longitudinal seating where crowding is greatest at the doors and placing transverse seating in the centre of the carriage. This approach is indicative of the conflicting solutions to the design problem; that passenger flow is better accommodated by open vestibules blending into wide open corridors flanked by longitudinal seating. Transverse seating narrows the corridor and congeals the passenger flow into the interior but provides greater seating capacity and in an orientation more comfortable for longer journeys.

The outcome of the sketch studies was a conceptual and experimental design that combines the merits of the two seating arrangements. To create better boarding and alighting five doors per side have been created. However, only three doors are operational all of the time. Having two doors operational for only peak periods allows the design to accommodate folding seats in the immediate door area. During peak periods when these 'extra' doors are in operation these folding seats are locked in a closed position to avoid being an impediment to passenger boarding and alighting.

To further enhance the movement of passengers, floor indicators direct patrons to pass on the left of the door to facilitate simultaneous boarding and alighting. Simultaneous boarding and alighting is facilitated at each door with graphic symbols indicating the correct side to use. In figure 4, below, these floor indicators at the door are in an orientation as seen from someone inside the train, a green arrow suggesting the exit and a red and white no entry sign indicating no exit. The carriage is sufficiently broad to house longitudinal seating along the windows and then seat clusters of four along the central axis of the train. A large open vestibule area has been created at one end (indicated in green on the illustration) to accommodate bicycles and prams. The seats shown in orange are specifically for persons of reduced mobility (PRM's) and do not fold.

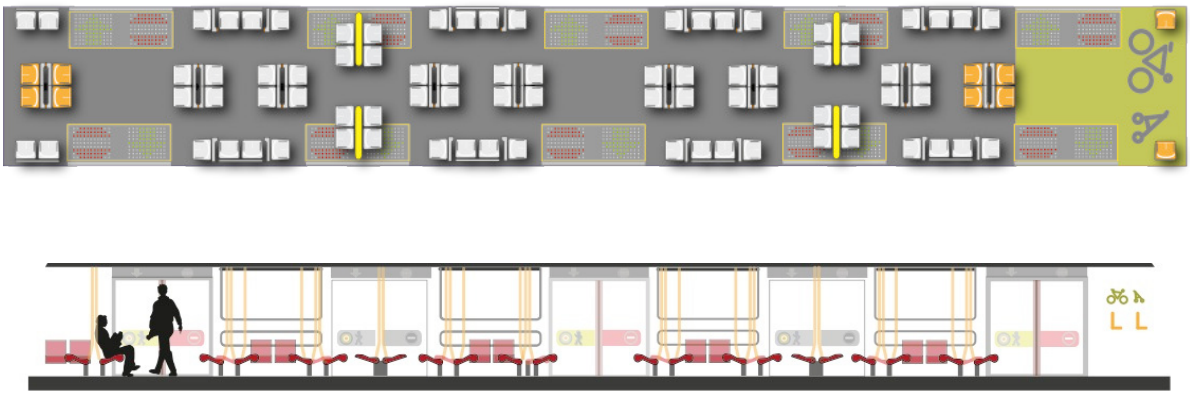

Figure 4. Plan and side view of the alternative concept of a seating and door layout.

The use of perch seats and folding seats, as well as mixing the orientation of the central seat clusters, attempts to overcome some of the problems of having two gangways rather than a single wide central corridor, as is currently the case in Melbourne's rolling stock.

4. Evaluation of the design computational modeling

Two-dimensional studies prepare the groundwork for discussion around a new interior arrangement. The two-dimensional studies also enable the ideas to be disseminated amongst interested parties in the process. However, they do not indicate adequately the efficacy of the design and for this the Authors have collaborated to look at experimental ways of determining the likely practical outcomes of an operational train in the configuration created thus far.

The purpose of evaluating the layouts is that it will not only show how passengers might behave but also how these interactions lead to larger scale outcomes. Modeling full size mock-ups is expensive and since they are mock-ups, fraught with problems of authenticity. In recent years it has become more accessible and accurate to measure crowd simulations by computer modeling and in particular by Agent based Modeling (ABM).

ABM interactions exhibit the following two properties:

1. The interactions are composed of individuals with a designated set of characteristics (Agents).

2. The system in which these interactions take place exhibit emergent properties. That is new properties arising from the interactions of the agents that cannot be deduced simply by aggregating the combined properties of the agents.

ABM begins with assumptions about agents (in this instance passengers) and their interactions and then uses computer simulation to reveal the dynamic consequences of these assumptions. For problems such as determining the ebb and flow of large groups of

train passengers where predicting the effects of individuals upon each other is difficult, then ABM techniques have great potential. What is difficult to determine is how accurate and representative the salient aspects of the agents are of the cross section of passengers travelling in any network. In highly sophisticated simulations it is possible to equip the agents with the ability to learn and develop over time. The key issue is the extent to which the resulting outcomes are orderly within the environment they have been placed.

There are a number of commercially available and research computational tools for simulating crowd behavior. It is outside the scope of this research project to make a full review of the merits of each system. For the first evaluation of the conceptual layout *ESim* software was used. This software was originally designed to simulate evacuation and panic situations. It has been used for two reasons. First it is accessible to the viewer and second, the dynamic characteristics of the agents can simulate the jostling of crowds through narrow doorways (due to evacuation) in the ways that other systems cannot.

EmSim is an example of a crowd simulator that uses a '*social force'* model to replicate human movement as one person interacts with another or a fixed surface. *EmSim* is a two dimensional microscopic continuous model updated in discrete time steps. Patrons described as small circles have instantaneous acceleration based on the collective forces acting upon that individual. These collective forces are formulated and mathematically modeled based on empirical data from previous experiments with ants and modifications of the approaches used to describe collective animal dynamics and pedestrian dynamics. The collective forces consist of random impulsive forces and local interactive forces including pushing behavior. With the instantaneous acceleration, the position and velocity of each individual is updated in each time step from the integration of the Newtonian equations of motion. Detailed mathematical derivation can be found in (Shiwakoti, Sarvi, Rose and Burd 2010). This model has been extensively calibrated and validated for both normal and panic conditions (*Ibid*).

The main outputs required from the simulation are: -

- Crowd movement through the doorways during boarding and alighting.
- Dispersal within the train.

Within the confines of the simulator framework the agents were given the following characteristics: -

- Velocity
- Mass

4.1. First analysis - egress at a train terminal

The graphical outputs of *ESim* are by contemporary media standards crude and require elaborate programming. To simplify the first test and determine the efficacy of the simulation a single door was created and passengers funneled out of the door from the train

interior as though at a terminating station. Two layouts were created in two dimensional plan form that represented a) the current Melbourne Comeng single corridor layout and b) the proposed twin corridor central seat cluster design. The seat clusters in both simulations where treated as though they were solid walls and no allowance was made for the step down onto the platform from the carriage which was treated as entirely level throughout. The section of carriage created around the door catered for seventy-five passengers (i.e. 0.25m^2). Their distribution was random and upon moving to the door they all had a common speed of 1m/s. Upon advice from the simulators programmers egress time was only counted across sixty five passengers to accommodate any errors caused by initialization effects of the program. All the passengers were assigned the same mass. Ten simulation trials were conducted for each of the two train layouts. Figure 5 shows a snapshot of the simulation for the existing layout (a) and the experimental design layout (b) respectively.

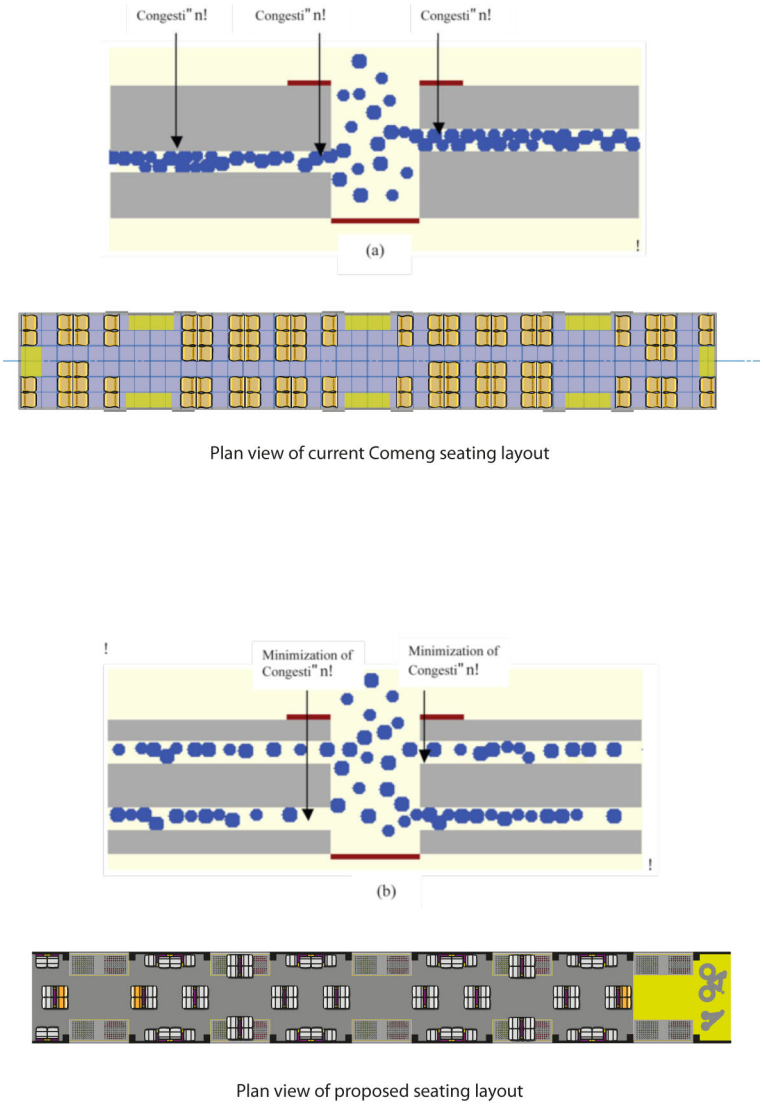

Figure 5. Screen shot of EmSim agents moving through the carriage accompanied by plan views of the train layouts to which they are being compared.

In figure 5 the upper image denoted as (a) clearly shows a congested corridor and multiple interactions about the space where the corridor turns into the vestibule. In figure 5 (b) the same number of passengers moving towards the exit does so with less congestion at the vestibule and door. Figure 6 (overleaf) shows a comparison of egress time for the existing and experimental design. With the existing design, mean egress time for the 65 passengers was 21.54 seconds (± 2.50 standard deviation across ten simulations), while with the experimental design mean egress time was 19.18 seconds (± 1.73 standard deviation across ten simulations).

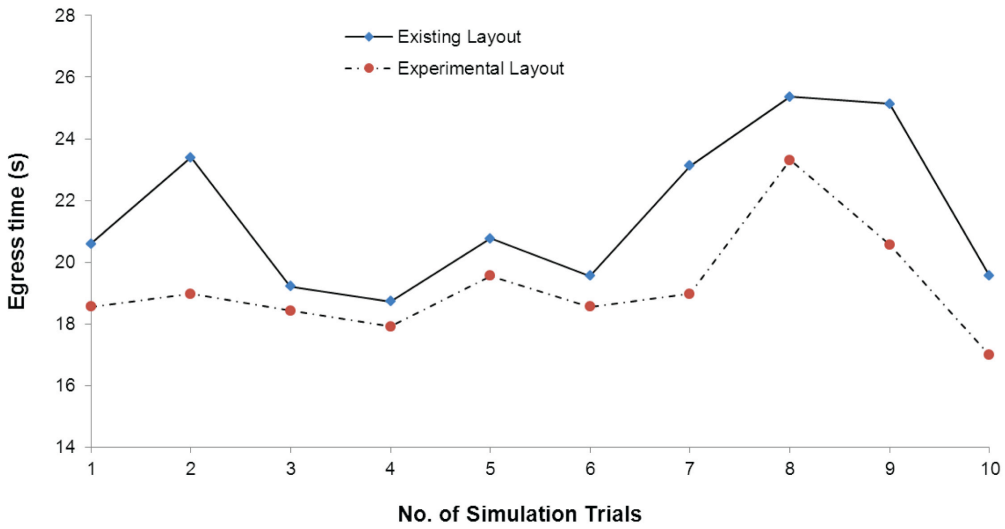

Figure 6. Time graph comparison between simulations.

These results show that the dual corridor experimental design is around 13% more efficient in reducing the egress time compared to the existing layout as described by Melbourne' Comeng train interior. The difference in egress time for the two considered cases ranged from 0.80 seconds to almost 5 seconds.

4.2 Reflection upon these results.

As an initial exploration into ABM simulations these results are very encouraging since they demonstrated that significant potential effects could be achieved by merely adjusting the structural features of the train interior. The presence of a central series of seat clusters and dual corridors in experimental design minimized the number of interactions and thereby speeded up egress. These adjustments suggest major implications in reducing the dwell times.

However, these results present a number of significant shortcomings. Only half the problem of doorway occlusion is addressed. A simulation with boarding passengers is needed. Given the area that the modeled passengers occupied it is likely that some patrons would turn and look to another door rather than the single egress offered in the experiment. At

inner city cordon stations high passenger densities mean that few patrons would be alighting, more would be attempting to board and most seated passengers would remain in their seats.

Equally from a communication point of view the simulation by way of a plan view and dots representing the passengers lacked the visual sophistication from which a more informed evaluation could be made. It was therefore determined to create a second and more sophisticated model in which three-dimensional humanoid figures would be created and their movements dictated by the *ESim* software.

4.3 Second simulation using three-dimensional figures.

In the second simulation the experimental train carriage was replicated in basic terms in 3D *Maya* software. The full carriage was built with correct number of doors and seating clusters both folding (to create perch seats) and in a fixed position. The passenger 'agents' were created also in three-dimensions so that they could take on plausible characteristics and move and behave as passengers might in the real world.

In the first simulation all patrons contained the same mass and velocity. In this second simulation the Authors determined that there should be some human differences so as to reflect more accurately the make up of a high density carriage. Choosing the characteristics is difficult. Other organizations, the French National Railway SNCF are an example, have also attempted to model passengers as a series of archetypes to inform their simulations. The difficulty concerns both the gathering of the data and where it might contravene passenger privacy (if filmed) and to how the movement, mass and speed of patrons can be grouped with any accuracy.

4.4 Creating archetype characters.

To avoid the onerous task of creating a vast anthropometric range of patrons a number of assumptions need to be made. Firstly that the patronage of the trains during the peak period contains range of patrons that are of working age (between 20 and 60). A minority of passengers will be of retirement age. There is also the assumption that segment of the passenger profile will be unaccompanied school children. This is still a very large slice of the community. They have been split further to create archetype agents.

1. Working age women (between 20 – 40). Presumed fit and healthy and therefore with a consistent velocity of movement.
2. Working age man (between 20 – 40). Presumed fit and healthy and therefore with a consistent velocity of movement.
3. Teenager (representing school children). Presumed fit and healthy. Encumbered by bags / rucksack, but with greatest acceleration of movement.
4. Working age man (endomorphic 40 +). Presumed fit and healthy but of a wider girth (endomorphic) and with an slower velocity than the younger age groups

5. Working age women (endomorphic 40+). Presumed fit and healthy but of a wider girth (endomorphic) and with an slower velocity than the younger age groups
6. Old woman / man (with carry bag for shopping). Slowest velocity. This represents the anticipated minority of passengers outside the normal range who might still require travelling within peak periods of the day.

Note: - that with the exception of school children height has not been made a factor. The presumption is that the trains all have sufficient height for all patrons to move in and that the significant factor being measured is the horizontal plane in which passengers of different girth and velocity will interact in different ways.

These six stereotypes were modeled in the 3D modeling software and applied to the game engine *Unity*. Significant challenges were overcome in creating computational coding to translate *EmSim* data into animated figures. The environment for the simulation to take place was also created within the game engine with figures applied to the carriage in varying numbers. School children were grouped in clusters whereas working age passengers were placed more individually (Regirer, S. and Shapovalov, D, 2003) and spaced to reflect the observations that passengers prefer to create a level of personal space around them where possible (Hoogendoorn et al 2002). The total number of passengers created reflected the capacity of a single carriage i.e. 100, and split up into the following proportions: -

1. Teenagers / Schoolchildren (15%)
2. Old woman / man (5%)
3. Working age women (30%)
4. Working age man (30%)
5. Working age man (endomorphic 10%)
6. Working age women (endomorphic 10%)

Patterns of behavior reflecting the intentions of the experimental design where the direction of the three dimensional figures to obey the rules of pedestrian flow around the pillar adjacent to the peak doors. The Authors felt that while this was an imposition in the behavior of the passengers it was not unreasonable to suggest that patrons in a society such as Melbourne would be very likely to follow cultural conventions of moving either to the left or right in an entranceway as directed by signage. Salient features built into the agents included motivations as to where passengers needed to go and what determined them to stop i.e. sit at a seat, into or out of doors and between seats.

4.5 Results of the second simulation.

The second simulation was divided up into two parts. First *ESim* was used to predict the random movement of patrons throughout the carriage. Some passengers remained in their seats while a percentage moved to the door meeting an equal number coming the other way attempting to board. The movement of these agents was then translated into the three dimensional model so that their movement could be better understood in realistic visual

terms. Figure 7 shows two stills demonstrating the observed behavior of passengers through the doors and within the carriage.

Figure 7. Still images of the animated representation of passenger dispersal into and within the train carriage.

A fully modeled interior environment for existing rolling stock has not yet been completed but is intended as part of future work. The animations although limited in number of patrons and behaviors was more illuminating than the two-dimensional appearance of the first

EmSim simulation allowing the researchers to understand better some of the visual characteristics and impact of the experimental design.

6. CONCLUSION AND IMPLICATIONS FOR RESEARCH

Many suburban railway systems around the world are experiencing a rapid increase in patronage. Higher passenger densities particularly during peak times of the day have implications upon punctuality, crowding and the passenger perception of comfort. The design of carriage interiors has a significant influence upon passenger movement through doors, dispersal on board, and the carrying of objects. Conventional design rationale dictates that trains commuting over short inner city networks run longitudinal rows of seats with their backs to the windows, and with open space through centre of the carriage. Regional trains of longer commuting distances arrange seating in a transverse orientation facing or back to the direction of travel. Melbourne's network has the particularly onerous problem of running a train network that has to accommodate both long distance commutes and a short metro service.

An experimental carriage interior design that accommodates both longitudinal seating and a central row of transverse seating and extra doors has been evaluated using a pedestrian crowd modeling simulation (*EmSim*) the relative merits of the experimental interior were compared to one of the existing, and most common, rolling stock designs. Results demonstrate that significant improvement in dwell time can be achieved by adjusting the internal arrangement of seating and doors. Doors that operate only at peak times provide better passenger flow without the loss of seating amenity during none peak periods. This could have major implications not only in reducing the dwell times but improving passenger dispersal within the carriage.

Research on crowding in train carriages is a continuously challenging process and this work has assumed ideal passenger behavior within a narrow framework of ingress and egress. A significant contribution to the efficacy of the experimental design resides with the prevailing passenger cultures ability to conform with the expectations of moving to one side of the door to the other and understanding when seats are deployed and when they are not; when doors are operational and when they are not. While design and the control of the physical space goes a long way to directing passengers into expected and desired behaviors it remains the role of future research to better understand the passenger experience in the space. Motivations yet to be applied in the simulations could include sitting next to known people or away from strangers. Sitting in the direction of travel and next windows. By better refining the simulation tool the implication for other networks is that rolling stock interior configuration can be experimented and tested without recourse to expensive and time consuming full scale mock-ups of rolling stock that carry with them inaccuracies and ambiguities associated with their lack of realism.

7. Bibliography

Aguirre, D. (2008) Vehicle layout options study for Connex Comeng. – Interfleet commissioned report ITLR-T22459-002. 24th June 2008, p13.

Baker, J. Myers, N. Murphy, P. (2007) Placing a value on overcrowding and other rail service quality factors. European Transport Conference proceedings. 17th – 19th October 2007, Leewenhorst, Lieden, Holland.

Burdett, R and Sudjic, D.(2007) The Endless City – The Urban Age Project. London School of Economics & Herrhausen Society, Phaidon London.

Costa, L. Costa, F. (2010) The evolution of the Rio de Janerio Subway System 12th World Congress of Transport Reasearch. July 11-15th 2010 Lisbon Portugal.

Currie, G. (2010) Quick and Effective Solution to Rail Overcrowding. Transportation Research Record: Journal of the Transportation Research Board. Volume 2146, Pages 35 – 42.

Daamen, W. Lee, Y. Wiggenraad, P. (2008) - Boarding and alighting behaviour of public transport passengers. Transport Research Record: Journal of the transportation Research Board, No 2042, Transportation Research Board of the National Academies, Washington, D.C. 2008 pp 71-81 DOI: 10.3141/2042-08.

Douglas, N. Henn, L, Sloan, K (2011) Modelling the ability of fare changes to spread a.m. peak passenger loads using rooftops. Paper delivered at the 34th Australasian Transport Research Forum (ATRF) held in Adelaide on 28th-30th September 2011.

Harris, N. Anderson, R. (2004) An international comparison of train boarding and alighting rates. Excellence in Railway Systems Engineering and Integration.

Hirsch, L. Thompson, K. (2011). I can sit but I'd rather stand: Commuter's experience of crowdedness and fellow passenger behaviour in carriages on Australian metropolitan trains. Conference paper delivered at the 34th Australasian Transport Research Forum (ATRF) Proceedings held on 28 - 30 September 2011 in Adelaide, Australia.

Hoogendoorn, S. Daamen, W. de Boer, A. Vaatstra, I. (2002) Assessing Passenger Comfort and capacity bottlenecks in Dutch train Stations. - Transport Research Record: Journal of the transportation Research Board, No 2002, Transportation Research Board of the National Academies, Washington, D.C., 2008 pp,107-116 DOI: 10.3141/2002-14.

Kenworthy, J. Laube, F. (2001) The eco-city: ten key transport and planning dimensions for sustainable city development. Environment and Urbanization 2006 18: 67.

Kroes, E. Kouwenhoven, M. Duchateau, H. Debrincat, L. Goldberg, J. (2007) Value of punctuality on suburban trains to and from Paris. Transport Research Record: Journal of the Transportation Research Board, No 2006, Transportation Research Board of the National Academies, Washington, D.C., 2007 pp.67-75 DOI: 10.3141/2006-08.

Lau, S. (2005) Evaluating Interior and Door Configurations of rail vehicles by using variable loading densities. Transport Research Record: Journal of the transportation Research Board, No 1927, Transportation Research Board of the National Academies, Washington, D.C., 2005 pp. 268 – 276.

Litman, T. (2005) *Impacts of Rail Transit on the performance of a transportation system*. Transportation Research Board 1930, Transportation Research Board 2005, pp 23-29 Washington DC.

Morlok, E. Nitzberg, B. (2004) Speeding Up commuter rail service – Comparative actual performance of train and station platform designs. Transport Research Record: Journal of the Transportation Research Board, No1872, Transportation Research Board of the National Academies, Washington, D.C., 2004 pp. 37-45.

Mees, P (2007) Infrastructure constraints or poor service planning? Increasing service to Melbourne's city loop and Dandenong rail corridor. Conference paper delivered at the 30th Australasian Transport Research Forum (ATRF). Proceedings held on 25-27 September 2007 in Melbourne, Australia.

Regirer, S. Shapovalov, D, (2003) Filling Space in Public Transport by passengers. Automation and Remote Control archive, Plenum Press New York, NY, USA Vol 64 No. 8 pp.1301 – 1309.

Ruger, B. Tuna, D (2008) Influence of railway interiors on dwell time and punctuality. Railway Interiors International, UKIP Media Events, Dorking Surrey November 2008, pp32-36.

Sato, Y. (2000) Development of new commuter trains in Tokyo. Proc Institute of Mechanical Engineers Vol 214 Part F pp.159 -171.

Shiwakoti, N. Sarvi, M. Rose, G. Burd, M (2010) Biologically inspired modelling approach for collective pedestrian dynamics under emergency conditions. In Transportation Research Record: Journal of the Transportation Research Board, No 2196, Transportation Research Board of National Academies, Washington, D.C., 2010 pp. 176-184.

Stone, J. Mees, P. (2010) Planning public transport networks in the post-petroleum era. Australian Planner 47:4, pages 263-271.

Wiggenraad, P. (2001) Alighting and boarding times of passengers at Dutch railway stations. -TRAIL Research School, Delft, December 2001, Faculty of Civil Engineering and Geosciences, Delft University of Technology.

Wolf, A. (2005) Double-deckers dominate the loco-hauled coach market. Railway Gazette International, London, Vol. 161 No. 12 pp. 777-779.