A design study of metropolitan rail carriage interior configuration to improve boarding, alighting, passenger dispersal and dwell time stability

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Dedication

Success has many fathers. Failure is an orphan

Exegesis submitted as partial requirement for the degree of Doctor of Philosophy at Monash University.

August 2014.

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Contents

Abstract

Suburban railways 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 for train punctuality, crowding, for accessibility and passenger comfort. Lau (2005) and Daamen et al. (2008) suggest that the design of the train carriage interior has a significant influence on accessibility and passenger dispersal. Evidence from current literature connects these factors to determining the length of time a train is held at a station, with consequences for service punctuality and network capacity. There is also evidence (Mees 2007) that rail transport operators face conflicting responses to the problem in balancing consistent timetables with passenger comfort.

This exegesis describes a design study into the creation of an alternative train carriage design based on the physical parameters of Melbourne network infrastructure. Melbourne's network was chosen for its proximity to the candidate's studio activity but also for its particularly onerous problems of accommodating both a metro (short trip) system with a lengthy outer suburban service on tracks shared with regional and freight services. This research centred on a studio methodology that collated evidence from a wide range of related contemporary literature on the topic to inform an empirical design activity. The study embraced drawing, computer aided design, physical models and computer simulations to determine the efficacy of suggested concepts. The outcome is a design concept that consists of a series of innovations not only pertinent to Melbourne but with resonance further afield.

These innovations embraced three key features to effect an improvement to dispersal and passenger ingress and egress:

1. extra doors that operate only during peak periods for increased passenger exchange. During off-peak periods, the space behind these temporary doors is occupied by seating. Accompanying the extra doors are physical and graphical devices to encourage patrons to move to the left to facilitate simultaneous boarding and alighting.
2. a central aisle of seating clusters with both longitudinal and transverse seating, creating two corridors down the length of the carriage.
3. folding seats that can be locked into an upright 'perch' position to create more standing positions during peak periods and released to form conventional seating during less crowded periods.

These design innovations were modelled by computer crowd simulation software to establish their efficacy. The outcome of the modelling has shown that the concept design demonstrates a significant improvement in passenger accessibility, dispersal and dwell-time stability compared to existing Melbourne rolling stock for the same passenger loading capacity at peak time.

This outcome represents a significant contribution to the research field and, if adopted, could have positive implications for network operations. However, a limitation of this research is acknowledged in that devising the concept from first principles, transport-operating companies and passengers would need to embrace a moderate level of cultural change to the prevailing norm. Exploring this adoption would point to the development of a future study.

1

Chapter 1. Introduction

1.1 The problem

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 world's population lived in cities. Now in the early 21st century, over 50% of the world's population live in a city (Burdett & Sudjec 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 thousand square kilometres in area with a population of over 35 million inhabitants, 80% of whom use the subway. This is one of the highest levels of patronage anywhere in the world, with some 2939 million-passenger journeys for the year 2009 (ibid).

The technology of suburban commuter rail directly relates to its success (Alouche 2005). Rail electrification with associated high-torque motors creates a level of acceleration and braking that makes frequent stopping and starting possible and energy efficient. The relatively long life of the rolling stock (30 years), permanence of the track and high level of patronage make rail the lowest operating cost per passenger kilometre of any mode of transport (Vuchic 2005).

In addition to low operating cost, the appeal of suburban commuter rail to city planners is in its peak-hour carrying capacity (Costa & Costa 2010). This capacity is determined by the size of the carriages, number of carriages per train and 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 over other forms of transport for people in cities (Litman 2005).

Trains are independent of congested road-traffic conditions and therefore have the potential to be faster at delivering passengers into city centres. Automation and advances in signalling reduce the impediments to a smooth and timely rail system. However, rail networks in many cities in the world struggle to be punctual. The most significant variable in the journey of a train is the length of time it will be stopped at each station. This 'dwell time' depends on the interval it takes passengers to board, alight and disperse within the train carriage or across 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 planners attempt to predict extensions of dwell time during peak periods. However, with sudden spikes in increased patronage, the predictability of dwell times decreases. Extended dwell times reduce the headways between services, therefore affecting network capacity, ultimately impacting on the operator's revenue and contributing to poor passenger perceptions of the mode.

1.2 The anatomy of dwell times

Dwell time predictability is important in the creation of service timetables. To this end, operators subdivide the dwell time in order to better understand where the 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 the extent to which passengers have been slowed down by the circumstances of other passengers, width of the doors and carrying of belongings. Figure 1.1 shows an example of a dwell time formula used in calculating dwell times on Comeng trains in Melbourne in 2008 (Puong 2000).

$$\textbf{Dwell time} = C + (f_1 * A) + (f_2 * B) + (f_3 * TS^3 * B)$$

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 1.1 Dwell time calculation formula (Interfleet 2000).

Take 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:

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

Since clearly the variables of this calculation can be many, the results are normally analysed in a graphical form (Figure 1.2). Figure 1.2 has been drawn from a study on dwell time commissioned in 2008 by Connex the then franchisee in Melbourne, which expresses the impact that crowded vestibules have on the ability of passengers to board and alight in a timely manner.

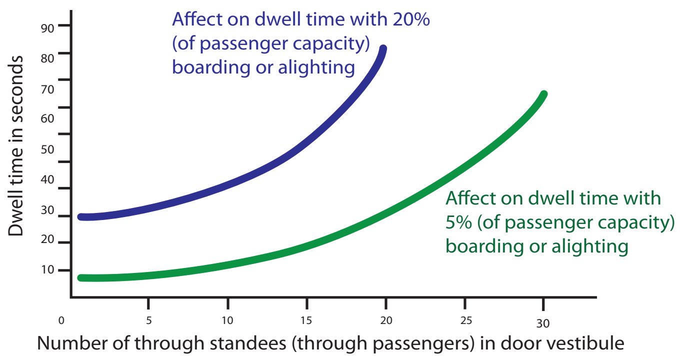


Figure 1.2 Dwell time against doorway occlusion.
(Data from Connex June 2008)

Embodied within the coefficient (0.984) in Figure 1.1 are data relating to a wide range of empirical studies. Transport operating companies (TOCs) choose the level of detail they wish to build into the coefficient. In the example on the previous page, the coefficients of friction (f_1 and f_2) were based on studies of Dutch passengers (Wiggenraad 2001) even though they were applied to Australian patrons. It has been argued (Harris & Anderson 2004) that the data are robust for a wide range of international applications. There is a great temptation to simplify and create an average set of results (Buchmueller 2008). However, 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 affecting 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, their motivations to finding a seat, the gap between the platform and the train, and the level of the occlusion at the door. These human factor variables are difficult to determine quantitatively and they relate strongly to the interface between the passenger and carriage.

Figure 1.3 (overleaf) encapsulates, as a flow chart, each of the 'factors' that affect the ability of a 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, their impact on dwell time becomes much more significant.

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 world's largest cities and very much so in Melbourne, where there was 43% growth from 2005 to 2010, (Currie 2010 p36). An increase in employment in the central business districts, congested streets, petrol prices and competition for land for parking have drawn people back to the railways. Buses as an alternative still fall victim to the same gridlock in cities without Bus Rapid Transit (BRT) and so trains become an attractive alternative (Gunton 2010). Higher passenger densities, particularly during peak times of the day, have implications for crowding and with that passenger perceptions of comfort and customer satisfaction (Baker, Myers & Murphy 2007). High patronage leads to doorway occlusion, extended exchanges of boarding and alighting passengers and thus a lengthening of the train dwell time. A number of reports (ABS 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 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 is,

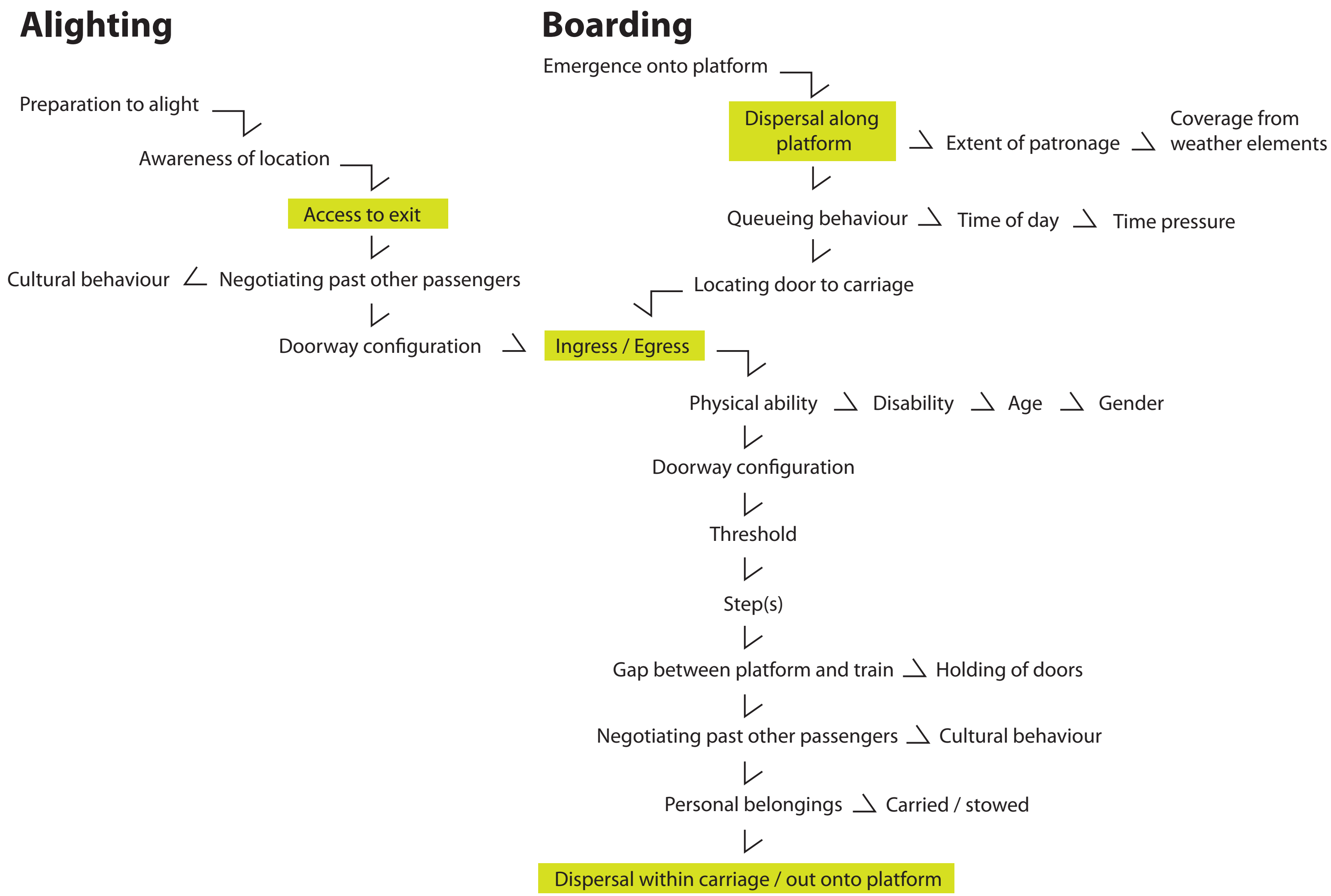


Figure 1.3 A cascade flow chart of the factors involved in dwell times.

however, a general obligation in franchise contracts to avoid 'excessive' overcrowding. In addition the driver or guard of a train can also refuse to operate a train if they feel it has become dangerously overcrowded.

There are a bewildering number of methods by which crowding is quantitatively measured. Within Australia TOC's of five capital cities, (Those of Melbourne, Sydney, Brisbane, Adelaide and Perth) have differing definitions of crowding. These include 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 that passengers are required to stand.

In the United Kingdom, there are two contrasting methods of measuring capacity. One method contends that for journeys of 20 minutes or more, a train is full when every seat is occupied. Any standing passenger during this journey length is deemed to be 'excess of capacity'. For journeys of less than 20 minutes, an allowance, depending on the rolling stock design, is built in. The number created is known as the PIXC figure (Passengers In Excess of Capacity). The allowance for standing varies with the type of rolling stock but, for modern sliding door stock, it is approximately 35% of the number of seats (135 passengers in a carriage equipped with 100 seats). This method is closely aligned to protocols implemented in Melbourne, although different methods are used for peak and off-peak (Metro Load Standards Survey 2011) due to the use of different length trains, 3 carriages rather than 6 on some lines.

Despite variations in Melbourne's rolling stock, the maximum capacity for each peak service is 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 crowded. Under this method, a count is undertaken, once a year or after significant timetable changes, measuring how many passengers are travelling in the weekday peak hours (Figure 1.4).

Figure 1.4 Manual train passenger load counting, Richmond station, Melbourne, May 2011.

Counting is carried out at strategic points in the network, often where loads will be perceived as the greatest, just before the city centre and significant interchanges. In Melbourne's case, these stations surround the CBD and form what is referred to as a cordon. Cordon stations are shown in Figure 1.5; they are: - North Melbourne, Clifton Hill, Burnley and Caulfield.

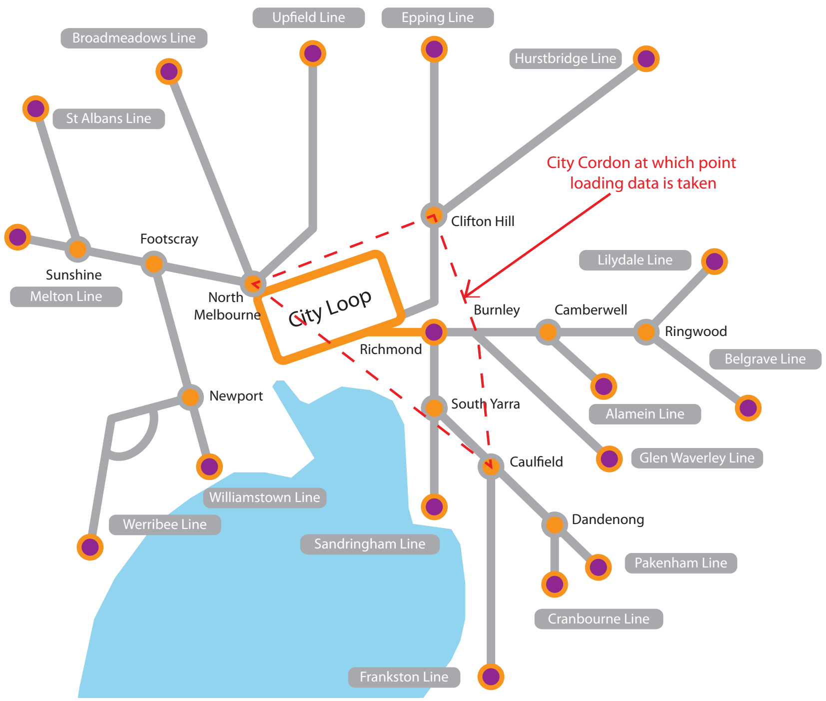


Figure 1.5 Cordon stations around Melbourne, May 2011.

Figure 1.6 shows data aggregated by the author from Melbourne Metro's loading report of May 2011 and presented as a graph. The horizontal axis shows the number of trains and total number of passengers each half hour of a morning peak period measured from 6.00 am to 9.00 am. The figures are averaged across all the services of a particular half hour. The result of this analysis is that all services appear to be under capacity i.e. less than the nominal 798 passengers of a full train. The total number of minutes lost by trains arriving at the cordon during a specific half hour is divided by the total number of services during the same period to give an average lateness. As the peak period reaches its high point, the total lateness has risen to nearly six minutes. While the reasons for lateness are not revealed in the data, it is clear that as the trains become more loaded, they are taking longer to reach the following station, eventually passing through the cordon stations later than indicated in the timetable.

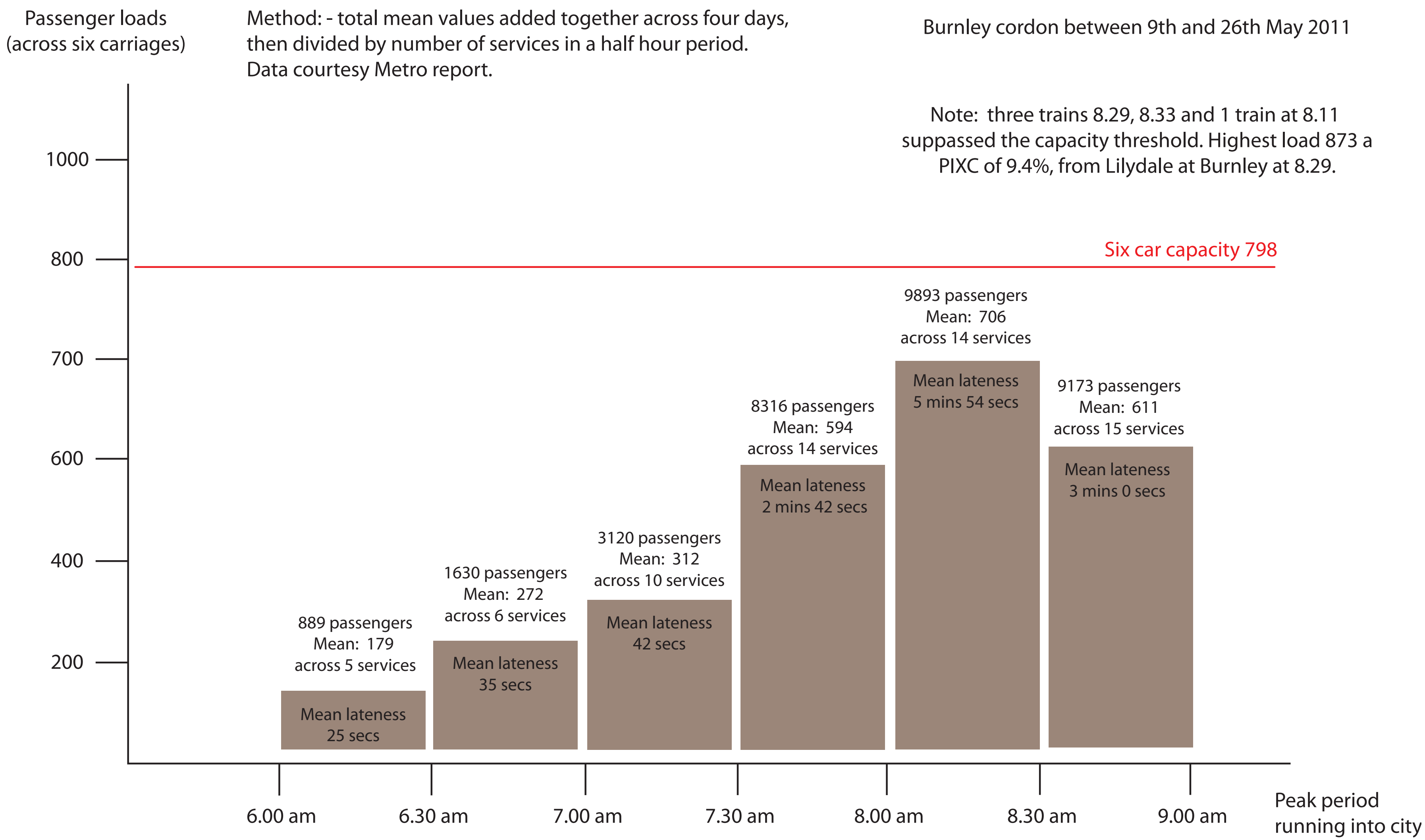


Figure 1.6 Aggregated loads across the peak morning period 6.00 am to 9.00 am, trains coming in from eastern suburbs, May 2011.

Average loads as reported in the Metro report of May 2011 smooth out the apparent crowding. When the data are explored in greater detail on a train by train basis as shown in Figure 1.7 it becomes clear that during the high peak period of 8.00 am to 9.00 am individual services are loaded beyond the nominal six car capacity of 798 passengers. Indeed, as the number of patrons on board the trains increases it is possible to deduce a percentage figure of passengers in excess of capacity (PIXC). The most crowded train during the load counting survey is seen to be the 8.25 am heading into the city with 1093 passengers, creating a PIXC of 36%. This train was at the time of measurement 17 minutes late due to picking up extra passengers as it progressed towards the city, each stop extending its dwell time.

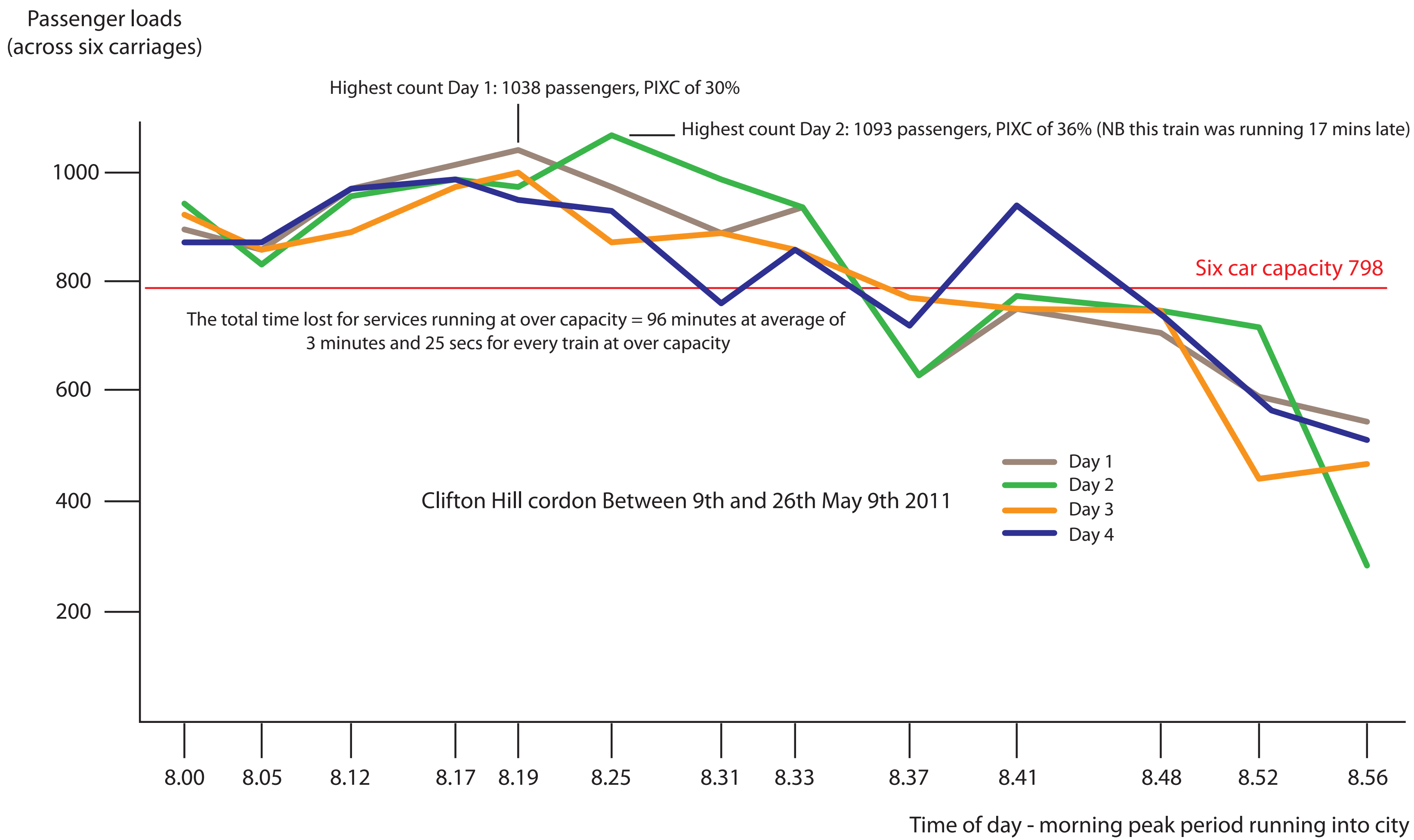


Figure 1.7 Individual service loading at Clifton Hill for four days between 9 and 26 of May 2011.
Data courtesy of Metro, Metro Load Standards Survey 2011.

An alternative method of measuring capacity is by proxemics, i.e. measuring the number of passengers per square metre of available standing space. To illustrate how this measure compares to the PIXC figure, the PIXC score of 40% for Melbourne equates to around five passengers per square metre of available standing space. The Tipping Point Institute (2009 in Hirsch & Thompson 2011) conducted a survey of crowding on Sydney trains and determined that 0.88m^2 space per passenger defined a comfortable space. The determination of 'comfortable' space is open to debate since it includes not only physical wellbeing but also the parameters of physiological comfort through the notion of personal space (Hirsch & Thompson 2011).

Crowding creates a great deal of discomfort for passengers and can even be dangerous (Turner et al. 2005). Passengers caught in the middle of the vestibule area with no accessible handholds can fall onto other passengers as the train moves. The situation is worse for shorter people who cannot reach the handholds. Evidence from the literature suggests that this makes dispersal within the train uneven, with increased bunching at the door vestibules (Hirsch & Thompson 2011). People who have managed to find a handhold are reluctant to move down the train to create space for others. In hot conditions, discomfort can escalate to fainting. General psychological stress levels go up in crowded carriages, which may result in unsafe behaviour (ibid.)

Leurent (2009) makes the assertion that passengers in Paris change their routes to work, seeking services where passenger crowding would be least. Seating or standing are distinct states that passengers associate with their feelings of comfort. A stated preference experiment carried out in Paris on RER and SNCF services (Kroes et al. 2006) determined the value of passenger comfort as 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 equivalent to an increase of 27 minutes of 'disutility'.

Crowding as described in the literature (Hirsh et al. 2011) and as evidenced by the Metro Loading Standards Survey (Metro report 2011) 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 of the value that passengers place on 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 made 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 and b) building in a margin in the expected trip time.
- Stated preference experiments conducted among passengers identify 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, and intercity and train delays occurred more frequently at certain times of the year such as winter and during weekdays.

1.5 The research question

This introduction has outlined that while suburban rail offers many benefits and has a rapidly growing mode share, passengers and operators are beset by significant challenges in crowding and its negative impact on extended dwell times and service punctuality. The causes of these problems are layered, interconnected and therefore complex. Figure 1.8 captures the problem and aims to describe the type of intervention that might ameliorate the problem. The evidence presented in this chapter indicates that when the Melbourne network is faced with accommodating passengers in excess of carriage capacity, the outcome is extended dwell times at stations. These delayed trains, arriving late at subsequent stations, are met with the accummulation of more patrons and so the delays are exacerbated.

From these issues, influences, conditions and opportunities, the research question has been framed, seeking a design intervention that examines the physical and spatial interior of the carriage as the means by which passenger dispersal, boarding and alighting might be influenced for the better. The research question is therefore posed thus:

How can the interior of a suburban metro train carriage be designed to improve boarding and alighting, with respect to stabilising dwell times, and by implication enhance the passenger experience during periods of crowding?

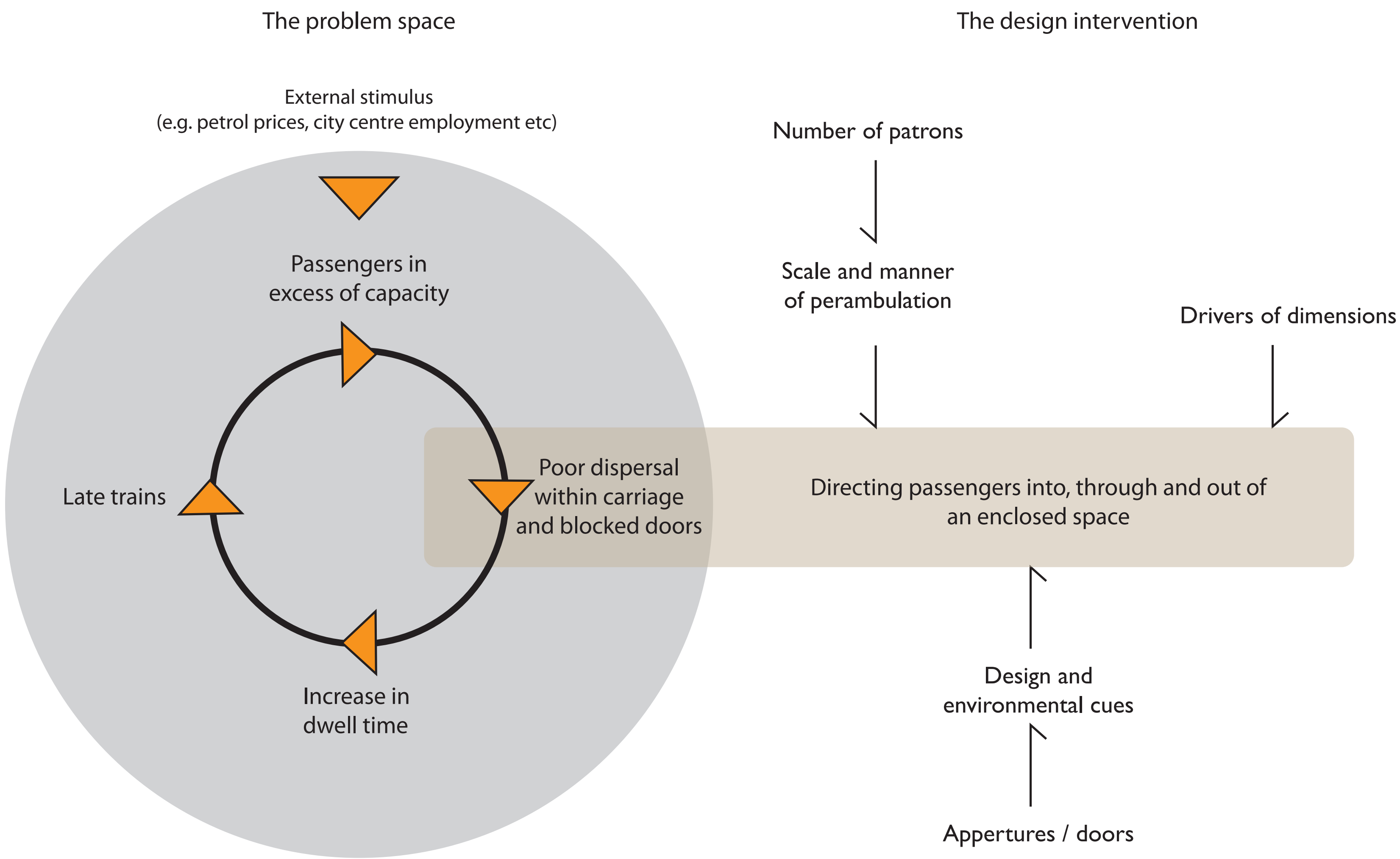


Figure 1.8 Framing the problem and identifying the design intervention.

2

Chapter 2. The literature review

2.1 General overview of the literature

The previous chapter described the research problem, indicating the inter-relationship between crowding, extended dwell times and punctuality. It is clear that the problem of passenger boarding, alighting and implication upon dwell times is multi-faceted with interconnected relationships between the system, its infrastructure and human interaction. This chapter serves to inform a future design concept by exploring the existing literature concerning contemporary approaches to alleviating the problem and is divided into the following sub-sections:

2.2 Operational strategies to address crowding and punctuality

2.3 Carriage interior layout strategies

2.4 Door ingress and egress occlusion

2.5 Door threshold issues

2.6 Door holding behaviour

2.7 Disability access

2.2 Operational strategies

Passenger loading data, as discussed in the introduction, are used by TOCs to determine patronage spikes and signal adjustments in their service provision. These adjustments come down in economic terms to either increasing capacity or reducing or spreading 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 or so called 'pricing-off', 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 2007). Economic measures to reduce demand can be counterproductive since they negatively affect revenue streams.

2.2.1 Increase the number of services

Network capacity is driven by the frequency of services that can be operated along the line. The period between trains is known as 'headway'. 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 signalling. It has been argued that service capacity improvements could be made in Melbourne by improvements in signalling (Mees 2007).

Harris and Anderson (2002) make the claim that a high frequency service would be in the range of two minutes between trains. This figure is made up of 60 seconds for run-out (slowing down) and 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 load data discussed in the introduction (Metro Load Standards Survey, May 2011) reveal that at some cordon stations, at peak hour, as many as 18 services are coming together from two lines. Caulfield from 8.00 am to 8.30 am is an example of this. The data reveal a headway of 1 minute 39 seconds. At other points in the Melbourne network, for example Burnley, where lines converge from the eastern suburbs, it is found that headways of two minutes are achieved from 8.30 am to 9.00 am. From 5.00 pm to 5.30 pm, the results are the same. The northern corridor measured at North Melbourne reveals similar approximate two minute headways at both peaks in the day. Only the Clifton Hill cordon, measuring commuters from the north east, has a lower frequency at similar peak periods. These data do 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 on its own indicates that the Melbourne network is at capacity, at least during peak periods, and there is no capacity available to increase the number of services.

2.2.2 Increase the length of the trains and platforms

The length of trains today is limited by the length of platforms created decades ago. In cities with long established infrastructure and old stations, the opportunity to undertake expensive modifications to platforms is limited (Figure 2.1).

Figure 2.1 South Yarra station showing a narrow end of platform; existing buildings make extending difficult.

If it is not possible to extend trains by the addition of carriages, then many TOCs have taken the opportunity to go taller and increase carriage capacity. Double-decker carriages are a popular option in

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 & Anderson 2002).

The inclusion of stairs in a double-decker carriage to access seating inevitably has implications for universal access. Larger objects such as prams, wheelchairs, 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 at platform height contains only a longitudinal arrangement of seats, for example the 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). 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 appears that double-deckers are relatively few where there is high overcrowding and greater standing room is necessary, for example in Japan.

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 passenger loads (Ruger & 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, which also has very short two minute headways.

2.2.3 Track amplification

The most expensive, most difficult option and the one slowest to affect change available to TOCs is to increase the number of rail 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 have invested heavily in road infrastructure (Kenworthy & Laube 2001) in the second half of the 20th 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 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; the last major rail line in Melbourne was opened in 1930. It should be noted that despite this apparent stagnation existing lines have been extended or electrified and new stations built, for example, Craigeburn on the Broadmeadows line in 2007.

The report to the Victorian state government 'Investing in transport – east west needs assessment' (Eddington 2008) highlights options for public transport growth in Melbourne in the future. However, it is argued that Melbourne is in a weak position to respond to recommendations in improved public transport infrastructure, especially rail, as the city carries the burden of decades of land use policy predisposed to the building of roads (Eddington 2008, Mees 2005, Stone 2009).Track amplification as a response to train crowding therefore represents the most politically difficult, most costly and most long term of the strategies available to a TOC.

2.2.4 Reconfigure the interior of the rolling stock.
Re-configutring the rolling stock interior can provide some respite from crowding by the manipulation of seat numbers, their positions and the location of hand-holds (Interfleet report for Connex 2007). Suburban trains typically have a life span of thirty years. They might typically be refurbished after fifteen years and reconfiguration can occur at these times representing a lower cost option in comparison to those already discussed.

2.3 Carriage interior layout strategies

In Lau (2005) a theoretical process attempts to determine the optimum layout for the largest capacity design of carriages. This is 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 affecting 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 and facing towards the centre of the carriage, as shown in Figure 2.2. This arrangement is the choice of train designers when the track gauge is Standard or narrower (i.e. equal to or less than 1435 mm inside rail to inside rail). This arrangement is commonly referred to as 'metro-style seating'. On networks of traditionally high patronage the wider central floor space makes passenger flow quicker and less obstructed (Ruger & Tuna 2008).

The second arrangement is transverse, with seating at right angles to the windows. Typically this composition of seating is used in wider carriages, regional and intercity trains (Figure 2.3). There is evidence (Ruger 2008) that passengers favour sitting in the direction of travel or alternatively with their backs to the direction, but seldom sideways. Transverse seating is used for services covering longer trips, where the tolerance for discomfort is less than on short, inner-city journeys. Transverse seating narrows the space between doors, forming corridors, which is the least effective at encouraging passenger flow on frequent stop services.

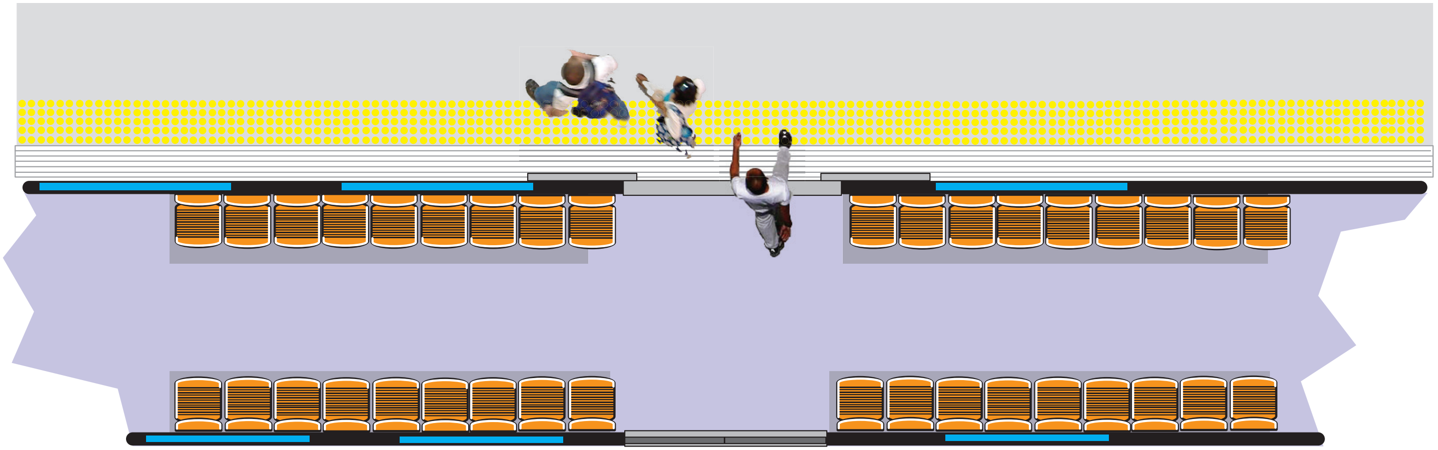


Figure 2.2 Longitudinal (metro style) seating.

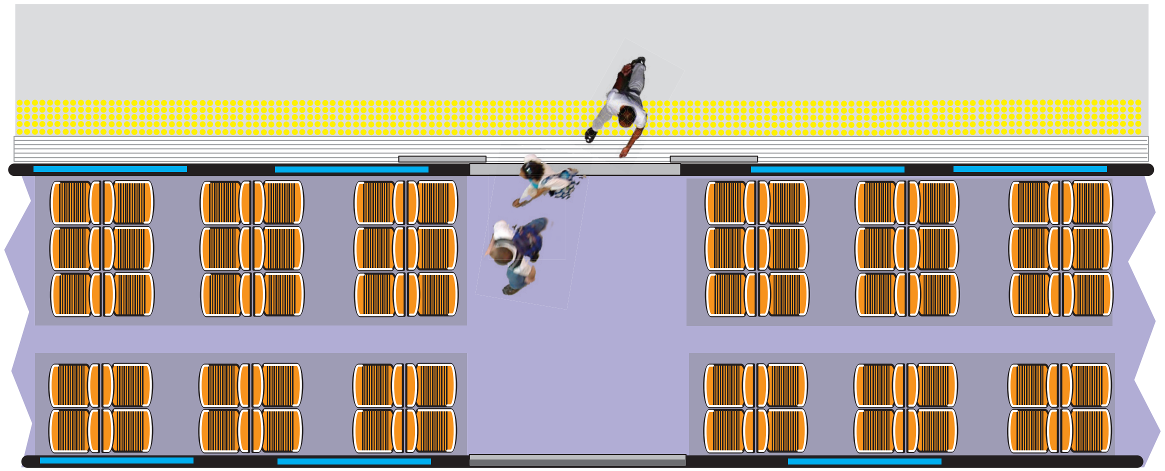


Figure 2.3 Transverse seating.

The Melbourne network has the advantage of a broad gauge at 1600 mm and can therefore accommodate a mixture of transverse and longitudinal seating in its fleet. The extent of the network also means that in many ways the services need to perform as both metro and to some extent regional services. Australian urban land use has low population densities leading to extensive commuter distances for a metropolitan service. Journeys from the outer reaches of the Melbourne rail system take 63 minutes (Online Metro timetable accessed 4/7/14).

Morlok and Nitzberg (2004) describe modifications carried out to rolling stock on New Jersey Transit, Northeast Illinois Commuter Railroad, South Eastern Pennsylvania Transport Authority, New York Metro and North Commuter railroads. These modifications removed the manual operation of carriage end doors known as End Vestibule Entranceways (EVE) and made them automatic, along with an additional, centrally located door. The door apertures were made wider and the former high step down of 203 mm was removed to create level boarding. Such doors are known as Short Dwell Entranceways (SDEs). Morlock and Nitzberg claim that this arrangement enables a substantial reduction in dwell time. SDEs apparently have other benefits; fewer injuries when boarding or alighting (75%) and greater compliance with disability legislation.

The design of commuter trains in Tokyo was overhauled in 2000 with the introduction of the Series E231 vehicle. One of its principal specifications was to cope with the huge patronage at peak times. Sato (2000) states that central to this strategy was a wider carriage body with a longitudinal arrangement of seats. The wider central standing area catered for more standing passengers, increased still further by folding seats during peak periods or when not in use.

A critical feature of all carriage seating arrangements is how they affect passenger dispersal. Studies in Russia (Regirer & Shapovalov 2003), concerning buses, have tried to determine the motivations of passengers when boarding the vehicle in order to better predict the comfortable filling level for potential future configurations of the vehicle. Their conclusions determined that the rate of boarding is driven by the crowd density of those trying to board. 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 relate to the spread of the stops. There is an inter-connected relationship between the schedule and the distribution of passengers within the vehicle. According to the findings of the study, passengers move further into the vehicle if their journey is longer and they do not anticipate needing access to the door soon after boarding.

In more recent studies in Australia carried out as part of research for the RailCRC (Hirsch & Thompson 2011) reveal that a range of behaviours are prevalent among passengers, determining their on-board behaviour. Of significant priority to passengers is the acquisition of a seat, followed by the creation of personal space by a variety of means including the use of carried items and personal behaviour, including 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 same study, are:

- the cleanliness and hygiene of either those one might have to sit next to or the seat itself (food spillage, for example)
- access to the doors; during peak loads, crowding in the vestibules and with this the corresponding occlusion of doors is exacerbated by the unwillingness of passengers to move further into the carriage
- ventilation; during summer when carriage air-conditioning struggles to maintain comfortable temperatures, passengers express a preference for standing next to doors so they can take some fresh air at each stop
- the behaviour of fellow passengers is also cited as a deterrent to sitting close to someone who might represent a threat or create psychological discomfort or anxiety.

The Melbourne network runs a majority of its 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 during crowded times because it means 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.

To investigate further strategies around carriage interior layout, the Author has examined more closely two initiatives carried out by transport operating comapnies. Firstly an example from Stockholm's suburban train network and then Melbourne's strategy at improving passenger flow.

2.3.1 The Stockholm experience

Storstockholm's Lokaltrafik AB (Greater Stockholm Local Transit Company), commonly referred to as SL, is the TOC for all of the land based public transport systems in Stockholm. In 2008 SL embarked on an investigation into alternative carriage interior design as a response to increased crowding and a decrease in punctuality. The data from the experiment served to inform a specification for new trains and the refurbishment of exisitng stock.

The existing CX seating arrangement consisted of transverse clusters of two seats abreast with a central corridor linking three door vestibules, as shown in Figure 2.4. The carriages contain 48 seats.

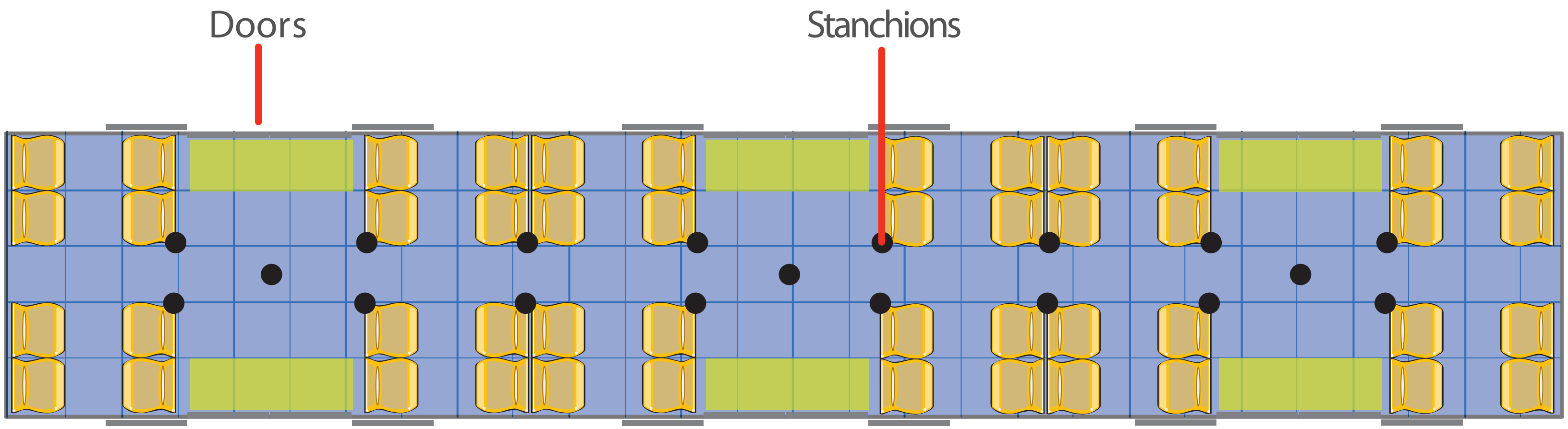


Figure 2.4 Plan view of the existing interior of the Stockholm CX series rolling stock.

SL has two types of rolling stock, the C20 and the CX. The latter actually refers to a sub series of older carriages. For the purposes of the experiment the last carriage of a CX EMU was used. The process of redesigning the interior layout was largely predicated on increasing the capacity for standing. Since existing rolling stock was to be used, limitations were placed on the engineers in terms of locating handrails and fixing points by virtue of the existing mechanical structure of the carriage.

However, two prevailing philosophies were embedded within the rationale of the experimental carriages. The first design continued with a transverse arrangement but removesd 22 seats from the carriage, leaving a 26 seat cariage; 8 of these seats were folding, a feature not present in the original design.

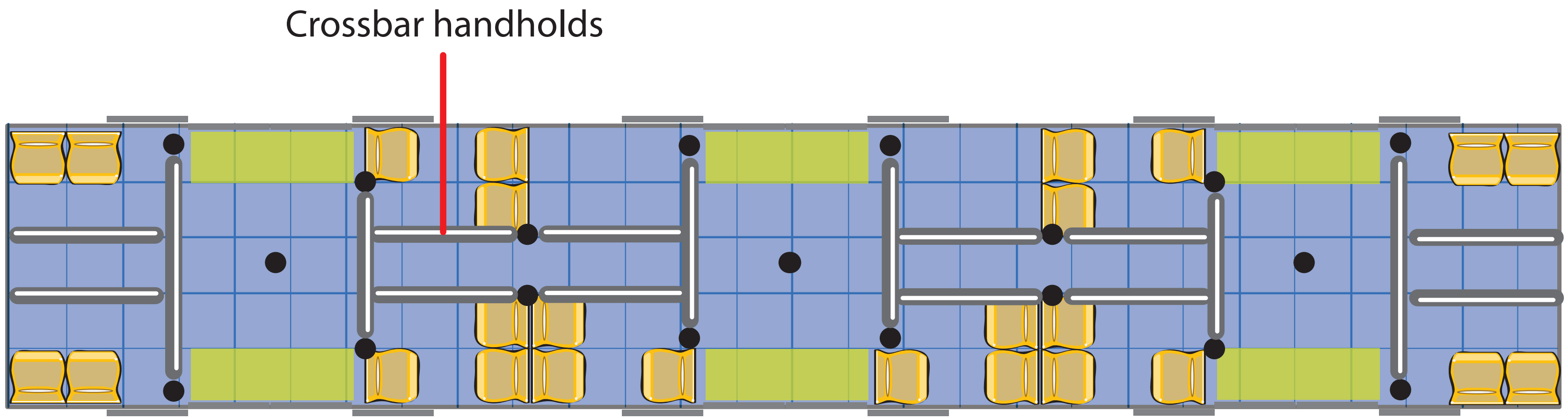


Figure 2.5 Plan view of the Type 1 experimental interior with 26 seats.

The second carriage interior adopted a longitudinal arrangement of seats the full length of the carriage. This arrangement created a capacity for 32 seats, 24 fixed and 8 folding. The interior was entirely symmetrical.

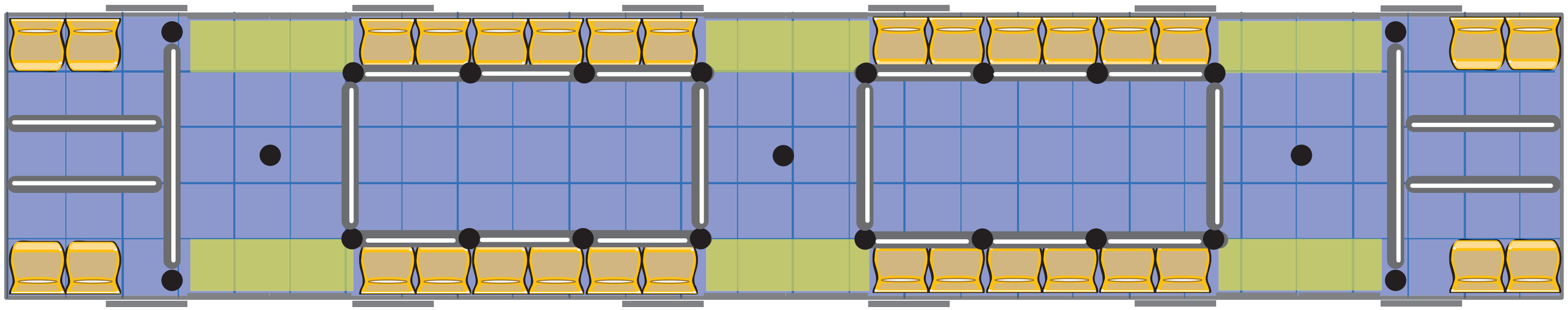


Figure 2.6 Plan view of the Type 2 experimental interior with 32 seats.

Both designs had the following features in common:

- no changes to doors or window positions
- refurbished interior with a modern scheme
- 1.5m turning circle for wheelchairs and prams
- contrasting colours for the visually impaired
- marked seats for the disabled
- a common flexible area positioned by the first door
- stanchions floor to ceiling
- stanchions located with respect to passenger flow
- reduction of holding places nearest the door
- wider aisles.

These carriages were introduced onto only one line of the network: Morby Centrum through to Fruangen, 19 stops with 6 interchanges, for an eight-week period. The experimental carriages were placed within a set of regular interior arrangement carriages in an eight car set in the following way:

- Type 1 as the last two carriages of the set
- Type 2 as the last two carriages of the set
- Type 1 at the back and Type 2 at the front of the same set.

During the period that the trains ran, SL conducted two methods of retrieving data, one qualitative and the other quantitative. Qualitative methods included the running of focus groups and an on-board questionnaire. The focus groups were subdivided into two groups; one with children aged 9-14 who travelled without an adult and the other with adults. Within the adult focus group, the number of respondents was kept to 5 or 6. They were also split into groups by age and time of day they normally used the train, i.e. rush hour and non rush hour. For the on-board questionnaire, 20 questions were asked of a total of 600 respondents over the eight-week period. For the quantitative data, counting measurements were taken of the train dwell times, the number of passengers and their distribution within the carriage.

The qualitative data collation revealed that more than 90% of the respondents felt punctuality was important or very important. 75% gave higher priority to arriving on time than having a seat. Having a seat became more important than arriving on time when trips were over 20 minutes. Those travelling in rush hour were most satisfied with the test cars. The advantages with Type 1 were appreciated most by disabled persons. Those travelling during non-rush hour did not like the test cars; sitting was very important to them. Some respondents reported that they would have liked the experimental cars to be identified and that in both Type 1 and 2 there were too few locations to hold onto. It was also reported that the banging of folding chairs was a noise disturbance.

The quantitative analysis revealed a 2 to 4 second reduction in dwell time for both interiors, with Type 2 (longitudinal seating) being slightly quicker. Along the whole line a 20 to 45 second saving could be achieved. Small time gains from shorter station stops contributed to better compliance with the timetable. The position of the test car in the train was observed to be significant; whether first or last car in the set. The significance was attributed to late arriving passengers emerging onto the platform and dashing to the nearest carriage, usually a first or last car in the set.

2.3.2 Removing seating from the door vestibule

From 2004 to 2010 the French TOC Connex held the franchise for Melbourne's suburban train network. Melbourne has 15 lines, 830 kms 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).

The Melbourne metropolitan system has four different types of rolling stock with differing door positions and seating arrangements. The track is broad gauge (1600 mm) 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.

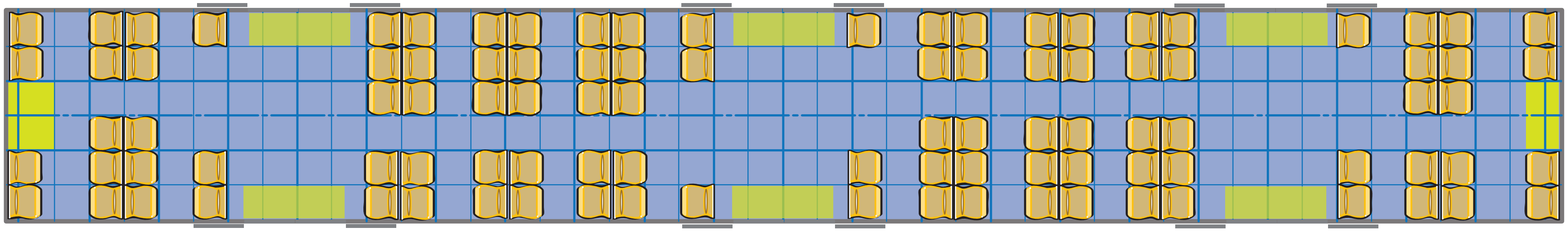
The nature of the Melbourne network dictates that multiple services from outer suburbs are funnelled into the central business district into a section of the line known as the 'City Loop'. During peak periods and short headways any extension to dwell time as commuters board and alight can have major consequences for 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.

Melbourne has an additional extra dimension to its problems, in that the network and the city are so sprawling that services begin to function as quasi-regional trains. The Frankston train to the CBD takes just over one hour. The same service is then 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 and none with multiple types of rolling stock and population growth.

In 2008 Connex, in collaboration with industry consultants, sought to determine what could be done to reduce extended dwell times. The Comeng model, which is the most numerous 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 and 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 with less seating due to driver's cab) and one trailer car.

The study considered of 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.

Comeng original layout



Comeng with altered interior layout - and extended vestibule circulation space

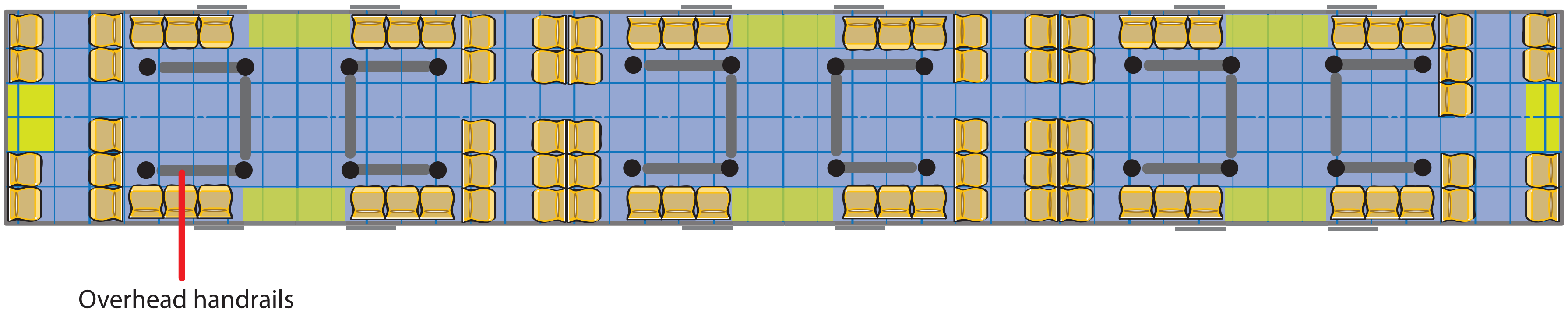


Figure 2.7 Plan view of a Comeng train interior before and after vestibule, seating and handhold positions were re-appraised.

To do this a number of assumptions and considerations were put into the formula. For example, in order to make useful comparisons, the numbers of boarding, alighting and through passengers were kept the same for each layout tested. Not unexpectedly, these calculations revealed that the layout with the largest number of seats removed offered the best improvements in dwell time; see Figure 2.7.

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 positions above the door and along the edge of the draught screen. This positioning encourages passengers to block the doors by standing to either side of the threshold in what is referred to as the 'sentry position', if they cannot 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 stanchion 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.

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 2007 et al.) TOCs are reluctant to be perceived by the general public through the media as reducing passenger comfort onboard their trains. Having more standing passengers 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 comsequences for network capacity.

As part of the 2008 Victorian Transport Plan, 38 new six-car Xtrapolis trains have been procured. The seating layout will be 2+2. The current incumbent TOC (2011) Metro Trains Melbourne are required to alter the seating layout of the Comeng fleet to 2+2 seating and, as an initiative directed on the platform side, the TOC has introduced more staff at major stations to encourage flow and passenger movement.

2.4 Door ingress and egress occlusion

Doors are the most significant arbiters of bottlenecks. They determine platform flows and, as seen in Hirsch and Thompson (2011), influence passenger dispersal within the carriage. Lau (2005) describes trade-offs such as increasing the number of doors, forcing a reduction in the number of seats. Parkinson and Fischer (1996 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 is usually hoped for. Six-door carriages (three per side) have a capacity advantage over two doors per side when fully loaded (ibid.). This is due to the increased standing space in the vestibules, as with Melbourne trains. It is also noted that where opening doors slide into cavities, 'deadlight' areas are created where there can be no window. Passengers standing in the sentry position in doorways narrow the door significantly, constraining the ability of boarding and alighting passengers to move easily between train and platform.

While there is a wide body of work regarding the dynamics of crowds in general (Helbing et al. 2005), there is less dealing with the specifics of urban trains. Researchers in this latter area (Daamen et al. 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 are features of an active bottleneck (Hoogendoorn et al. 2002). A momentary period of doorway congestion is also exacerbated by the following conditions (ibid.):

- step up or gap
- narrow gap with obstacles (other people or luggage etc)
- locations where flows from different directions meet
- Locations where both standing (through) passengers and moving passengers are present
- incidents (tripping and falling).

There are a wide variety of design responses to bottlenecks. The following list describes examples, but they are not solutions exclusive to those cities:

- wider doors (Mexico City 1900mm +)
- more doors per carriage (MTRC Hong Kong); longitudinal seating 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. The speculation is that it takes longer to disembark a train from a position between two widely spaced doors than to negotiate between a three-door carriage in comparable capacity situations
- fewer seats per carriage (Vancouver); Figure 2.8
- separate platforms for boarding and alighting (Sydney, Homebush, Rio de Janeiro); Figure 2.9
- graphic floor patterns to encourage efficient behaviour (Paris, Brisbane, New York); Figure 2.10
- bleepers for doors (most countries) and military music

(Copenhagen)

- more frequent services with short headways (Moscow and Santiago).

Figure 2.8 Vancouver metro system vestibule area (2010).

Figure 2.9 Rio de Janiero, passengers board only from the central platform and alight only from the side platfroms shown to the right and left of this photograph. Photograph courtesy of Fliker (2009).

Figure 2.10 Graphic patterns on the platform to assist better door flow; (left) Brisbane 2008 and (right) Paris 2009 respectively.

2.5 Door threshold issues

Both Daamen et al (2008) and Hoogendoorn et al (2002) identify the importance of the door threshold in boarding and alighting efficiency. Central to this is a passenger's ability to navigate the gap between the platform and the train. It has been seen (Rotter, Daniel 2010) that patrons approach doors at different speeds and have a tendency to slow at the door threshold. The extent to which this happens varies according to width and level of gap (Daamen et al. 2008) but also the passenger's age, the carrying of items, accompanying small children, wet platforms, pushing or jostling, and gender (Rotter, Daniel 2010).

Gap distance is determined by the clearance between the structural gauge (platform and fixed infrastructure) and the loading gauge (outer envelope) of the train. In systems with mixed rolling stock, especially of differing ages, the gap between platform and carriage can vary (Moug 2013). Too wide a gap can be a cause for anxiety about stepping across. Too narrow a gap and there is the danger of trains striking the platform.

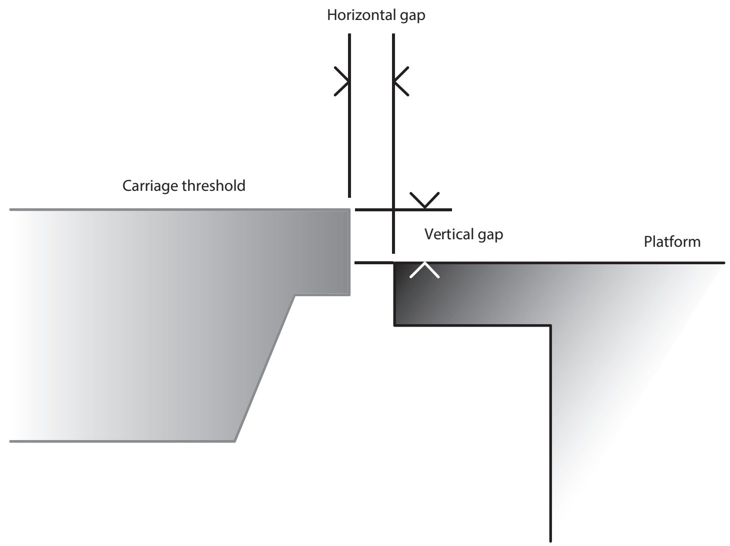


Figure 2.11 Horizontal and vertical gaps between door threshold and platform.

Train floor heights are generally above the platform. This is a legacy of a time when eager commuters flung the doors open before the train stopped and doors were mounted on hinges that swung outwards. Door height in relation to the platform often varies along the length of the platform. Where there is old building infrastructure that has had alterations and extensions to platforms, gaps can have significant variation. At Flinders Street station in Melbourne, for example, a carriage at one end of the platform will require patrons to step up onto the platform while further down the train passengers step down when alighting.

Gap-related accidents are a serious problem for TOCs and passengers. In the UK, it was reported that 4287 gap accidents between January 2001 and May 2005 occurred during boarding and alighting and during door closing, and a fifth of those passengers actually fell into the gap (Rail Safety and Standards Board, July 2006). However, this report goes on to reveal that these accidents were more the result of risky behaviour on the part of passengers than defective rolling stock. Examples given were the propensity of passengers to rush through an already closing door and the distraction of using a mobile phone and tripping up while boarding or alighting.

Rotter and Daniel (2010) examine focused attention; the phenomenon of focusing on one aspect of the environment over another. Their analysis reveals a correlation between the gender of passengers looking down at their feet when boarding or alighting and the number of threshold-gap accidents experienced by each gender. A larger percentage of women have boarding accidents than men. A larger proportion of men look down than women. The same is the case for alighting. The research claims that women are generally less attentive to the gap; however, this Author observes that no attention in the study is given to footwear. It might be the case that women have a greater risk of a stepping injury due to the wearing of high heels.

The Rotter and Daniels data (ibid.) point to level boarding as an aspirational goal of TOCs; however, according to full-size mock-up experiments reported in Fernandez et al. (2010), the optimum relationship between vehicle and platform is reported as 150 mm. The measure of this optimum was the impact of this dimension on dwell time. The experimental work revealed that passengers made a small jump as they stepped down from the mock-up vehicle and this quickened the overall boarding and alighting time. This work also reports that increased door width had a greater impact on reducing dwell than the step height.

Daamen et al. (2008) tested boarding and alighting activities by using a mock-up wooden vestibule and a team of volunteers passing across a gap and through doors. The gap height and width were varied and the experiment repeated and the time taken recorded. In these experiments, it was observed that the time taken for passengers queuing in front of a door to pass though it, when alighting, was shorter than when boarding. This could be put down to a sense of preparation for alighting as a train pulls into a station, creating bunching at the door. Passengers on the platform side are dispersed more widely in front of the door, especially if it cannot be accurately predicted where the door will draw up (e.g. different rolling stock). In these experiments, increases in the gap distance, both vertical and horizontal, between carriage and platform slowed passengers down. An exception was for small vertical gaps (actual values were not discussed), which saw a marginal increase in passengers speeding up. Passengers with luggage move much more slowly and the experiments revealed that this is significant in the lengthening of dwell times (25%). An increase in gap width, rather than height, has a much greater impact on those carrying items of luggage than changes in vertical height.

The most compromised sector of the community in terms of boarding and alighting the door threshold are those with disabilities, particularly wheelchair users. These issues will be discussed in section 2.7, disability access.

The literature concerning the door threshold reveals that the gap distance and height between platform and carriage are significant in determining dwell time performance. Passenger approaches to the moment of boarding or alighting varies with the extent to which the threshold presents itself as an obstacle and how much they are carrying.

2.6 Door holding behaviour

Among the unpredictable incidences that occur while a train is stopped is the interference to door closure by passengers. The deliberate holding of doors delays the train from getting underway and doors that have been held open for extended periods can have their closing actuators burned out. This renders the carriage inoperative for carrying passengers and is the cause of the removal of the whole train from service.

While customer annoyance at deliberately delayed trains is clear, passenger attitudes to the implications of holding doors are mixed. Since most regular passengers find themselves at some point holding train doors, often with the best of intentions, the effects are not perceived as damaging. According to one New York blogger, door holding as an anti-social behaviour on trains was rated on a personal scale of one to ten as only a two (Chan 2009). Yet despite this, research carried out by the New York Metropolitan Transport Authority (Rivera 2008) identified six causes of train delay in which the holding of doors was the second highest source of impediment after track work.

There appears to be no body of academic literature reporting on this phenomenon. This section of the literature review is therefore drawn tangentially from a narrow range of related sources such as blogs from passenger user groups and material particularly from the department of the French National Railway (Société Nationale des Chemins de fer en France SNCF) concerned with passenger security (Direction de la Surété – Stratégie et Observatoire). This organisation has conducted research with the Author into this particular problem.

SNCFs own research in the Ile-de-France describes the following reasons for passengers holding doors:

1. The train is full, or the vestibule immediately adjacent to the door is blocked, but patrons outside the train still try to gain access by squeezing into the carriage while the door is closing on them. An individual restrains the doors from closing and the arrangement of people within the vestibule changes to accommodate the boarding passenger.
2. The doors are held by a passenger within the train to assist a late approaching passenger to get on board. This action, from passenger user group websites, is perceived as an act of courtesy and assistance to a fellow passenger, rather than an action that could damage the train or prolong the journey. The urge to provide assistance to persons with prams arriving at the platform late and attempting to board is hard for passengers to resist.
3. The train vestibule is clear but a person with reduced mobility (PRM) is being assisted to board and once again the holding of the doors is seen as an act of courtesy, rather than something antisocial.
4. Doors are held by someone smoking so that they can evacuate the smoke from the carriage.
5. Doors are held in mischevious behaviour to deliberately detain the train. As in point 4, the central act is of defiance:

the individual sees themselves as able to impose their will to determine the actions of others (Alexa, SNCF 2009).

SNCF, as with most rail TOC networks around the world, uses audible alarms to alert passengers to the impending closure of the train doors. They have also, during 2009, employed staff to patrol platforms (at the busier stations) and police the door closing process. In 2009 SNCF embarked on a publicity campaign, producing posters and flyers targeted at creating awareness among passengers that holding doors is detrimental to the service and their fellow patrons (Figure 2.12). Studies show that the presence or absence of warnings can influence behaviour (Silver, Braun 1999).

Door holding behaviour is an additional variable in the determining of dwell time. The repercussions of such passenger behaviour are not seen as particulalrly detrimental and it can even be viewed as a courtesy to late arriving passengers. However, for the train operation, such actions mean delays and potential damage to doors.

Figure 2.12 SNCF poster campaign.
"If you like your trains to run on time don't delay"
Courtesy of SNCF (2009).

2.7 Disability access legislation compliance

Public transport is by definition required to accommodate a wide range of human diversity. This diversity reflects a range of physical and intellectual abilities that at some time or another will create usability difficulties for a passenger. Progressive societies look to include those citizens who have disabilities. However, whether it is a parent with a child in a pram or a person carrying shopping, at some time most people will be 'disabled' in some way. If the performance of public transport can be measured by its accessibility, then determining what this means in terms of physical design becomes essential.

The Disability Rights Commission (UK) reported (Wilson 2003) an overview of the literature concerning the experiences of disabled people in accessing public transport in the United Kingdom. Of each of the modes discussed, the train was perceived as the most difficult to use, principally due to the issue of ingress and egress. Access to train services is essential for disabled patrons to participate fully in the community (Johnson et al. 2008). Countries with advanced rail networks e.g. Australia, the UK and the US, have policies that prohibit the discrimination of patrons with a disability. In Europe, the European commission oversees obligatory specifications and standards of accessibility expected of rail manufacturers and operators e.g. The Trans-European Convention of Technical Specification for Interoperability 2007. In Australia, the Disability Discrimination Act (DDA) 1992 establishes minimum accessibility requirements of both stations and rolling stock. These requirements are mostly articulated as physical dimensional specifications in areas such as:

- access pathways
- manoeuvring space for wheelchairs
- ramps and boarding devices
- allocated space and handrails
- doorway dimensions
- controls (door actuators, for example)
- symbols
- payment of fares
- provision of information.

UK legislation has been criticised as confusing (Tyler 2002 cited in Wilson 2003) since components of the legislation create exemptions and mismatches between infrastructure and the vehicles themselves. It has been suggested (ibid.) that minimum standards leave little room for improved development, and that instead of dimension based standards, services should have performance based standards, e.g. to arrive and leave comfortably and with dignity.

Rolling stock manufacturer efforts at improving vehicle accessibility have been directed to the issue of the gap between carriage and platform. Daamen et al. (2008) have, after creating full size mock-ups and evaluating various gaps with disabled patrons, determined that there is a relationship between gap distance and the type of mobility aid employed by the passenger. The study found that the vertical gap distance between door threshold and platform is more significant than the horizontal gap distance for wheeled mobility aids, the maximum dimensions before some patrons encounter problems being five centimetres horizontally and two centimetres vertically (Daaman et al. 2008).

Reducing gap distance is important since it avoids the use of time consuming and expensive lift and ramp systems. Consistent, absolutely level boarding and alighting are considered very difficult to achieve in engineering terms, especially on existing stations, since platforms need to be straight and without a significant incline. With the Melbourne network, the problem is compounded by the use of four differing rolling stock types. Melbourne's response is to have manual driver deployed ramps, stowed adjacent to the doors nearest the driver cabin. This policy stretches dwell times and can lead to complications for patrons if drivers forget which station their disabled passenger wishes to alight at.

An overview and evaluation of technological responses to assisting boarding and alighting was conducted by Monash University's Institute of Transport Studies (Dejeammes 2010). This body of work shows that the inclusion of technology that assists disabled passenger access encourages greater patronage. The issue of manageable gaps is contentious. In Dejeammes (2010) there is some doubt cast on the Daamen et al. experiment as not being representative enough. Further

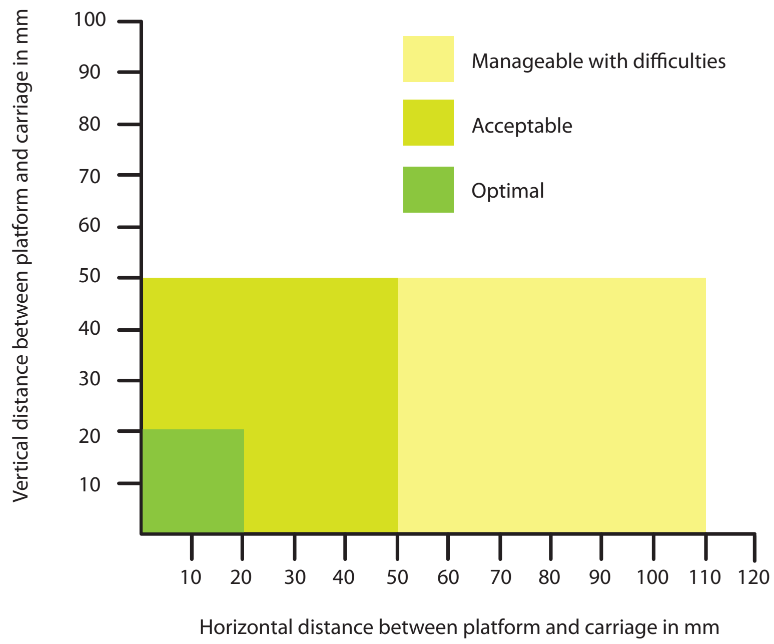


Figure 2.13 Optimum gaps for disabled people (Daamen et al. 2010).

research (Grange-Faivre 2009) shows that electric wheelchairs encounter more difficulties or failures to pass over gaps more often than manually operated chairs or walking frames. This research also points to the variability of gap distances caused by vehicle passenger loading. It has been recognised that strong improvements in assistive technology are being in made in Europe with regard to ambulant impairments, such as automatic ramps and vision impairments, such as wayfinding and guidance systems. Whether or not the motivation for implementing such technology has come from legislation or policy, the economic benefits to both disabled patrons and the TOCs have been significant. In Paris, an increase of nearly a third in disabled patrons has been reported between 2007 and 2008 (ibid.).

There are implications for dwell time and service punctuality in the operation of ambulant assistive technology. It is desireable that the activation of ramps is quick and reliable. Wheelchair restraint systems, where employed, are also reported as requiring further research.

Figure 2.14. Two examples of vehicle built-in ramp systems: a train example on left (Innotrans exhibition, Berlin) and a Paris bus example on right.

Some TOCs in Europe are using platform infrastructure to go some way to reducing the height differential, creating fixed ramps at strategic points on the platform, normally placed near the front of the vehicle; see Figure 2.15.

Figure 2.15. Platform ramp, Strasbourg.

In addition to physical impairment visual impairment is also an issue. Initial problems lie with the communication of information. For the blind, as well as sighted passengers, the policy of loudspeaker announcements is common. The provision of guidance systems, especially at complex interchanges, varies from guiding tactile surfaces on platforms to highly sophisticated electronic wayfinding technology (Lamy 2009). Trains in the UK and France are required to have contrasting colours for doors to aid their location (Figure 2.16). This is not the case in Melbourne.

Figure 2.16. Contrasting door colour; example of its implementation on South West trains in the UK.

2.8 Impact of platform design on crowding and dwell time

2.8.1Platform Characteristics

Some of the research literature reveals that the station platform design influences the dynamics of crowding and the implications for dwell time. Key factors in platform design are:

- arrangement of seating and shelters
- exits and entrances to the platform
- passenger knowledge of door stopping positions and presence or absence of platform edge doors

Platform infrastructure such as seating and overhead cover can affect the dispersal of waiting passengers and form impediments to large numbers of passengers moving along the platform to and from the train.

The point at which passengers enter the platform is influential, especially for just-in-time arrivals, as the carriages closest to where the passenger has emerged onto the platform will receive the highest loads. Empirical studies such as those undertaken in Stockholm have shown that loading increases at the ends of the train rather than the middle. Douglas et al. (2011) show that passengers have a propensity to include time to get to the station and waiting for a train as part of their overall trip time. Experienced commuters familiar with their local station and timetables will try to time their arrival at the platform to minimise their wait, often boarding the train at the nearest point of arrival. For large interchange stations on the Melbourne train network, this means boarding the front or back cars of the set. In networks with consistent rolling stock and door positions, patrons will move along the platform to where they anticipate a door to stop, expediting the act of boarding so as to maximise their chances of finding a seat.

Platform edge doors (PEDs) are used on a wide number of networks around the world and serve largely to protect waiting passengers from falling into the track pit. Door position is consistent and clear, though the opening of two sets of doors has some implication on a slower operating component of dwell time. It is a requirement that the train stops with very accurate alignment usually meaning the service is driverless. Examples of implimented systems both with PEDs and driverless are Line 14 of the Paris Metro, London Docklands Light Railway, Dubai metro system, the Jubilee line of London Underground, Washington Metro, Singapore MRT amongst a growing number of other train systems.

2.8.2 Dual platform boarding and alighting.

The meeting of passengers moving through the same door exacerbates doorway occlusion. For an overwhelming majority of networks around the world single side boarding and alighting is the only option due to the legacy of station design. Some airport shuttles and occasional suburban lines will have dual boarding and alighting at termini. Rio de Janeiro Metro is a good example of a transit system with this passenger management feature at major interchange stations (Carioca, Saens Peña, and General Osório).

The dwell time components of a Rio Metro train include the opening of doors first on one side of the train (the side platform) and then some few seconds later doors open on the opposite side of the train where passengers board from the island platform. The opening and closing of the doors is now longer than conventional single sided operations. But this procedure has removed the severe occlusion that might otherwise occur as the boarding and alighting passengers move in the opposite direction (Costa B & Costa F 2010).

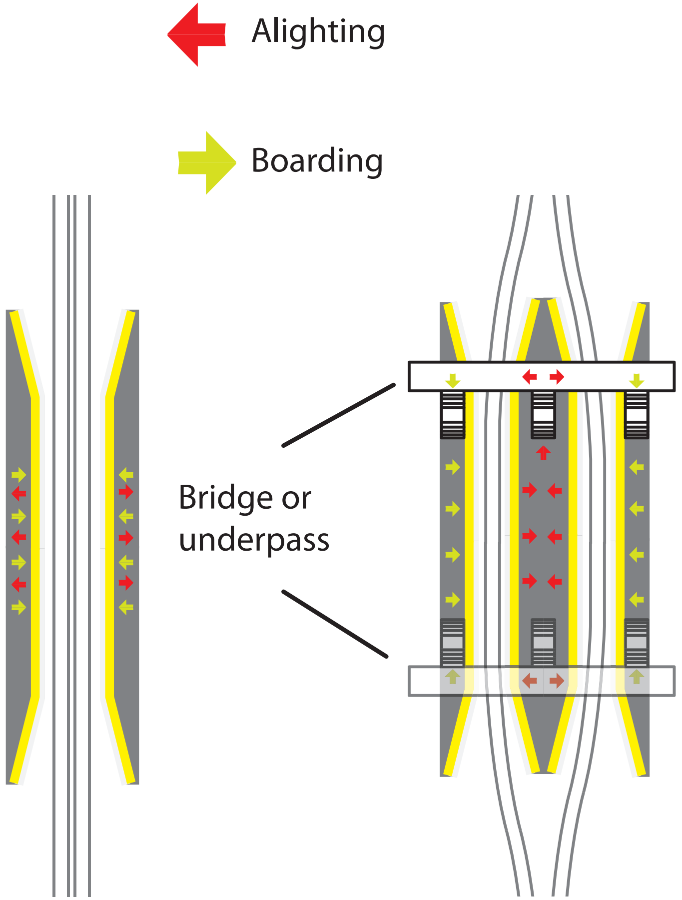


Figure 2.17. A plan view of the principle of dual boarding as exemplified at the Botofogo station in Rio de Janerio, Brazil.

Rio Metro is just over 30 years old and has not gone through any major interior design refurbishments associated with increases in patronage. Passenger trip times are short, at less than 20 minutes, and within tolerable limits standing for physically able patrons. As a result, a lot more standing space is provided. With an expansion of the network underway and journey times set to increase, the operator may be forced to consider increasing the number of seats per carriage.

2.9 Discussion

The published literature and examples examined in this chapter reveal complex interlinked relationships among the issues attending to the essential research problem of crowding and extended dwell times. 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". This chapter has examined those measures that have been taken to respond to extended dwell times and passenger crowding. What has emerged from this review is that these measures are often in conflict with each other. The methods available are:

- operational strategies; very costly solutions that embrace long term building strategies such as longer platforms or laying more track to increase capacity, but also pricing policies to redistribute passenger loads in relation to journey time
- interior seating layout strategies; increased patronage has pushed operators to reduce the number of seats in carriages at the cost of reduced passenger comfort. Seating arrangements such as orientation and aspect to doorways. Aisle and vestibule accommodation for passenger dispersal
- door ingress and egress occlusion; doors create bottlenecks as passengers try to board and alight. Widening or increasing the number of doors puts more pressure on reducing the number of seats in a carriage. Doorway occlusion, people standing in the doorway, particularly at peak times, negates effective ingress and egress, with repercussions for accessibility for a wide patronage e.g. disability, prams, luggage etc.
- door threshold issues; level boarding is desireable for TOCs as it reduces accidents, enables wheelchair access and accounts for a swifter exchange of passengers. However, railway station infrastructure and train rolling stock are rarely compatible to achieve this. Also door location, their number and dimensions, gap distance and gap height
- door holding behaviour; passenger actions in delaying the train through keeping doors open has the effect of increasing dwell time as well as damaging the doors themselves, sometimes to the point of putting the train out of operation
- disability access legislation; legislative and progressive policies towards disabled passengers mean that TOCs have to look closely at the relationship between platform and carriage in order to improve accessiblity.

The research revealed in this chapter also points to poor passenger dispersal due to platform infrastructure arrangements as well as train internal configuration. These have been exposed as:

- spread of passengers along the platform – implied knowledge of the position of doors on arrival
- accessibility – absence of steps into and out of the carriage and wheelchair friendliness
- the carrying of objects, including the accommodation of bicycles
- cultural behaviour; a radical design response would require potential change in the prevailing cultural norms.

Figure 2.18 outlines the opposing relative dimensions of designing a train carriage based on the information gleaned from this chapter's review. For example, increasing the number of doors, as pointed to in some of the literature, reduces the number of seats. A reduction in seats reduces passenger perceptions of comfort. Increasing the number of seats means less standing, reducing overall capacity during peak time. The balancing of these relative dimensions is at the centre of the studio design process described in the following chapters.

2.10 Conclusion

It is clear that there are a finite number of passengers that could fit into the space afforded by a railway carriage. This occupancy is transitory and, in the management of capacity and in particular its dispersal, there have been a wide range of attempts to gain improvement. Solutions are driven by location specific criteria, making a universal solution challenging. The cycle of rolling stock upgrades and procurement is generally shorter than for rail and station infrastructure, making legacy issues an important determinant in carriage design. Patronage growth, accessibility legislation and differences in cultural norms have all been seen to influence train service provision through the design of the passenger accommodation.

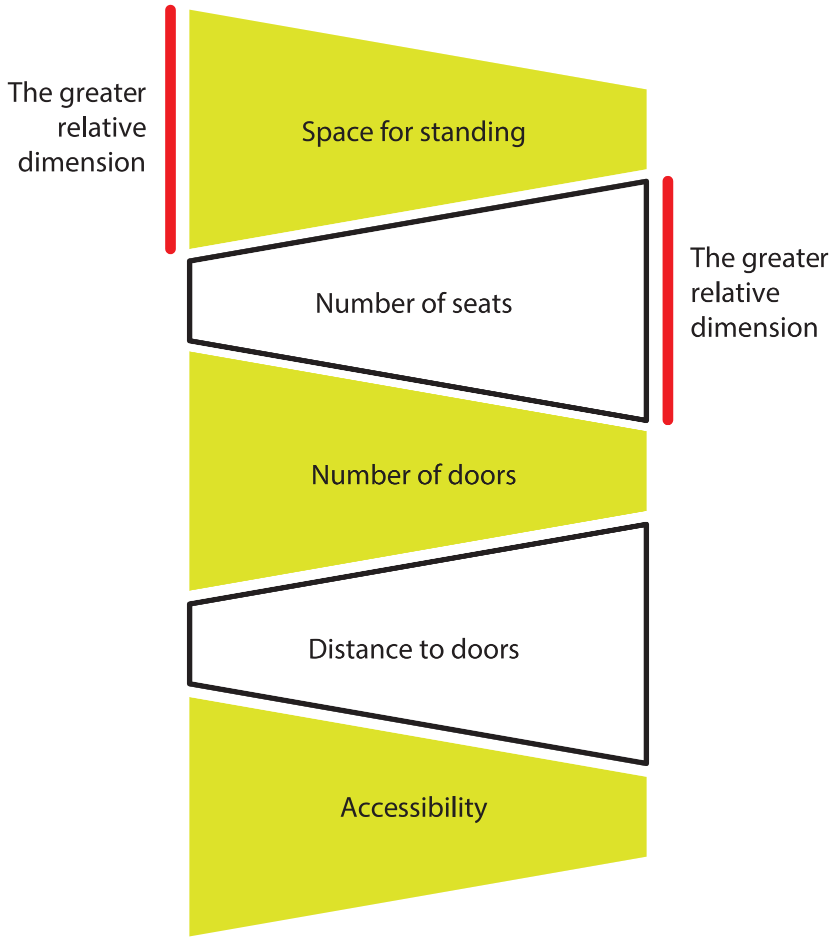


Figure 2.18 The conflicting relationship between the design aspects of a rail carriage.

Notes on Figure 2.18:

Reading down the left hand side -
An increase in standing space means a reduction in seats. Having fewer seats can increase the number of doors, which reduces the distance to those doors and by implication improves accessibility.

Reading down the right hand side -
Less space for standing implies more seats, with a consequent reduction in the number and width of the doors. Having fewer doors has implications for accessibility.

3

Chapter 3 . The research method

3.1 The research methodology

This research aims to develop and propose a design response to the problems of extended passenger boarding, alighting and dispersal on board suburban trains. The previous chapters have described the scale of the problem and the parameters within which that design response is to be made. The problem concerns itself with the geometry and placement of objects such as seating and handholds and the control of negative space such as door apertures and vestibules. These qualities of the reserach problem help to indicate the appropriate method with which it can be investigated. There are a wide panoply of doctoral methodologies available to the researcher. Broadly speaking two major philosophical approaches can be made (Williamson 2000); one scientific using deductive reasoning and quantitative data collection and the other qualitative and open to an interpretivist method of measuring reality. The research question links the hypothesis that the interior of a suburban metro train carriage could be designed, something rather open ended and qualitiative to improve a quantitative problem, captured in measurable data; stabilising dwell time. Then further going on to ask how might the outcomes improve the passenger experience during periods of crowding, which is a question that appeals to an interpretative methodology.

The research question presents itself as design project in that it is particaptory rather than concerned with entirely observational outcomes to reveal new knowledge. Doctoral research where design projects have undertaken are often intended to bring about change in practice rather than reveal a phenomenon. Design is exploratory, immersive and reflective and most aligns with a studio methodology as described as 'action research' (Oosthuizen in Williamson 2000).

Action research is carried out in discrete cycles of exploration followed by evaluation of that exploration to then inform the next stage of investigation. This is a cyclic approach to knowledge creation that aligns with the studio practice of creation then reflection to determine changes toward a design project outcome. A studio methodology requires information gathering and subsequent synthesis to inform the direction of creative ideas and the development of design concepts. Studio methodology is an expression of action research in that an experimental approach is made using sketching and modelling of both real and the virtual to articulate ideas. These 'experiments' on paper are reflected on in the light of the information gathered and their efficacy tested against a desired outcome. This outcome is not definitive but forms part of a continuing process of iteration and improvement.

Figure 3.1 describes a largely linear process of data gathering that informs a set of specifications, which in turn form the basis against which the hypothesis of each design study is tested. At this point the design method frequently folds back on itself, testing differnt nuances of the design by variable means of expression such as physical modelling to scale or full size. The information gleaned during this process informs a more sophisticated interation of the potential problem solution.

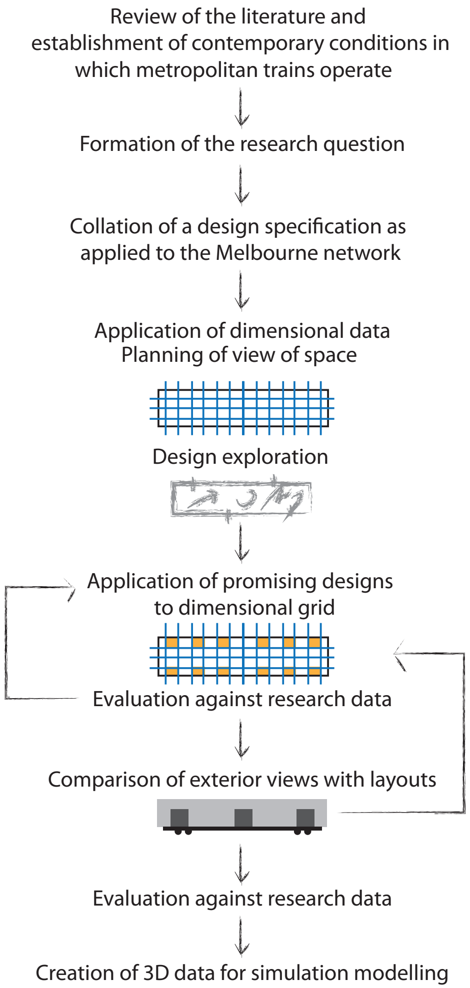


Figure 3.1 The design studio research methodology for this project.

Ultimately the most viable design iteration is transformed into a virtual three dimensional model so that the hypothesis contained within the concept can be tested through computational simulation.

For an object as large as a train carriage, testing the efficacy of any proposed design concept is constrained by the practical means of making design iterations quickly and effectively. Scale models and paper studies are weak facsimiles of a proposed reality. Therefore the use of a suite of methods to articulate the design intent is required. The overall appearance geometry can be replicated to scale. The door vestibule area and the geometry of boarding and alighting as it may appear to an individual can be replicated by a full-size mock-up. But the most useful test of a concept is by replicating the conditions under which a passenger exchange might take place during peak loads. To this end, computational modelling, whereby evaluation is made by observing a simulation in which animated human figures behave in the way evidence suggests they would in reality, gives the best opportunity to test a concept hypothesis to date. Examples of this technique can be found in crowd evacuation modelling software such as *Legion* and *EmSim* and in computer gaming such as *Unity*, or in the television and film industry with software platforms such as *Massive*.

3.2 Four approaches to the design intervention

The literature review discussed in chapter 2 revealed the range of variables contained within contemporary train design that affect the research problem. For the purposes of this research, the author has divided them into four sub-projects:

1. the spatial placing of the interior impediments to movement; the seating and passenger standing arrangement and their relationship with ingress and egress
2. the detailed design of the doors and their impact on the crossing of the platform/carriage threshold.
3. the detailed design of the seats themselves, including their relationship with handrails and poles
4. the exterior design and the interface with the platform.

While prepared as distinct sub-projects, each outcome influences the others. This is most evident in the relationship between the doors and the interior seating arrangements. Therefore this relationship forms the primary project from which the other two emerge. The detailed work in the remaining three projects serves to enhance and support the outcomes of the work in Design project 1. Figure 3. 2 captures this relationship.

The research question asks how the passenger experience could be enhanced by this design intervention. At this point should examination the quantitative data indicate any improvement in dwell time and therefore based upon the prevailing literature it can be interpreted that improvement in dwell time creates a cascade effect of improvments in service that ultimately better the passenger experience (q.v chapter 2).

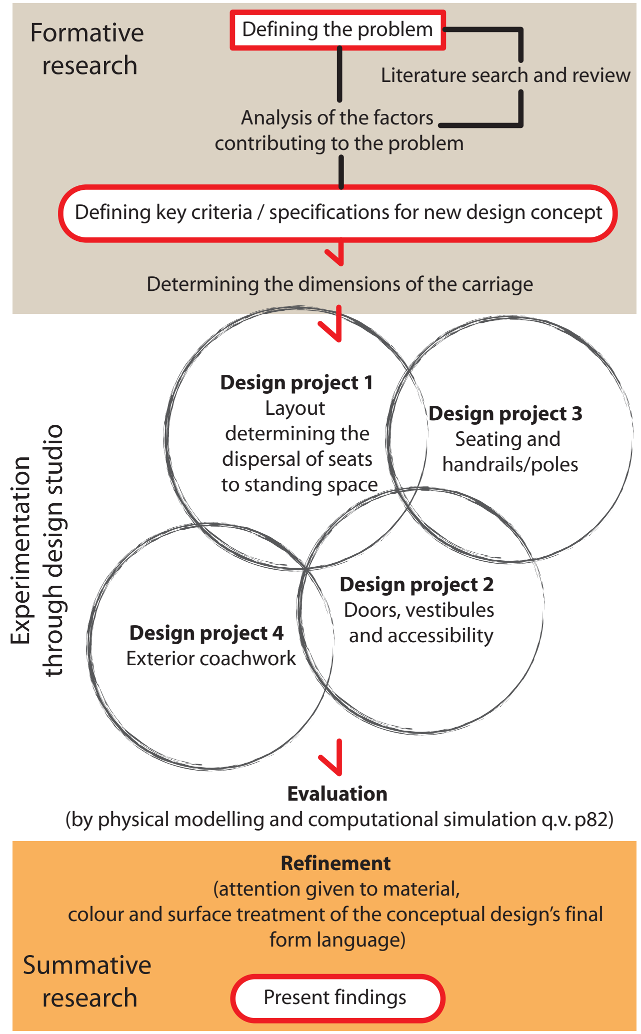


Figure 3.2 The inter relationship between the four sub-projects of the design intervention.

4

Chapter 4. The design specification

4.1 Approach to creating a specification

In beginning to address the design problem contained in the research question, i.e. improving boarding, alighting and passenger dispersal within the train carriage, this chapter describes the boundaries within which the design work is to take place. The first of these is the recognition that rail networks around the world hold unique characteristics and features such as culture, scale and physical size, e.g. track width. Therefore this research, while informed by wide examples of current practice, is for reasons of geographical proximity focused on the dimensional framework of the Melbourne rail network.

The following list outlines each of the steps in defining the specification for a rail carriage interior:

- determining the carriage dimensions, working space and therefore the design envelope
- determining standing and seating proxemics
- determining an optimum seating, standing and door layout (Design project 1)
- evaluating the efficacy of the proposed carriage arrangement
- developing the details of the seat and handhold geometry (Design project 2)
- developing the details of the door and threshold accessibility (Design project 3)
- platform-side train exterior design (Design project 4).

4.2 Determining the working space

The aim of a new carriage design is to improve the ingress, egress and dispersal of passengers within the train carriage. Implicit within this aim is the creation of forms, structures and an interface that assist passengers to board and alight during peak periods in a more timely manner. A secondary aim of the new design is to address the contrasting issues of providing a train service, such as that in Melbourne, which caters for relatively long distances with many journeys greater than 20 minutes, with those of a metropolitan short-trip service.

The dimensional extremities within which to work are dictated by a series of gauges. These vary from network to network around the world and are determined by a range of historical, political and topographical reasons. For the purposes of this study, the gauges used are pertinent for the network in Melbourne.

4.2.1 Gauges

The overall dimensions of carriage space are defined by:

- the track gauge, defined as the distance between rails, shown in Figure 4.1
- the loading gauge, which describes the outer extremities of the train coachwork, shown in Figure 4.2
- the structural gauge, which determines the closest external point of the carriage to any infrastructure, seen in Figure 4.3.

There are more than 1900 gauge widths utilised around the globe. The guiding principle of determining a track gauge is that the broader the width between rails, the longer that rail curves need to be and therefore the faster and smoother the ride can be. This excludes the addition of banking as utilised for high-speed trains. A narrower gauge makes for tighter corners and slower trains and is the more practical option for coalmines, fairgrounds and areas of limited space. The history of why certain gauges have been adopted in some parts of the world over others is complex, reflecting political as well as engineering aspirations. An effort to standardise gauges has been attempted and indeed 60% of the world's railways use 'standard' or 'international' gauge (1435 mm from inside rail to inside rail). However, this research is focused on Melbourne, where the gauge is 1600 mm and falls within the group of gauges known as 'broad gauge' (in this instance Irish broad gauge). The benefit of broad gauge is that carriages can sit wider across the track, delivering more passenger capacity.

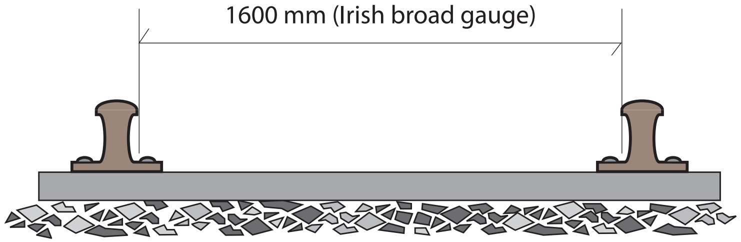


Figure 4.1
Track gauge.

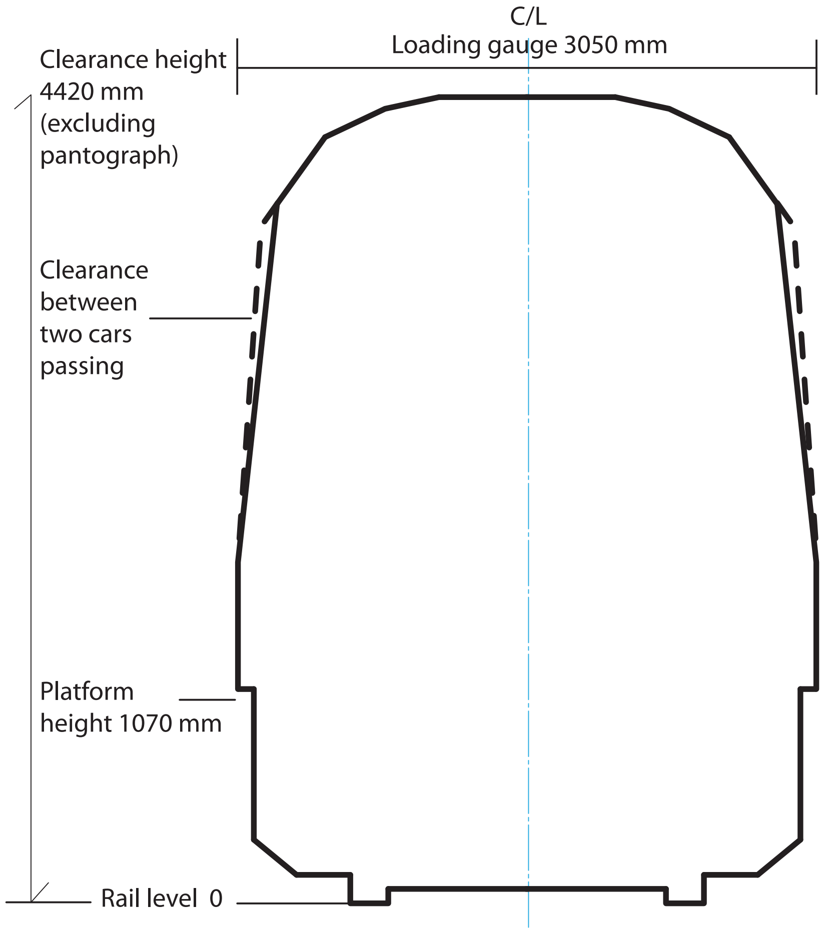


Figure 4.2
The loading gauge describes the outer shell (or integument) of the train. Data supplied by Bombardier.

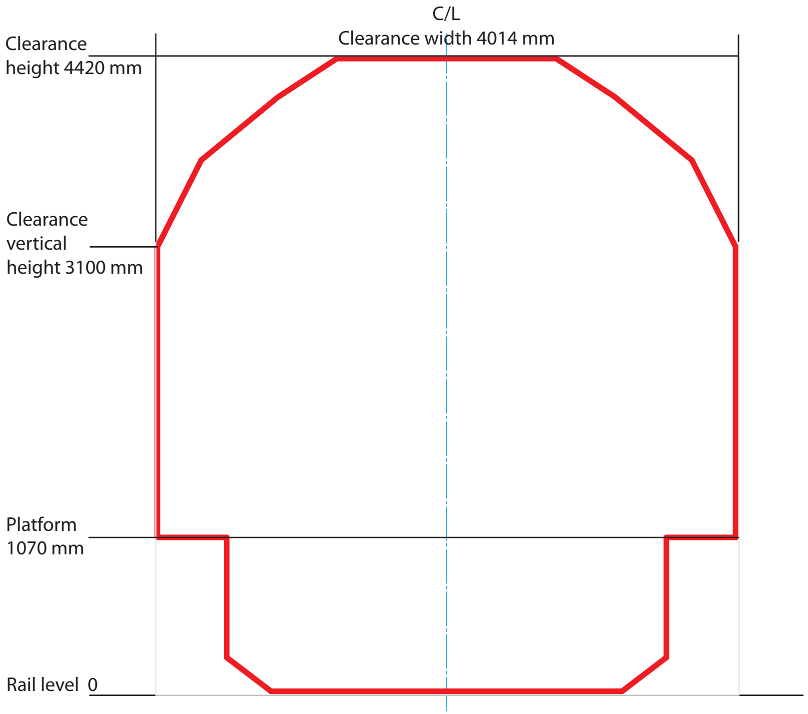


Figure 4.3 The structural gauge for Melbourne. Data supplied by Bombardier.

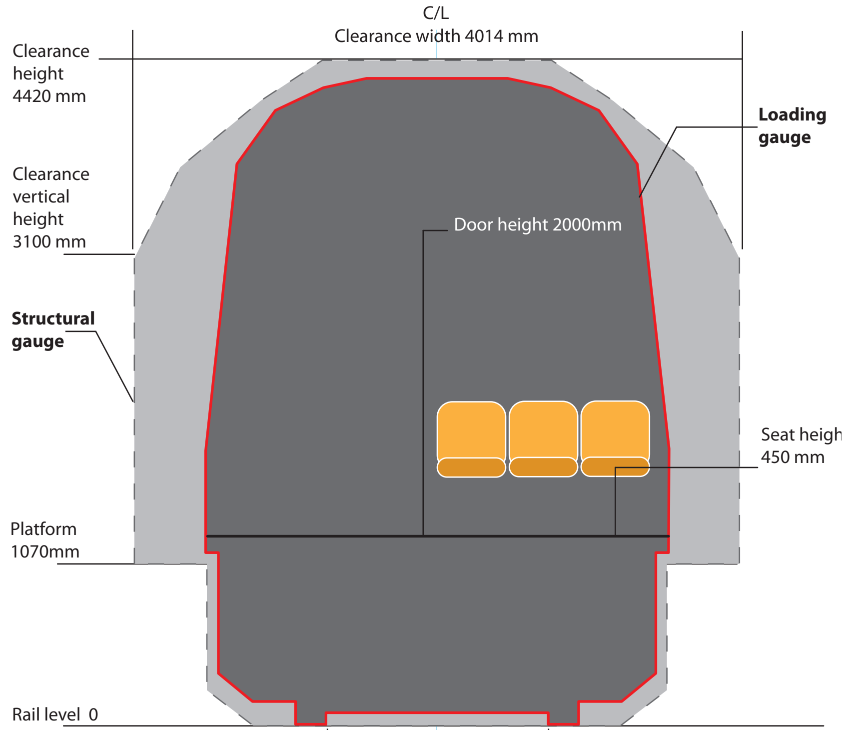


Figure 4.4 Combination of loading and structural gauges describing the envelope for building Melbourne carriages. Data supplied by Bombardier.

The overall carriage length is determined by two factors:

- the prevailing length of platforms at stations.
- the clearance with the structural gauge at bends.

The historical legacy of stations and the bounds of land ownership dictate the length of platforms. Melbourne has a wide range of stations built at various periods over the life of the network. Trains that ran engines separately to the passenger carriages serviced the first stations. Modern electric trains are made up of two motor cars pulling one trailer car. This is a single Electric Motor Unit (EMU). It is the practice on Melbourne's rail network to run two EMUs. Less patronised spur lines of the system and some off-peak services are serviced by a single set. Most of Melbourne's services are made up of two sets, therefore creating six carriages altogether (Figure 4.5).

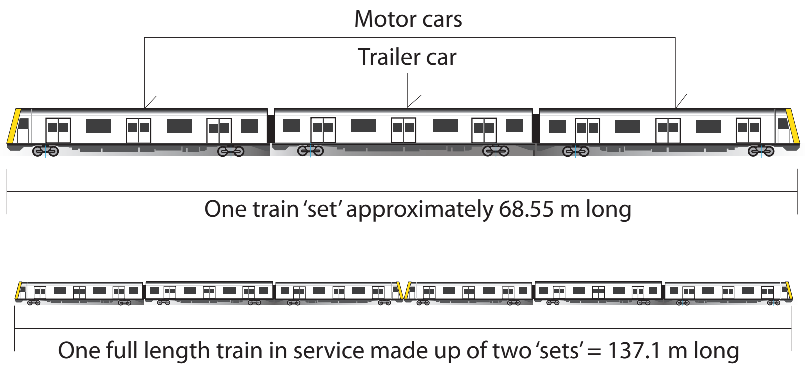


Figure 4.5. The make up of train sets on the Melbourne network.

The second determinant of length is the clearance dimension required for corners. Depending on the location of the bogie the extremities of the corners of the carriages, where there is coupling, will protrude into the clearance space between the loading gauge dimension and the structural gauge. More caution is directed towards longer carriages than shorter carriages as they are more likely to extend out at corners. Long sweeping curves of track of over 100 m radius mitigate this effect (Figure 4.6).

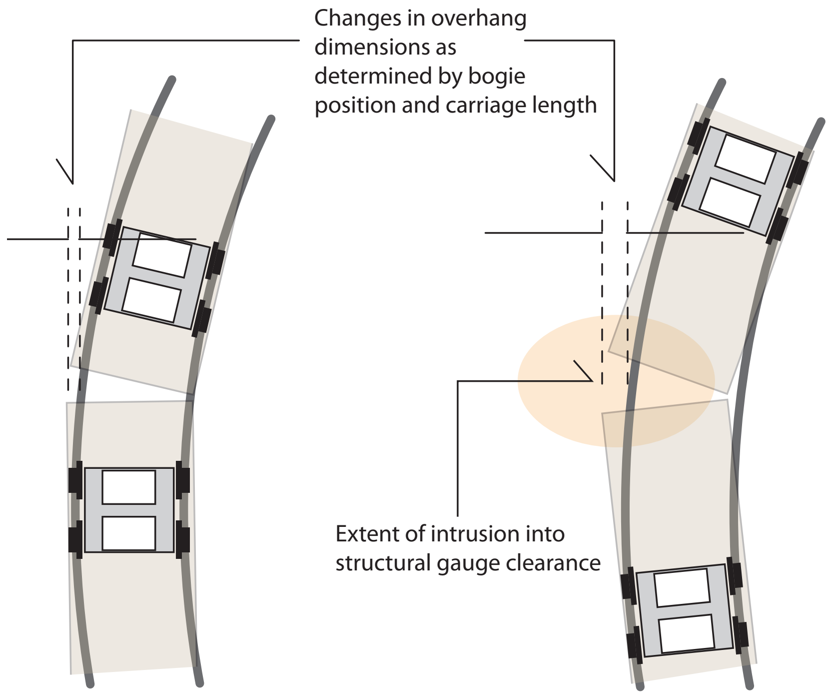


Figure 4.6 Relative position of longer and shorter carriages at corners. Data supplied by SNCF.

4.2.2 Carcase structure

The next dimension to affect carriage capacity is the extent to which the carcase structure of the carriage intrudes on the available space for passenger accommodation. Figure 4.7 is illustrative of contemporary techniques in the manufacture of train walls, floors and ceilings. Large scale extrusions have become the manufacturing method of choice as the technique is cost competitive and structurally strong and offers overall weight reduction. Weight reduction is a major issue in the design of contemporary train carriages, since load weight has implications for energy use during braking and accelerating.

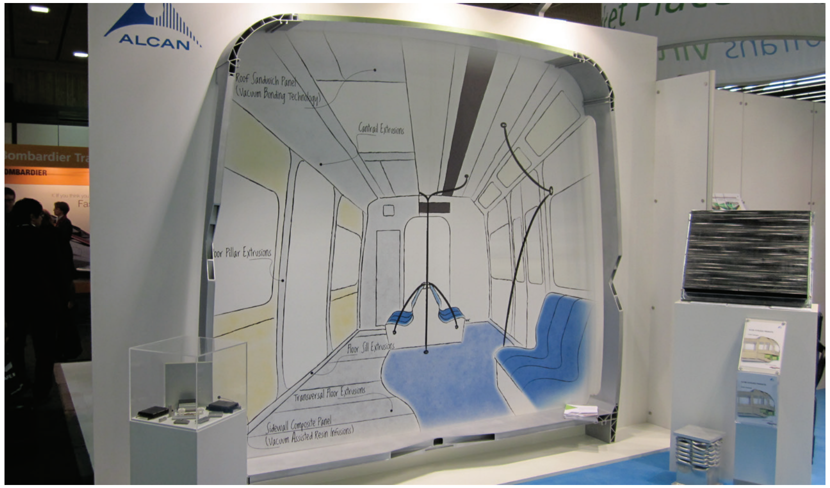


Figure 4.7. A section of an extrusion system demonstrating contemporary construction techniques. Innotrans Exhibition, Berlin, September 2010.

4.2.3 Structural integrity

The Rail Industry Safety and Standards Board oversees the design and code of practice legislated for rolling stock in Australia. These requirements run from Australian Standard (AS numbers) AS7503.6 to AS7534.4, some 103 documents in all, excluding codes of practice. All detail the performance required of rolling stock, especially wheel and axle loading under braking and dynamic loads deemed safe and robust enough for service. AS7521.1 to AS7521.4 focus on the carriage interior crash worthiness required for a Rolling Stock Design Compliance Certificate.

4.2.4 Space utilisation

Based on the envelope provided by the pertinent gauges and a basic appreciation of the carcase structural requirements, an informed set of data can be prepared to describe the working space.

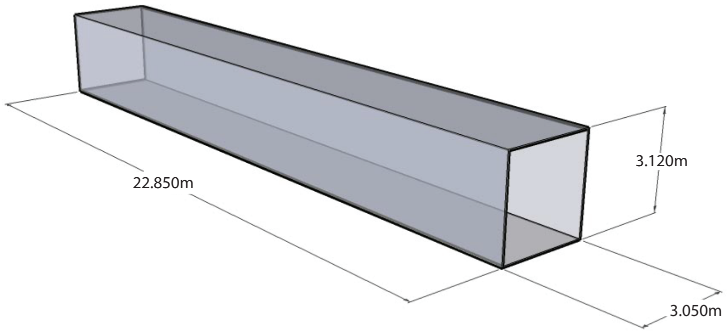


Figure 4.8. Overall volume available for occupancy of a trailer car. Based on Melbourne gauges.

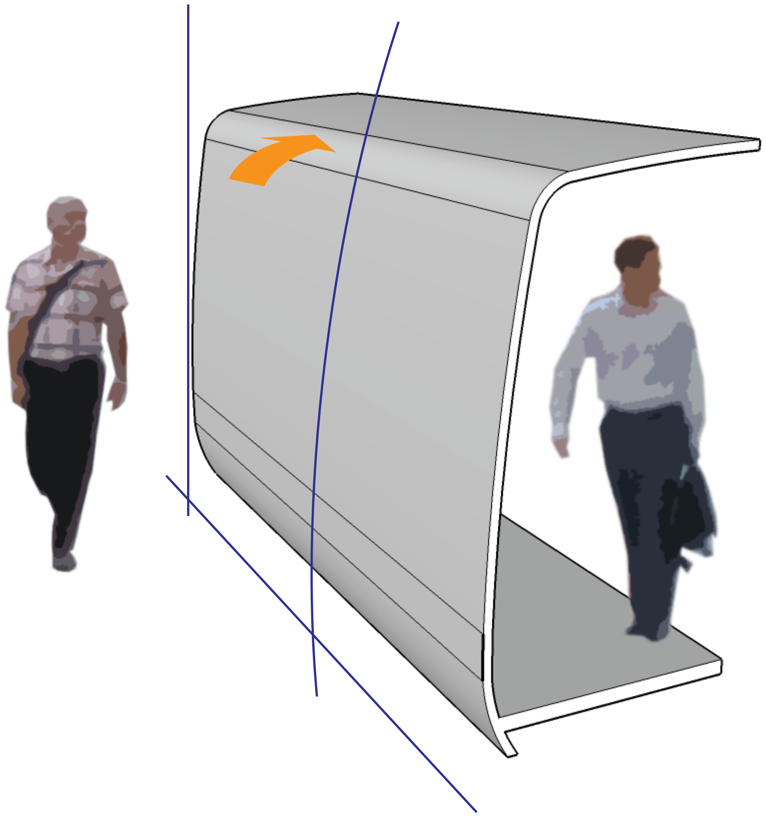


Figure 4.9 Curving the integument towards the centre line of the carriage.

As indicated by the loading gauge train structural walls often employ a convex curve (Figure 4.9). The curvature of the carriage integument has four implications for the form of the train: -

1. It allows for the sway of the carriage outside its normal loading gauge when passing another train.
2. It reduces the internal dimensions of the interior, albeit at the most marginal positions of the top corners above passengers' heads.
3. It creates a superior external aesthetic by leaning away from the awaiting passengers reducing the box-like slab appearance and creating a form more suggestive of motion, aerodynamics and speed.
4. The curvature in the extrusions promote superior structural strength for the box section.

4.3 Determine standing and seating proxemics

The area allowance for a standing person is based on rail industry norms, although it is not entirely clear how this is derived. British crowding figures allow for four people to occupy one square metre when the train is at capacity, a figure that is prone to different interpretations. Literature concerning human perceptions of space or proxemics frequently describes spatial zones between individuals in terms of layers, ranging from the most intimate to distances that require the raising of voices to communicate. In crowded situations on board trains, it could be argued that the need for space between individuals has crossed social norms and that an intimacy exists between strangers that is not normally tolerated. Hoogendoorn et al.

(2002) refer to a minimum distance that passengers (on a platform) are prepared to tolerate between each other and objects. This 'shy away' distance has been calculated to be 45 cm, although the exact details of how this distance was determined is not clear. It is also noted that, as people move more quickly, this distance is reduced.

Individual territory for oneself and one's belongings is eroded as the train fills, until a crush is reached. It is the intrusion into these minimum spatial territories that people find stressful (Hall 1969). It is observed (Oborne, Heath 1979) that people will tolerate more intimate intrusion of personal space by strangers when side by side, rather than face to face. Ceiling height is also a factor, as it has been observed that the lower the ceiling, the greater the distance between people that seems to be required (Savinar 1979).

Looking solely at physical area, a 95th-percentile male's shoulder breadth (widest part of the body) requires an area of 0.25 m^2 (figure based on US adults, including an allowance for clothing – Pheasant 1988). There is an assumption built into this figure that shoulder clearance of 500 mm is not unusually endomorphic. Given the diversity of human populations, especially in a multiracial city such as Melbourne this might be inaccurate. When Connex made their calculations in determining a new interior layout for their Comeng train (2009) these Pheasant (1988) dimensional data were used to determine standing space (Figure 4.10).

The main impediment to passenger movement through the carriage is the arrangement of seating. More seating, while providing a level of comfort sought by patrons, does mean a corresponding decrease in standing space. Standing takes up less spatial area than a seat occupied by a passenger. There is a wide body of literature concerning recommendations for seat dimensions (Dreyfuss 1960, Pheasant 1988). Their focus is on determining the correct angles and dimensions to support the human frame, skeletal and muscular, for a wide variety of human sizes. For TOCs there is considerable commercial pressure to keep seat dimensions to a minimum.

Figure 4.10 Spatial allowance per standing passenger on a Comeng train regardless of percentile dimensions.

The essential drivers of seating geometry are:

- the popliteal height; for a 5th-percentile woman, this is 435 mm. (Pheasant 1988)
- seat depth; can be anything from as little as 300 mm, to 540 mm for those of large stature, assuming the seat is horizontal (Pheasant 1988)
- seat width; For the purposes of support, this can be narrower than the width of a range of buttock dimensions. However, elbow-to-elbow width has more relevance in creating a width dimension that seats people next to each other without touching. A 95th-percentile clothed man requires a seat width of 550 mm (Pheasant 1988)
- backrest rake; the further a backrest is tilted back the more support that is offered to the body trunk; however, this is not without the risk of sliding the seated person forward and increasing the effort required to get up. The seat back rake also increases the overall front to back dimension of the seat, taking up more space. Short backrests require less tilt (95 to110 degrees) and are common on metro rail services since there is an assumption that the journey is not a long one. Longer journeys where the passenger is required to sit down for greater periods tend to favour a longer back rest and a greater tilt of +110 degrees (Vink 2009)
- forward legroom; This dimension comes under the most commercial and spatial pressure to be reduced, as seats are packed more and more closely together. Ergonomic orthodoxy determines legroom as the distance from the buttocks to the back of the knees, plus foot length, plus a distance determined by the trigonometric calculation of seat height and knee to heel length. For a 95th-percentile man on a seat 400 mm from the ground, the total front-to-back dimension is around 1190 mm (Pheasant 1988) (Figure 4.11). This recommended distance is generous compared to the reality of commuter trains with transverse seating. Face to face transverse seating such as that employed on Comeng trains in Melbourne provides only 410 mm from front edge to front of the seat pan. This necessitates passengers positioning their knees between each other to remain seated.

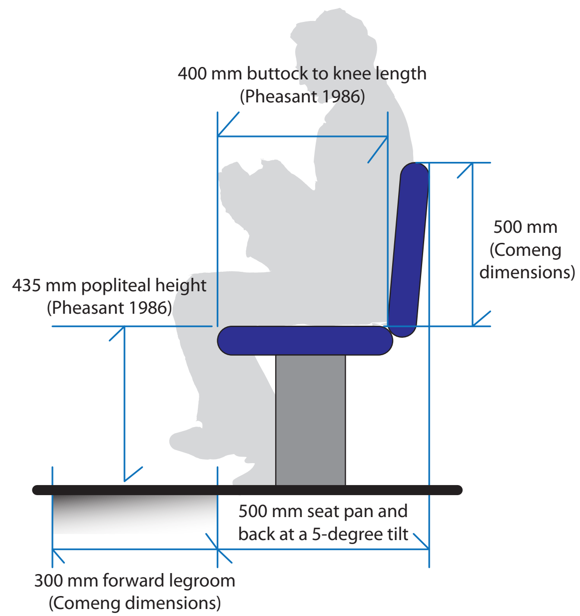


Figure 4.11 Spatial allowance per seated passenger on Comeng trains.

4.3.1 The impact of accessibility on interior space

Section 2.7 in chapter 2 outlined the general issues surrounding accessibility. In quantitative terms the author has drawn on the Disability Discrimination Act (DDA) 1992 and Disability Standards for Accessible Public Transport (DSAPT) 2002 to provide data that assist in describing the spatial specification. When applied to train services, these requirements translate into the following:

- access path – a continuous path of travel 1200 mm minimum wide clear of all obstacles (bollards, bins, seats, shelters etc,) textured flooring along the edge of platforms
- manoeuvring areas - circulation requirements 1540 mm x 2020 mm min (1740 mm x 2270 mm preferred but not mandatory) for wheelchair and scooter users to turn 90 degrees, accommodation within the vestibule area
- passing areas – circulation requirement of 1800 mm for two wheelchairs passing
- waiting areas - space for wheelchair users and priority seats identified, surfaces that are non-slip, and can shed water
- handrails (horizontal) and poles (vertical) – detailed design and location requirements.

Level changes are probably the most important issue concerning the movement of wheeled mobility aides. Continuous step free access at an appropriate grade is mandatory for accessibility. The gap between the platform stop and the vehicle is critical for passengers with wheels and must follow these rules (q.v. chapter 2 section 2.5):

- platform ramps – grades 1 in 14 maximum, handrails located on both sides
- boarding – maximum gap between vehicles and platforms 40mm x 12 mm or deployment a boarding device or ramp with maximum slope 1 in 4, with raised sides.

All information must be 'accessible' to everyone in multiple formats; visual, audible and tactile, as listed below, to assist people with vision and hearing impairments:

- symbols – which identify accessible services
- signs – minimum lettering sizes varying with reading distance, minimum colour contrast, dark on light preferred
- textured tiles – edges of platforms, top and bottom of stairs and ramps, changes of direction, obstacles, colour luminance contrast required; minimum 30%
- lighting – 150 Lux minimum in interior spaces
- hearing augmentation – hearing loops required or visual information equivalent.

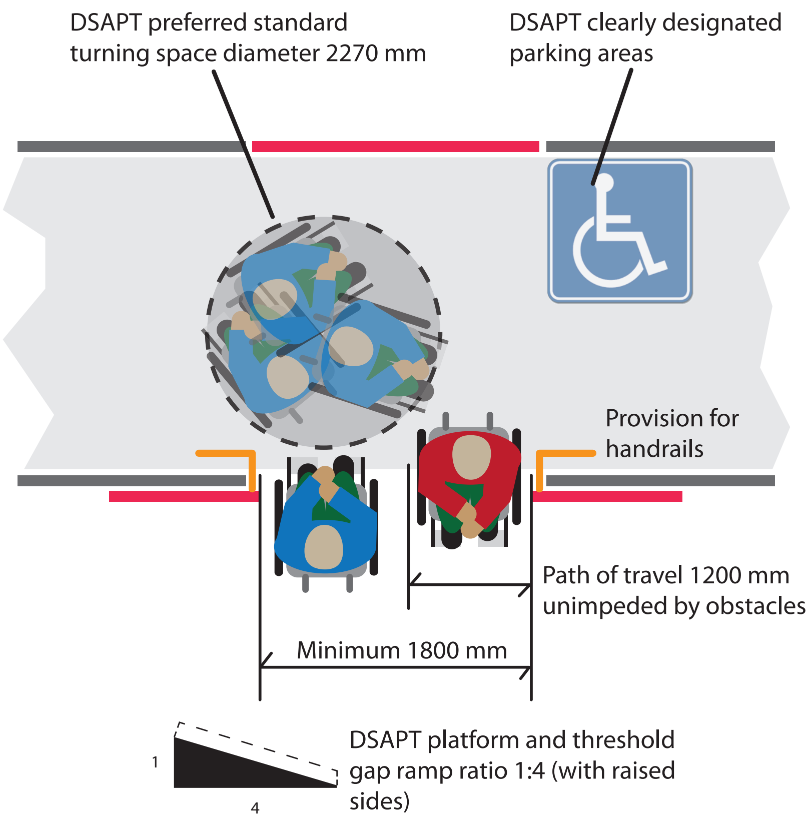


Figure 4.12 Disability accessibility compliance requirements as applied to interior carriage specification.

4.4 Conclusion to the specification

This chapter has discussed the physical constraints that determine the parameters of the Melbourne rail network. While there are parallels with other rail networks, it can be seen that specific physical dimensions, gauge size and platform length are location-specific and so the geometry of any conceptual design needs to respond to these constraints.

The Melbourne network affords the advantage of a broad-gauge track at 1600 mm and a loading gauge of the maximum permitted width of the carriage, 3050 mm, therefore enabling the widest possible capacity for metro type rolling stock. The length of the train is constrained by platform lengths. The TOC for Melbourne runs six carriage trains. Their lengths vary according to rolling stock and whether or not it is a motor car containing a driver's cab or a following trailer car. From the perspective of increasing the useable space along the length of the carriage the driver cabs offer the most opportunity for change. Each six-car train will have four cabs, of which three are redundant at any one time, thus wasting approximately 5100 mm. Height restrictions are generous in the context of this project, with a structural gauge of 7000 mm from track to overhead infrastructure (VRIOGS-001 2012).

These physical limits describe the envelope within which the creative design process is to be undertaken and this is described in the following chapters.

5

Chapter 5. Design project 1

An alternative interior layout

5.1 Creating an alternative interior layout

The previous chapters have described the scale of the problem and the parameters within which a design response is to be made. In this chapter the first and most essential of the design problems is addressed: the interior layout. The aim of this chapter is to explore and document variations of interior arrangements in seating, standing and door location, with the purpose of improving boarding, alighting and dispersal.

Sketching is the primary means of articulating ideas in industrial design. The design problem concerns itself with three-dimensional space and the author must first select a projection view into the space that most encapsulates the key articles contained therein. To determine door and seating geometry across the length of the carriage and for the sake of clarity, a scale-plan view is used based on 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 (q.v. chapter 4).

The plan view is an effective 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:

First, carriage capacity. Existing measures as applied to the Melbourne rolling stock cater for 133 passengers per carriage and 798 across a six-car set when at 100% capacity, seating and standing combined (q.v. chapter 2). The author's benchmark for an alternative interior solution seeks to match or better this capacity. No differential has been made between the motor car and the trailer car. Trailer cars tend to have slightly more space than motor cars by dint of the removal of the driver's cab. For example, the existing Comeng design has approximately 1.7 m less passenger accommodation in a motor car than in a trailer car. A single trailer car accommodation contains 100 seats and 33 standing spaces. A maximum of 270 people could stand in a completely empty carriage (Melbourne gauge) assuming they were of uniform stature and not unduly endomorphic and the area allocated was 0.25 m^2 per person.

The second quantifiable measure under consideration during the sketch process is the quantity, 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 and therefore the efficacy of sketched solutions is harder to determine.

The third consideration, dispersal, is more qualitative and relies on the mapping of designs that are based on the literature (Hirsch 2011, Helbeing 2005). Sketch layouts explore the creation of visual mechanisms that, in part due to prevailing cultures and instinctive

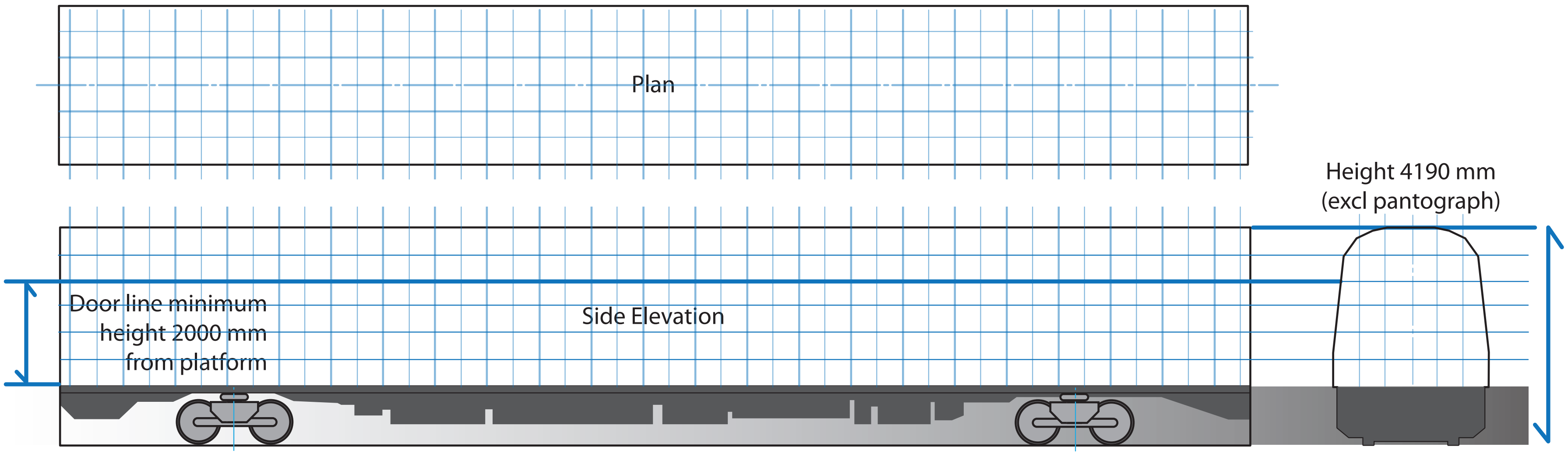


Figure 5.1 Spatial area to design within marked up in 500 mm squares.
Key ergonomic data points shown are ceiling height and door line minimum height.
Carriage length based on a trailer car of 23500 mm.

behaviours (Norman 2008), encourage passengers away from doors and further into the carriage.

5.2 Sketch studies

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

Figure 5.2 outlines the maximum limits each orientation could accommodate where they are the only arrangement of seating in operation. In the transverse arrangement, a large number of seats (168) could be fitted, assuming multiple doors per row and that passengers are prepared to knit their legs closely between each other. An end vestibule would accommodate a wheelchair bound passenger. Although carriages of this type, made up of a series of compartments, are reminiscent of the earliest passenger trains, the impracticalities of this arrangement today are many, including the territorial nature of human beings in capturing a ‘compartment’ and the potential difficulties therein.

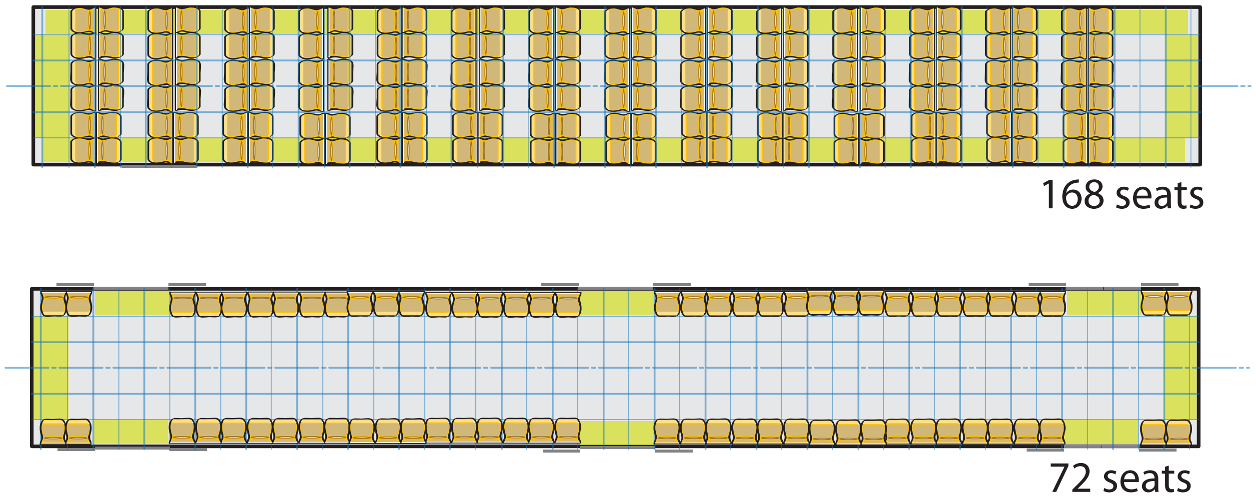


Figure 5.2 Bookmarking each end of the longitudinal versus transverse arrangement.
Standing passengers occupy the squares unpopulated by seats.
Door thresholds marked in green.

There is the danger of passengers on the platform moving down the train looking for an empty or somehow more desirable compartment to enter. This is likely to lengthen dwell times. Some improved capacity is needed for bicycles, prams, wheelchairs and other expansions of the available space. Melbourne's network, as with many others in the world, requires that police officers or their auxilaries are able to pass through the carriage and length of the train. Finally, the use of multiple doors presents challenges in maintaining comfortable heating, air-conditioning and ventilation, as well the increased level of maintenance that such a multi-door carriage requires.

The opposite approach, a carriage made up entirely of longitudinal seating (Figure 5.2), creates only 72 seats, assuming three doors per side, each wide enough to accommodate a wheelchair. This arrangement creates a great deal more circulation space and standing capacity. However, longitudinal arrangements pose questions concerning the number of doors and their dimensions. Locating seating along the interior wall of the carriage inevitably compromises accessibility by creating bottlenecks at some points in the structure.

As 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 in an orientation more comfortable for longer journeys.

Concept A, Figure 5.3, illustrates a layout that in effect puts two longitudinal metro carriages side by side, creating two corridors and four rows of seats. To encourage better dispersal, the ends of the carriage doors have been designated entry points and a central large vestibule and correspondingly wider door have been set up for alighting passengers only. There are precedents for mandatory boarding and alighting protocols, for example, on many bus systems around the world (Japan, France etc). By entering from only one door, there is no expectation of meeting someone alighting. The opposite validity applies to the exit-only door. The entry doors are narrower; however, since they are placed at the end of the carriage, they are in close proximity with each other (at the end of the next carriage), effectively creating a wide door with the same flow capacity as the central exit. End doors are entry points as they are the closest to the platform entrances, thus accommodating the last moment dash of the late patron.

This concept accommodates 112 seats laid out in longitudinal formation, as recommended for high capacity short trip designs (q.v. chapter 2 literature review). All seats against the window are fixed. Along the central spine of the carriage, clusters of folding seats are located in groups of six. This provides two aisles approximately 0.5 m across. To encourage better dispersal, passengers are motivated to move down the carriage so as to place themselves closer to the exit door. Forcing the flow of passengers in and out of specific doors requires discipline and a change in the prevailing culture to make this manageable. Passengers would need to be able to predict the position of the doors at stations to fully appreciate where to stand along the platform. This layout attempts to leverage the principle that crowds will divide around obstacles (Helbing et al. 2005) such as the centre clusters of folding seats and move down into the carriage, in the knowledge that the deeper they go, the closer to the exit they will be. However, those passengers sitting nearest the entry-only door are likely to find it difficult to resist exiting there rather than moving through the carriage, especially during non-peak times.

When all the fold-down seats are deployed, the corridors will be barely 0.5 m across and therefore populated by interlocking knees. This could render moving through the carriage difficult. If there are bags or other impediments, the problem is amplified.

Figure 5.3 Concept A Fixed entries and exits with three rows of longitudinal seating. Green seats denote folding operation to form perch seats.

Concept B, Figure 5.4, captures some of the essence of Concept A in that it encourages passengers to move in a specific direction from a boarding point through to alighting. Three equal-sized doors run along each side of the carriage (2m wide). The seating is a mixture of folding and fixed seating accommodating 108 seated passengers in total. Some of the central cluster seating has been turned at 90 degrees form the adjacent cluster to keep knees out of the path of passengers passing through the carriage. There is a reduction in overall fixed seating to accommodate movement within the carriage. This is likely to have an impact on perceptions of comfort. Fixed seating now runs down the centre of the train, with folding seats populating the longitudinal positions by the windows. These are coloured green in Figure 5.4.

Folding and fixed seats are placed strategically so that as the train fills, passengers are expected to fill the fixed seats first and deploy the folding seats last. This concept also introduces the 'perch' seat. Popular in a number of networks on various modes, the perch seat affords an able-bodied person more comfort, reducing the amount of weight on the feet, and stability by providing an additional anchor point than standing would, but taking up less space than a full seat. However, if the height of the perch seat is too low, then tall people (90th percentile and above) are likely to put their legs further out from their body to maintain stability and thus take up as much space as they would if seated.

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 narrow gangways rather than a single central corridor, as is currently the case in Melbourne's rolling stock.

Simultaneous boarding and alighting is facilitated at each door with graphic symbols indicating the correct side to use. To avoid a crowd within the vestibule area during busy peak periods, passengers are encouraged to move to the left of the door when boarding so that they will be best placed to move down into the carriage to eventually step out on the left. This tendency to the left is reflect road traffic conventions. However, the narrow corridors continue to create an impasse for persons of reduced mobility (PRMs). For wheelchairs it would be impossible and they would have to alight from the door through which they boarded.

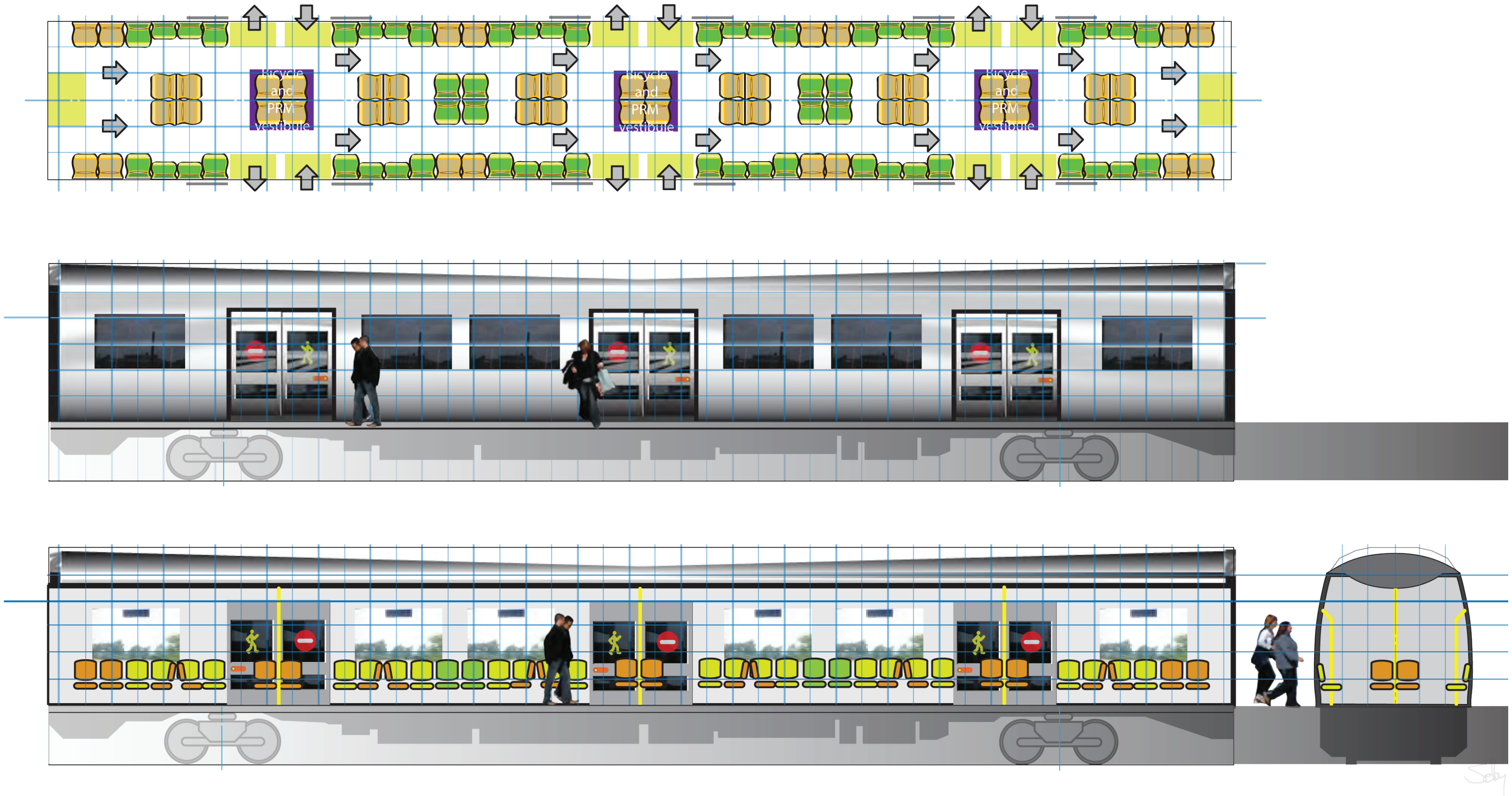


Figure 5.4. Concept design B two way flow doors with mixed transverse and longitudinal seating. Green seats fold to form perch seats.

Concept C (Figure 5.5) is the most radical departure from current design orthodoxy. In essence, the design offers the idea that most of the sidewall of the carriage opens as a large sliding door that telescopes within itself. All the seating accommodation runs in clusters through the centre of the vehicle. The seating capacity is a diminutive 80, some 20 seats fewer than current Comeng trains running on Melbourne's system. The open expanse of such a telescopic door would create many heating, ventilation and maintenance issues, although it would be highly accessible. The central area of the carriage, which takes up the closed door, would be in shadow and require extra illumination.

Concepts A and B take the philosophical position of encouraging uni-directional passenger flow into and through the carriage. Since the door width is a significant impediment to timely boarding and dispersal, the subsequent concepts looked more radically at the notion of reducing the amount of external wall and thereby increasing accessibility to the interior. As in concept C where the wall is all but removed.

By extension of this thinking Concept D pulls back from the fully open side to capture a multiple doors solution, reminscent of much older rolling stock to try and capture the essence of the open sided carriage.

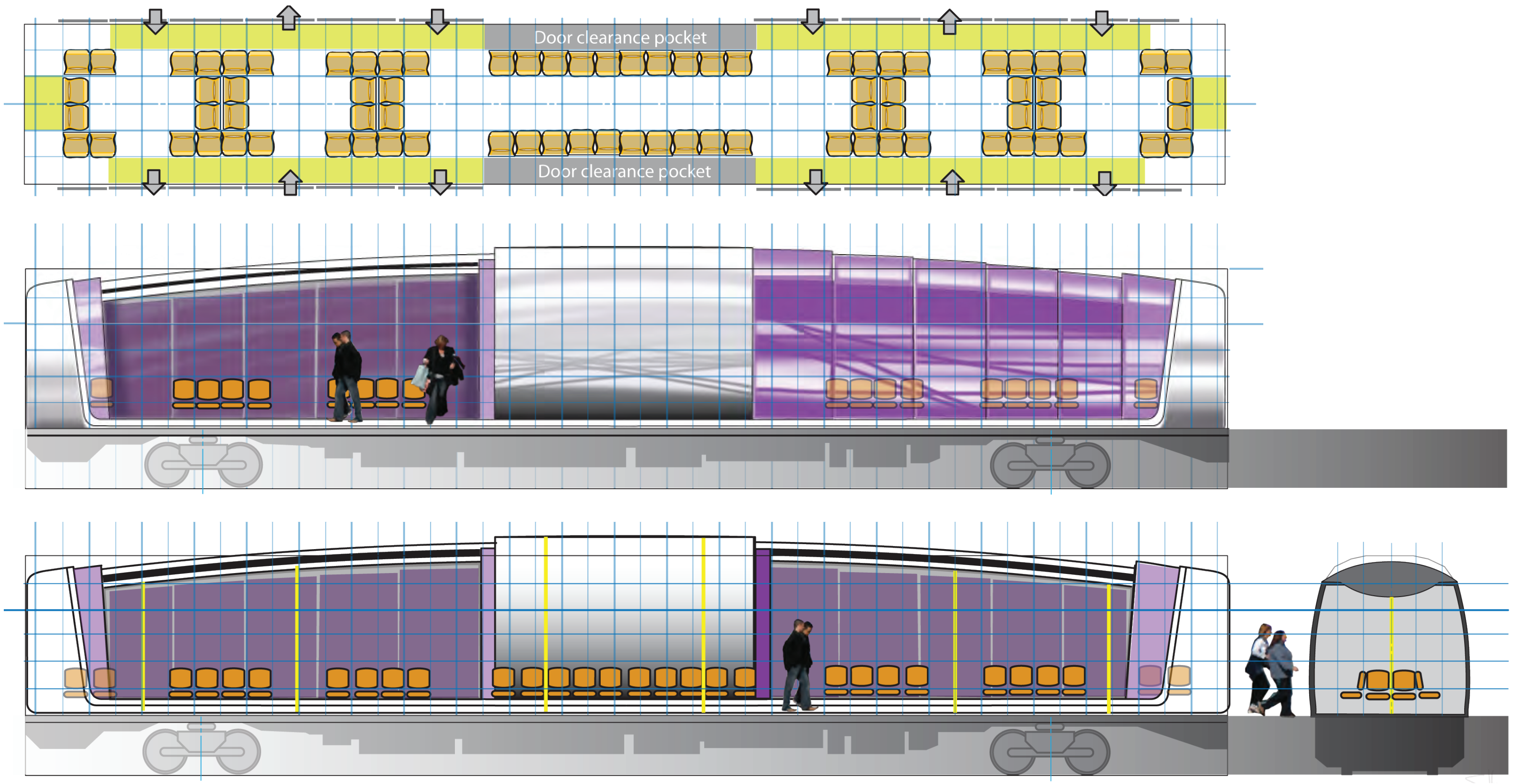


Figure 5.5 Concept C large open sidewall door.

Concept D, Figure 5.6, is effectively a tri-level carriage with 114 seats. Conventional multi-door access is afforded to the two end thirds of the carriage, which are level with the platform. The central third of the carriage has accommodation for passengers on a lower and an upper deck. While this sort of solution contradicts the evidence presented in the literature concerning extended dwell times for vehicles of this type, the purpose of the transverse seating accommodation is to make it available for those travelling the furthest along the network. It is the first of the author's experiments with designing accommodation that is deliberately set up for those travelling further than others. Managing this idea in practice would once again take considerable cultural intervention.

Further rationalising the aspiration of the open sided carriage, while not losing sight of the seat arrangement experiments of concepts A and B, led to an examination of the notion that a fully exposed carriage would only fully utilsed during peak periods, and that for a large part of the day be largely superfluous. A balance was therefore sought between opening up the sides of the train when busy and keeping the doors to a minumum when service was off-peak.

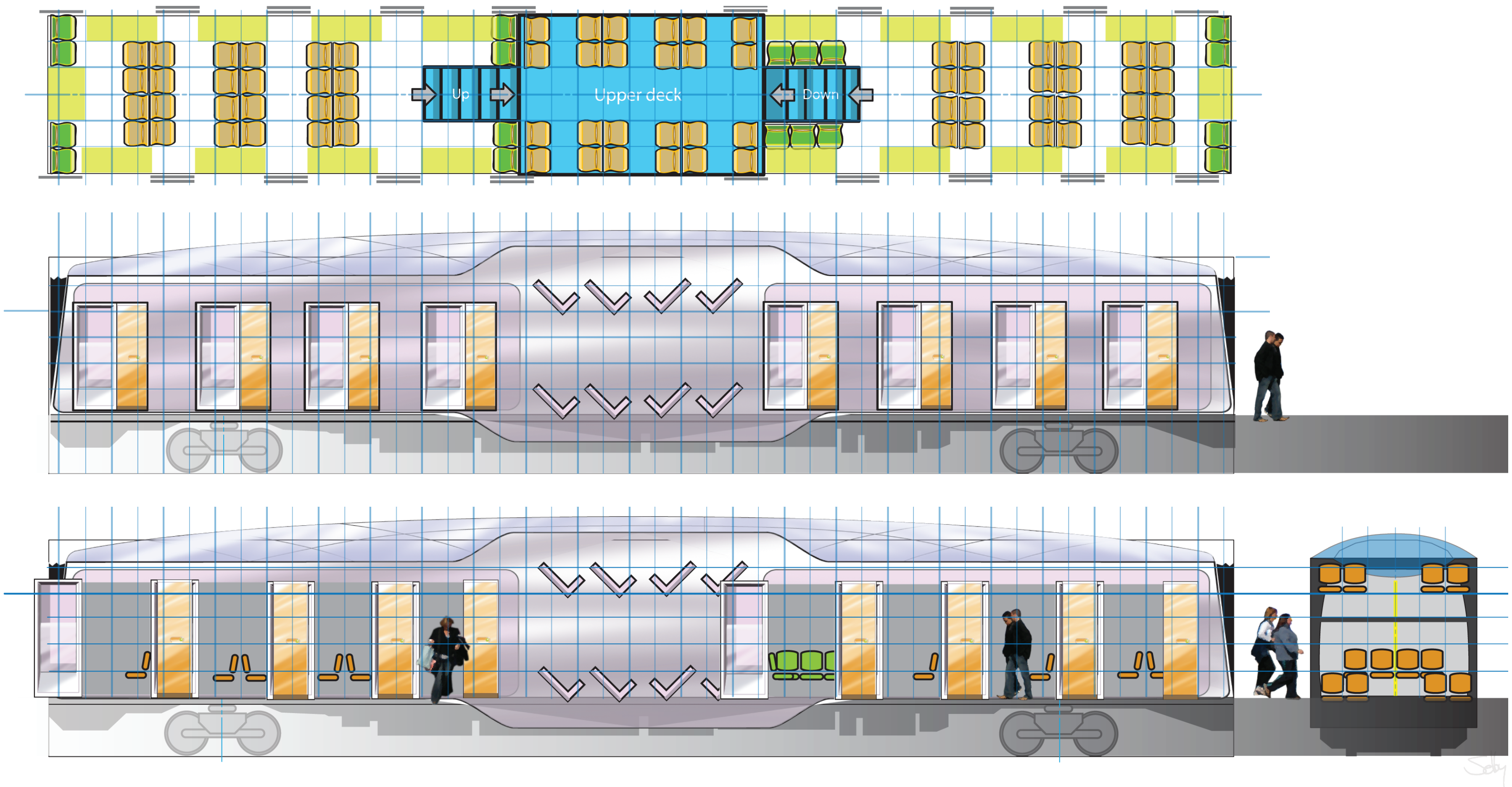


Figure 5.6 Concept D tri-level multiple-door solution.

Concept E, Figure 5.7, contains a similar central arrangement of seating clusters with dual corridors running along the length of the carriage and high numbers of folding and perch seats; 104 in total. The central innovation offered here is the concept of the 'peak door'. In essence, the author is speculating that the three-door arrangement as utilised today remains in place and that extra boarding and alighting capacity is only required at certain times of day and at those times an extra two doors per side become operational. These peak doors would be relatively discreet during the off-peak period and indeed folding seats would be located across the temporary vestibule. These seats would fold into the door framework at designated times on the early shoulder of the peak period, locking into place as the doors become operative. Seating would be lost but standing space increased.

The operational mechanism by which these peak doors are implemented would be aligned with the start and finish of services. Once again a cultural change would be required for passengers to come to expect extra doors to be operative at certain times of the day. This concept opens up the notion of internal space being flexible beyond the use of folding seating. For most of the day, the services can manage a dispersed patronage through the carriage, and, with the exceptions of some accessibility issues, only at peak times do crowding, poor dispersal and lengthened dwell times reflect negatively on the carriage design. The use of peak doors used only temporarily overcomes the issue of the loss of seats due to multiple vestibule spaces.

Figure 5.7 Concept E five door solution with temporary doors for peak periods.

5.3 Developing the concept

To separate these concepts and determine a viable direction, the author chose to make a quantitative comparison chart, Figure 5.8, in which each concept is measured against key criteria in the study and in turn measured against the existing rolling stock on the Melbourne network. Seating capacity and doorway occlusion have been identified in the literature as significant issues in the causation of crowding and extended dwell times; therefore these issues form the following criteria:

- seating capacity
- number of doors per side
- the longest distance to a door (measured as walking distance, not a straight line)
- door width
- note of the method of encouragement to disperse within the carriage.

The comparison chart reveals that there is some quantitative improvement in some key criteria between the conceptual designs and the current rolling stock. There is no conclusive best performer across all criteria. Three of the concepts improve seating capacity to 104 seats although at the cost of standing capacity. This is also achieved since the conceptual carriages are trailer cars or even a driverless carriage altogether, thus clawing back more space along the length of the train. Concept C has the best accessibility with two doors, each at 7 m wide, making the total ingress/egress opening 14 m, over half the length of a carriage, while Concept D provides eight narrower doors giving 12 m of opening. Interestingly, for those located in the centre of the carriage, the distance to one of these opening doors remains longer than for Concept E, which utilises part-time doors for peak periods, rendering the longest possible walk to only 2.5 m from a seat at peak time. Indeed, at this rudimentary stage of analysis, Concept E appears to outperform dimensionally all existing rolling stock in providing increased seating capacity and wider doors but without the complexity of the ambitious door opening and closing mechanics contained in concepts C and D.

These two dimensional paper studies carried out to scale give some feedback to the designer as to their relative efficacy. To make a better evaluation of Concept E and develop the design, three-dimensional mock-ups at various scales including 1:1 mock-ups were prepared.

(T) Trailer car
(M) Motor car

Type of rolling stock	Seating capacity	Accessibility as measured by number of doors per side	Longest walking distance to a door (unimpeded)	Door width(s)	Encouragement strategy to disperse away from the door
Hitachi	96 (T) 85 (M)	3	5 m	1.42 m	Longitudinal seating at vestibules
Comeng	84 (T) 73 (M)	3	5 m	1.37 m	14 seats removed in the door vestibules
Siemens	96 (T) 84 (M)	2	7 m	1.68 m	Wider doors
Alstom Xtrapolis	96 (T) 86 (M)	3	6 m	1.38 m	None specified
Concept A	112	3	8 m	3.5 m / 1.5 m	Ingress and egress only doors
Concept B	108	3	3.5 m	2.0 m	Ingress and egress only doors forced flow
Concept C	80	2	3.5 m	7.0 m	Open wall of train
Concept D	114	8	6 m	1.5 m	Multiple doors
Concept E	104	3 or 5	2.5 m (at peak time)	2.0 m	Peak only operated doors

Figure 5.8 A comparison chart of the relative dimensions/criteria of each design concept and the existing network rolling stock.

Figure 5.9 shows a first look at the three-dimensional qualities of having a central array of seat clusters. The scale of the model is 1:22.5 or G Scale; a modelling scale that is commonly used in the industry. The benefit of seeing the layout even on a relatively small scale is that, when populated with human figures as in Figure 5.9, the essential benefits and difficulties of moving along the dual corridors become clearer.

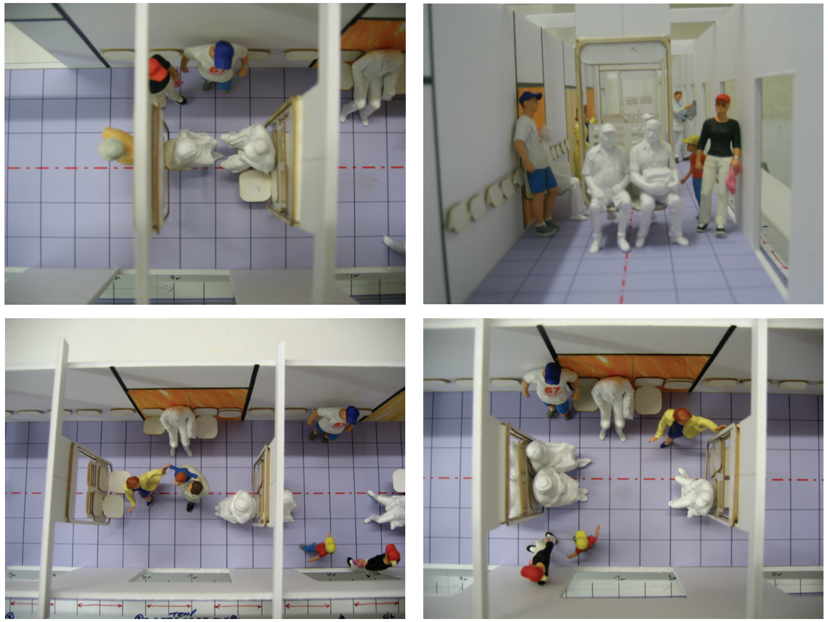


Figure 5.9 Card model at G scale 1:22.5 of a central seating arrangement. The squares shown on the carriage floor represent 500 mm.

In Figure 5.10, a portion of the carriage length, 6 m or approximately a quarter length of the carriage, has been built from arranging chairs that approximate very closely the volume of space taken up by a fully deployed set of seats. The blue upholstered seats are indicative of the fold -away seats adjacent to peak doors. Even without using a group of real people to move about the carriage and making allowance for the legs of the studio chairs which protrude from the seat, a fully deployed seat arrangement is likely to hinder dispersal through the carriage. To cater for the variability of passenger trip distance, the author considered the notion that the carriages themselves need not be the same throughout the length of the train. Some carriages could be designated 'short-trip' and others 'long trip', the difference being manifest in the number and arrangement of the seating (Figure 5.11).

Analysis of the first full-size mock-up exposed flaws in the design, principally in the side corridors, that led the author to reconsider the orientation of the wall-mounted seating. To this end, the seating was repositioned in a transverse arrangement, as described in Figure 5.12. This developed arrangement of the proposal was then revisited as a full-size mock-up, but this time the seating was created from cardboard so that it could be pivoted to provide a more accurate interpretation of the space implications of folding seats and transforming them into perch seats.

Figure 5.10 First full-size mock-up.

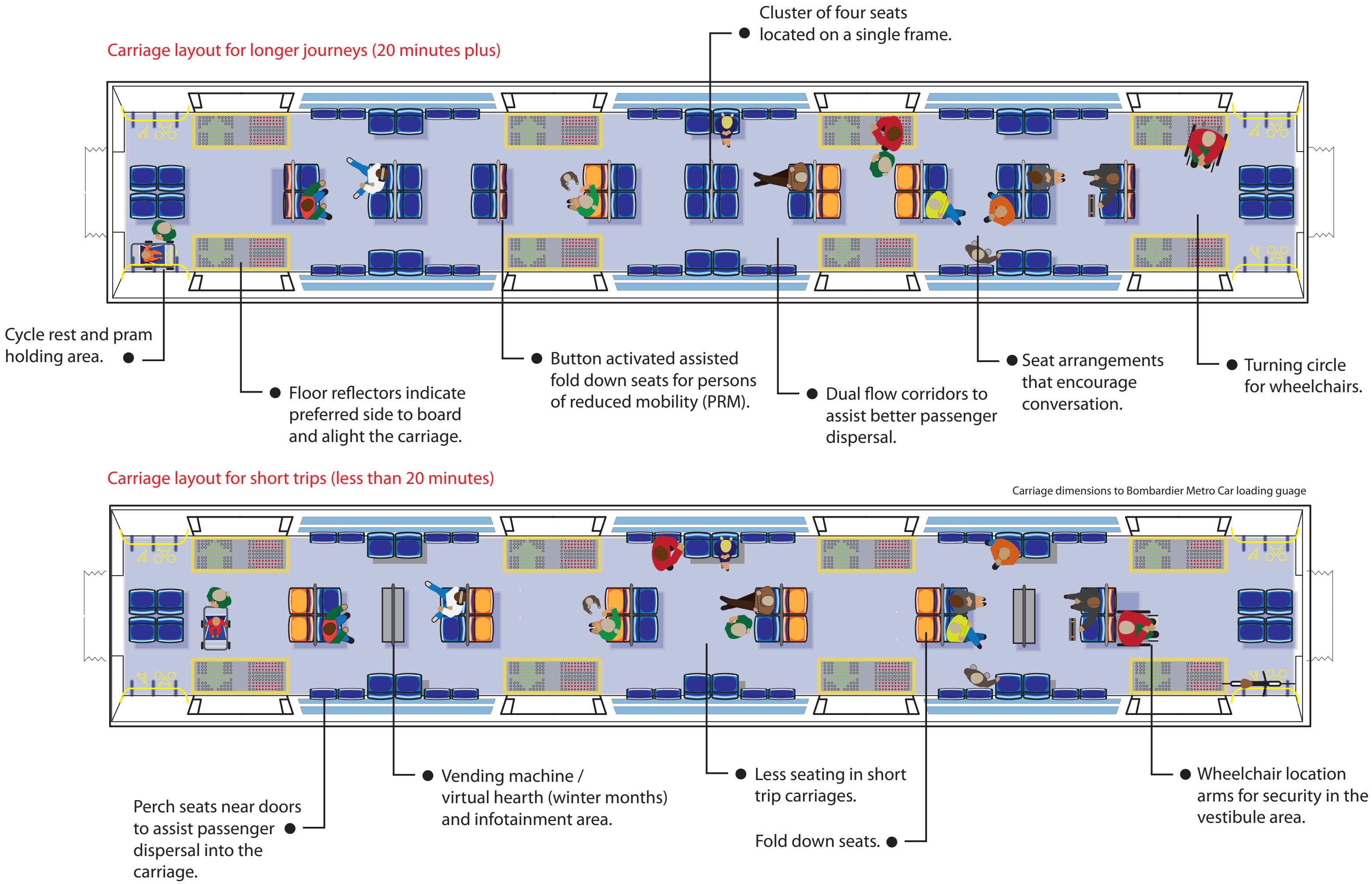


Figure 5.11 Carriage interior layout to match specific trip-length characteristics.

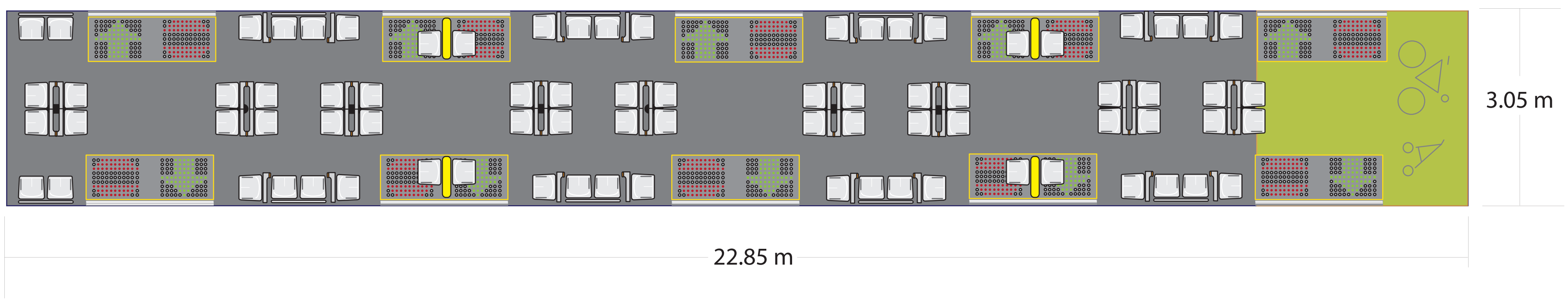


Figure 5.12 Final concept layout proposal.

Figure 5.13 Second full-size mock-up arrangement.

5.4 Conclusion to the concept stage

An iterative sketch design process has been undertaken considering the arrangement of seating and doors largely from the projection of a plan view. The design decisions have been based on the cumulative perceived wisdom of current networks, along with research in crowd dynamics, all within the parameters of the working space created by the design specification discussed in chapter 3.

Five distinct concepts have been created in scale illustrations. Paper studies have allowed the author to be wildly speculative, for the contemporary rail industry, in creating potential solutions in glass with complex total wall telescopic doors, as well as technically more manageable concepts within a reasonable engineering framework.

Each design concept has attempted to manipulate passenger flow with the following strategies:

• rearranging seating into centrally mounted clusters to open dual corridors through the carriage
• door arrangements that dictate passenger flow either by dint of their width (greater than 2 m) or by the implementation of 'rules' to impose passenger behaviours, particularly in determining the direction of movement to and away from ingress and egress.
• creating the largest possible seating capacity.

Since the central arrangement of transverse seating with adjacent longitudinal seating is a common thread, a number of three-dimensional studies were prepared to support design decision making from a three-dimensional perspective, firstly in scale form using model figures to determine potential crowding points, and then by creating simple full-size mock-ups for greater learning.

Central to the outcomes of the sketch studies have been the conflicts between standing space and seating, and between moving away from doors within the carriage and yet being close to them for alighting. There is likely to be an optimal spatial solution for these states and correlations therein, with more seating and fewer doors for off-peak periods and less seating and more accessibility for peak periods. These two states of being have implications for fixed infrastructure that are challenging to resolve.

The sketch studies and subsequent experimentation at full scale with a vestibule section of the train carriage have led to the conclusion that a flexible response is required that provides both seating and standing conditions. In terms of how seating might change state, there is a long precedent for folding seats, especially around vestibule areas, and so this has been continued through the length of the carriage. Concept E speculates on the premise that if doors effectively remove seats from the path of dispersing passengers, then time-dependent use might allow for temporary seats to be placed across the path of a door that is not operational all the time.

The novelty of a time-dependent arrangement of seating to standing capacity, rather than a fixed structure, presents challenges to both engineering and prevailing cultural norms. At this stage, the research offers a potentially innovative direction. Paper studies and even full-size mock-ups can only go part of the way to describing the likely dynamics of passenger flow for a flexible dual-corridor interior arrangement. This concept therefore needs to be further evaluated in order to determine its efficacy. The following chapter discusses the methodology for evaluating passenger flow performance and how the results can then inform the development of this design direction.

6

Chapter 6. Concept evaluation

6.1 Introduction to evaluation

Chapter 5 explored the seating and door layout options in two-dimensional plan schematics and later in three-dimensional form in both small-scale and in full-size mock-ups. A basic evaluation of these conceptual responses to the design problem was drawn up by tabulating quantitative data from the existing specification of Melbourne's rolling stock with the five conceptual iterations. This data comparison identified improved capacity in two areas, seating and door aperture width, for one of the concept designs. However, it is clear that the performance of this conceptual seating and door arrangement is predicated on how passenger crowds might actually move into, out of and through the space, a key evaluation not clear from simple measures of quantity and geometry. To this end, chapter 6 charts the evaluation process:

- methods of evaluation
- two dimensional quantitative data comparison
- results of the two dimensional quantitative data comparison
- the use of computational simulation using EmSim
- EmSim results
- computational animated simulations using Unity software
- Unity results
- conclusion to the evaluation process

6.2 Methods of evaluation

The scale orthographic paper studies described in the previous chapter provide some direction to the designer as to their relative efficacy. Historically, methods of determining the relative merits of a train interior have fallen to the building of full size mock-ups and inviting a sample group of passengers to enter and alight from the interior. This method has had varying degrees of success. Documenting the experimental process through, for example, video aids the evaluation and decision making of the manufacturer. However, this method is time consuming and costly and to some extent flawed by the unreal nature of the setting (Daamen et al. 2008). Proof of the efficacy of the conceptual arrangement needs to be more empirically robust in order to support the validity of pursuing the design to the next stage of refinement. To this end two distinct techniques have been used. The first uses the industry accepted calculation model described in Puong (2008) and developed in Karekla and Tyler (2012) based on a range of quantitative data that can be drawn from the fixed dimensions on a drawing. The comparisons are made between the existing rolling stock on the Melbourne network and the design concept created at the end of the previous chapter, five different sets of dimensional data. This technique is applied in section 6.3.

The second method, Agent Based Modelling (ABM), a computational simulation, is significantly more sophisticated and seeks to direct animated 'agents' by way of a series of algorithms originally derived empirically. The primary benefit of these methods of evaluation is that they take away the expense and lack of realism present in experiments with full-size mock-ups. Certainly in computer simulation animated passengers are programmed to undertake simple tasks with directed goals, e.g. board and find nearest free seat. This is done irrespective of any sense of urgency that might be present at a real boarding or lack of urgency at a static mock-up. This technique is described fully in section 6.5.

6.3 First numeric data comparisons

In Karekla and Tyler (2012) key dimensions that influence dwell time calculation are described as step height, gap width, vestibule setback, and door width. For the purposes of comparison, the first three of these parameters are considered the same, with only the door width being different between the existing rolling stock and the conceptual door.

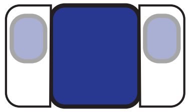
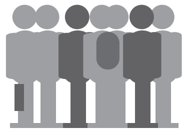
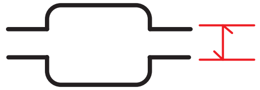
The comparative door widths on existing Melbourne stock are:
Comeng = 1370 mm
Siemens = 1680 mm
Xtrapolis = 1300 mm
Hitachi = 1160 mm
Author's concept (described as Concept E in the last chapter) = 2000 mm and 1600 mm (peak door with two corridors around a folded seat).

Widening door widths allows the same number of passengers to cross the threshold in less time. Fujiyama (2008) observed that for a standard desirable dwell time of 20 seconds, a door width of 1500 mm could accommodate 20 passengers boarding and alighting at the same time, while an increase in door width to 1800 mm accommodated 28 passengers over the same period. This creates a ratio of 1 extra person accommodated per 75 mm extension in door width.

Therefore it is reasonable to suppose that, were the same ratio of width to passenger flow applied to the above door widths, we might see passenger flows of the following dimensions : -

Comeng = 1370 mm accommodating a flow of 18.26 passengers/20secs
Siemens = 1680 mm accommodating a flow of 22.4 passengers/20secs
Xtrapolis = 1300 mm accommodating a flow of 17.33 passengers/20secs
Hitachi = 1160 mm accommodating a flow of 15.46 passengers/20secs
Author's concept = 2000 mm accommodating a flow of 26.66 passengers /20secs
Peak door, two channels around folded seats = 800 mm (1600mm) accommodating 21.33 passengers /20secs

No allowance for anthropometric variablity or a nominal clearance distance between passengers and the door is considered in these simple flow calculations. If these figures are applied across a whole carriage

	Door width mm (x number of doors per carriage)	Flow of passengers through a single door	Flow of passengers over length of train	Corridor width mm	Passenger capacity in corridor
Comeng	1370 (x3)	18	328	512	7
Siemens	1680 (x2)	22	269	900	12
Xtrapolis	1300 (x3)	17	312	1200	16
Hitachi	1160 (x3)	15	278	556	7
Author's concept with 'peak time' doors	2000 (x3) 1600 (x2)	27 21	480 256	600 (400) 600 (400)	8 (5) 8 (5)

Figure 6.1 Comparison of the variable flow rates for the Melbourne fleet and the author's research concept design. Note that the Author's concept during off peak periods, while longitudinal seats are in use, will narrower the corridor dimension to approximately 400mm.

and then multiplied across the length of a six-car train with all doors assumed to load evenly, then the following flow might be supposed:

Comeng = three doors of 1370 mm width (flow rate of 18.26 passengers over 20 seconds) x 6 cars = 328 passengers.

Siemens = two doors of 1680 mm width (flow rate of 22.4 passengers per 20 seconds) x 6 cars = 269 passengers.

Xtrapolis = three doors of 1300 mm width (flow rate of 17.33 passengers over 20 seconds) x 6 cars = 312 passengers.

Hitachi = three doors of 1160 mm width (flow rate of 15.46 passengers over 20 seconds) x 6 cars = 278 passengers.

Author's concept = three doors of 2000 mm width (flow rate of 26.66 passengers over 20 seconds) x 6 cars = 480 passengers plus two peak doors of 1600 mm width (flow rate of 21.33 passengers over 20 seconds) x 6 cars = 256 creating a passenger flow of 736 passengers along the length of a six car train.

The author's concept by these measures is a significant improvement on the existing rolling-stock performance for moving people into and out of the train. Results like these should be expected as the concept contains two extra doors, which is approximately a 223% increase in door aperture width over the next type of carriage (Comeng).

While it might be encouraging and obvious that an increase in passenger throughput can be achieved with the wider and more plentiful doors, the next dilemma is how people disperse in the door vestibule. To this end, the next parameter to be compared is corridor width. This is calculated as the narrowest gap between seats that passengers have to negotiate to move into the train (q.v. Figure 6.1).

Comeng corridor = 512 mm between offset banks of transverse seating.
Siemens corridor = 900 mm between transverse seating.
Xtrapolis = 1200 mm corridor between transverse seating.
Hitachi = 556 mm corridor between offset banks of transverse seating.
Author's concept = two corridors with a width of 600 mm (1200 mm total).

Note that in off peak situations the longitudinal seats may well be occupied reducing the effective width of the corridor. For the purposes of comparison this reduction of corridor width, due to the intrusion of passenger knees, has been estimated at 200mm. Leaving a 400 mm corridor. Depending upon the stature of the individual passenger this knee intrusion could be greater or less than and so is referenced for comparison purposes. The intention of the design concept is that passengers will be stood or perched in the longitudinal seats during those periods that really impact upon heavy passenger flow and impact the most upon dwell.

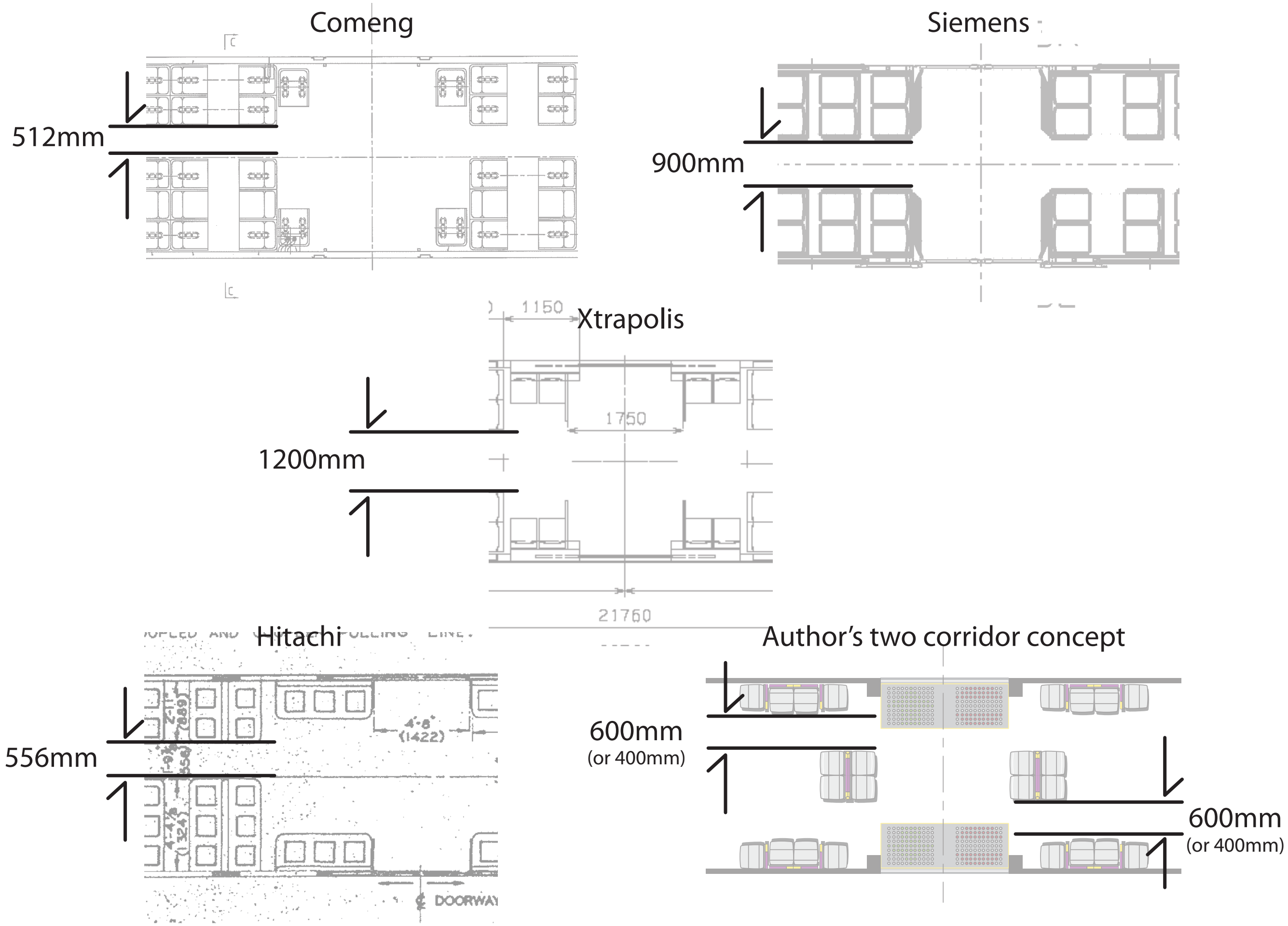


Figure 6.2 Comparison of vestibule to corridor bottlenecks on Melbourne rolling stock. Note that the corridor in the Author's concept is narrower when the seats are occupied during off peak time and not in perch mode. This could for the purposes of comparison be a width of 400mm.

Applying the same ratio of spatial width to passenger accommodation then:

- Comeng accommodates 34 people in the immediate vestibule area, tightening to 7 people in the centre of the carriage.
- Siemens accommodates a uniform width from vestibule to corridor (except motor-car ends, which open out) and accommodates 12 passengers flowing down the corridors.
- Xtrapolis has an initial vestibule corridor accommodating 17.33 passengers, reducing to 16 passengers at the narrowest point.
- Hitachi has an open corridor of transverse seating moving away from the door vestibule which accommodates the movement of 22 passengers. At the narrowest point in the carriage, the passenger flow drops to 7.

For the author's concept containing two corridors, the passenger accommodation is 8 seats each side of the central seating arrangement, making 16 places all together. While it can be seen that the corridor width immediately adjacent to the vestibule is enabling greater passenger flow for the Comeng and Hitachi trains, it soon forms a bottleneck as passengers move further into the body of the carriage. It can be asserted that this bottleneck would discourage passengers from moving down into the body of the carriage. The author's concept remains stable at 16 passengers across two corridors, making it at least as good as the existing rolling stock and possibly better given that there are two corridors to disperse into and out of (Figure 6.2).

6.4 Reflection on first numeric evaluation

The widening and increasing in the number of doors to accommodate greater passenger flow seems compelling on first reflection, especially if in the accommodation of doors that are only in service during periods of high passenger density, seating can still be maintained and not lost. The flow of passengers within the train through the vestibule and corridor is less clear. The Fujiyama (2008) empirical research assumes a constant rate of passenger movement over time. It can be supposed, as observed in Karekla and Tyler (2012), that as more passengers board, the vestibule area fills, passenger flow is slowed and the door and vestibule areas begin to occlude. The only way to maintain a constant flow rate is to reduce the train population with alighting passengers. The trains which start with larger vestibules, Comeng and Xtrapolis, soon narrow to create central corridors. While these initially accommodate boarding passengers quickly, they eventually become crowded if not releasing alighting passengers quickly enough. The author's concept with two corridors and a split dual boarding policy, either through signage or with a crowd 'splitter' by way of seats located at the peak door, might be speculated at this point as being better at maintaining a constant rate. However, this requires all passengers to obey signage requirements and the way they should proceed down either of the two corridors passing the central seating clusters. A lack of clear evidence of the repercussions of passenger behaviour around the impediments of the author's concept indicates that the design requires further evaluation and analysis.

6.5 Agent Based Modelling (ABM)

In the last ten years, computer simulation techniques have developed to a point where they form standard practice for many TOCs in determining the impact of patronage at railway stations. As the literature described in chapter 2 has revealed, the mechanics of human interaction combines to create the undesirable effects of train crowding, doorway occlusion and extended dwell times. Increasing sophistication in the replication of these effects by computer simulation has enabled the author to experiment with an improved degree of authenticity. The purpose of evaluating the layouts in this way is that it will show not only how passengers behave, but also how the interaction of many individuals leads to larger scale outcomes. Creating behavioural or physical dimensions to a simulated passenger by computational methods is a form of simulation known more commonly as Agent Based Modelling (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 exhibits 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 the agents (passengers) and their interactions and then uses computer simulation to reveal the dynamic consequences of these assumptions. ABM researchers can investigate how large-scale effects arise from the micro-processes of interactions among many agents. Large-scale effects of interacting agents can be surprising because it can be hard to anticipate the full consequences of even simple forms of interaction.
For problems such as determining the ebb and flow of large groups of train passengers where predicting the effects of individuals on each other is difficult, ABM techniques have great potential. What is difficult to determine is how accurate and representative the salient aspects of the agents are of the travelling public. In highly sophisticated simulations, it is possible to equip the agents with the ability to learn and develop over time. The key issue here is the extent to which the resulting outcomes are orderly within the environment where they have been placed.

There are a number of commercially available computational research tools for simulating crowd behaviour. It is outside the scope of this research project to make a full review of the merits of each system. The software employed is one that the author had access to as part of a collaboration into the general effects of crowd movements in confined spaces and was originally scripted at Monash University (Institute of Transport Studies). This software is known as *EmSim* and was originally designed to simulate evacuation and panic situations. The value in this software for this application is that the algorithms dictating the movement of the agents (representative of passengers) closely approximates the dynamic characteristics of the jostling of crowds through narrow doorways and confined spaces, which is an advantage over other simulation software systems. At an initial simplistic level, the simulation is able to consign numeric variables pertaining to the number of passengers their velocity and their mass. The motivation and direction of movement are determined by a simple plan view of the train whereby agents can only move dynamically between designated walls (Figure 6.3). As a comparison to measure the efficacy of the conceptual design, a plan view of a single-corridor train was created closely equating to the dimensions of the Comeng rolling stock, which is the most populous of the Melbourne network. The structure of the *EmSim* software is such that in this simulation, the passengers can only leave the train. So the simulation is indicative of a terminal arrival, rather than a station on the line.

6.6 Results of the *EmSim* egress simulation

Figure 6.3 is a screen shot of the *EmSim* software showing a plan view of two carriages; (a) is a Comeng layout where passengers, represented by blue dots, are seen to move along a single corridor in close proximity to each other moving towards the door. Their relative proximity to each other both stalls and perpetuates the flow of movement in what is known as a social force model (Sarvi & Shiwakoti 2011). There is insufficient space between fixed objects, walls and seats represented in grey, to allow the passengers to reach their full expected walking velocity (1m/s). This is especially true of the slowing caused by interactions with other passengers. In (b) it can be seen that for the same number of passengers moving towards the door, the two channels or corridors have diminished the impediments to the passengers' progress, therefore allowing them to reach the door and egress at closer to their walking velocity with less 'bumping' interaction with other passengers.

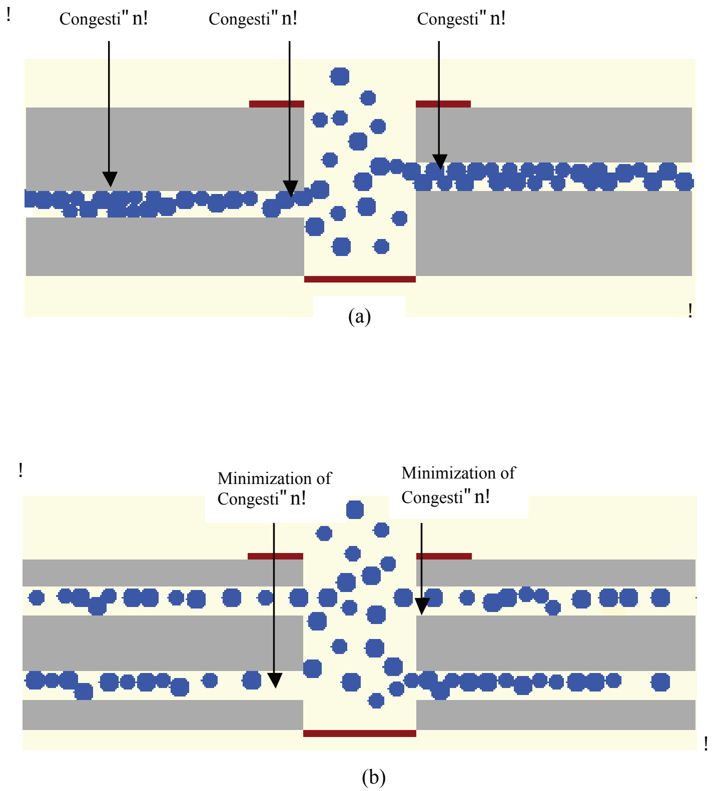


Figure 6.3 Comparison screen views of the Comeng train and the conceptual design using EmSim. *Images courtesy of Dr Nirajan Shakowoti, Institute of Transport Studies, Monash University.*

Figure 6.4 shows a graphical representation of the number of repeat simulations with time taken to alight the 65 passengers. While the simulations are stochastic, so that on some occasions passengers bunch more than on others, it is clear that the dual-corridor arrangement is quicker at alighting passengers than the single-corridor arrangement. With the Comeng-type 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). This represents an improvement of 11% in time to alight.

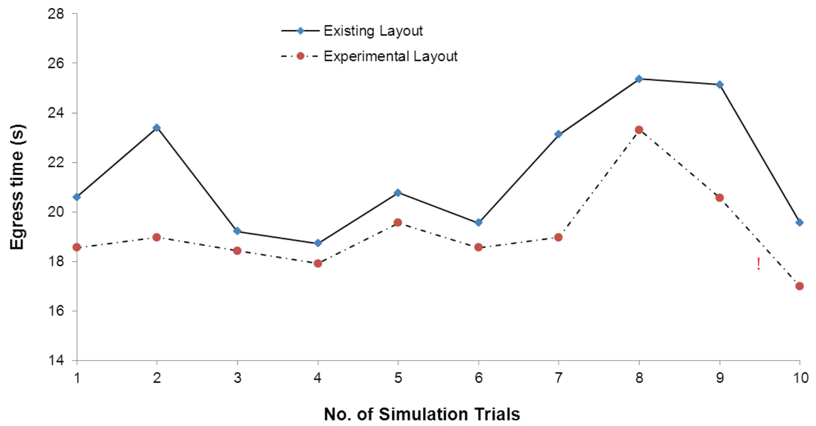


Figure 6.4 Comparison graph of the Comeng train and the conceptual design using EmSim. *Images courtesy of Dr Nirajan Shakowoti, Institute of Transport Studies, Monash University.*

6.7 Animation simulations using *Unity* software

The initial explorations into ABM simulation is encouraging since they demonstrate that significant effects could be achieved by adjusting the structural features of the train interior. The presence of a central series of seat clusters and dual corridors in experimental design have minimised the number of interactions and thereby speeded up egress. However, these results present a number of significant shortcomings using only an evacuation model. Only half the problem of doorway occlusion is addressed. A simulation with boarding passengers is needed. Given the area that the modelled passengers occupy it is likely that some patrons would turn and look to another door rather than the single point of egress offered in the experiment. At inner-city cordon stations (q.v. chapter 1) 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. From a communication point of view, a simulation of passengers represented only by dots lacks 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 directed by the algorithms of the *EmSim* software.

The animated simulations used the game engine *Unity*. This software platform enables simple pathways to be coded between the animated agents or passengers and an intended end 'destination' in their animation profile. Boarding passengers would aim to leave the platform, find a door and look for a space to sit or stand. Alighting passengers would look for a door and leave into the open space of the platform. While the start points and the end destinations of the agents are predetermined, the manner in which these agents negotiate impediments such as other agents travelling in the opposite direction, seats, walls and doors is completely random. It was now possible to replicate the distribution of patrons around a door and within a carriage and observe their exchange through the doors in a way that closely resembled such an exchange in real life.

The representative carriage illustrated in Figure 6.5 was built in the 3D modelling software *Maya* with the correct number of doors and seating clusters, both folding to create perch seats, and in 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 initial *EmSim* only simulation, all patrons contained the same mass and velocity. In this second simulation, the author determined that there should be some human differences so as to reflect more accurately the make-up of a crowded carriage. Choosing accurate characteristics is problematic since there are little data in the specific area of rail passenger anthropometrics. TOCs such as SNCF have attempted to gather a representative collection of data on passenger sizes, speed, movement and general complement of a train. The difficulty concerns both the gathering of the data and where this might contravene passenger privacy, if recorded, and how the movement, mass and speed of patrons can be grouped with any accuracy.

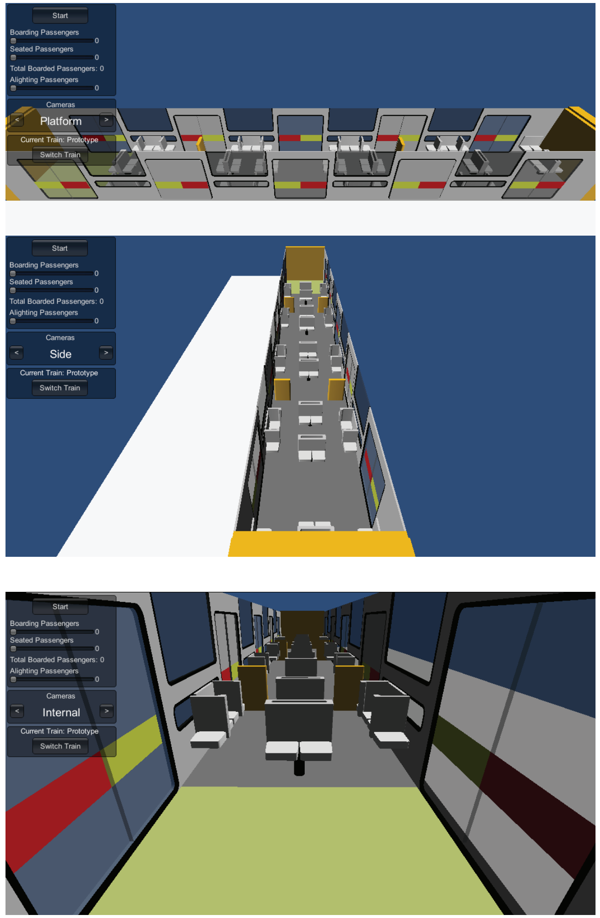


Figure 6.5 Images of a simplified replica of the proposed carriage concept used for the animation simulation.

6.7.1 Creating archetypal passenger models

The purpose of the simulation is to determine the dwell time required to board and alight a certain number of passengers and their likely dispersal during the peak period of service. 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 a range of patrons who are of working age (between 20 and 60). A minority of elderly passengers will be outside this range. This is not an unrealistic assumption on the part of the author since many networks 'price off' sectors of the community, in this case seniors, with concession-fare discounts for avoiding peak periods of the day. A further assumption has been to include a segment of the passenger profile that is unaccompanied school children. The archetypes have been created still further:

1. working-age woman (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/backpack, but with greatest acceleration of movement
4. working-age man (endomorphic 40+); presumed fit and healthy but of a wider girth and with a slower velocity than the younger age groups
5. working-age woman (endomorphic 40+); presumed fit and healthy but of a wider girth and with a slower velocity than the younger age groups
6. old woman/man (with carrybag for shopping); slowest velocity. This represents the anticipated minority of passengers outside the normal range who might still require travel within peak periods.

(Figure 6.6)

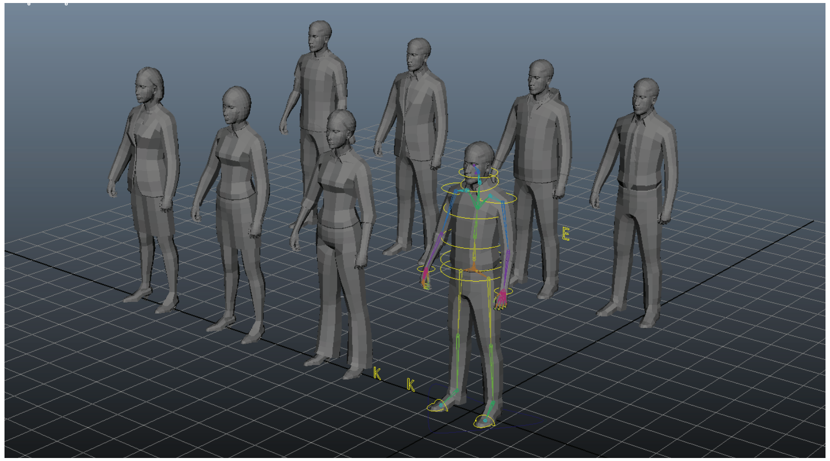


Figure 6.6 Passenger archetypes used for animation purposes.

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 and that the significant factor being measured is the horizontal plan in which passengers of different girth and velocity will interact in different ways.

These six stereotypes were applied to the carriage in varying numbers that reflect a demographic balance observed on Melbourne metro trains. School children were grouped in clusters, whereas working-age passengers were placed more individually (Regirer & Shapovalov 2003) and spaced to reflect the observation that passengers prefer to create a level of personal space around them where possible (Hoogendoorn et al. 2002). The total number of passengers created reflects the capacity of a single carriage, i.e. 133, and split up into the archetypes.

The number of figures of any one archetype was weighted to the working-age men and women as a reflection of the likely proportion onboard a peak time train. In terms of overall anthropometric dimensions, these archetype groupings were very similar, so apart from appearance and velocity (older figures moved more slowly) the overall area occupied by a figure, $0.25m^2$ as determined in chapter 3, meant that across the length of a train, only negligible discrepancies in passenger movement dynamics might emerge across the carriage. Without accurate data from the real world to calibrate this dynamic, the author was unable to make an allowance for human dimensional diversity in the results of the simulation.

Other patterns of behaviour reflecting the intentions of the experimental design were the directing of the three-dimensional figures to submit to the expectations of pedestrian flow around the pillar adjacent to the peak doors, e.g. move to the left to pass obstacles in the doorway. The author felt that while this was an imposition on the behaviour 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.

6.7.2 Simulations using *Unity*

The simulations built in *Unity* start with the premise of the carriage being full and that the only available space is standing space between seats and door vestibules. The following two simulations set in these circumstances were then built:

a) Simulation with current Comeng three door mixed longitudinal and transverse seating:

1. All 84 seats are occupied by passengers. Only standing passengers will move. Train doors open. Timer starts.
2. The simulation interface contains a sliding control which enables the setting of different numbers of through, boarding and alighting passengers. The first setting is for 26 alighting passengers. This is 20% of a 133 capacity carriage.
3. A second slider is adjusted to determine the number of platform patrons who will board the train, starting again with 26 people spread randomly along the platform.
4. The animated figures are free to jostle their way between the exterior and interior until all are settled at standing points either side of the door.

5. The door then closes the timer stops and the dwell time is established for that simulation.

The process is repeated, each time adjusting the sliders so that they increase the number of people engaged in the exchange. (See Figure 6.7).

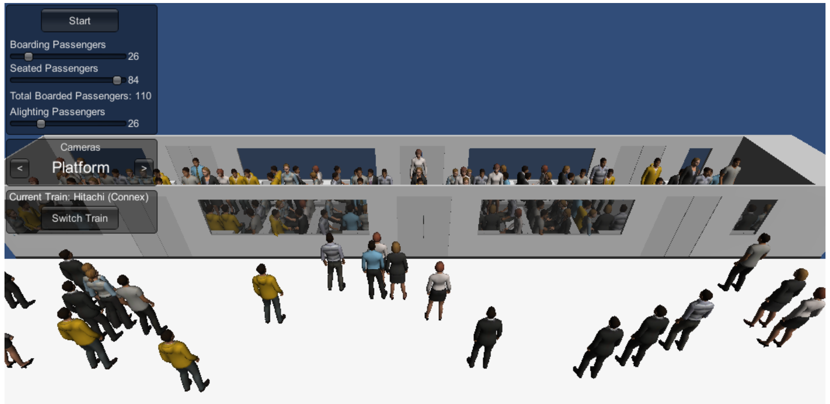


Figure 6.7 Simulation with a Comeng layout.

b) Simulation with the five door two corridor concept train interior -

Most seats are in the up position so effectively do not exist as seats. Eight remain as seats for PRMs. Theses agents do not leave their seats during the simulation. Only standing passengers will move. Train doors open. Timer starts. Again a number of the standing passengers will make for the doors, beginning with 20% or 26 passengers. Another slider determines the number of exterior persons attempting to board the train, starting again with 26 people spread evenly near the doors.

For the three open doors, the animated figures are free to jostle their way between the exterior and interior until all are settled at standing points either side of the door. For the two doors with a splitter, the animated figures are directed to pass on the right alighting and on the left – boarding. In the simulation, there will be a small percentage that attempts to board or alight on the wrong side of the door splitter. This splitter is expected to push the crowd to move from the door to within the carriage. Once the exchange is completed then the door closes, the timer stops and the dwell time is established for that simulation.

Figure 6.8 shows the animated agents as they move between carriage and platform, and platform to carriage. Those agents entering the carriage are predisposed to find the nearest seat; in the event that all are occupied, then the agent adopts a standing position.

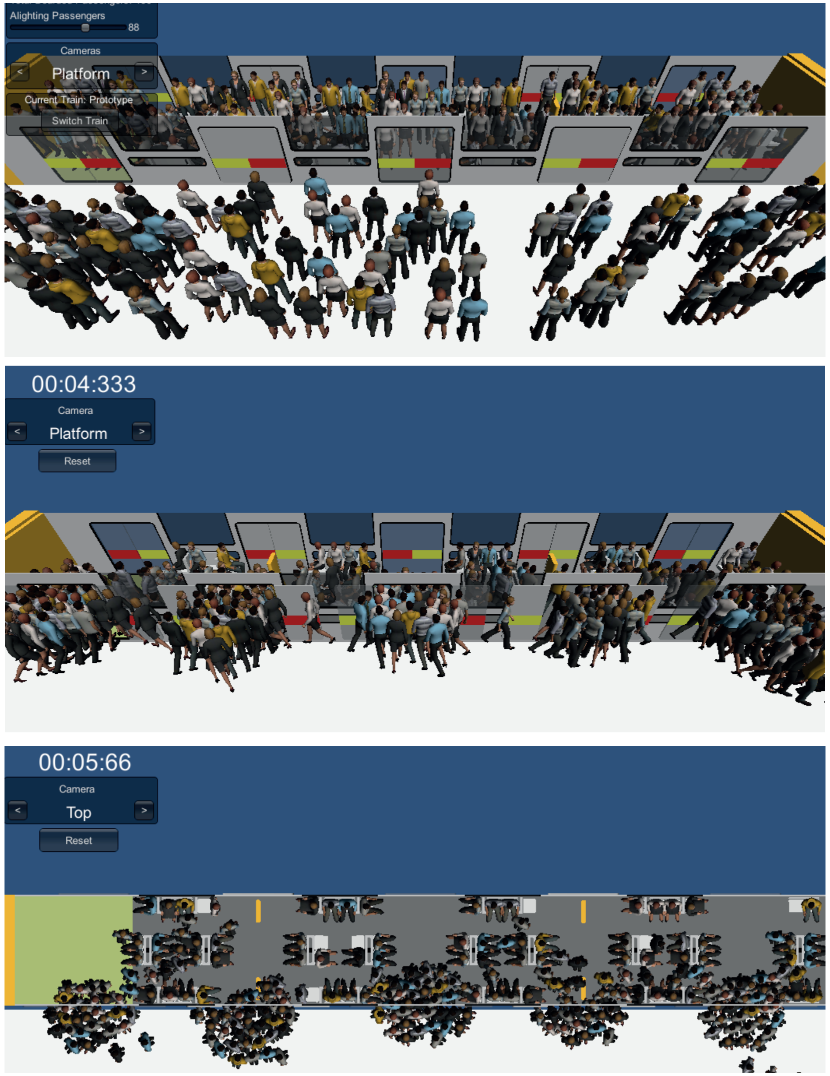


Figure 6.8 Boarding and alighting through 5 doors.

Under the algorithm rules of the social force model, as the agents move towards each other and reach a certain distance, they move away and around each other in a way that replicates the movement of real passengers attempting to board and alight. The simulation quickly makes apparent the problems of dual boarding and alighting without some sort of protocol, i.e. wait until passengers have alighted before attempting to board.

6.8 Results of the second simulation

The simulation serves to validate via experimentation the improved exchange suggested by the first *EmSim* simulation, when patrons were only seen to alight from the train. The validity of the conceptual carriage interior as an arbiter of improved passenger exchange and stabilised dwell times is seen most keenly by applying the simulation to the highest loads.

The worst case situation for dwell-time delays is caused when all the seats in the carriage are taken and the excess in capacity is beginning to build as standees cluster around the door vestibules. When such a train arrives at a significant interchange, where passengers need to alight and significant numbers need to board, then delays in dwell time occur.

In these simulations, both the Comeng and the concept carriage are populated to the capacity of the simulation; 250 passengers seated and standing. There are no data sets indicating exact numbers of passenger exchanges, boarding, alighting and standees, so a number of simulations were created, incrementally increasing the percentage of passengers alighting and boarding. The percentage increments are based on the Connex case study, in which Weston's formula was used to calculate a graphical distribution of anticipated dwell times, (q.v. Figure 1.2 in chapter 1). In each simulation, the number of passengers either boarding or alighting is increased by 5%. The distribution of these passengers both within the carriage and on the platform is randomly driven by the software and so no two simulations can be exactly repeated. The results are expressed graphically in Figure 6.9.

Figure 6.9 shows that for each of the conditions, both carriages fall within the generally accepted dwell time of 20 seconds; however, the peak door two-corridor solution gives consistently quicker passenger exchanges. Only for very small numbers (5% equating to 14 patrons) were exchange times roughly comparable. As the number of passengers in the boarding and alighting exchange increased, the value of extra door and corridor space had an observable impact on dwell time reduction.

As an example of an extreme exchange, simulations were run based on the very high PIXC figures (36%) recorded in the cordon loading data discussed in chapter 1 at Clifton Hill during May 2011 (q.v. Figure 1.7). In this scenario, the train was carrying an average, assuming an even distribution, of 182 passengers per carriage. The test aimed to determine, at this high loading, the results if all the seats remained occupied and the remaining standing passengers all alighted from the carriage to be replaced by the same number boarding. Figure 6.8 shows that over 100 repeated simulations, on average the concept train carriage had a 33% shorter dwell time; note that neither achieved the desirable standard 20 second dwell time.

6.9 Conclusions

This chapter has described the use of three methods of evaluating the proposed design concept for a new carriage interior. The first was a two-dimensional arithmetic measure based on the expected passenger flow for certain widths of door. The second and third methods concerned the application of agent based modelling computational techniques to simulate passenger behaviour, first in 2D and then later in 3D versions. The purpose of these simulations was to either refute or support the concept of a central seating arrangement with dual corridors and extra doors operational at peak time.

The first of these computational simulations was based on the *EmSim* crowd-modelling software, which replicated egress only of the whole carriage, a model that responds to a service terminating condition. The results of these simulations showed an improvement in the speed of passenger flow for alighting under the conditions of the two-corridor concept design. The increase in the number of doors and the reduction in bottlenecking through a single corridor have made this a likely outcome. However, dwell time stability is at its most volatile when

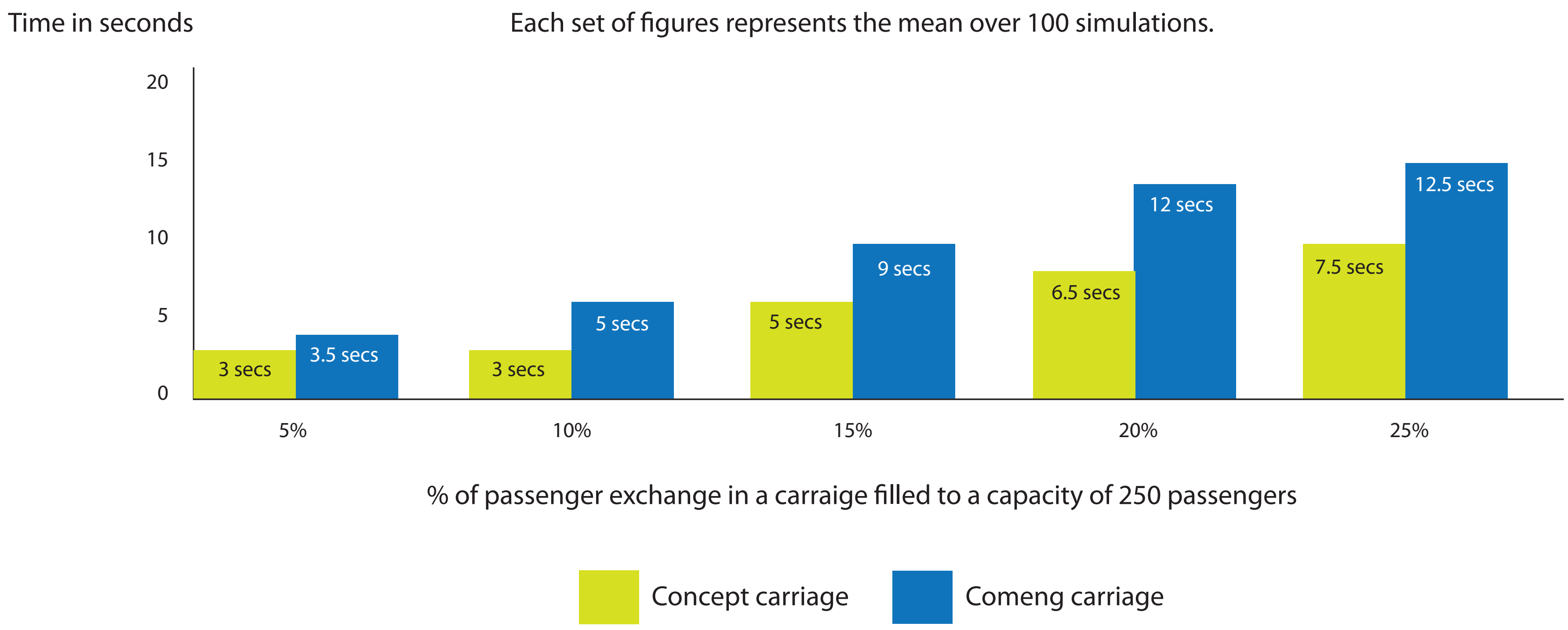


Figure 6.9 Graphical analysis of dwell time against numbers of passenger exchanges for both Comeng and concept train interiors.

through trains are waiting for a passenger exchange of both boarding and alighting passengers. This simulation was better measured by using the three-dimensional *Unity* software. With this 3D model populated with animated figures or agents, a better replication of the passenger exchange could be achieved.

In these final simulations, it can be seen that multiple doors, dual-flow passenger exchange and dual corridors made for consistently shorter dwell times for the same numbers of patrons as in a Comeng train simulation. Certain assumptions have been made. Motivations for agents to seek a seat and obey certain cultural norms have been assumed and while observable evidence would suggest these assumptions have validity (Hirsch 2011), this does not negate all possible behaviours that might be encountered at stations. The simulation needs to nuance the distribution of passengers in certain crowded situations where the intrusion into private space seems unrealistic i.e a passenger is more likely to move into open space where it is available, rather than form a crush grouping with others. The determining of personal space as indicated in the literature can vary from the spacious as in seated static situations to tighter dimensions as people move thoriugh a space or are forced by circumstance to reach crush loads.

Equally, passenger motivations discussed in the literature but not applied in these simulations due to technical difficulty include sitting next to known people or away from strangers, sitting in the direction of travel and next to windows, bunching at certain doors, as in rainy or sunny conditions and when some patrons circumnavigate control conventions and so work against prevailing crowd movements.

7

Chapter 7. Design project 2
seating design

7.1 Introduction

The previous two chapters established that a central arrangement of transverse seating flanked by longitudinal seats creates improvements in passenger flow and dispersal. Hitherto the layout has been seen as crude manipulation of space in block form. In this chapter the design nuances of the seating clusters are developed. The on-board seating is both the essential instrument of comfort and the main impediment to passenger flow (Baker et al. 2007, Lau 2005). As a designer, the challenges of this project are to develop a solution that provides an acceptable level of comfort within the context of use, while at the same time reducing the impact of the seating on passenger movement through the carriage. This chapter is organised in the following way:

- determination of key specifications required of the seating and hand hold arrangements
- series of sketch studies to experiment and evaluate design options
- conceptual design with detailed development.

7.2 Determination of key specifications

7.2.1 The requirements of seating

Seating is the central means of securing the body, by lowering its centre of gravity, while the vehicle is in transit. Specific literature about sitting in the context of train carriages goes back many decades, for example, Branton and Grayson's (1967) evaluation of train seats by observation of sitting behaviour and Oborne's (1978) 'the ergonomics of passenger comfort'. Much contemporary literature concentrates on high speed and long distance trains rather than short distances, for example, Vink (2009).

Comfortable seating directly relates to managing the pressure exerted by the body on the supporting seat structure (Looze et al. 2003). This pressure builds up over time and is instinctively redistributed by a change in pelvis angle (Lee et al. in Vink 2009). The pelvis is moved in three directions: yaw (twist in the horizontal seated plane), roll (leaning to one side or the other) and pitch (leaning forward or back). The feet and posterior take most of the weight. Movement is triggered when the pressure in one position reaches a critical threshold.

Chapter 3, which determined the design specification, established the dimensional envelope of the seat. The data were drawn from the ergonomic orthodoxy in the field. Building a specification of comfort, as described in the literature, is more difficult to articulate from definitive data. The MEDLINE database (2009) holds 261 papers with 'comfort' in the title: however, most of these are about thermal comfort (140). Comfort is influenced by many factors in the environment and is most frequently described as a neutral state in which there is the 'absence of discomfort' (Vink 2009). Individuals have their own meaning for comfort: however, common observations in the literature for discomfort on trains have been:

- restricted leg space, reduced movement and reduced movement possibilities resulting in back and neck pain and injuries
- vibrations and shocks; small differences of pressure on the posterior and buttocks can be perceived (Goosens et al. 2002)
- discomfort related to descriptors such as fatigue, restlessness, pain/biomechanical strain and circulation (Zhang et al. 1996).

Other elements such as softness of seat, armrest material and texture of the seat appear to be of lesser importance in research but are frequently specified by TOCs. Cloth finish, despite its many disadvantages in the public domain, is seen as an arbiter of comfort (Participatory Ergonomics 2010).

In addition to the basic dimensions described in chapter 3, the following elements have been folded into the dimensional criteria of the seat design:

- The sitting height has been established as the vertical distance from the sitting surface to the vertex, i.e. the crown of the head, with some variability for seat compression, approximately 10 mm (Pheasant 1986).
- Clearance has been created between the seat back and obstacles, such as other passengers knees and/or opposite facing seats. The buttock-to-knee length is defined by the horizontal distance from the back of the uncompressed buttock to the front of the kneecap. An added benefit in the train carriage context is flattening of the lumbar support, which means that seats can be brought closer together. The angle of the seat-to-back is tilted at 5 degrees: this transfers more upper torso weight to the seat back rather than through the pelvis and seat pan, reducing pressure on the buttocks.
- Buttock popliteal length is defined by the horizontal distance from the back of the uncompressed buttocks to the popliteal angle, (the back of the knee where the back of the lower legs meet the underside of the thigh). This dimension defines the acceptable seat depth.
- Shoulder breadth or bideltoid is defined by the horizontal breadth across the shoulders, measured to the protrusions of the deltoid muscles plus a correction for outdoor clothing (40 cm) (Pheasant 1986).
- Hip breadth is defined as the maximum horizontal distance across the hips in the sitting position.
- Perch seat height; to maximise space at certain times of day, if seats fold to provide standing space or a ‘perch’ seat, then the dynamics of the seating area change. The legs are splayed to balance the body, redefining some of the dimensional requirements (see Figure 7.1).

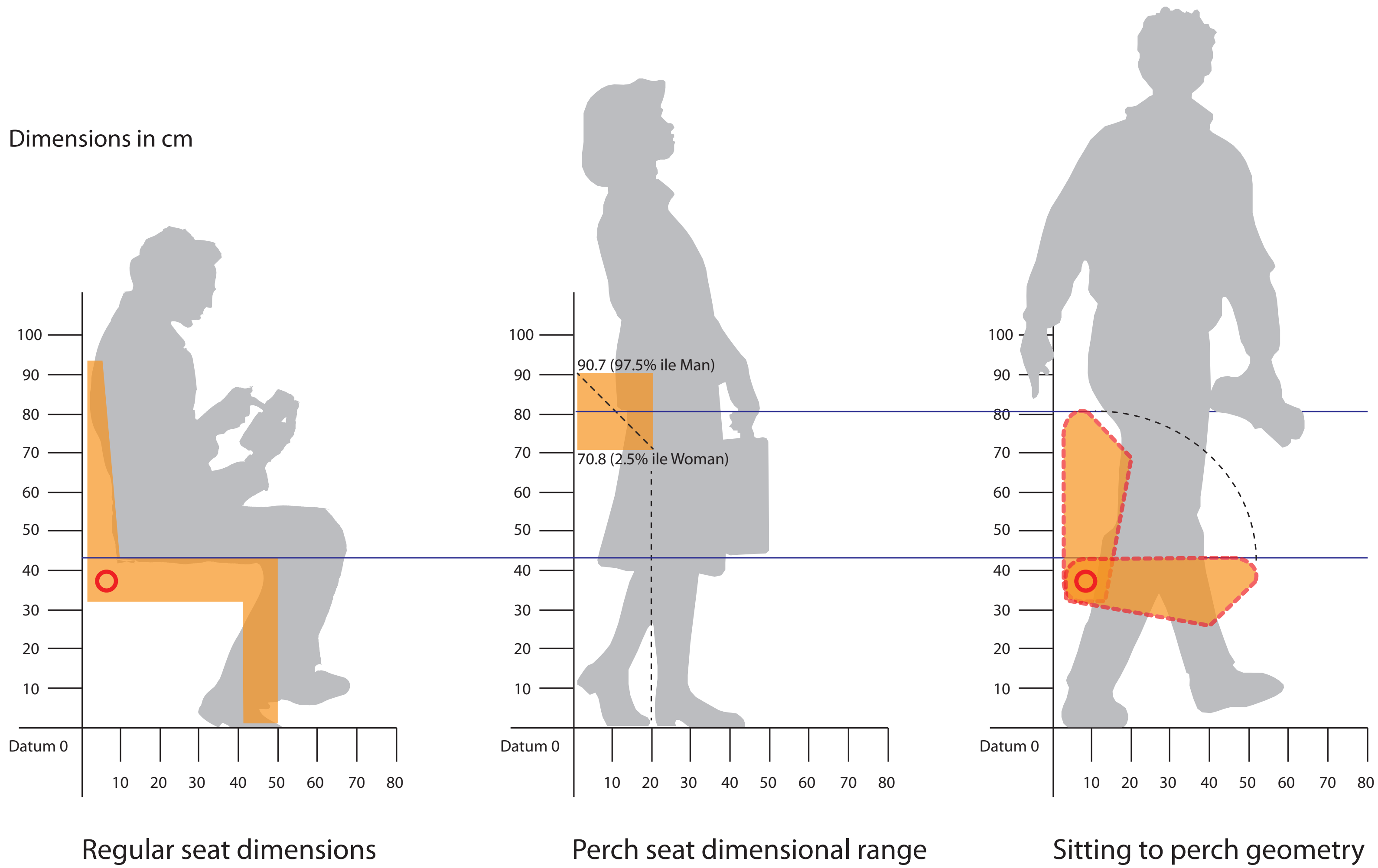


Figure 7.1 Seat geometry when converting from sitting to perch posture. Data from Pheasant (1986).

7.2.2 Designing to accommodate sitting behaviour

There are some data regarding the variation of posture while sitting on trains. Observations made on a regional train for research by Bombardier (in Vink 2009) collected 1700 posture observations. The length of the journeys was not recorded and the real value of the data lies, in the opinion of the author, on the extent of difference in posture between genders. The seating design for these observations differs from metro seating since the seats have tall backs and generally face in the direction of travel.

Postures observed:

- leaning against backrest, men 63% women 73%
- leaning forward, men 4% women 4%
- slumped in seat, men 20% women 10%
- leaning forward to the right or to the left, men 13% women 13%
- legs parallel feet on the floor, men 24% women 52%
- legs wide, men 41% women 10%
- legs stretched out, men 7% women 5%
- legs crossed, men 14% women 22%
- feet on heater, men 8% women 4%
- legs propped against seat in front or on other chairs, men 6% women 5%

Activities observed in the same test:

- sleeping/napping 29%
- listening to music/talking/staring 36%
- reading a newspaper 18%
- reading a book or magazine 13%
- writing or typing 4%
- of the 500+ observations, only 45 passengers chose to sit in the middle seat of a bank of three, approximately 250 preferred the aisle seat and 465 choose to be by the window.

The author's own observations of the Melbourne network include the propensity for patrons to put their feet on the seats facing them. It can be seen that the close proximity between facing seats is at just the right affordance to encourage a natural inclination for passengers to stretch their legs to increase their comfort. This behaviour affects the maintenance of seats by contributing detrimentally to their wear and tear.

7.3 Design sketch exploration

Unlike some design activities, the rigorous framework of the anthropometric nature of seating negates a wide variation of design outcomes. The author is concerned with creating a flexible seating design and this is most evident in the accommodation of folding seats. The interior layout as explored in chapter 4 and evaluated in chapter 5 predicates the notion of clustering the seats, either singularly or in banks of two. Early sketch studies explore the pragmatic replication of multiple variables from single forms, a common theme of multiple production in the industrial design discipline.

The author's approach throughout these sketch explorations has been to create the following outcomes:

- The design, while sat in a pair, should be sufficiently separate to allow individuals to sit adjacent to each other.
- The design would have folding seats so as to create standing space
- Integration of hand-holds with the construction of the seat, to support standing and facilitate passing through the train.
- The design should be of a plastic moulded character, including any form of foam and fabric cushioning but supporting comfortabling sitting through the elastic properties of the moulded material.
- Single seats located along the window sides could offer either a detached amenity or the possiblity of inclusion in wider circles of patrons travelling together.
- Little infrastructure is needed to secure the seats so that cleaning of the floor could be easily undertaken.

Figure 7.2 illustrates the seat groupings as block impediments to the flow of passengers. The dimensions and volume of these blocks form the envelope around which the seats are designed. The method of studio experimentation from this point is described in Figure 7.3.

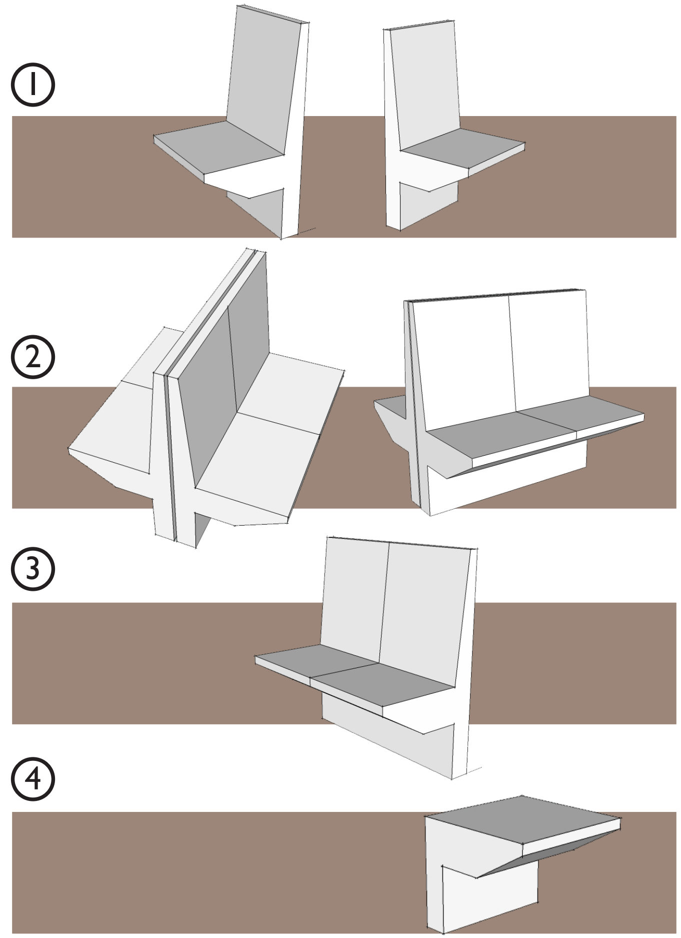


Figure 7.2 Seat cluster groupings as required by the concept layout: 1. single seat with back 2. island four seat cluster with back 3. twin seat bank with back and 4. single seat without back.

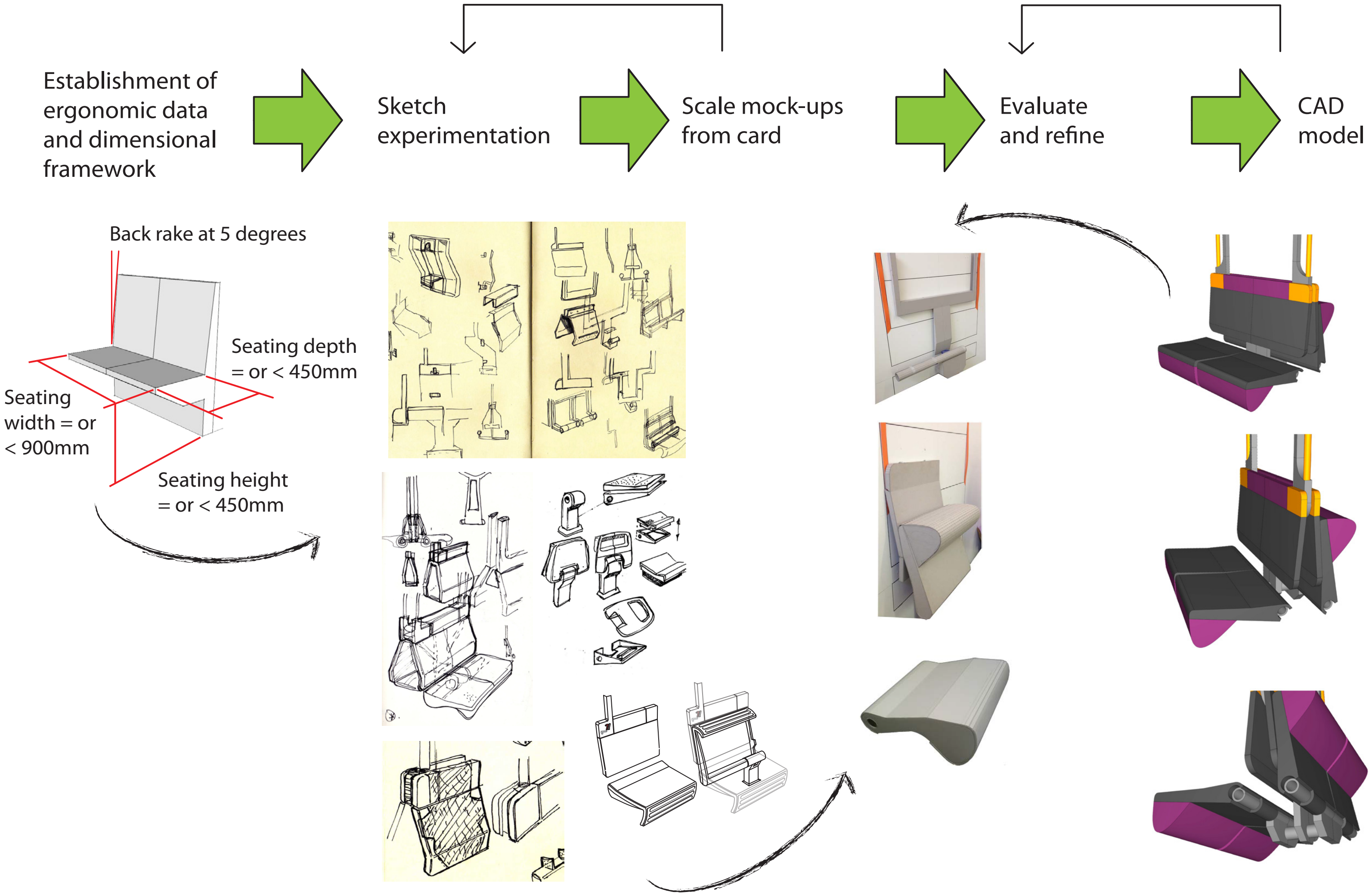


Figure 7.3 Seat design process.

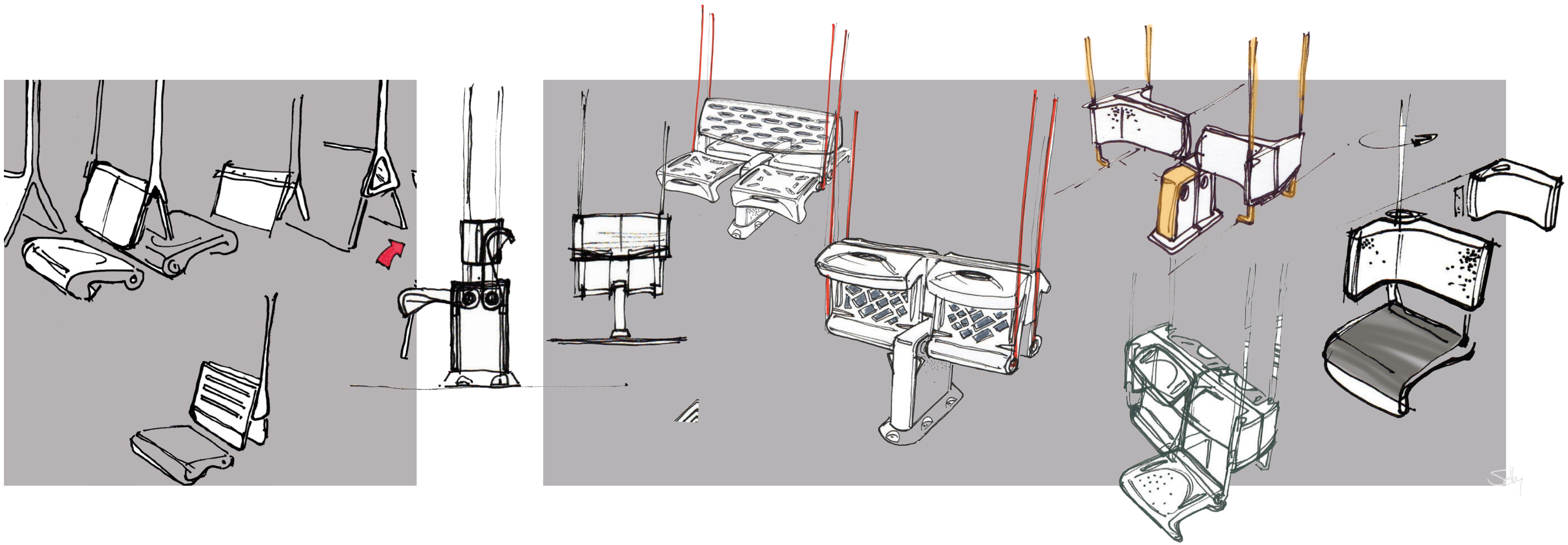


Figure 7.4 Range of initial sketch studies.

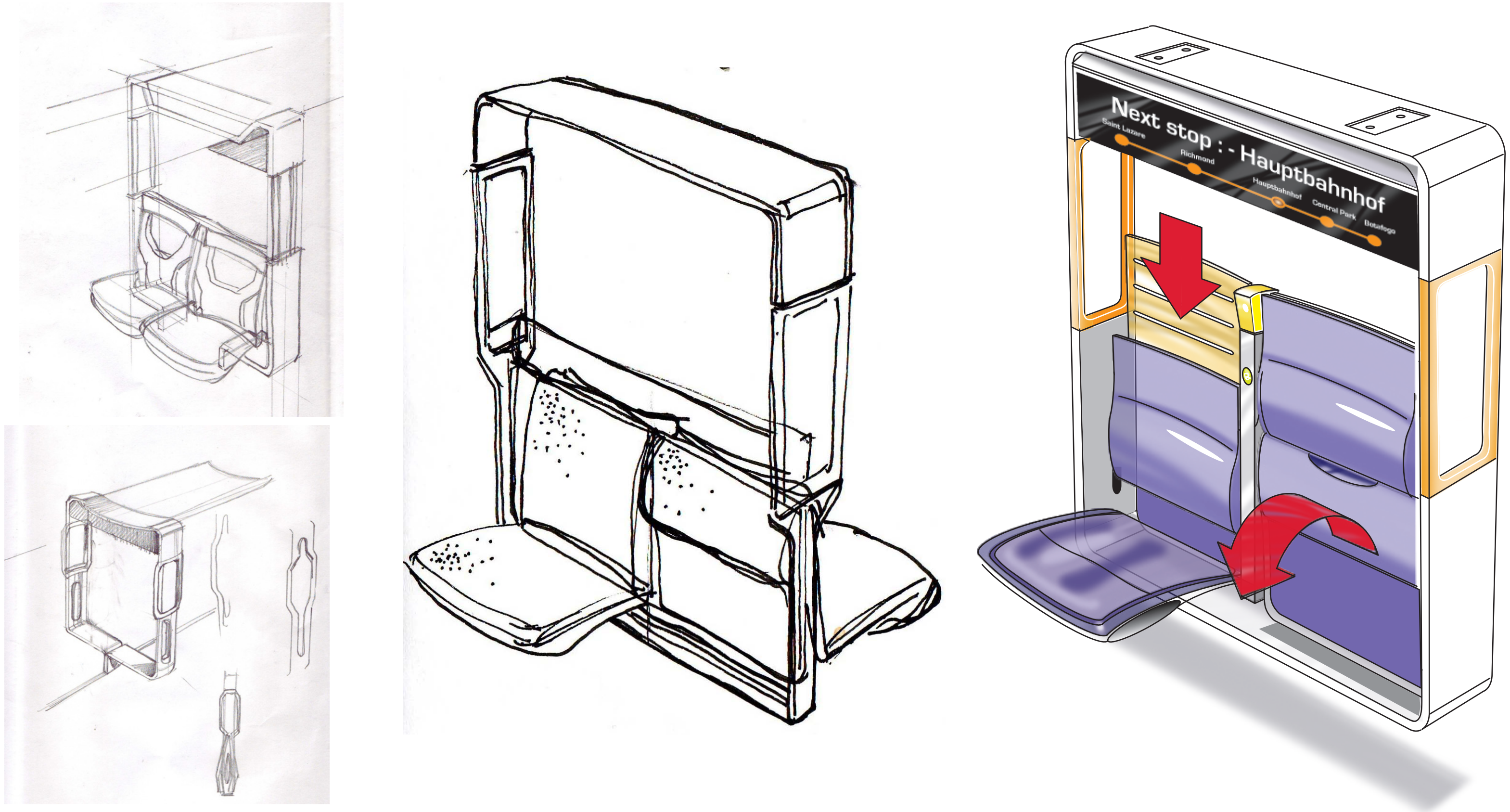


Figure 7.4 (b) Range of initial sketch studies.

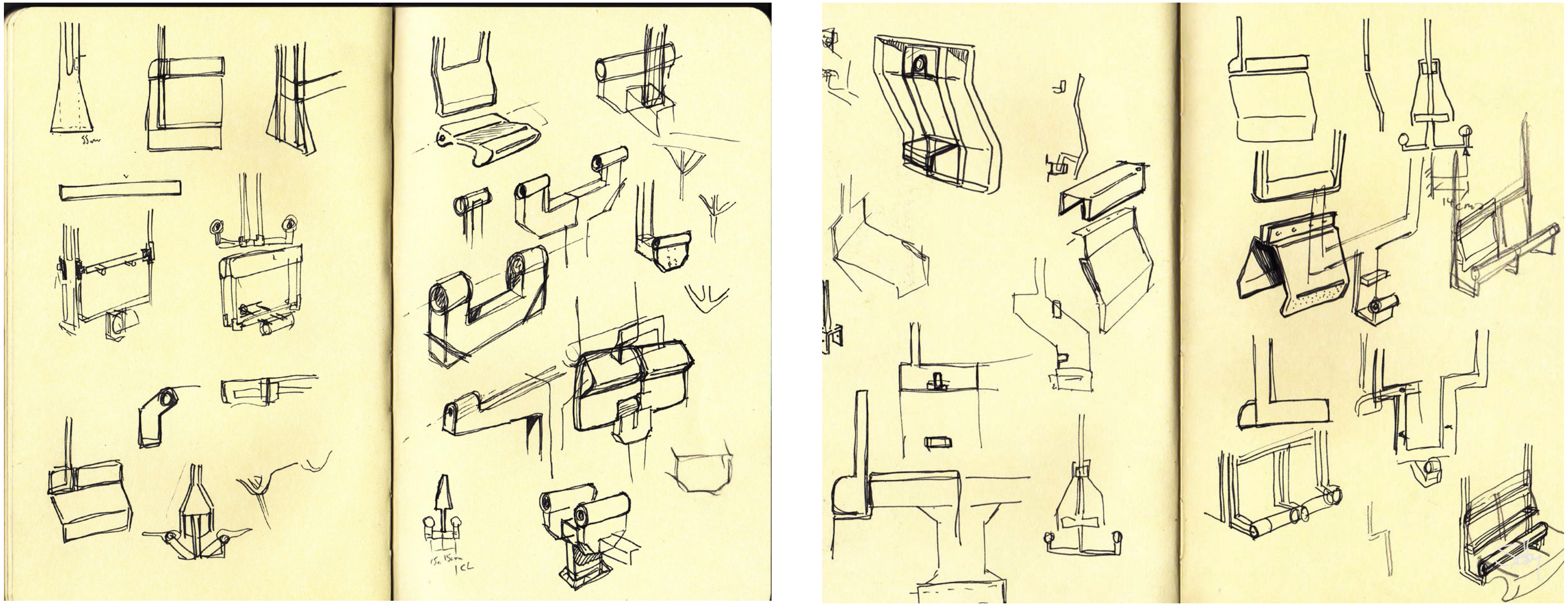


Figure 7.4 (c) Range of initial sketch studies.

The images seen in Figure 7.4 show the author's concern for creating a seat that works in both the horizontal plane and as an upright perch. By including the vertical poles in the general structure of the seat cluster, a sense of enclosure is created around facing clusters. The hitherto public space is transformed into a private or semi-private space by the creation of home territories, that is, the taking over of a space by a group of like-minded individuals on certain occasions known to each other. There is fluidity to the spatial order on public transport through the unplanned and uncoordinated actions of individuals and sub groups. This transient colonisation works against the prevailing spatial order each time the train, tram or bus pulls up at a stop. These could be groups of school children, football fans or patrons on their way to a concert or even periods in which perhaps more elderly passengers might be using the transport system. The process of creating 'colonies' is continual as is the process of abandoning them. The colonisation process makes the immediate environment safer for those who belong to that group. When sufficient numbers are reached, they feel free to act in a way that is in contrast to the actions of others in the same locality, yelling across an expanse, using obscene language, laughing at in jokes and displaying proprietary behaviour. Territorial behaviour can be formalised by creating zones pertinent to specific needs, for example, train carriages for the exclusive use of bikes or areas reserved for prams, designated quiet carriages etc.

With this behaviour as inspiration, Figure 7.5 shows a series of studies in which a sophisticated central cluster is created that, while accommodating predominatly seating, can be adapted to include extra amenities such as audio video material or even vending of some kind. Inappropriate behaviour such as engaging in activities for which the space was not intended leads to fear from other passengers and anti-social behaviour. Social group dynamics on board transport modalities have a great influence on the general atmosphere of the transit experience. For example, it has been observed (Stewart-David 2005) that a critical mass of considerate travellers has a greater prospect of establishing a colony of respectable behaviour onboard the vehicle. Stewart-David also argues that it is not improved technologies that improve people's expectations of public transport, but just nicer people.

The appeal of the amenity clusters is that they offer a potential re-arrangement of the interior such as pitch distance between clusters or a flexible space that responds to the demands of differing times of day. Flexible space means accommodating the variations of patronage throughout the day, for example, more or less seating depending on crowding and the provision of space for special interest groups such as carriages for cyclists or prams only. Some modes try to cater for these activities but they are generally fixed and limited to space adjacent to vestibules etc. Some flexibility can be introduced relatively easily, as exemplified by folding seats and as seen in the suburban system in Wellington, New Zealand and older Sydney trains, with bench backs that swing across the seat pan to suit the direction of travel.

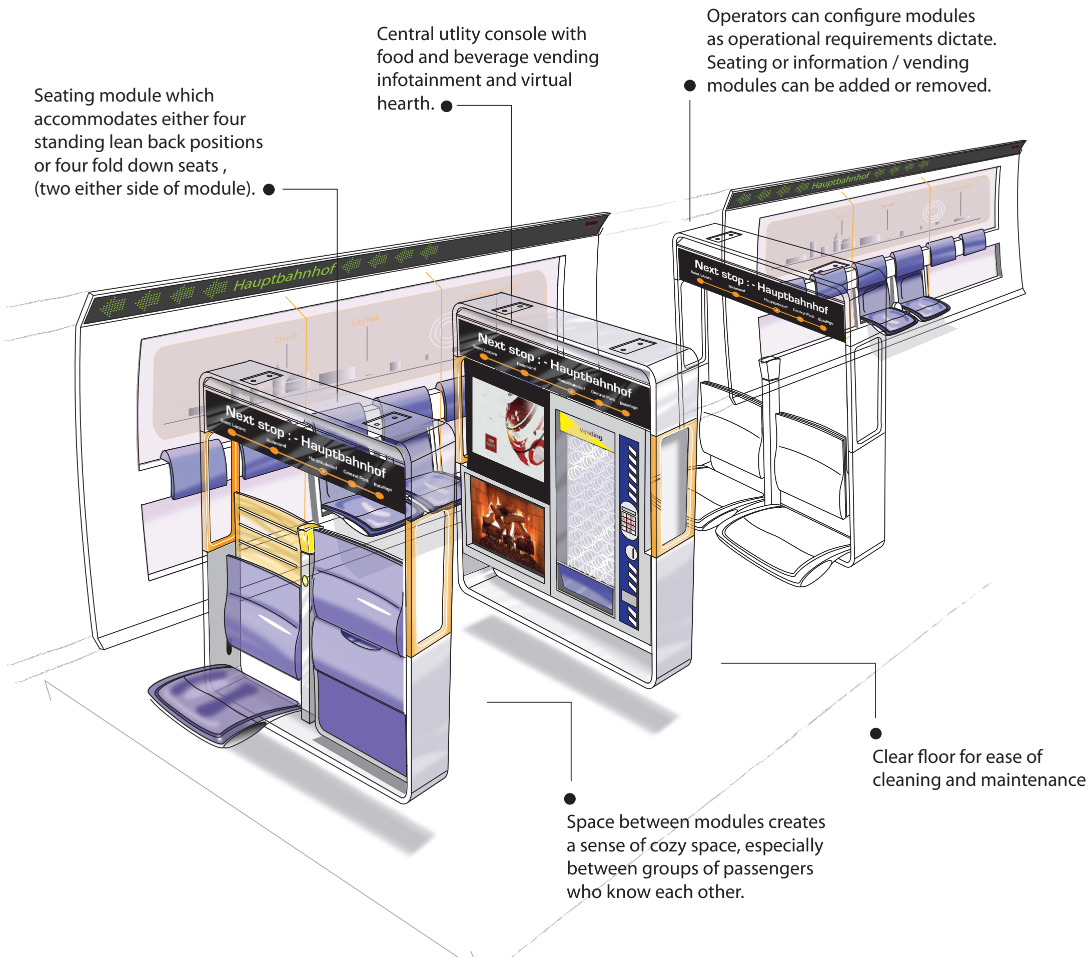


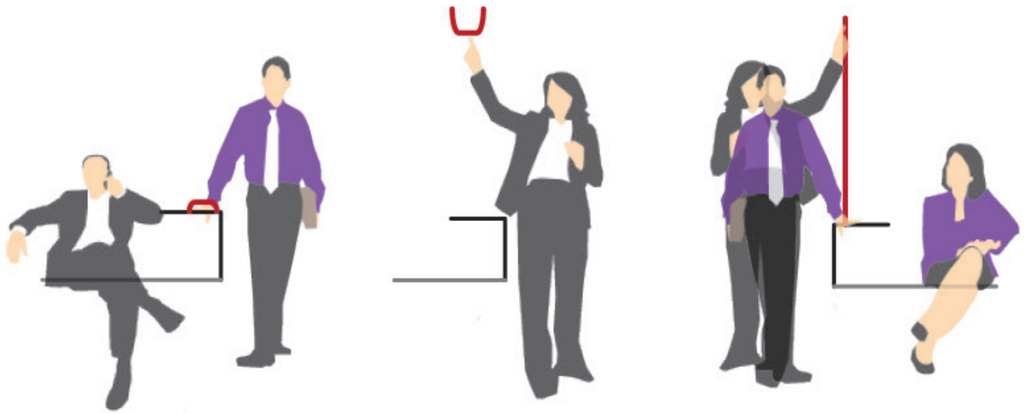
Figure 7.5 A range of potential amenities associated with a central cluster design.

Further reflection on the studies led to abandoning those design ideas that would prove too complex without delivering an outcome superior to that which is already available. To this end, the clusters became less rectilinear in form, creating a more open space within the carriage.

A key aspect of developing the seat cluster was the manner in which the vertical handhold poles were integrated into the design. The decision to use vertical poles was borne from the concern for patrons of differing height stature being able to support themselves. Overhead rails are out of reach for children and those of short stature.

The inclusion of incorporating handles at the shoulder edge of the seats was abandoned due to the reluctance on crowded trains of standing passengers to use a handhold imposing on the close proximity of seated passengers (see Figure 7.6).

The author intends that the seat be moulded and the seat pan and back have sufficient spring to provide the comfort normally afforded of upholstery with resulting use of closed-cell foams or fabrics.



[A] Handhold positions located at edge of seats. This opens the interior space up but this position is masked by seated passengers.

[B] Handhold positions located on the ceiling. This increases visibility but caters only for passengers tall enough to reach. Is uncomfortable for extended periods.

[C] Vertical bar handhold is visible and caters for a wide range of passenger heights as well as enabling more than one person to find support at any one time.

Figure 7.6 Handhold geometry.

Observations of various networks suggest that the use of fabric on seats is largely cultural. Fabric suggests comfort through softness, while at the same time providing an immense expense in maintenance and general cleanliness. Plastic seating is utilised in many other networks where these sensibilities are not the same. They can make the interior look brutal, but not necessarily so, if by judicious design, form language and perhaps the presence of two materials in a two-shot moulding process the seating might remain robust and comfortable but with fewer maintenance issues.

The following Figures 7.7 to 7.9 show the seating design as a collection of modules that build up to create the seat clusters, central group of four, and window bank of four. The peak door bank of four is discussed separately.

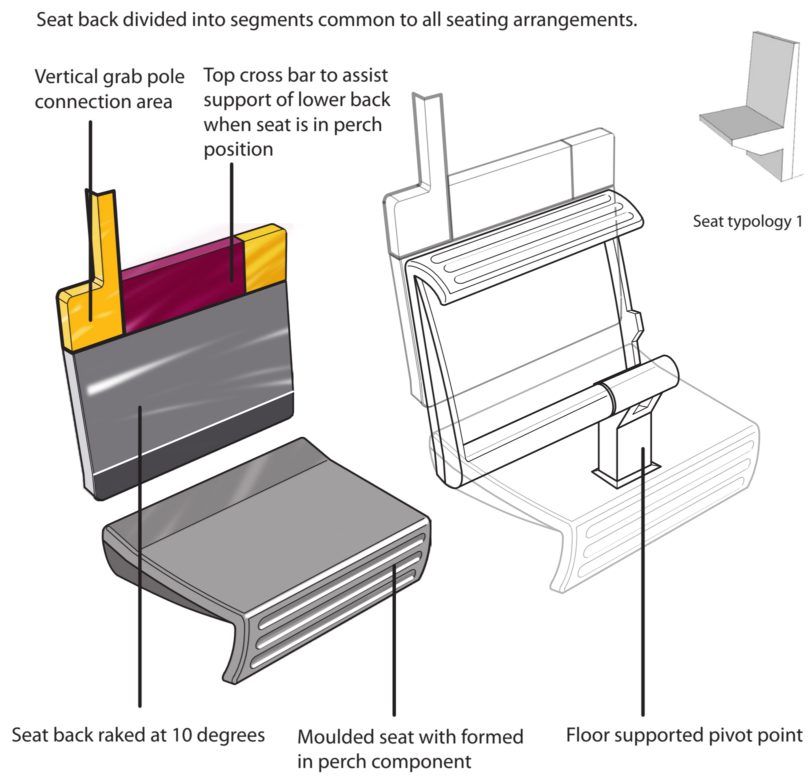


Figure 7.7 Single seating module.

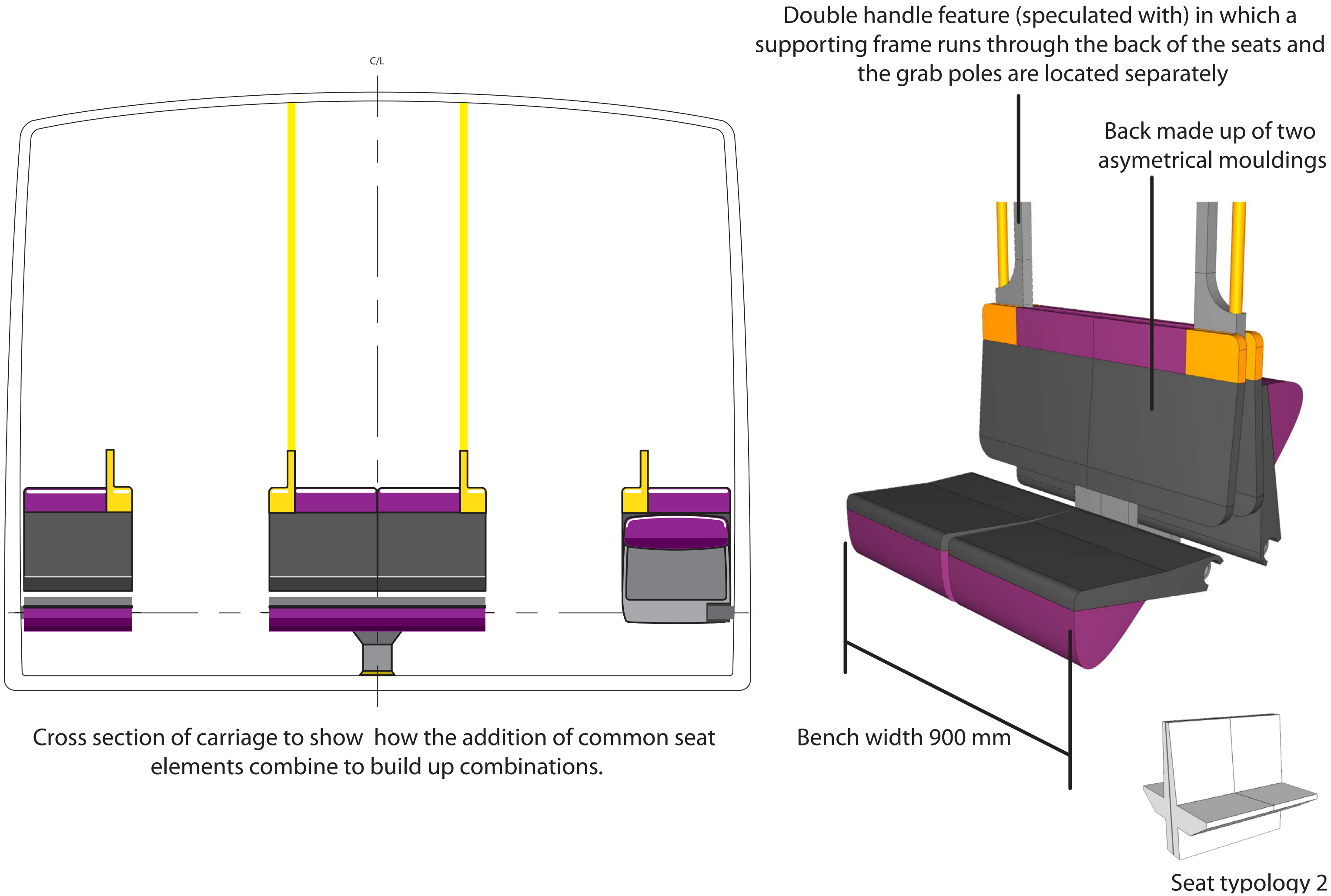


Fig 7.8 Central seating cluster.

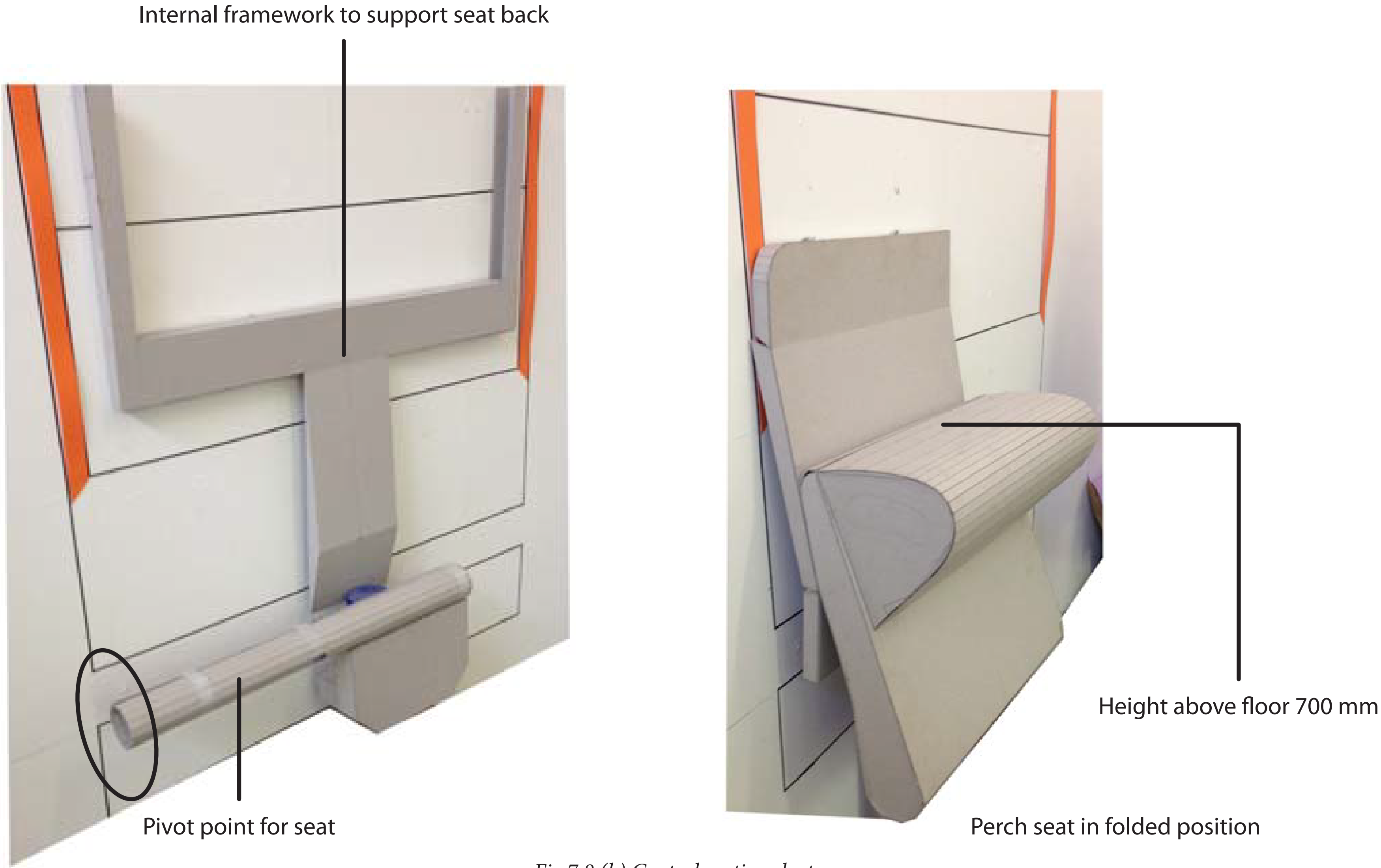


Fig 7.8 (b) Central seating cluster.

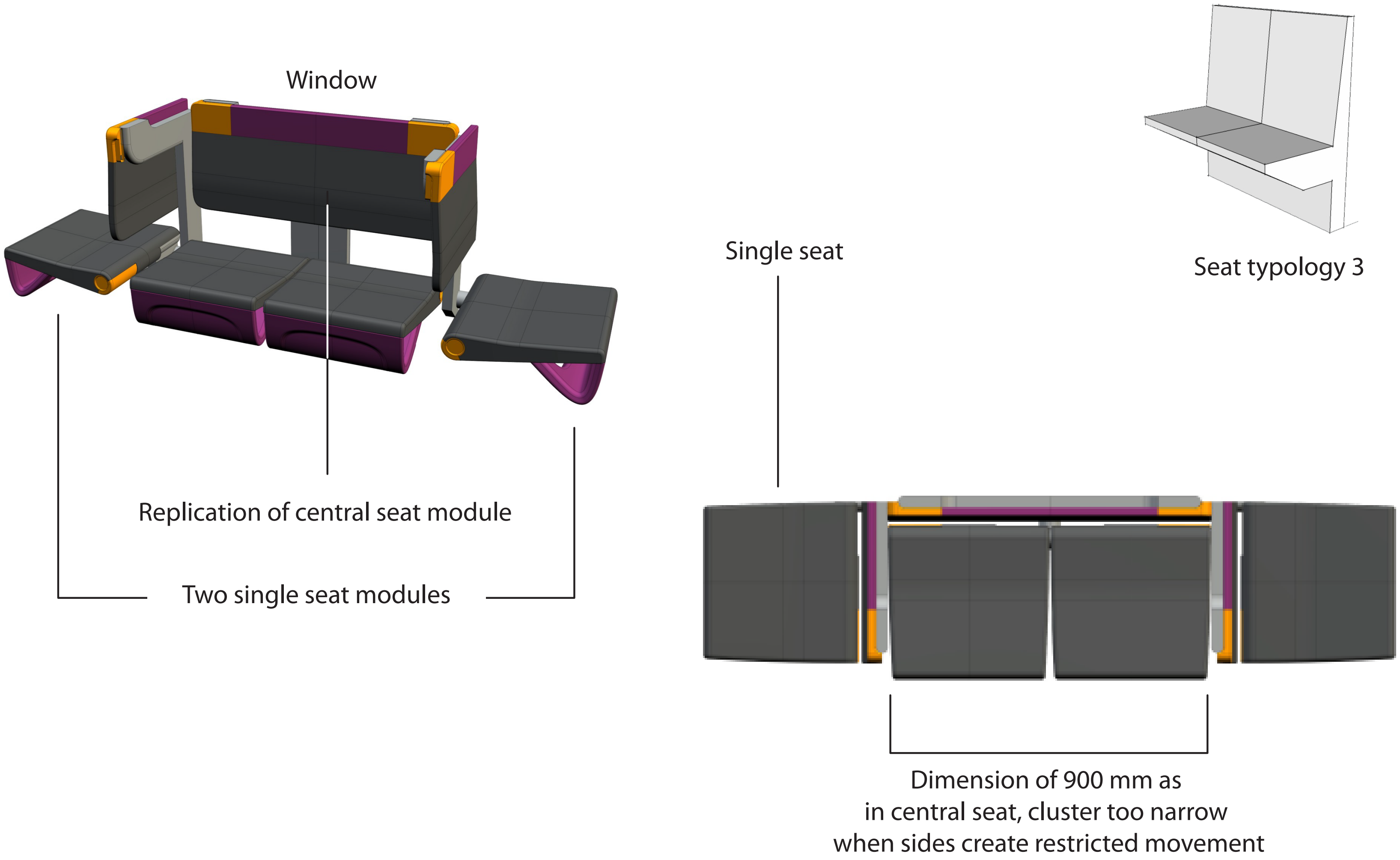


Figure 7.9 Wall seating cluster.

Window wall bench requires an infill of 200 mm to
create more comfortable proximity between passengers.

1100 mm allows for more shoulder width
(comparable with current Comeng seats at 840 mm across
a bank of two seats).

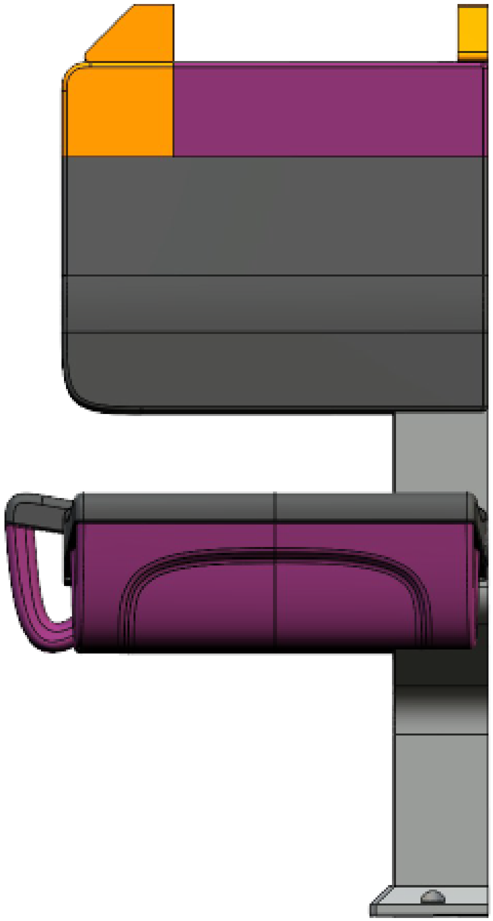
Shoulder inhibited by rear of adjacent seat,
although this does afford some separation from the
rear of a standing or perched passenger.

Figure 7.9 (b) Wall seating cluster.

The imagery shown in Figures 7.7 to 7.9 chart the conversion of the basic seating typologies from sketch development to more refined conceptual seating design. Some essential philosophies are brought to bear. The author has sought to keep to a simple design that utilises many of the same parts in more than one configuration. A single leg design supports both cluster and window side seats, the remaining support to the seat being provided by the roof and handrails. This open and light configuration opens out the space and keeps the use of multiple parts to a minimum.

The following figures, 7.10 to 7.12, chart the refinement from CAD model to a more significant mock-up. Key issues that have been brought into consideration have been the reduction of the double grab rail to a single rail, with most of the seat support coming from attachment to the floor, the finessing of the local handholds about the window wall side and the treatment of the seats adjacent to the peak door. In this latter instance, it is important to remove objects that encourage perching or standing at these seats, as this would further occlude the door, negating the intended benefit. The grab rails for the peak door seating cluster include provision for a passenger information display (PID) to indicate to patrons when these doors are operational (Figure 7.13).

Front elevation of window wall seat.



Refined detail of seat back crossbar and the treatment of the grab rail entry into the corner blocks.

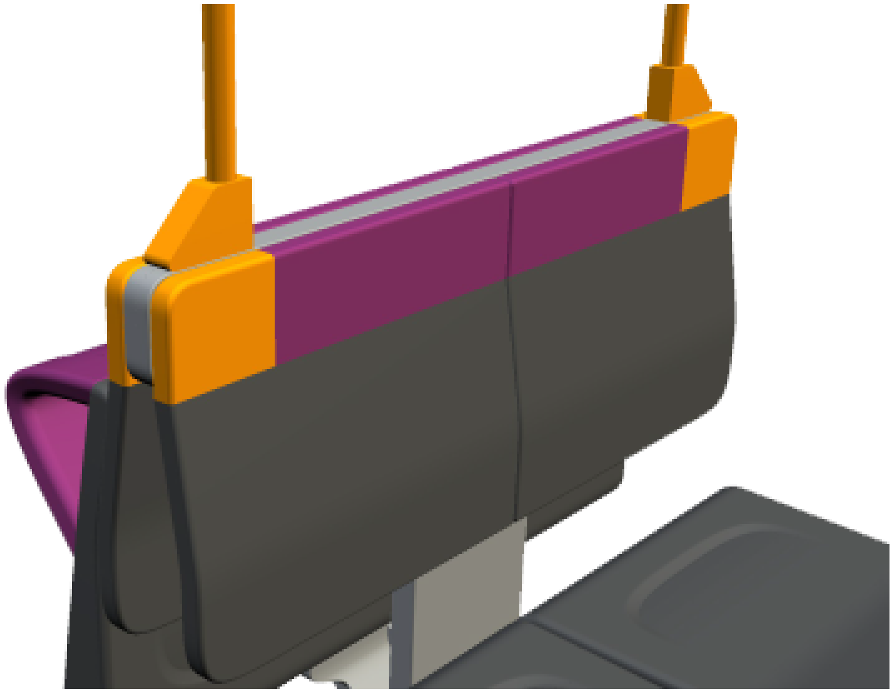
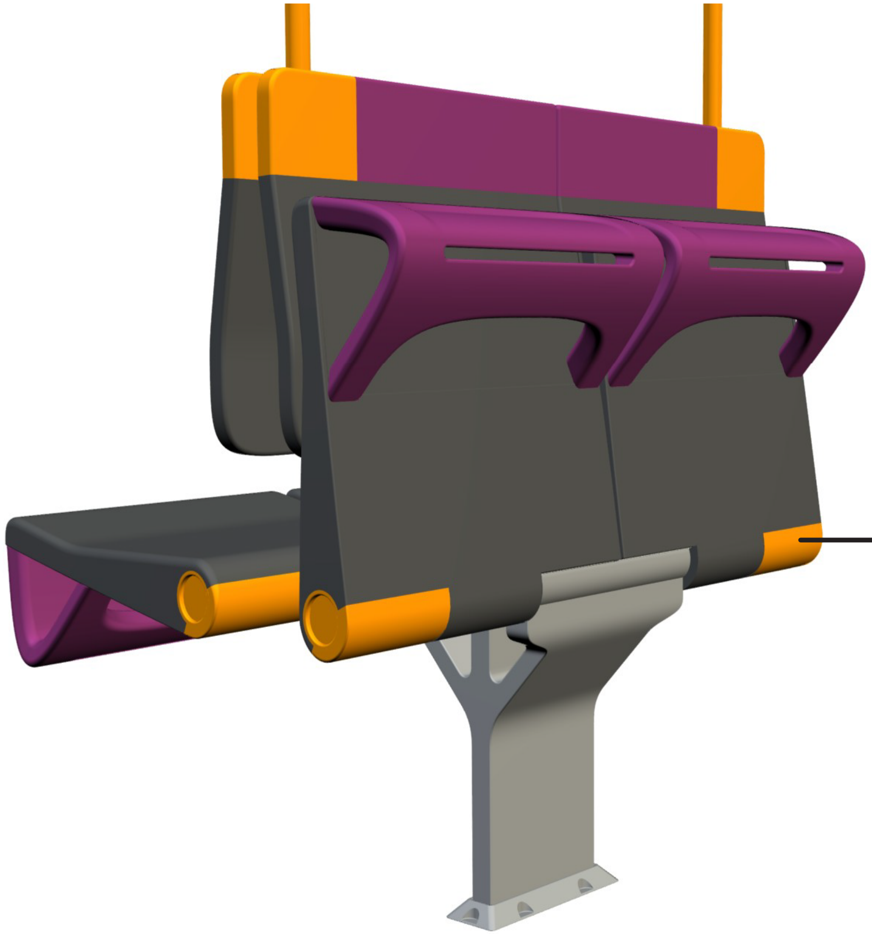


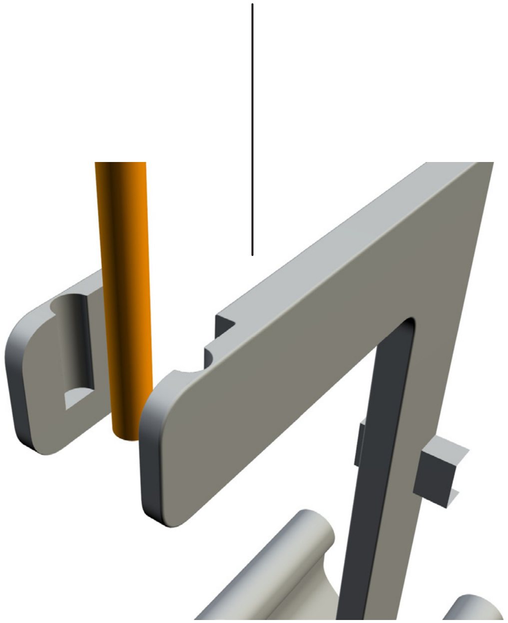
Figure 7.10 Refinement of seat cluster.



Perch seat moulding with relief pattern to improve comfort and slotted to avoid accidental or intended storage of items or liquid spills.

Location of electromagnetic switching gear. This facility enables the guard to 'lock' the seat into the folded postion. During off-peak periods the switching gear is disabled, allowing passengers to pull down the seat. A damping unit located here reduces the speed of the seat as it swings up.

Figure 7.11 Refinement of seat cluster.



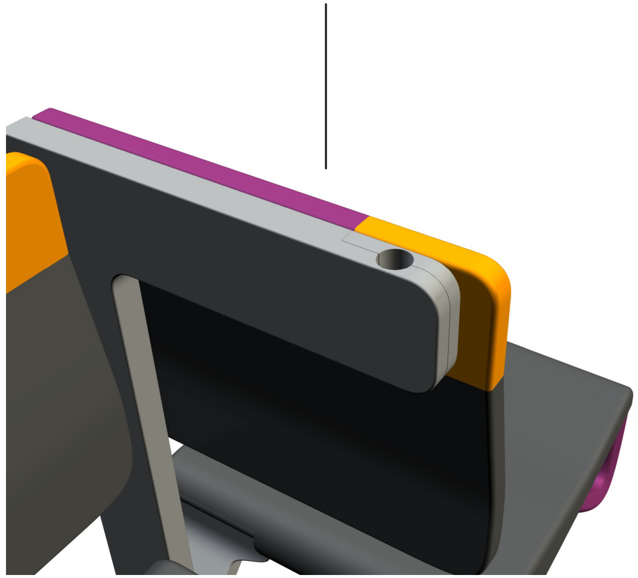


Figure 7.12 Refinement of seat cluster.

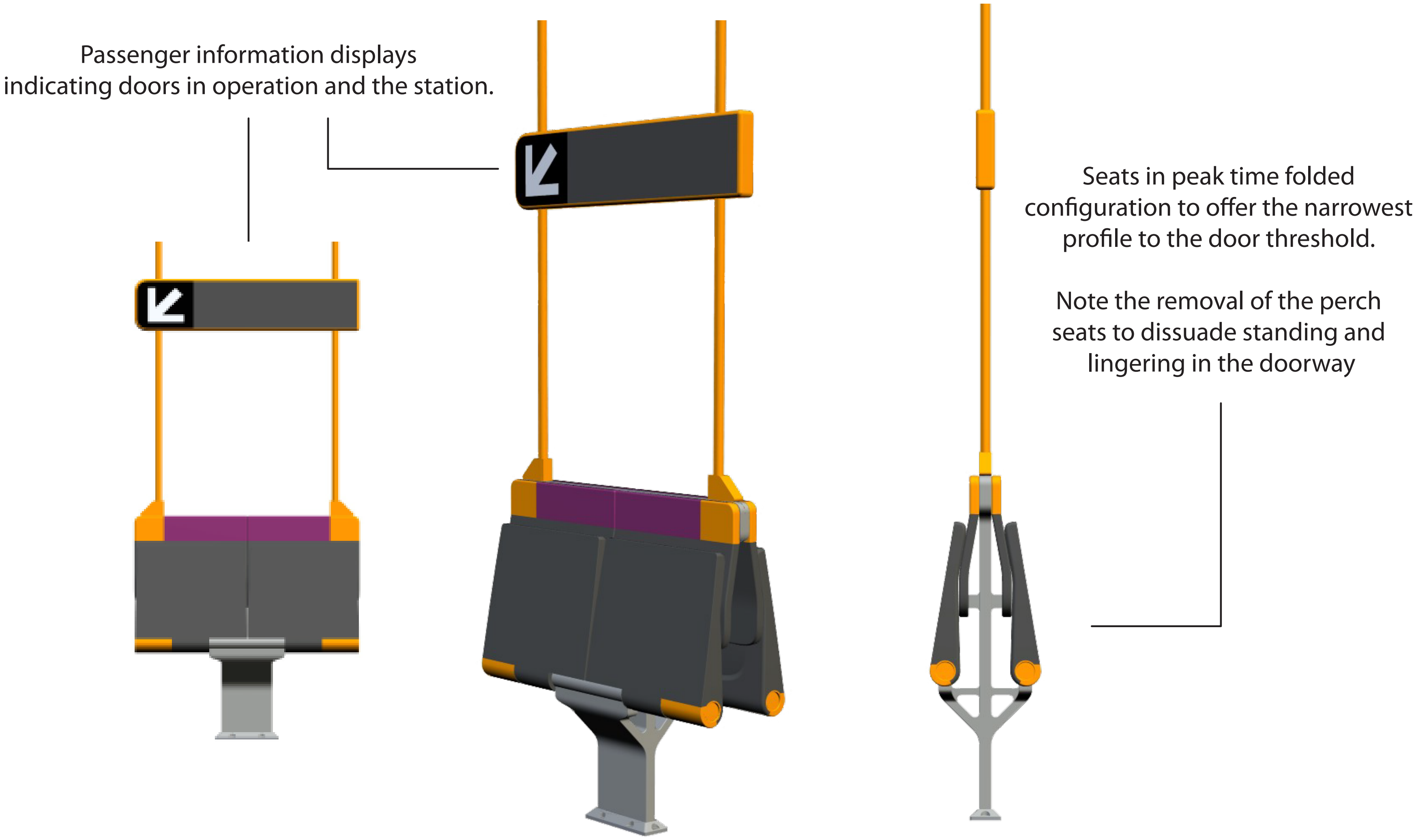


Figure 7.13 Peak door indicator.

7.4 Operation of the proposed seat deployment system

Chapter 4 described the proposed layout of the seating arrangements of the carriage and this chapter has discussed the details of the seat design. An essential element of the design of the seats is that they can function as perch seats in an upright position and as regular seats when deployed. This change of geometry can effectively change the available floor area of the carriage. The control of this state of deployment rests with a guard on driverless automated trains, who retains the authority on board. Changing the available floor area and activating the extra doors for peak periods (q.v. chapter 4 and chapter 8) creates flexibility within the interior to accommodate the changing levels of patronage. The guard, by way of a control interface, Figure 7.14, can determine the configuration of the seating interior to suit the time of day and the anticipated patronage.

The key parameter is controlling the floor space by the release or locking upright of the seating in relation to crowding. Figure 7.14 explores the premise that the guard can see, by way of a flat screen linked to CCTV in each carriage, the relative crowding of that carriage and, by way of a wall mounted touch screen, can release and therefore deploy banks of seats in the carriage. The circumstances, process and timing of re-configurations is an important operational issue. The author suggests two distinct operating patterns to reflect the functioning of this concept:

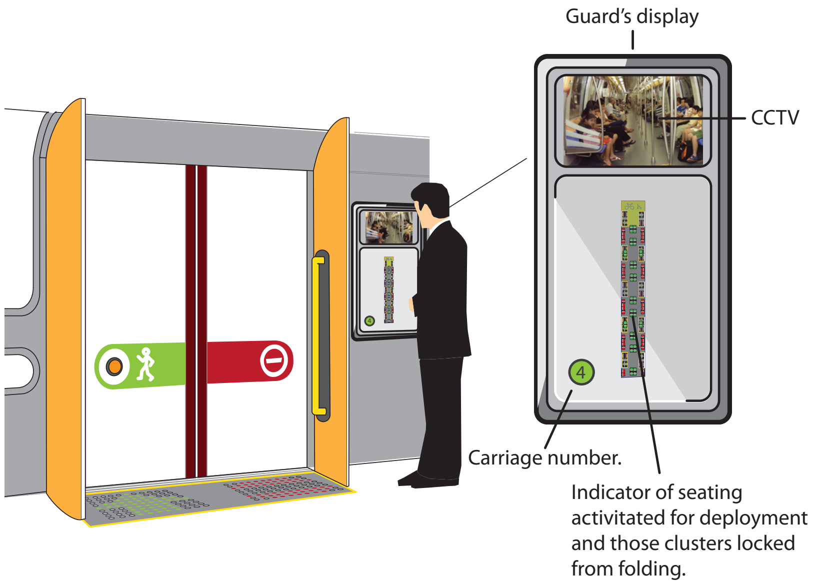


Figure 7.14 Drivers cab seating deployment control.

7.4.1 Morning peak services – seating profile

Morning peak concerns trains moving towards the city. Operational data show that these are trains picking up more passengers than are leaving, until the train is at or above capacity by the time it reaches the cordon stations discussed in chapter 1. For the train operator, the configuration of the train needs to be settled before beginning its service. Once running, it will not be possible to switch normal seating patterns to perch seats while passengers are seated. Therefore operators need to make decisions according to loading data about how many seats will be 'locked' into the perch position and how many seats will be enabled for folding down into a horizontal position. For these inbound services, it would not be comfortable to have all the seats in a default upright position, forcing passengers to perch or stand longer distances. In this situation some carriages would be seat enabled, allowing patrons to sit. An estimation of how quickly the train will fill can be made from the operator's loading data. Therefore some carriages, perhaps the very first and the very last, need to be identified clearly as a standing or perch only carriage from the very start of the service. As this train fills on its way through the suburbs, passengers boarding nearer the city will be encouraged to make their way onto carriages with more space offering perch seats and greater standing capacity. While this might seem initially unsatisfactory for those living in the inner suburbs, the rationale is that they have a less fatiguing journey than those patrons travelling over 20 minutes and being in greater need of a seat. Figure 7.15 describes the operational process.

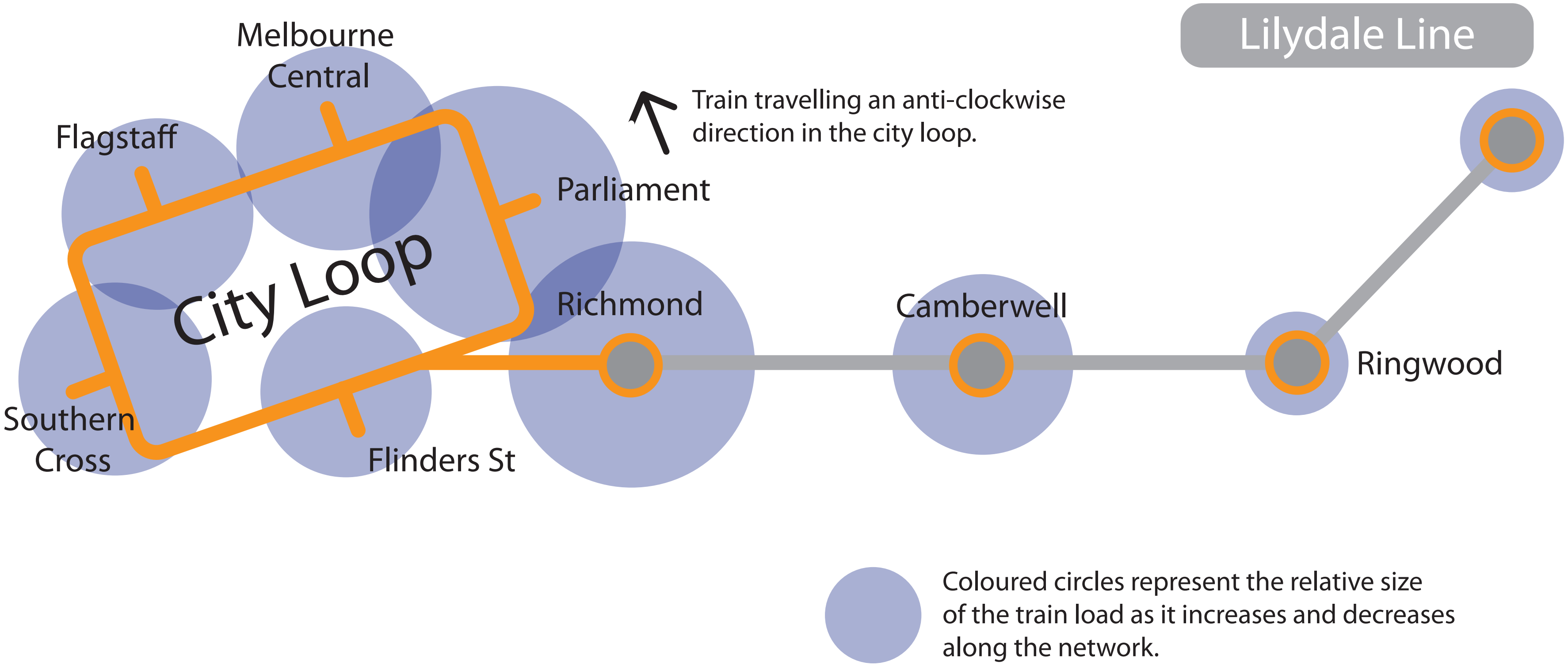


Figure 7.15 Operational profile of deploying folding seats during morning peak.

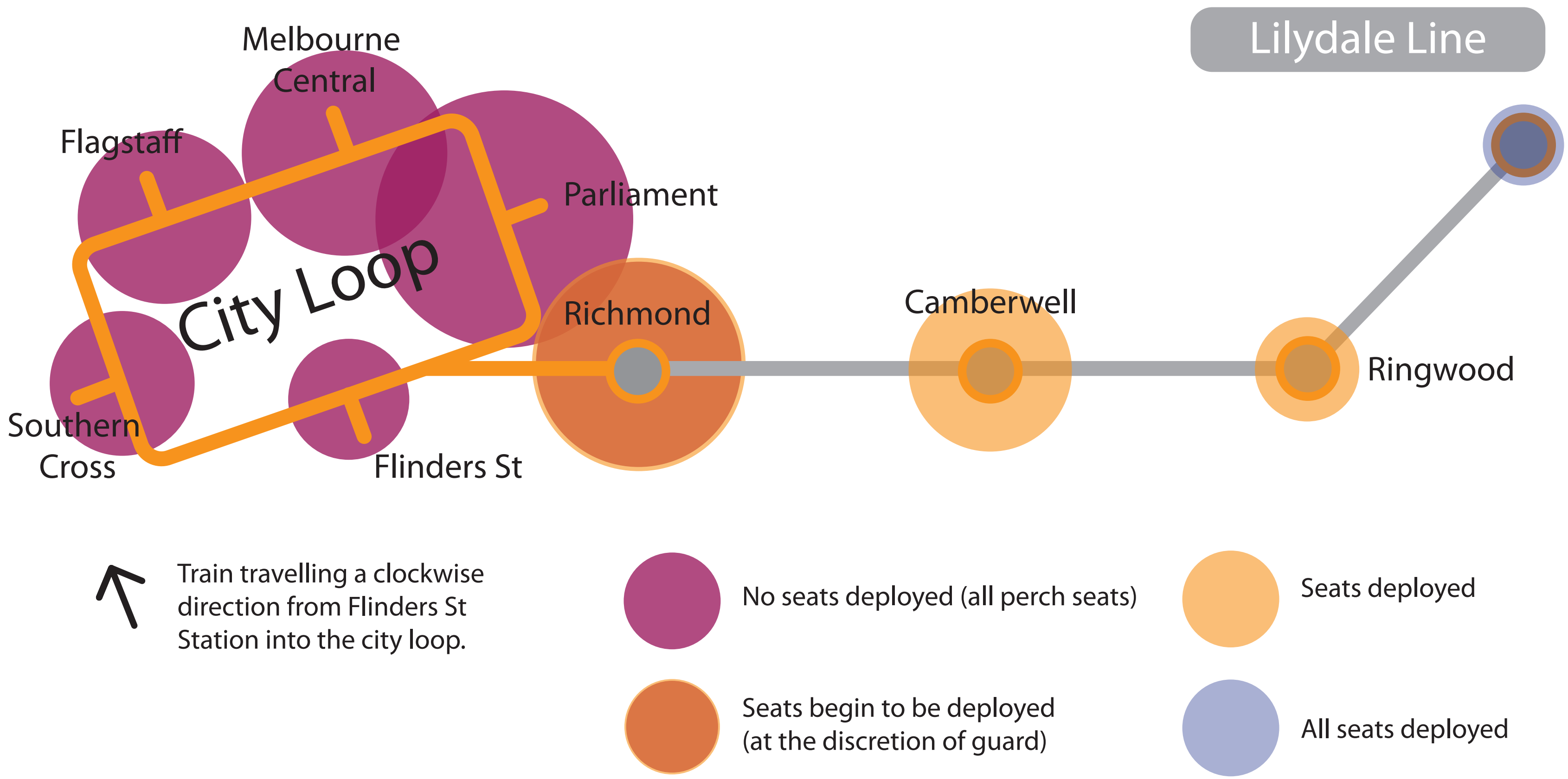


Figure 7.16 Operational profile of deploying folding seats during afternoon peak.

7.4.2 Afternoon peak services – seating profile

Afternoon peak trains start at the central business district termini with high loads and quickly become at or above capacity, and then proceed to unload passengers progressively along the network. In this instance, all the carriages can be at maximum floor space capacity, with all seating locked into the upright perch condition. While this means passengers will be standing or perched initially, there will at least be many more of them per carriage. This condition need not last long, since as the service moves away from the cordon stations and out into the suburbs, progressive numbers of alighting passengers will create more and more space within the carriage. The guard is then able to release perch seats from their upright and locked position and enable passengers to fold down seats into a horizontal position, a condition more suitable for the longer journey times. Alerting the passenger to this change of state is an interaction design problem. In some early sketch studies the notion of a light located somewhere on the seat cluster was experimented with, but found to be too easily hidden. The Author has elected to allow the passenger to 'discover' the newly released seat by feel. Damping units mean that the seat will not give way but move only under deliberate force of hand movement directed upon the edge of the perch component of the seat. This part now becomes the waterfall underneath the back of the knee.

7.5 Conclusions to the seating design

There are two challenges central to the design of the seat: to provide both an acceptable level of comfort within the context of metro travel i.e. relatively short trips, and to take up the least amount of space possible. As a result of the design study, the author has determined that the onerous volume of space taken by the seating might be mitigated to some degree if it is made to change by folding. The seating postulated for the new interior concept would be adaptable for variable conditions. Nearly all seats would fold up to form perch seats. Exceptions are made for some seating near end doors for PRMs and at the peak doors. In off-peak conditions, the seats are all deployed, i.e. folded down. During peak loading, the train is prepared in such a way that the seats are unable to fold down (with the exception of those for PRMs). Space is therefore available for standing or perching.

The seating is in itself a large project with wide ranging outcomes. The author has sought to challenge the current orthodoxy of mostly fixed and fabric covered seats by adopting predominatly plastic moulded seats that rely on their intrinsic qualities of elasticity combined with the judicious use of introduced weaknesses in the form of small apertures. Visual finesse in terms of textures and colour splits is discussed in a later chapter as the complete design is put together.

Literature on the culture of public transport suggests that there would be considerable impact on the prevailing culture of suburban travel to implement a peak and non-peak seating configuration. However, it has been the intention of this seating study to make this culture change as plausible as possible, since it utilises contemporary technology and a seating geometry (folding seats) that is not unfamiliar to a wide range of the travelling public.

The seating forms a central part of the mitigating of passenger doorway occlusion and poor dispersal. The next chapter focuses on the relationship between the carriage interior and the platform, by looking at the communication of the doors and the door threshold.

Figure 7.17 Overview of carriage interior showing the seating cluster positions.

8

Chapter 8. Design project 3

door design

8.1 Factors affecting door design

The studio design activity has, thus far, concerned itself with the interior of the carriage in terms of the seating layout and the flexibility of folding seats and treated the door and vestibule area as apertures concerned only with the ingress and egress of passengers. No attention has yet been given to the dynamics of the door function. In this chapter the author examines in detail the door issues and proposes a conceptual design response. This chapter is divided into the following sections:

- factors affecting the door design
- conceptual design process
- conclusion and integration of the door details into the project as a whole.

As examined in the literature review of chapter 2, the doors present a number of challenges to the carriage design. The key points raised in the literature review were:

- The number and position of the doors influence passenger platform dispersal, the location of bottlenecks, and seating capacity
- Cultural convention (although it is not always adhered to) dictates that platform patrons board only when the door is clear of alighting passengers.
- Passengers standing in doorways reduce the effective width of the door. Windshields and handrails placed at the door threshold unintentionally encourage this behaviour.
- An increase in the number of doors is associated with a reduction in seating since each door removes space for seating, against the interior wall.

The literature also reveals work on door 'gestures' from the University of California, Berkley that concludes that the trajectory and speed of a door action can be perceived by people to express meaning or intention. This research originally aimed at retail environments might go some way to influencing negative passenger behaviours towards door holding.

Drawing from the above points, the following aims for a new conceptual door design were created:

1. a design that can accommodate simultaneous boarding and alighting
2. a design that can accommodate more doors without loss of seating capacity.

Figure 8.1 captures these door design issues and expresses them together. Some assumptions have already been made in the conceptual layout proposal described in design project 1 chapter 5, principally that the height and width of the door should accommodate at least two people passing in opposite directions and that a passenger with a bicycle or a wheelchair can manoeuvre easily. An overall height has also been determined for the purposes of the computer simulation, described in the previous chapter, as sufficient to accommodate a 95th percentile male.

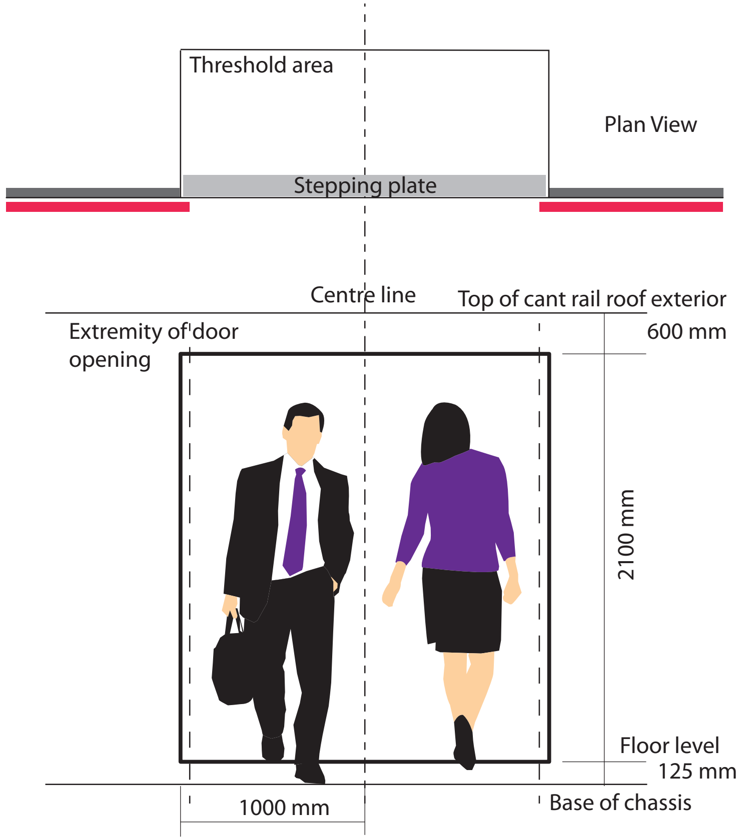


Figure 8.1 Door entranceway and threshold design issues.

8.2 Concept door design

8.2.1 Simultaneous boarding and alighting

Work on the conceptual seating layout and subsequent ABM simulation has encouraged the view that a five-door (per side) arrangement has positive implications for passenger flow. Parkinson and Fischer (1996 cited in Lau 2005) make the observation that multiple doors are more effective than widened doors, since they spread the ingress and egress points along the carriage. They also make the observation that a wider door soon becomes just a larger single stream of passengers, not a two-way flow. With more doors to gain access, passengers are able to disperse better along the platform and are less prone to bunching. Equally it is clear that passengers wishing to alight have much less distance to an exit, reducing the tendency to bunch at the doors. While the provision of five doors has implications for seating, this conceptual layout is predicated on two of the doors being operational only during peak times. During the off-peak periods when the two extra doors are redundant, fold down seating is made available in the newly created vestibule area. The manner in which these folding seats are supported provides an added benefit in that it provides a central dividing pillar in the door threshold. A dividing pillar here serves as a crowd 'splitter' and, when combined with graphical direction indictors located on the floor and doors, encourages a dual flow boarding and alighting behaviour. Figure 8.2 describes the design evolution of the door splitter column.

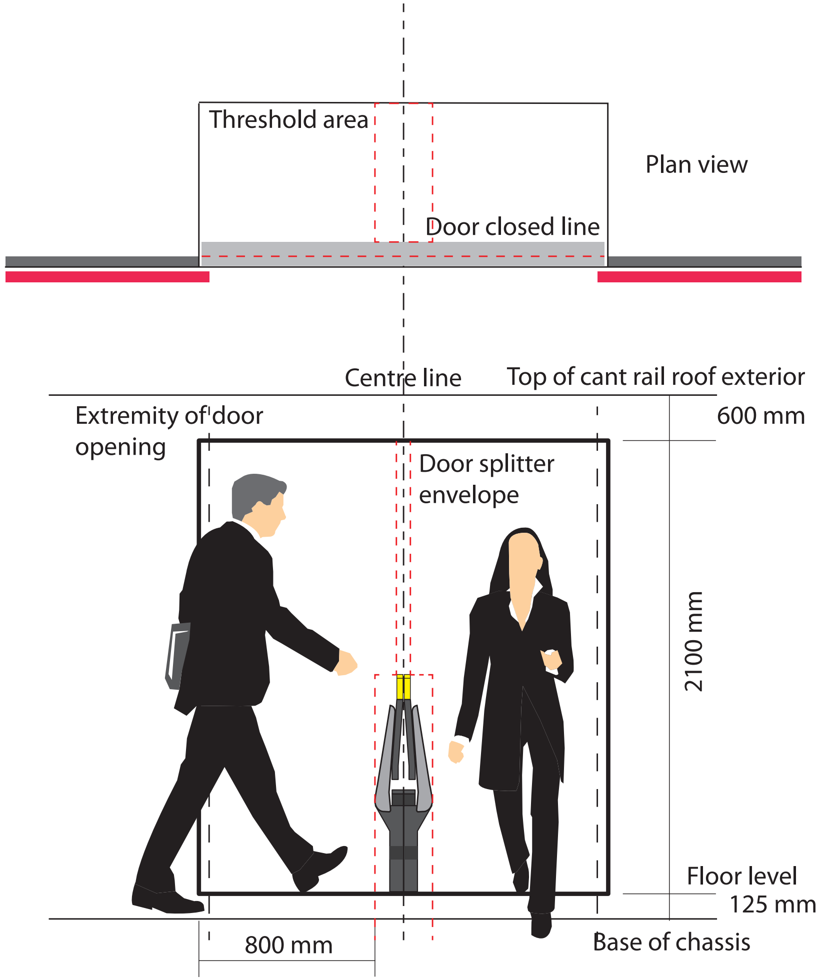


Figure 8.2 Door splitter and fold down seat.

The literature in this field states that a counter flow is better than a unidirectional flow because patrons can react better to avoid collisions when facing each other (Helbing 2005). It has been observed (ibid.) that it is easier for one person to follow someone while they are walking against an oncoming of mass of pedestrians, thus creating 'streams'. If passengers could board simultaneously rather than wait for alighting passengers, then this would have a shortening effect on a train's dwell time. In the initial layouts, various passenger flow regimes were experimented with (q.v. chapter 4). The author has collected some examples that show how graphical devices encourage the correct alignment of pedestrians when passing in opposite directions (Figure 8.3).

Figure 8.3 Examples of counter flow graphics: left Victoria Bridge, Brisbane (2011) and right Brisbane central station (2011).

Intersecting flows of pedestrians through a doorway are a significant dwell time management problem and under current doorway culture practically unavoidable. A simultaneous boarding and alighting activity will not clear the bottleneck problem at the door entirely but move any potential occlusion deeper into the carriage vestibule area. Again the author's intention in running a seating cluster down the centre of the carriage is to encourage dual flow or even present passengers with options in their chosen path both into and out of the train. It could be speculated that at a door through which a large group of people wish to board at the same time as an equally large group wish to alight, all pathways will merge. This scenario is likely to be confined to major interchanges, since services are generally biased towards boarding passengers as the train moves towards the city and alighting passengers as it moves away. Allowing the exit door to open just before the ingress door can trigger a counter flow and begin to create more space within the carriage. This is evidenced to some extent in the Rio dual boarding system, where one side of the train opens before the other to allow passengers to alight, thus clearing the vestibule for boarding passengers (q.v. chapter 2).

Large items such as a bicycle might also trigger an occlusion within the vestibule. To this end the author has furnished the end of the carriage with an open and more expansive vestibule for the accommodation of bicycles, wheelchairs and patrons transporting large items (q.v. Figure 5.3 in chapter 5).

For the three remaining doors that remain operational throughout the day, the author has retained an open vestibule with no folding seats and therefore no crowd 'splitter' and therefore it relies only on the graphic symbols to encourage passengers to stand to one side or the other.

8.2.2 The effect of more doors on seating

The peak door goes some way to reconciling the problem of losing seats with the inclusion of doors and vestibules. Folded seats will present obstacles. The extra doors will, the author speculates, go some way to relieving the pressure on the other doors at times of high loads and passenger transfers.

The area immediately behind the door is often the most problematic during peak loading. The vestibule contains the mass of passengers about to leave the train, as well as passengers who are not prepared to move down into the train. As the area of most open space, it attracts bicycles, prams and other objects likely to occlude the movement of people. From a design perspective, encouragement to move further into the train has always been a priority. This seems to be driven by having somewhere to sit/hold onto and ultimately avoid blocked access to the door. Equally the environment should be attractive, perhaps better lit or carrying entertainment of some sort so as to draw passengers into the body of the train. Large objects that cannot practically be drawn into the body of the carriage could have their own designated area, as described in the following sketches:

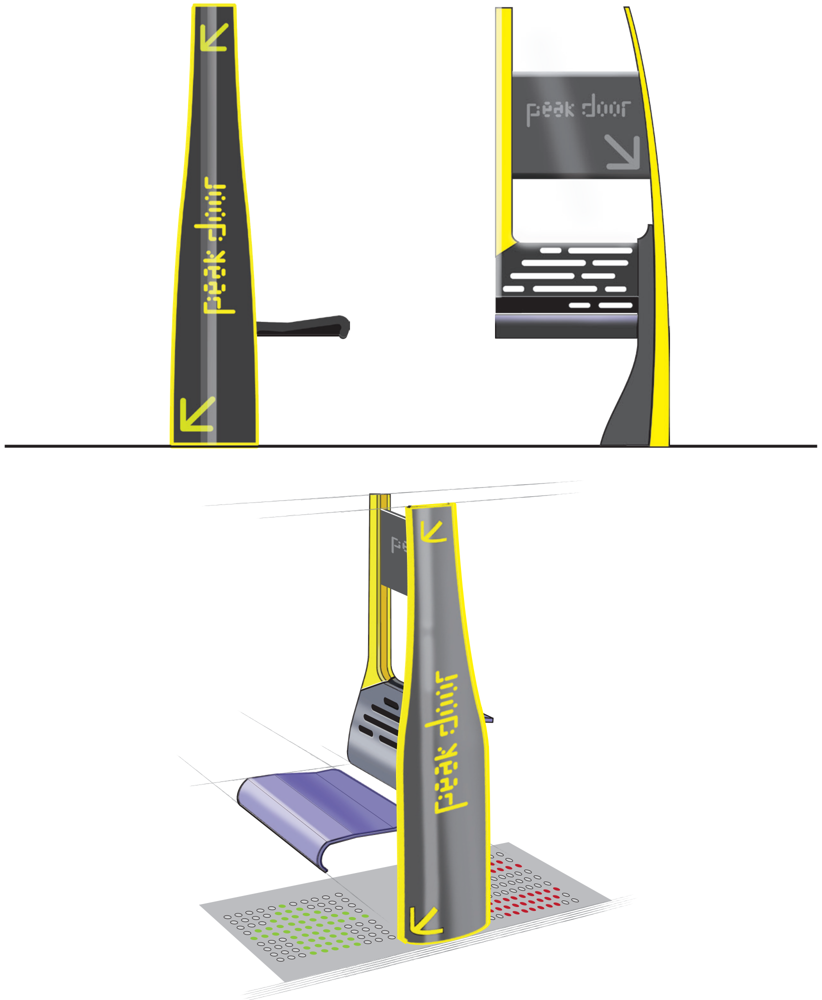


Figure 8.4 Early sketch studies of the crowd splitter and folding seat configuration.

8.2.3 Controlling door holding behaviour

The door closing and opening action has a number of implications for dwell time. Door opening and closing is a function as expressed in Weston's original formula for predicting dwell time (in Harris 2004 and Aguirre 2008). It is a design concern that not only must the mechanism of the door be robust in terms of maintenance, but the manner of its closure must not cause injury to passengers, especially those attempting to board when arriving late. Another factor with implications both on dwell time and maintenance, is that of passenger door holding behaviour.

The deliberate holding open of doors delays the train from getting underway and doors that have been held open for extended periods can have their closing actuators burned out. This renders the carriage inoperative for carrying passengers and is cause for the removal of the whole train from service.

Due to the lack of academic literature on this subject, this research has drawn on some specific aspects of human behavioural analysis to stimulate design innovation. The design studies responded to passenger behaviour and motivation in such a way as to deter malevolent actions. Although each of the designs offers a slightly different variation, they all contain the same essential themes:

- Make the undesired behaviour more difficult. Install double action door movements to make retention of the door harder after it has started to move.

- Provide bold visual stimulus that reinforces traditional sound based warnings with illuminated warnings.
- Use touch to create mild discomfort to the perpetrator's hand or shoulder pushing against the door.
- Encourage superior passenger flow over the door threshold by positioning the door actuator buttons to the outside of the door on the exterior of the train and the centre of the door on the interior of the carriage (Figure 8.5).

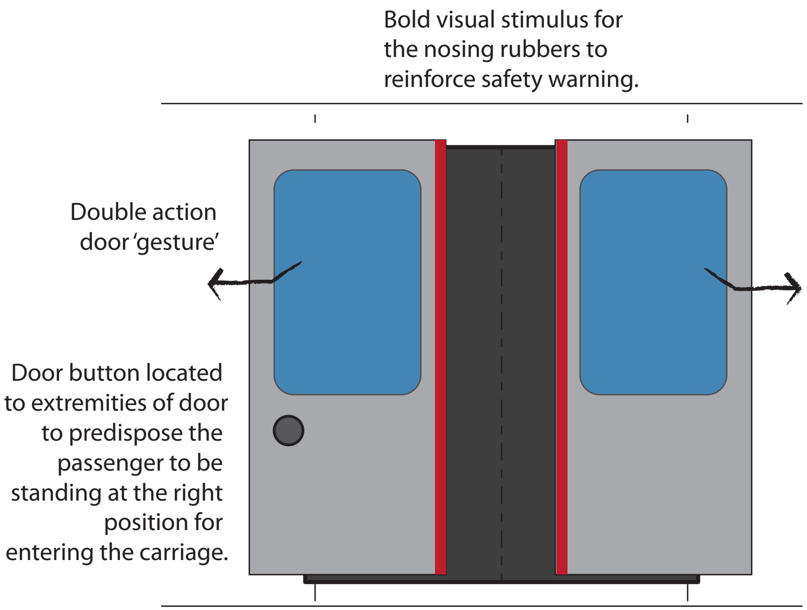


Figure 8.5 Strategies to mitigate door holding behaviour.

Doors with multiple actions such as the ones offered as sketch concepts are also slower to close than simple sliding doors, which is a factor to be considered in the design of trains designated for a frequent service. Without building the doors and running some sort of simulation, the performance of these concepts can only be speculated about based on contemporary examples of door mechanical design. However, the author suggests that the relative slowness of the door closure mechanism might be compensated for by the reduction or removal of delays caused by passengers blocking the doors. This remains to be modelled. Further research is needed to determine the cost/benefit of maintaining mechanically complex door actions, especially internal sliding doors, against the cost of disrupted timetables and defective trains put out of service.

Figure 8.6 Variations on the design theme to mitigate door holding behaviour.

8.2.4 Completed door concept

Figure 8.6 describes a range of door concepts when each of the strategies described in this chapter have been combined together. The doors are offered as a contribution to the overall design solution, responding to the issues described in the introduction to this chapter.

Five equidistant doors help to better distribute passengers both on board and waiting at the platform. Two of the doors are clearly indicated as time specific ‘peak’ doors. They are opaque with small windows placed at a height to suit the patrons using the seats immediately behind those doors during off-peak periods. The remaining three doors have an open expanse of transparent window and can clearly be seen as operational at all times.

Graphical symbols have been applied in order to respond to cultural norms to suggest left hand side boarding and alighting so as to stimulate a dual flow passenger exchange. These features are both applied as reflectors to the threshold floor as tactile mats and on the doors, to reinforce the desired behaviours.

The door buttons have been located to the left of the door centre line to encourage passengers to be standing in the right position to board without meeting an alighting passenger, who will be faced with an actuator to direct them to move to the opposite side of the door.

Draught shields have been removed and only minimal handrails in the immediate door area are available to discourage ‘sentry’ behaviour.

To counter the loss in seating generally associated with an increase in the number of doors, the peak doors have folding seats adjacent to them.

To dissuade passenger door holding behaviour, a number of mitigating strategies have been introduced into the door action. The first of these is the actual door ‘gesture’, which is a reference to its opening and closing trajectory and speed. The doors are of a ‘plug’ typology, meaning that they first move out from the aperture, forward into the platform space, and then slide along the sides of the carriage. Closing is the reverse of this action, hence they close on ‘plugging’ the door aperture. This movement in two planes and at variable speeds makes grappling with them during movement less predictable and more onerous to the potential door holder. The nosing rubbers lining the meeting edge of the door will vibrate when they meet an obstacle such as a hand before the door is closed. The purpose of this is to create a mild discomfort or unusual sensation that further deters someone from resisting the door movement.

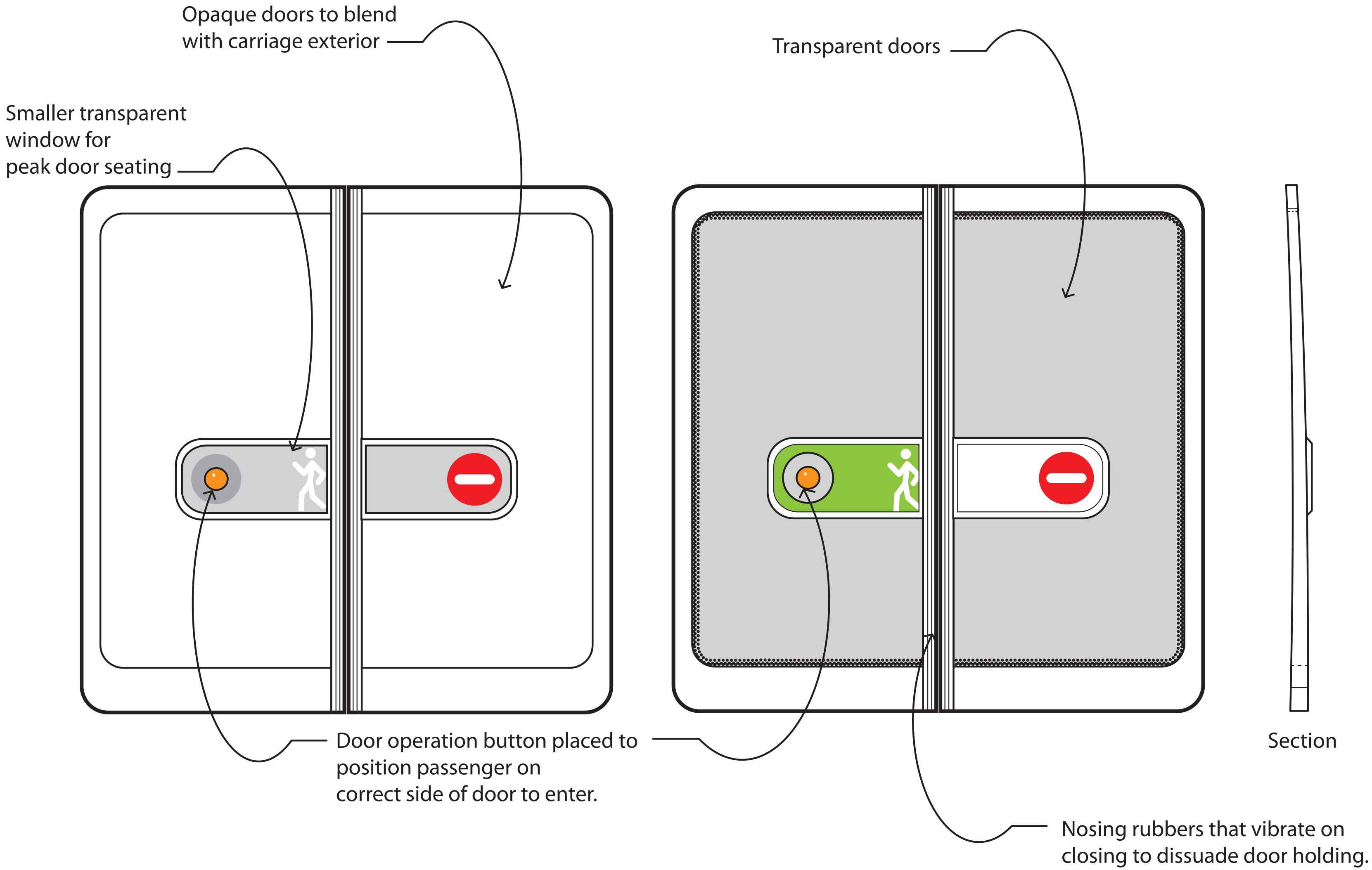


Figure 8.7 Final door design.

8.3 Conclusion and integration into the project as a whole

The management of ingress and egress sits at the centre of the dwell time problem and the doors illustrated in Figure 8.7 go some way to addressing the original design aspirations:

1. simultaneous boarding and alighting
2. more doors without detriment to seating capacity. Fold up seats located in the threshold of the peak doors.
3. Addressing door holding behaviour.

The simulations described in chapter 5 indicate that simultaneous boarding and alighting of large numbers of passengers can create occlusion deeper into the carriage. The extra doors mitigate this problem for numbers at or slightly above capacity (q.v. chapter 6), achieving dwell stability. Taking the cultural norm of driving on public roads it is quite acceptable to expect people to pass each other by moving to the left. While it is not impossible to move through the door threshold the 'wrong' way, the prevailing culture of general obedience and stimulation from signage would make an individual working against the directed flow less inclined to behave in such a manner, unless in uncrowded conditions

The peak door concept is the most demanding aspect of the carriage design on cultural norms. The appearance of the door has been created to make it as differentiated as possible from the all day operational doors. Speculation on its use at various times of the day, especially at the shoulders of the peak period, might lead to confusion and frustration. It would be important for the operating company to clearly articulate the system to patrons. The benefit of having doors that operate only during limited periods of excess capacity is that during the rest of the day there is no loss of seating, as a cluster of four seats remains adjacent to what effectively becomes a wall. The period of changeover in functionality needs to be handled carefully and is most appropriate between services, when there are no passengers on board (q.v. Chapter 7).

Door holding behaviour is a serious impediment to timely departure from stations, as well as a general safety issue. While the general discouragement of these actions has been built into the door movements and physical cues, the literature on human behaviour reveals that the adaptability of human beings could overcome these strategies. What was once novel will become familiar. Door actions will become 'learned' and new ways to disrupt door closing may emerge. Public consciousness of the problem needs to be maintained (Alexa, SNCF 2009) which is why a policy of publicity has been implemented in networks that suffer greatly from unwanted behaviour. Designers are therefore likely to be required to continue responding to changing passenger behaviour especially, when it undermines respect for public infrastructure.

An area that has been placed outside the remit of this research project is that of managing the gap distance between the platform and the train itself. The literature (Hoogendoorn et al. 2002) describes the threshold gap as a significant factor in dwell time extension, as both able bodied and disabled patrons negotiate the step height and length of the gap in various ways. This has also been exposed in the literature review described in chapter 2. The reason for its exclusion in the door design has been that a likely solution will require the collaboration of the platform infrastructure. As discussed in Moug (2013), the primary problem of gap and step height in the Melbourne context is that of variability between station types, especially old legacy stations, and rolling stock. New systems, where introduced in the world, look immediately to level boarding and a single type of rolling stock. Therefore as a research project on general passenger dispersal, the author has decided, while recognising the issue, to exclude the problem from the primary carriage based design concept. The following chapter integrates the door design with the overall carriage exterior.

9

Chapter 9. Design project 4
the carriage exterior

9.1 Introduction to Design project 4 - the exterior design

The primary aim of this research has concerned the crowd mechanics and geometry of the carriage interior. The exterior integument is in essence the containment of the vehicle for passengers' safety, comfort and protection. The exterior envelope of the carriage contains within it the research problem (q.v. chapter 1). The exterior appearance of the train does, however, assume significant functions and responsibilities, such as comprising the essential interface between waiting passengers and the vehicle itself, with the location of doors and the conveying of meaning such as boarding and alighting protocols, door actuators and windows that present and expose the interior within. This interface exerts a considerable influence on the mechanics of boarding and alighting. Three essential factors determine the exterior geometry;

- the location and appearance of the doors, especially in the prosecution of a carriage design that includes temporary doors
- the arrangement of windows
- capping and bridging of the carriages.

The form of the vehicle can be transformed from a rectilinear box to that of an engaging piece of transient architecture. Buildings suggest belonging and can define a sense of place, with forms, shapes and graphical treatments that become the emblems of a city. Trams are particularly good at conveying this message since they have for a period of time been rarer to find in metropolisis around the world. Buses and trains appear to have fallen behind this emotional affection, with the possible exception of London buses.

Much of the creative work discussed in this chapter has been framed by the emerging interior design. In this chapter, the author explores the form language of the carriage integument and the importance of its being 'read' by passengers. There are essential differences to the approach a designer can take concerning the aesthetic of the train vehicular form. There is not, for example, the sculptural freedom that is available to an automotive designer. While both the public and private sectors utilise industrial design expertise within their overall design strategies, the automotive industry has the luxury of designing to a varied and segmented consumer market. Car purchases are made based on a variety of factors: psychological, cultural, social and personal economic situation. Manufacturers offer the consumer a specific response targeted to their needs, resulting in a particular vehicular form.

Automotive design creates meaning through a targeted aesthetic. From this experience, consumers can draw conclusions about the vehicle's purpose, functionality and related features of confidences in performance and safety, e.g. off road or city driving, utility or luxury etc. Conversely, public transport vehicular design has to be, by its very nature, a single offering to fit all solutions. The business model for public transport modalities is driven by carrying capacity and the characteristics of wide patronage as well as economics, durability and a long life-cycle. Accommodation made for ingress and egress for a wide range of human sizes, allowance for perambulation and disability, the form of propulsion, track, platform and roadside kerb stops, all affect a spatial envelope that leads to a very utilitarian and rectilinear form.

Some variability exists in public transport with regard to nose cone and driver cabin design, most notably in tram and train systems. Elsewhere, along the body of a train, the impression of a large high-sided box is generated. This can lead to frustration or confusion in locating doors, anxiety about what one might find aboard, the vehicle's condition or whether or not there will be a seat.

Manipulation of the perception of form through the use of line and colour is a key feature of the designer's activity. The automotive designer strives towards the creation of elegance. Horizontal lines reduce the impact of upright lines and the blacking out of upright pillars gives the effect of a sleeker appearance, suggesting speed. Darker shades created by colour or shadow along the lower part of the vehicle reduce 'visual bulk' and make the vehicle appear to float. With regard to railway carriage design, the overall proportion of the vehicle is dictated by the package configuration that includes all the essential elements within the carriage and especially the adherence to gauges (q.v. chapter 4). Trains have become a predictable sequence of forms; the difference between the beautiful and ordinary is sensitivity to the nuances of proportion. The 'line' of the vehicle determines the reading of the vehicular aesthetic. The outline of the edges of the carriage are important since these reinforce a dynamism to the form and can accentuate speed and, with it, the perception of mobility. The proportions and line of trains conform to a mass slab sided vehicle – a building on wheels – with little to commend it for speed and comfort from an exterior impression. In an attempt to remedy this impression, some manufacturers have increased the break up of the slab side by creating larger windows and subtle gentle curves, as well as dynamic and pointed driver cabins. With this aesthetic sensibility in mind, the research moves to creating an exterior surface design to the carriage that communicates to passengers on two levels, firstly, the location of doors and the understanding of dual boarding protocols, secondly once on board, the increase in natural lighting through the introduction of larger windows affects the overall external apppearance. The removal of the driver cab means that some sort of visual expression to close off the end of the motor car is required, a visual expression that conveys direction, and since the front of the vehicle embodies the sense of control, also confidence.

9.2 Sketch studies of the exterior design

Figure 9.1 shows the framework geometry of the train exterior. This framework assists the author in establishing which parts of the train are fixed by functional and technical requirements and which surface areas leave some variability in the control of their form.

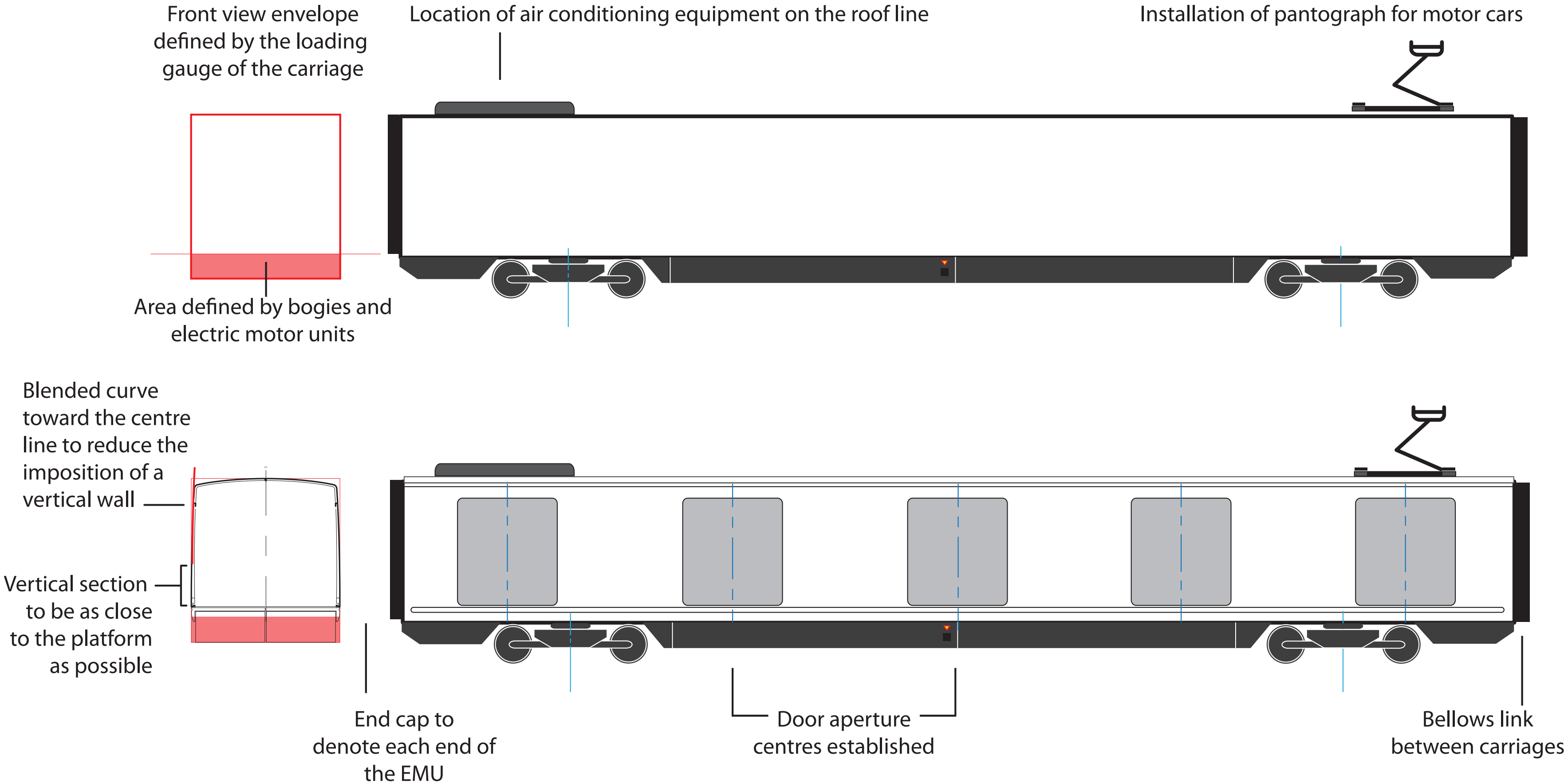


Figure 9.1 Essential exterior geometry of the train.

The diagram in Figure 9.1 reveals that the network gauges and the anthropometry of passengers dictate the essential envelope of the carriage. The stretched rectilinear nature of the train form (it is longer than it is wide by 8:1) lends itself intuitively to the notions of speed and motion. Door widths and heights have been established, punctuating the linear lines of the carriage surface. Door apertures are block-like at almost 1:1 proportionally, appearing to punctuate the skin of the train. The author is faced with three approaches for advancing the exterior design:

- Blend the door trim verticals with the roof of the train and in essence 'slice' the carriage length.
- Attempt to integrate the horizontal geometry of the doors, especially the windows, to accent the longitudinal nature of the carriage and by so doing increase the perception of speed and linear motion.
- Make the doors 'disappear' by way of colour and texture integration with the rest of the train.

The last strategy is the least appealing, as disguising the doors will make their location difficult for waiting platform patrons. In some networks, specific design rules stipulate a colour change for doors; Paris and London are two examples. The concept design in this research has established the five door scenario and with it the intention that some doors are always operative and others not. The author is keen to expose the regular 'all day' doors by way of colour and graphics, while understating the peak doors so that they do not confuse patrons when not in operation i.e. expecting them to open (q.v. chapter 8).

Figure 9.2 shows the author's thoughts concerning driving a form language that slices the length of the carriage, integrating colour splits from the floor of the train to wrap over the roof. The vertical orientation of the door feature does emphasise the continuous door positions but at the cost of compressing the visual length of the carriage, something the author feels detracts from the perception of speed that is afforded by a graphical language that plays to the linear proportions of the train.

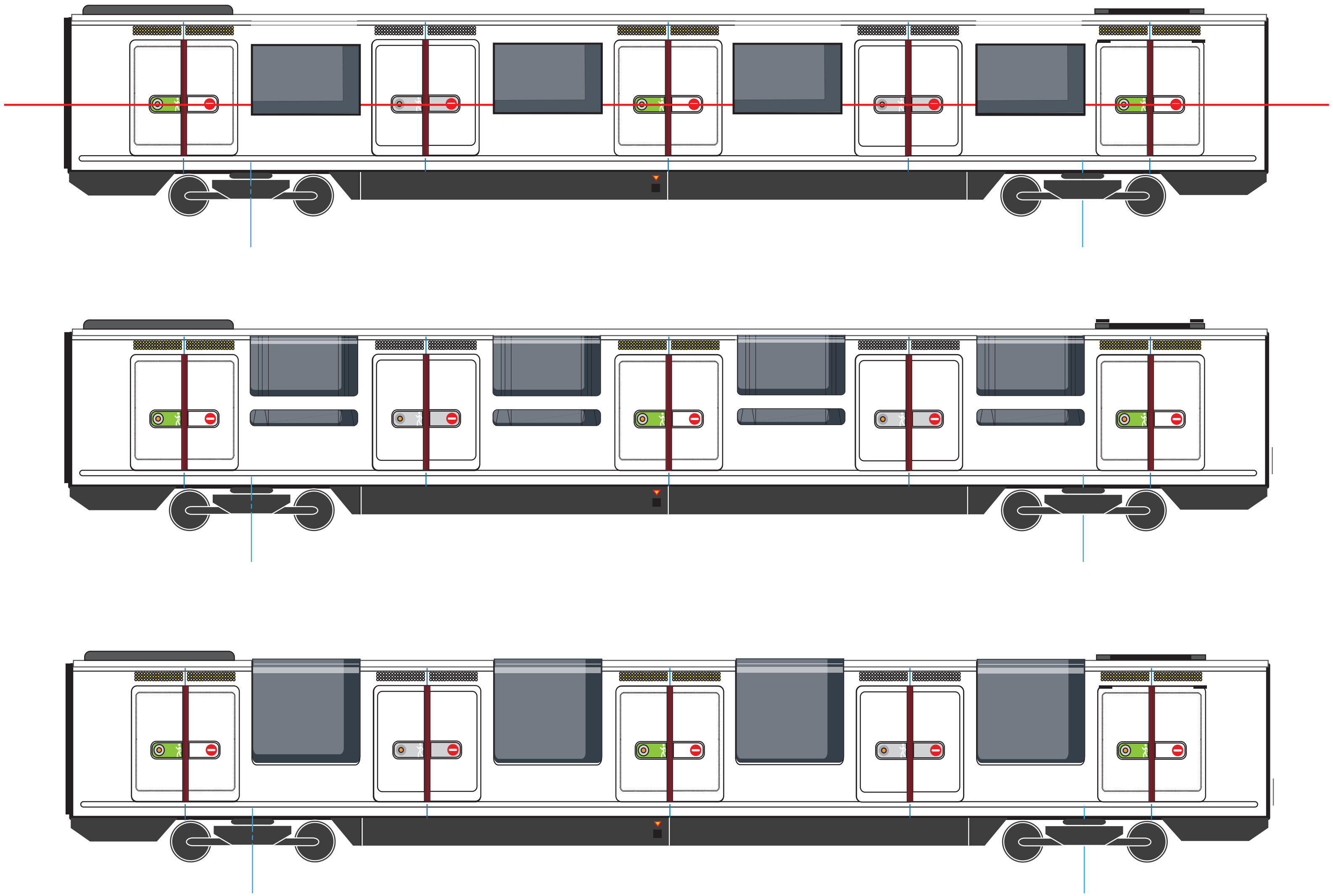


Figure 9.2 Sketch designs showing the geometry relationship between the door directional panels and window arrangements.

At this stage, the windows present more aesthetic problems. Like the door apertures, their position is fixed, between doors. The lower line of the window frame is set by internal wall protection to the structure of the carriage. The height is a little less fixed by structural compliance requirements, enabling the design some flexibility in the manner in which the windows meet the roof.

There is a trend (SNCF design office / Innotrans 2010 exhibition) towards passenger enthusiasm for larger windows. Larger windows expose the outside world and bring in light to the internal accommodation. The counter argument is that glass is relatively heavy compared to materials used elsewhere in the walls of the train. Heavier weight in train design equates to greater energy use under acceleration and braking. These opposing motivations make creating a compromise position for the design of the outer wall challenging.

There are also implications in using wide areas of glass for maintenance, particularly in response to vandalism. The contemporary trend for etching glass with graffiti, rendering the window obscured, requires expensive replacements. The author's design work at this stage has fluctuated between reducing the total window space to a series of more numerous but smaller windows or having single larger windows. The concept layout discussed in earlier chapters shows that only a minority of passengers will be able to sit adjacent to the window; for the majority of passengers, the windows will provide light and a sense of location on their journey but little more.

The series of small lozenge windows as shown in Figure 9.3 provide an exterior graphic visual language that is in harmony with the sense of linear speed, appearing as representations of dashed pulses along the outer wall. From a maintenance perspective, smaller panes are cheaper to replace when broken than larger windows, although a long inventory of stock is needed.

Apart from daytime illumination, windows also provide a view of the external world that reduces travel nausea. There has been a drive to increase window sizes within the passenger community. There is a perception that with increased light comes a feeling of space and the interior is less claustrophobic, even at night or on services that are predominatly tunnel bound.

While the physical requirements of doors, windows and the joins of materials and surfaces describe the vast mass of the train, the visual clarity of the exterior can be further enhanced by the application of graphic devices. This is particularly helpful in directing passengers to board and alight at the same time by choosing to walk on the left as directed by signage. Figure 9.4 demonstrates some of the graphic treatments applied to exteriors, maintaining a message that is pure and simple without conflict or clutter. Using established languages of interface, the doors take on a bold expression of green and red to emphasise positive, i.e. go and negative, i.e. stop or wrong way visual alerts.

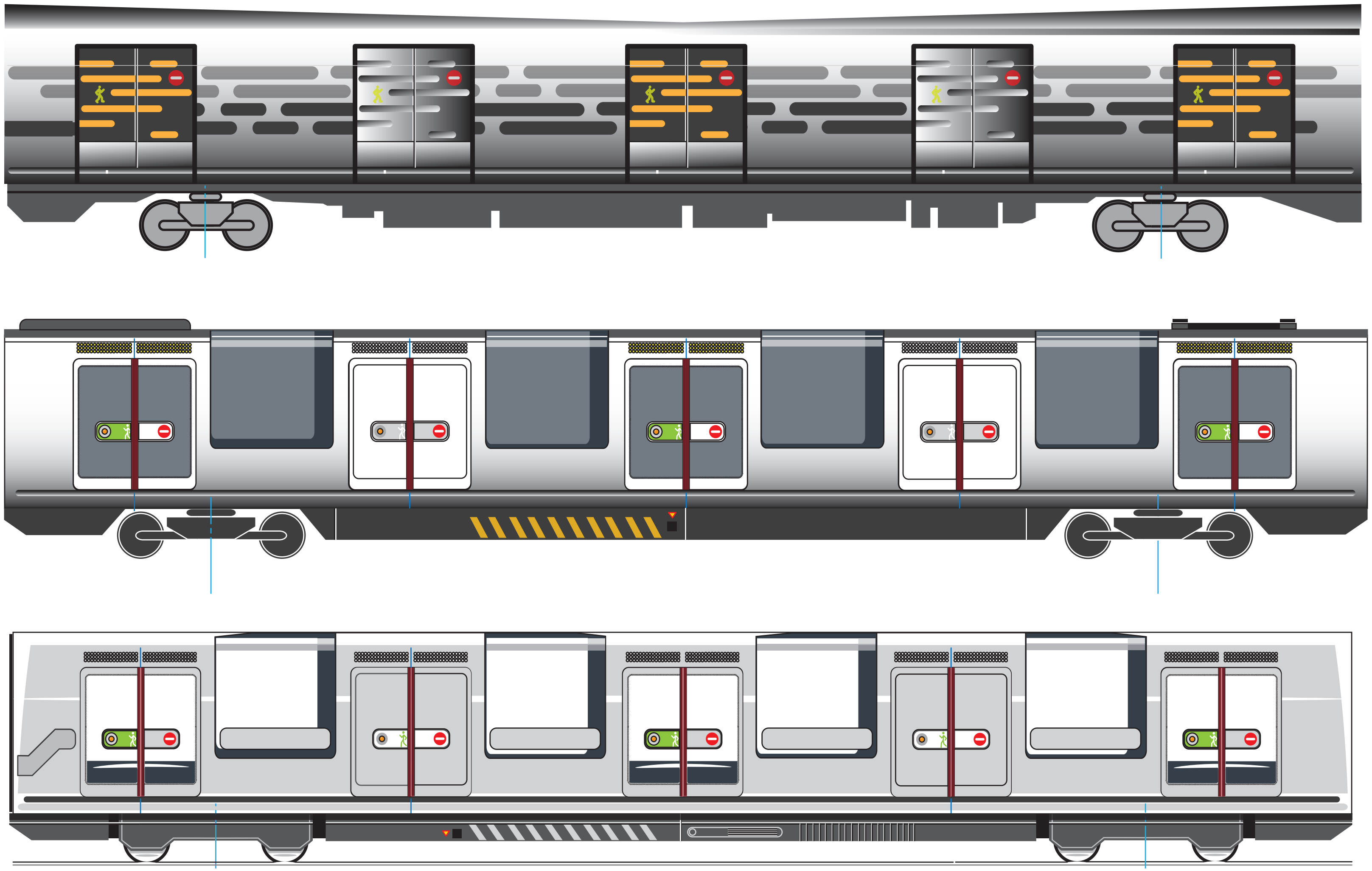
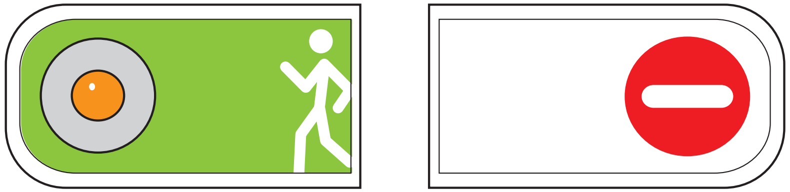


Figure 9.3 Orthographic studies showing alternative refinements to the door an window geometry.

Bicycle and pram floor location graphics for the extended vestibule

Door entry and exit indicators on the all day door.



Door entry and exit indicators on the peak door.

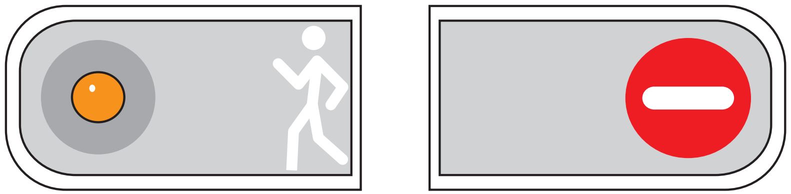


Figure 9.4. Carriage graphic treatments.

With the positioning and geometry of the doors, windows and their associated graphic treatements established the author next turns attention to the visual problem of terminating the reclilinear form and establishing a connecting visual device for between the carriages.

9.3 End cap design

While outside the central issue of the research study, a sense of completeness to the carriage design is provided by the capping of the enclosure with what amounts to the front face of the train. Since the train proposal is driverless (to provide extra interior space) the ends of each set of three EMUs provide a more open vista to the passenger. This is especially true of the front carriage in any set. The author has considered both an open window frontage and a closed front to provide a larger space for housing the control technology and systems. While large open fronted windows are popular on other automatic train systems around the world as passengers can enjoy the heightened awareness of where they are going, the added upon front might also influence passenger dispersal as they scramble for two front facing seats. In the following sketches the author has experimented with both approaches. Side protection is provided by the framework along with required lighting and destination indicator. To convey a sense of speed and forward motion, the author has sketched and investigated creating an angular front wedge to the form language. In the sketching, there is a concern to strike a balance between a sense of movement and dynamism and a simple utility. This type of train is not high speed and therefore a long nose and aerodynamic requirements are not required. A longer nose will lengthen the train without any benefit to the passenger and to the detriment of the platform length. Figure 9.5 describes the sketch process to the concluding concept end cap.

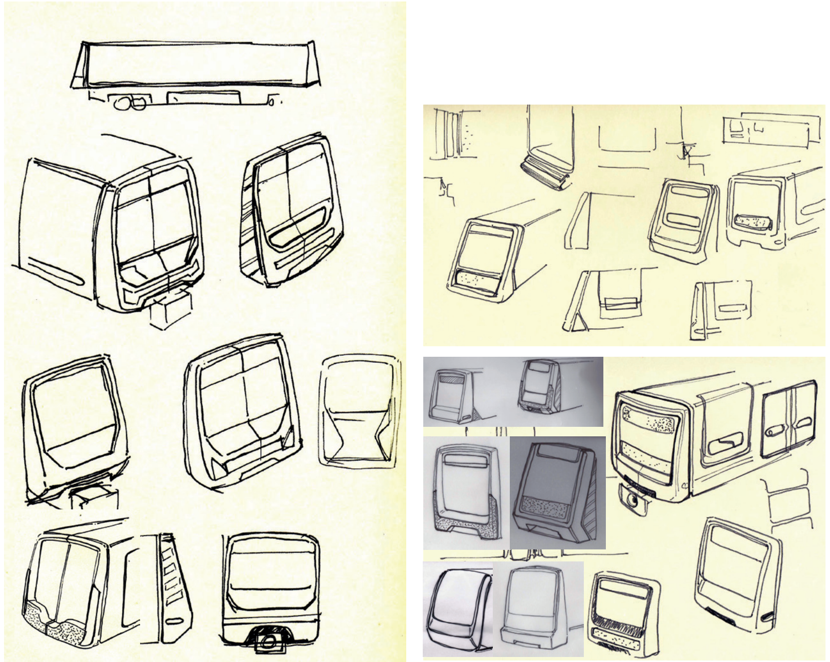


Figure 9.5 Sketch studies charting the evolution of the end cap design.

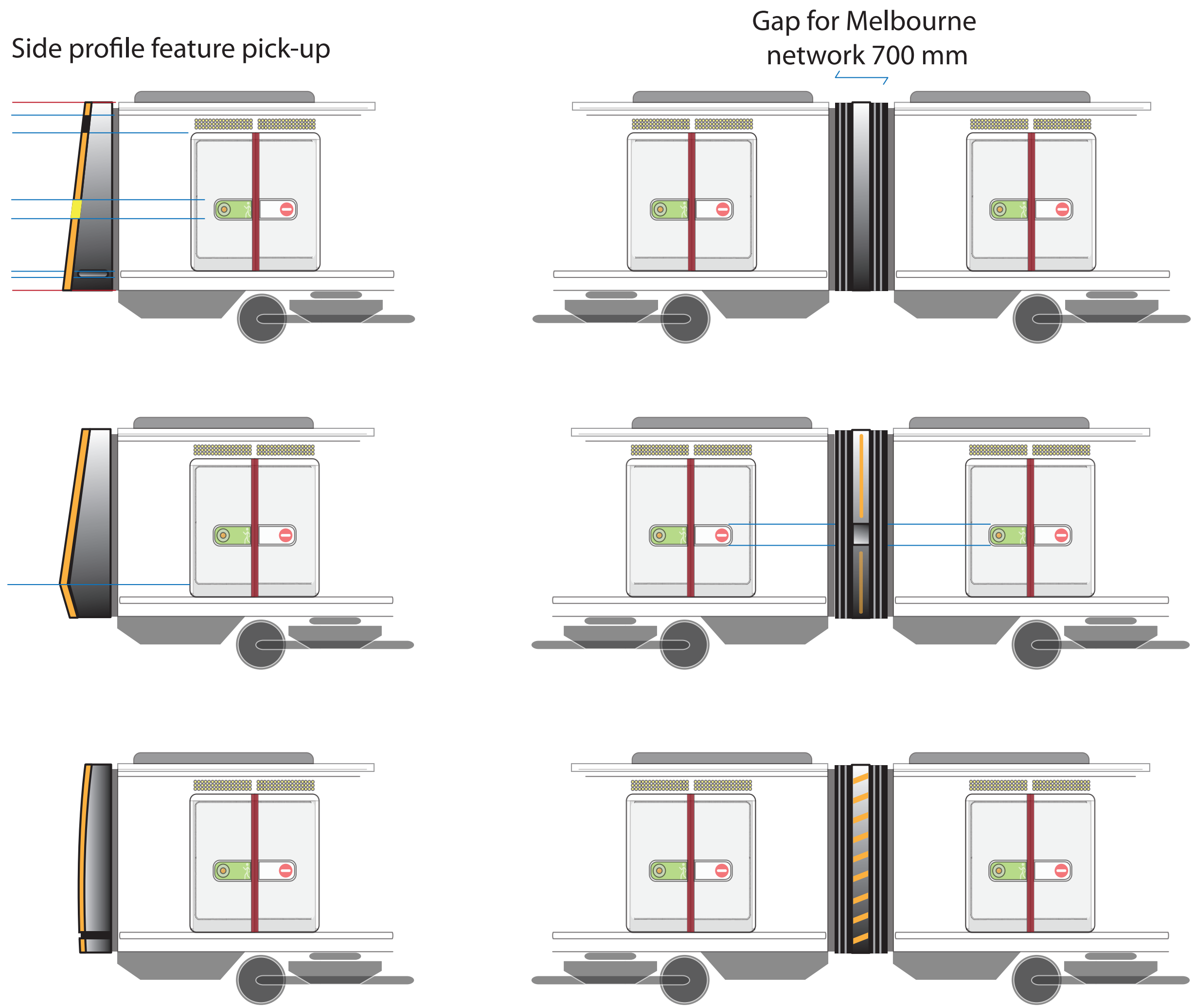


Figure 9.6. Side elevation of front end caps and between carriage bellow options.

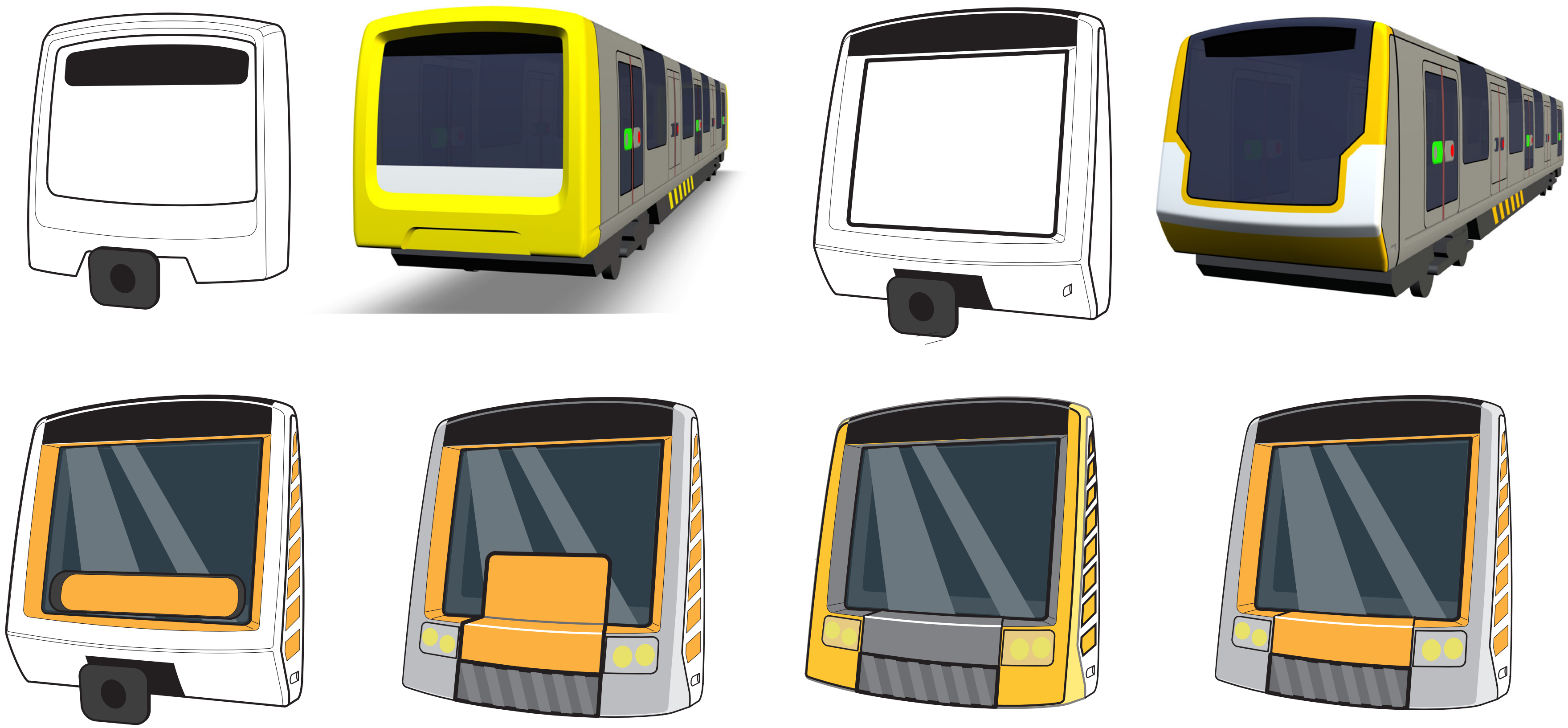


Figure 9.7. Principle criteria for these designs was to accommodate a large front window, a light cluster, an area painted yellow, a passenger information display (PID) and a carriage coupling housing.

Figure 9.8. Motor car front cap alternatives based on the idea of no window. This option can improve frontal impact safety by creating a housing for both damping equipment and the driverless technology as well as providing options for a more elaborate PID.

9.4 Conclusion the exterior design rationale

While the central focus of this research study has been concerned with the interior of the train, the exterior surface design arrangements of windows, doors and end caps all perform a range of functions. The outward looking face of the carriage is the predominating communicating tool that needs to direct, inform and suggest. The carriage is a considered structure that should imply the language of the object and exude meaning. The external surface offers the opportunity to present a unified statement. Attractive things are perceived to work better and while usability and utility are essential, not without pleasure or visual stimulus (Norman 2005).

The exterior design responds to patrons on a number of levels. Primarily, the exterior protects the passengers from the outer environment. At a visceral level passengers need to be clear about where doors are and clearly understand how to use them. Other practical qualities include the ability to see into the carriage as it draws to a stop, in order to see inside and make early decisions about where passengers may disperse to or what they will find once they step across the threshold. At a higher level, the exterior of the carriage is an opportunity for the TOC to engage in the visual dynamic of travel. The coachwork and graphics exude the notion of speed and safety. Expressions of this manifest in surface material treatment and colour, as well the form language employed.

The resulting surface treatment has attempted to create a balance between perceptions of speed and those of utility. Both windows and doors divide the vertical slab sides. The vertical axis of these elements 'slow' or truncate the otherwise streamlined effect of the long length of carriage wall. These elements can therefore have a detrimental effect in conveying the sense of speed and dynamism so essential to the notion of transportation.

The author has tried to balance these vertical axes with longitudinal elements such as the treatment of the door actuator buttons and the slotted windows on the peak doors, combining to create a line running the length of the train.

The window treatment is larger than current offerings and wraps up over the roof line to enable light to pass through into the interior accommodation from above. The purpose of this design feature is to encourage a sensation of natural illumination within the interior and reduce any sense of enclosure or claustrophobia.

Bringing more light into the carriage interior is part of the strategy of drawing people into the carriage and away from the doors. There is very limited space on the roof to accomplish this and there is the risk of creating a weakness in the structure. Most of the carriage interior space is determined by the air conditioning ducts, lighting and power lines from the pantograph running around the carriage to eventually flow down to the motors and the wheels. Even at night, an upward view of the world might not be without its advantages in creating a greater perception of openness.

The window of a moving train is a proscenium arch within which the changing composition of the outside landscape is constantly framed, temporary and transient. While this might not always be pleasant, or even visible in the case of underground trains, the relationship between the internal space and the changing outside world is one that might be explored further. If the notion of relaxation to the passenger is one in which they sit under sunlight bursting through treetops, then an interior cabin space that plays with light and graphical elements to evoke a similar effect will increase the pleasure of the transit time. Figures 9.9 to 9.12 shows the exterior of the final concept and demonstrates how these ideas have come together.

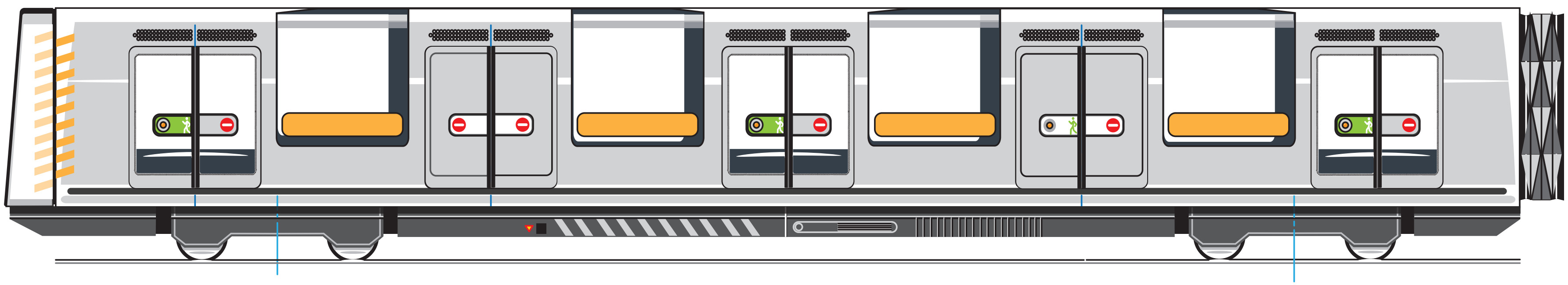


Figure 9.9. Rendering of exterior geometry of the proposed concept train.

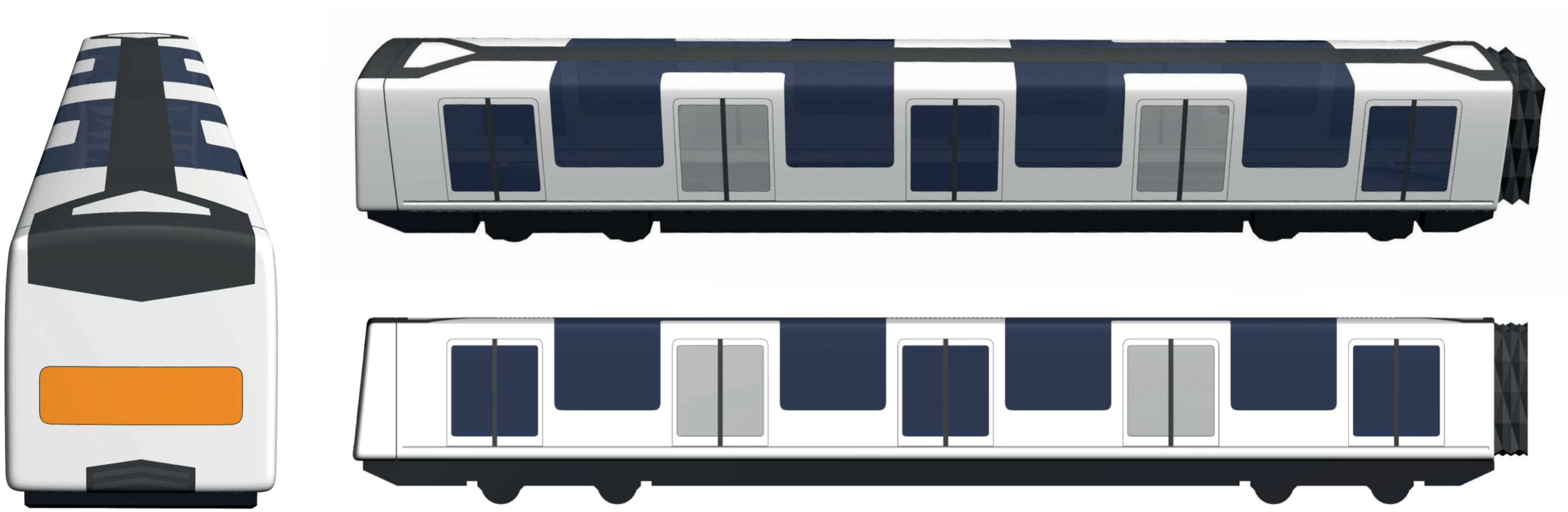


Figure 9.10. Concept design translated in to CAD imagery. Display roof glass suface graphic.

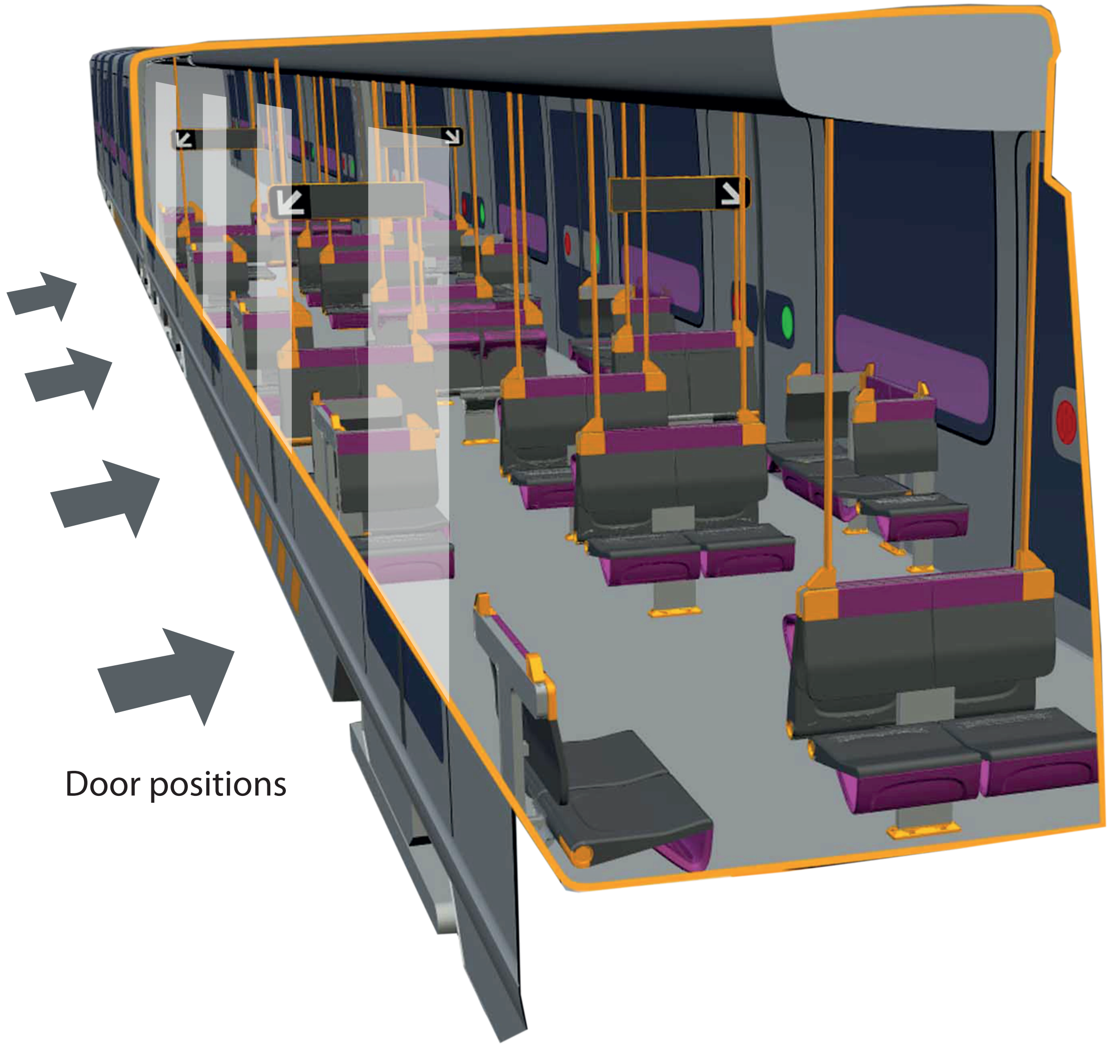


Figure 9.11. Exterior relationship with the interior

10

Chapter 10. Conclusion and future work

This chapter considers the outcomes of the research in the context of the original problem and considers where and how effectively the design has addressed the problem and where gaps in knowledge existed. Each of the elements of the redesigned train carriage are discussed and it's contribution to knowledge examined. The research has found that extended dwell times due to passenger numbers in excess of capacity can be reduced by stimulating passenger flow by three distinct rearrangements of the carriage interior layout:

- centrally located transverse seating separated from window adjacent longitudinal seating by a corridor on each side
- flexible seating types to match crowding conditions
- peak doors that operate during busy periods and retain extra seating behind them during non busy periods.

This chapter also recognises the limitations of the research results and identifies opportunities for further research. Finally, conclusions are drawn as to the impact this research might have on metropolitan train design.

10.1 The design problem

The design projects identified and responded to the challenges of peak time crowding faced by suburban rail operators, with particular reference to the prevailing conditions in Melbourne, Australia. Evidence as revealed by the research shows that higher passenger densities, particularly during peak times of the day, have negative implications for train punctuality, crowding, accessibility and passenger comfort. The research question formed from this problem was:

How can the interior of a suburban metro train carriage be designed to improve boarding and alighting, with respect to stabilising dwell times, and by implication enhance the passenger experience during periods of crowding?

The scope of this problem is described in Figure 10.1 overleaf, where it can be seen that stimuli such as population growth, centralisation of employment and petrol price volatility can all contribute to increased patronage. The dispersal and movements of high passenger loads extend the length of time the train is located at the station, thus delaying the service and inflating the problem further down the line, as passenger numbers build up at station platforms. Trains arriving late at the next station meet with increased numbers of waiting and newly arrived patrons, further increasing the excess of passengers. The TOC for Melbourne carries out train loading surveys twice a year. Data from those loading surveys reveal that crowded trains can run during the morning peak at levels as high as 135% of the intended capacity of the train.

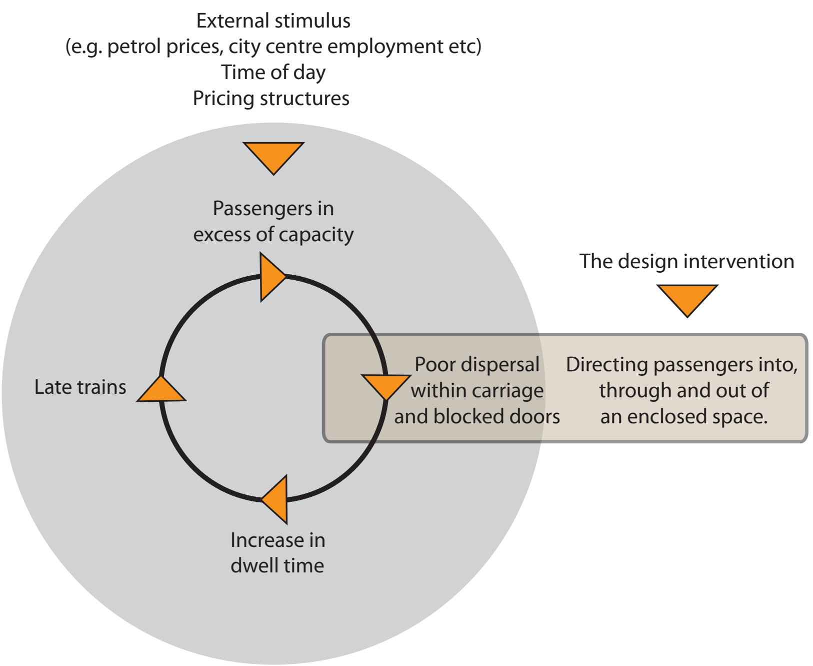


Figure 10.1 The design intervention into the problem space.

The contributions of lateness and cancellations to overcrowding can be severe, with trains following a cancelled service usually the most severely overcrowded. Studies of the value that passengers place on punctuality reveal not only an experiential perception but also a cost.

- Delayed trains mean that passengers may arrive at their ultimate 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 among passengers rate issues such as punctual trains and comfort along with ticket price and travel time as of high importance.

The design projects contained in this research break into this cyclic problem at the point of passenger dispersal during boarding and alighting, where the physical environment can be most influenced by a physical design intervention. This intervention is described on the right of Figure 10.1 in terms of directing passengers moving into, through and out of an enclosed space. This means the manipulation of seat and door positioning, as well as graphical devices to indicate and direct patrons through the train interior.

The literature review set out to capture the breadth and depth of scholarly research into the problem to inform the design response. This review identified that there are a wide range of micro issues that combine to determine overall efficacy of the carriage's boarding, alighting and dispersal performance.

It is also possible to discern from the literature that conditions local to cities and their networks have local implications for the problem, making a single solution to carriage design impossible. The specific conclusions to the literature review were divided into the following:

Platform factors in boarding and alighting:

- spread of passengers along the platform – implied knowledge of the position of doors on arrival
- accessibility – absence of steps into and out of the carriage and wheelchair friendliness
- the carrying of objects, including the accommodation of bicycles
- cultural behaviour; a radical design response would require potential change in the prevailing cultural norms.

Carriage factors in boarding and alighting:

- 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 for accessibility for a wide patronage, e.g. disability, prams, luggage etc
- the management of objects and belongings
- door location, their numbers and dimensions, gap distance and gap height.

The circumstances of Melbourne, in addition to the identified issues discussed in the literature, have to take account of:

- the legacy of old station infrastructure
- the widespread nature of Melbourne suburban sprawl which means that the outer reaches of the network function as a quasi-regional train (Frankston to the CBD takes 60 minutes); the same service is then obliged to perform like a metro system with short trips and frequent stops within the city centre loop
- four different types of rolling stock servicing the same network, each with their own door dimensions, number and position along the carriage.

Finally, as figure 10.2 exemplifies that there are a number of key dimensional contradictions presented in the literature. Increasing the number of doors reduces the number of seats. Increasing the number of seats means less standing room and so on. The balancing of these relative dimensions was at the centre of the studio design process.

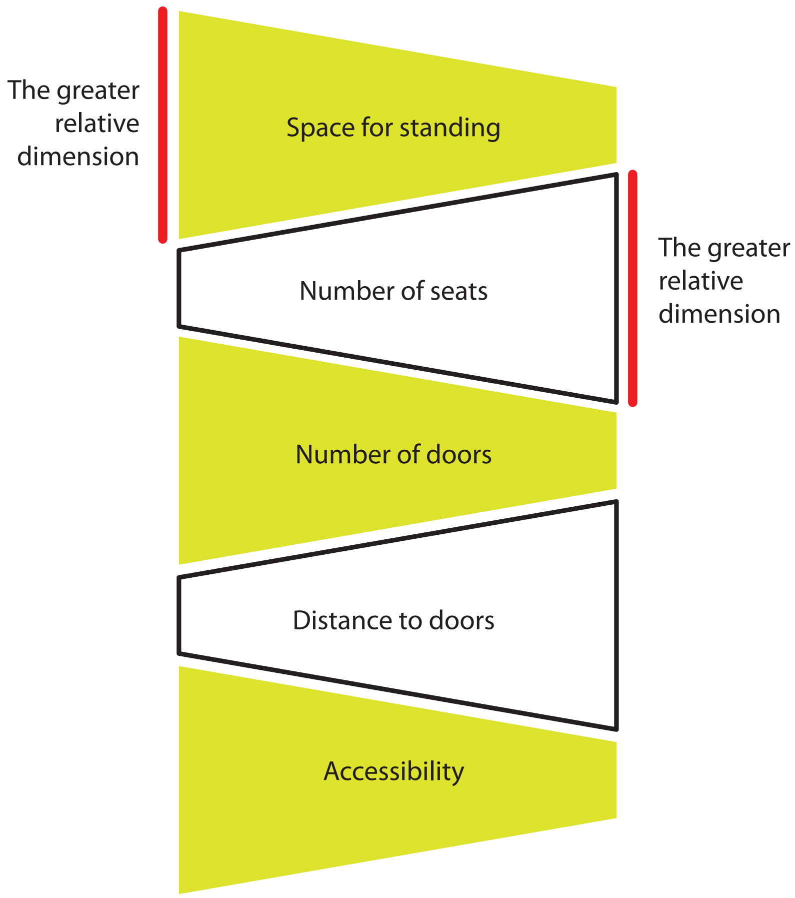


Figure 10.2 The conflicting dimensions of the carriage specification.

10.2 Outcomes of the research

There is a paucity of literature surrounding improvements in interior layout design. Some experimentation has been entered into, most notably with Stockholm's SL transit system and comparative tests with aged stock on a single line in the city. However, a complete cultural overhaul of the process has not been hitherto attempted. This research project sought to address this knowledge gap. The design advanced in this research represents a significant contribution to train carriage design in this segment of the mode.

The outcome of the research takes the form of three key design interventions:

1. improved passenger flow by way of dual corridor carriages with centralised seating combined with longitudinal seating along the windows (figure 10.3)
2. extra doors that function only during peak times, allowing flexible seating to be located behind them for off-peak periods (figure 10.4)
3. complete modularity of seating type so that seats can be deployed as regular seats or as perch seats when more space is required, at the discretion of a guard or conductor (figure 10.5).

The efficacy of the first two of these design interventions was tested by way of computational simulation. Combining an agent based modeller with a computer game engine it was possible to replicate both visually and mathematically the anticipated movements and behaviour of passengers. The results of this computational modelling indicated that in comparison with the most common carriage design on the Melbourne network (Comeng), boarding and alighting times were quicker. These results indicate that dispersal within the carriage during peak loads is also improved.

ABM begins with assumptions about agents (representing 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 on each other is difficult, 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 where they have been placed.

The efficacy of the third design intervention could not be modelled by computer simulation (q.v. Limitations to the study 10.3). This intervention, while not integral to the operational success of the first two, requires the testing and operation of a full-scale build to determine the outcomes. Forcing passengers to use only perch seats (PRMs excepted) and speculating on the timing of seat deployment are too open ended at this point in the research. This also requires the intervention of a significant culture change among patrons, difficult to establish within the bounds of this study.

10.2.1 The train interior seating layout

The passenger flow into and through the interior of the carriage is dominated by the impediment of the seating arrangement. The physical presence of the seats populates the interior and therefore by implication directs movement within the space. The carriage is sufficiently broad, being based on Melbourne's broad gauge 1600 mm network, to accommodate longitudinal seating along the windows and then seat clusters of four along the central axis of the train, with a large open vestibule area 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 (PRMs) and do not fold at any time.

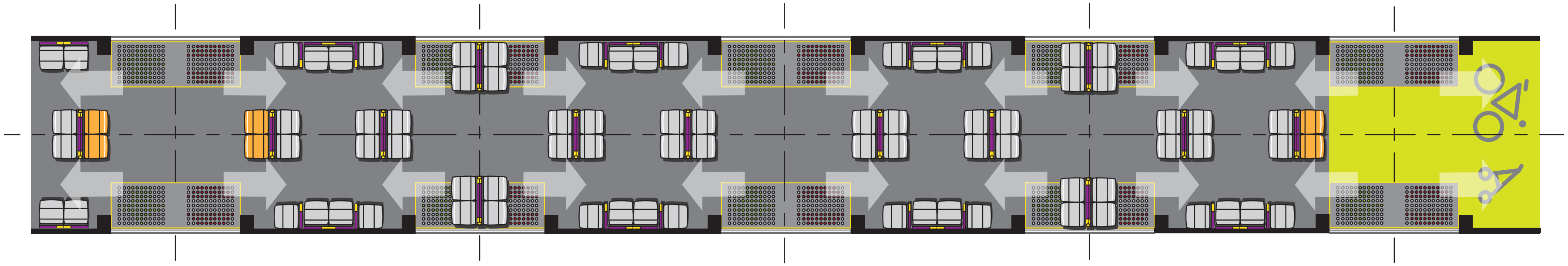


Figure 10.3 Outcome 1; improving passenger flow by way of dual corridor carriages with centralised seating combined with longitudinal seating along the windows.

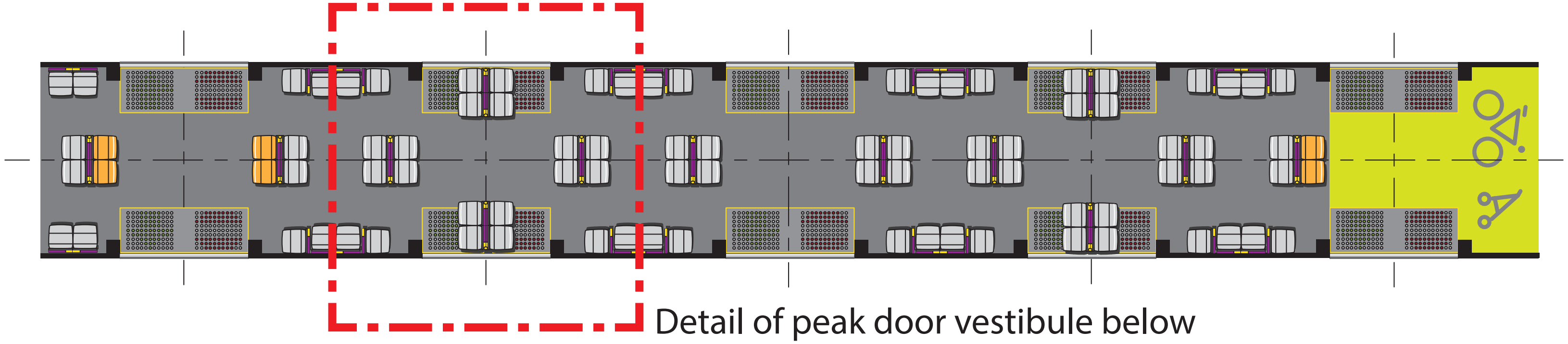
10.2.2 The peak door

To create better boarding and alighting, five doors per side have been provided. However, significantly, only three doors are operational all of the time. Having two doors operational for peak periods only enables the interior to accommodate folding seats in the immediate door vestibule area. During peak periods when these 'peak' 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 10.3 these floor indicators at the door are in the orientation as seen from someone outside the train, a green arrow suggesting the exit and a red and white no entry sign indicating no exit.

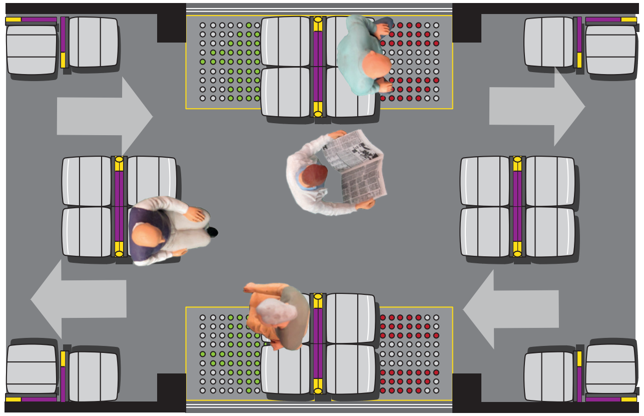
The design projects have demonstrated that a response to the diverse and often conflicting requirements of metro rail interiors can be managed but with some impact on prevailing passenger cultural behaviour. The two and three-dimensional visual devices are not in themselves radically new. They are drawn from everyday, expectations of moving to the left when passing or responding to a no entry sign. The peak doors are different (being opaque) to the all day doors. When signage and new operational protocols are put together, they form a considerable intervention in the context of the train. It is acknowledged that to fully understand the implications of this innovation, a full-size working prototype would need to be built and tested in a network operational environment.

Figure 10.4 shows in a diagramtic plan view the intended functionality of the peak door vestibule, the seating deployment convention and the anticipated passenger dispersal.

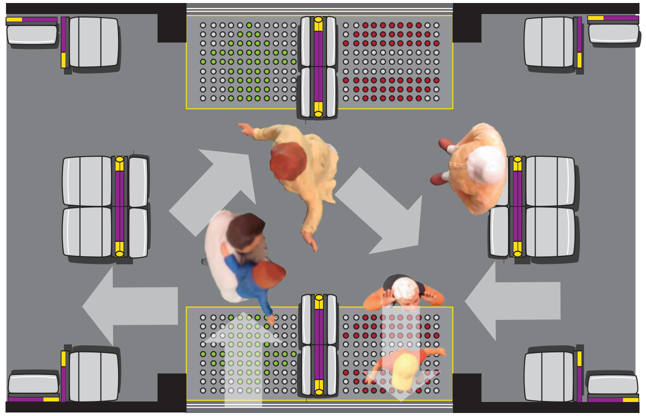


Detail of peak door vestibule below

Arrows indicate multi-flow options not mandatory directions of movement



Off-peak - doors non operational
all seats deployed



Peak period - doors operational
adjacent seats folded up

Figure 10.4 Outcome 2; The inclusion of extra doors operational only during peak times, therefore enabling folding seating to be located and used for off-peak periods of service.

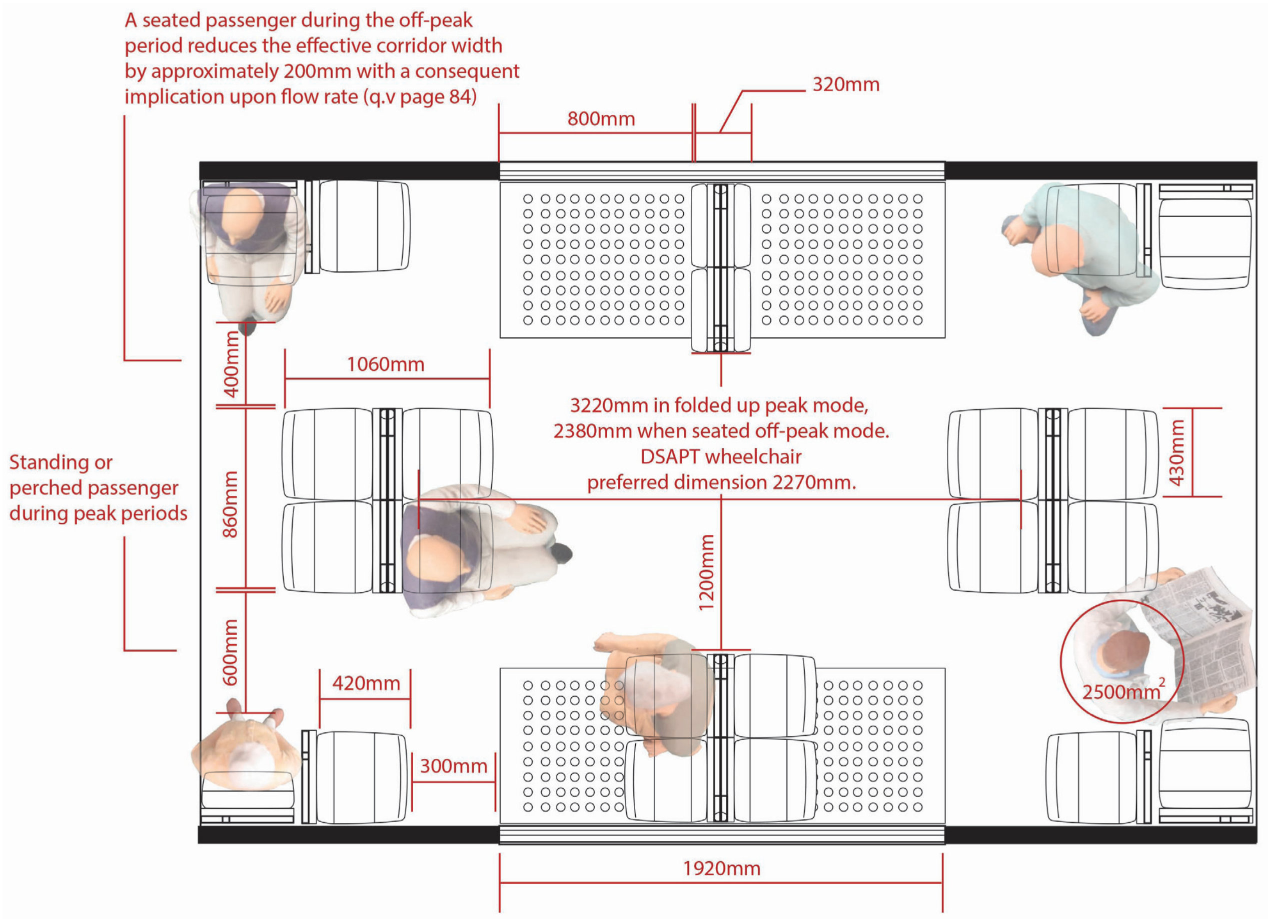


Figure 10.5 Spatial compliance dimensions for the peak door vestibule

10.2.3 Operational criteria for variable seat deployment

Central to the operation of the folding seats and the peak doors is the operating protocol in which they would be deployed. This aspect of the project is the most challenging to prevailing cultural norms. The literature review revealed the high level of importance that passengers attach to the opportunity to take a seat on a train. In this research, one outcome is to suggest an operating system in which during the start of services running during peak time, very limited seating is available and most passengers are obliged to stand or perch on the folded up seats. The ability of an on-board guard to reconfigure the train's interior to suit prevailing conditions, i.e. more standing when crowded and more seating when patronage diminishes, is a challenging proposition to current practice. However, as presented in 7.4 these challenges can be attuned to network demands.

Figure 10.6 shows a full scale mock up of the seating as it pertains to the vestibule area.

Figure 10.6 Outcome 3; Variation of spacial area created by folding seating. Shown here in the full size mock up form.

10.3 Limitations to the study and opportunities for further research

This research was built around studio research, which is an empirical methodology. Prior learning from a variety of fields, the literature, informs a specification to which an iterative design process is applied. The outcomes of the process leading to a suggested conceptual solution to the original design problem are limited, largely due to the scale of the artefact (25 m by 3 m by 3.5 m) and the degree to which it could be tested, i.e. the patronage of large numbers of people over a period of time. Therefore the perceived efficacy of the design intervention is predicated on the outcomes of the computational modelling. The ABM results are encouraging in that they show a significant improvement in passenger flow through the concept of multiple doors and dual corridors. This improvement in lowering dwell time was anywhere between 15% and 40% depending on the numbers of passengers boarding. The more noticable improvements at the upper end of the scale came when the doors were busiest.

While computational or agent based modelling is an improvement on the building of a full-size mock up in terms of validity of data, there remain gaps in the knowledge gleaned until such methods can improve in their layers of sophistication. For example, the agents used in the model simulation acted as individuals with simple motivations. There are circumstances where passengers may be in groups and seek to be accommodated in the carriage together. Carrying items, including in the Melbourne context bicyles, is another long with any indication of the affects of wet weather upon platform to door dispersal. Future developments in the refining of this tool can continue to enhance the realism of the simulation from mass movement model to a more sophisticated one that reflects social and psychological mores. These sorts of developments will have wider implications upon a other crowd and spatial design problems such as retail spaces and sports arenas.

Even as individuals, more layered passenger motivations exist in terms of choosing where to sit or stand and in particular next to whom. Individual behaviours, especially in contradicting the intentions of directional signage, might change the smooth flow of patrons. Indeed the breadth of possible passenger behaviours in a new environment is not predicted by the computer modelling. Determing private space and the intrusion of others into it needs to be nuanced to provide realistic passenger distributions. None of these details fundamentally undermine the validity of high patronage dispersal, as tested, but they would add detail. A future developed simulation tool would be enhanced also by the inclusion of more varied alternative rail carriages. This would help gauge a wider range of train dwell time performances under a range of conditions and passenger behavioural nuances.

In terms of the creation of form as an essential element of industrial design outcomes, the physicality has been described in two ways. The full-size mock up of a section of the train describing the key innovation of the peak doors is able to project the visual characteristics of the concept but not the electro-mechanical functioning of the system.

The G-scale model (figure 10.7 page 172) enables the observer a visual impression of the six-car train, as does the two-dimensional imagery.

The results of this study demonstrate that significant effects could be achieved by adjusting the internal arrangement of seating and door operations to suit prevailing passenger numbers. The conceptual design outlined in this exegesis is entirely without comparable industry examples. The flexible manipulation of the space while the train is in operation is new. Other aspects of the contribution clearly need to be dictated by the level of cultural norms that can be modified and encoded in passenger behaviour. The variation of networks around the world would indicate that this is not an unreasonable goal.

Research on crowding in train carriages is a continuously challenging process and future research can continue to explore how insight from the crowd simulation model can help to develop design solutions to enhance the comfort and safety of passengers. The ABM simulation of flexible interiors in the public domain demonstrated major implications for reducing or stabilising dwell times. 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

Figure 10.7 G-scale model (22.5:1).

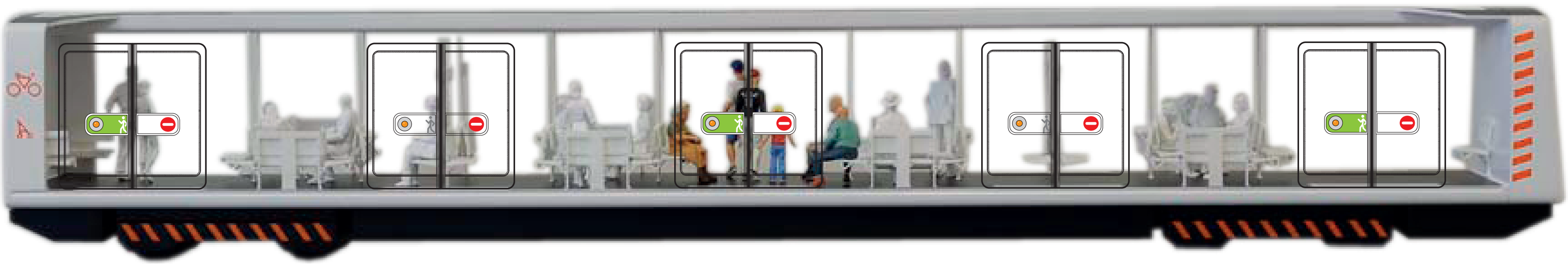


Figure 10.8 An impression of the concept train in service during off-peak mode. G-scale model.

Figure 10.9 Full-size mock up of the peak door vestibule.

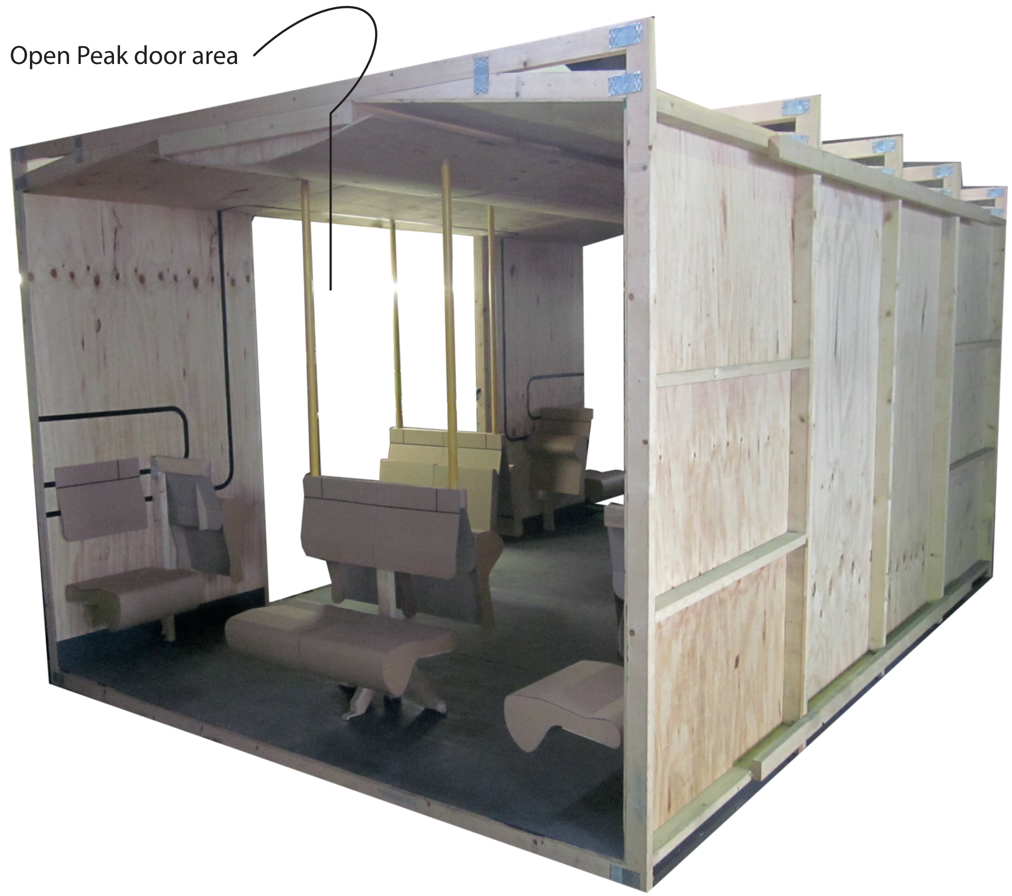


Figure 10.10 Full-size mock up of the peak door vestibule (seen from the exterior).

11

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Appendix

Glossary of abbreviations.

ABM - Agent Based Modelling.
ABS - Australian Bureau of Statistics.
AS - Australian Standards.
BRT - Bus Rapid Transit.
CAD - Computer Aided Design.
CBD - Central Business District.
CCTV - Closed Circuit TeleVision.
DDA - Disability Discrimination Act.
DSAPT - Disability Standards for Accessible Public Transport.
EMU - Electric Motor Unit.
EmSim - Emergency Simulation.
EVE - End Vestibule Entranceways.
G-Scale - Garden (UK) Grosse (Germany) Scale.
MRT - Mass Rapid Transport.
PED - Platform Edge Doors.
PID - Passenger Information Display.
PIXC - Passengers In eXcess of Capacity.
PRM - Persons of Reduced Mobility.
RER - *Réseau Express Régional*, Regional Express Network.
SDE - Short Dwell Entranceway.
SL - Stockholm Lokaltrafik.
SNCF - *Société nationale des chemins de fer français*, French National Railway Company.
TOC - Transport Operating Company.