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Impact of Rolling Stock Dimensions on Passenger Movement

Introduction

Mainline trains are normally designed to achieve a particular maximum speed, or carrying capacity, or for passenger comfort. Many metro vehicles reflect requirements to enable passengers to alight and board quickly, but only more recently (perhaps as a reflection of the growing demand for suburban rail services) have these issues been considered for mainline rail rolling stock.

The demand for passenger railway travel in Norway has increased significantly in recent years, especially in the Oslo area. This has been driven both by economic conditions (e.g. increasing population, and the development of the area around Oslo Sentral station) and by improvements to the train service (notably the introduction of new trains and a 10-minute frequency service between Drammen & Lillestrøm).

However, further new trains are going to be needed, and these will certainly need to consider their impact on station stop times, particularly when operating through the Oslo tunnel and especially at Nationaltheatret station, which is the bottleneck on this route. Current peak passenger alighting and boarding rates there are c. 1.1 and 0.85 passengers/second respectively at the critical door.

This note is structured as follows. A brief introductory section outlining the relevant factors is followed by a summary of the relevant international research. The main section of this note uses the best available information to assess the likely impact of rolling stock variables on passenger movement rates, parameter by parameter. A summary table of that demonstrates the relative impact and importance of each. A final section addresses the specification of new rolling stock designed to benefit from what is known, and how that might be evaluated if non-compliant designs are submitted, either to a Government authority and/or to a rolling stock leasing company.

Theoretical Background

There are several categories of factors affecting station stop times, including:

- the quantity of demand for travel, and the characteristics of those passengers (e.g. mobility, group size);
- the physical characteristics of the platform (e.g. its height, width, distance to exits);

- the design of the timetable (e.g. the frequency and even-ness of services affects the number of passengers per train);
- service regulation (is regularity maintained in practice?)
- station management (e.g. are there staff around to help with dispatch or information?);
- the design of rolling stock.

This note concentrates only on the last category of these, which is a key element but which needs to be understood in relation to the context of the others. In particular, the time required for passenger movement through doors is that left over, after platform reoccupation and station function (e.g. door opening & closing, despatch) times have been subtracted from the line headway.

Previous Research

Progress in understanding the impact of specific elements of rolling stock design upon passenger alighting and boarding rates has been made by a number of groups, including:

- Operational research work carried out by Gerry Weston at London Underground (1989);
- Ongoing work by Prof Ullrich Weidmann and others at IVT, Zurich;
- Wiktoria Heinz's PhD at KTH Stockholm (2003);
- University College London's PAMELA train mock-up;
- International rail benchmarking work carried out by RTSC Imperial College, London;
- Operational research carried out by the Railway Consultancy, for a range of train operators;
- Recent workstreams at the universities of Napoli (d'Acierno et al) and Panama (Alvarez et al);
- Work in Hong Kong (e.g. Lam et al 1998).

Weston established that the relationships with the number of alighters (A) and boarders (B) were non-linear, typically being of the form time/person = f (A^0.7). He also noted that there was an important interaction term A * B, and that the effective width of train door was enhanced by the presence of standbacks.

Weidmann's 1994 paper noted that the relationship with door width is of the form
Flow = f ($d^{-0.1}$)
with the exact value of the function being larger for the wider door spacing that occurs in suburban rail.

Heinz's work was physiologically-based, obtained data for a wide range of train types in Sweden, and noted the need to enable simultaneous movements if capacity was to be maximised.

RTSC has been able to demonstrate a similarity of rates across the world, and to derive (through multiple linear regression) specific parameters for a range of attributes of the underlying factors, including rolling stock. Rolling stock attributes enumerated (Harris et al, 2014a) include stepping distance, seating density, inter-door distance, car area/door width and standback – although, interestingly, some of these apply only to either alighting or boarding, and not both.

The Railway Consultancy has provided a number of valuable insights relative to the academic streams of work. First, we demonstrated the impact of stepping distance (RCL, 1996). Secondly, we proved (Harris, 2006) that the interaction term in the LU (London Underground) formula broke down at the highest loads, which is important in the design of rolling stock for really busy locations. In work with NSB (Harris et al, 2014b), we demonstrated that the relationship of passenger movement rates to door width is not linear.

Actual passenger flow is of course dependent upon a wide range of other factors, relating (for instance) to specific passenger characteristics, the weather, and the adherence of the service to the timetable. Alternative approaches to dealing with this include assuming some random variation around a best estimate value, and attempting to isolate specific factors at locations where they are important; latest research from the Railway Consultancy seems to have quantified the impact of luggage on passenger movement rates (reducing them by 81% in the conditions surveyed).

Ensuring Good Performance Through Design

Given the research that has been undertaken internationally, this section aims to provide guidance as to the optimum parameters for rolling stock design. Given Norske Tog's business objectives, we concentrate on trains designed for suburban operation on mainline railways.

Steps in and out of the Train

Heinz's research highlighted that the brain can automatically cope with minor gaps in a walking surface of up to 15cms, but above that has to make specific adjustments. This is the physiological theory behind the importance of avoiding steps – either between the train and the platform, or within the train. Level entry into trains is therefore very important for passenger flow reasons, the importance of a lack of steps of course being increased by the modern requirements for access by the mobility-impaired.

Much of Norske tog's existing fleet scores poorly on this measure (Figure 1 shows one of the stepped entrances to a Type 72). Because demand has risen, and the impact on passenger movement rates of steps into/out of trains is significant, future train builds must address this.

Figure 1. Entrance to Class 72 with Steps, Lysaker

Door Width

Pedestrian planners normally assume that people are 55-57 cms wide. However, there are established 'edge effects', in which it can be shown that people do not like touching either other people, or walls, doorframes etc., for which an extra allowance is needed. From this we can deduce that the minimum width for a train doorway needs to be at least 130cms if two people are to pass side-by-side. The benefit of having doors not able to cope with this width is substantially reduced, even though passengers can move 'shoulder-to-shoulder'. Note that this width needs take account of any obstructions such as hand rails.

There is potentially another step in the benefit of door width at around 1.8m (for really densely-trafficked urban areas); conversely, the existence of edge effects on both sides means that single doors should not be less than around 0.9m. The evidence to support this is provided from international benchmarking data published in Harris et al (2014b) and reproduced below in Figure 2.

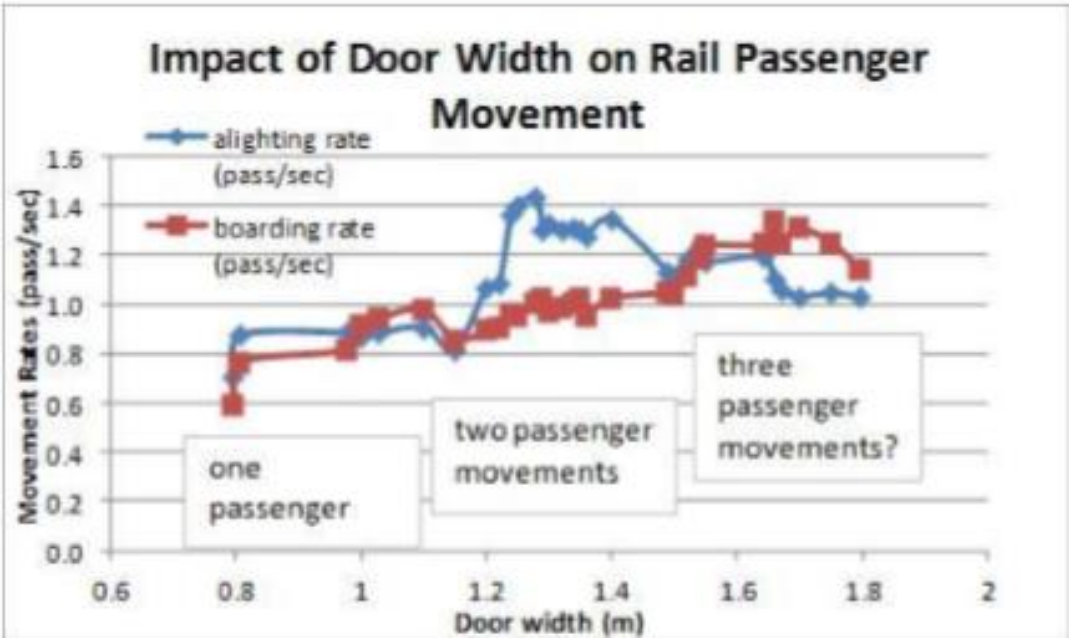

Figure 2. Impact of Door Width on Rail Passenger Movement
Source: Harris et al (2014b)

Standback Width

The purpose of a standback is to enable a person or large piece of luggage to be stored in a train vestibule without interfering with the effective door width. This means that standbacks have to be around 30cms deep, since this is a typical length of a human foot. Our judgment is that the benefit of increased standback size rises rather more slowly after that. In contrast, a standback of less than 20cms is not likely to be very useful at all, which raises the possibility that, in a vehicle with limited space, it may be better to have one large standback than two unhelpfully-small ones.

Number of Doors and Door Spacing

Doors provide the access into, and egress from, vehicles. The ratio of the number of them to the size of the train gives an indication of the relative quantity of doors. That, in turn, determines the number of passengers likely to use a particular door, whilst a variant of that (the number of passengers at the critical door) is a direct determinant of station dwell time.

Although variations in seating density mean that the number of seats per vehicle may vary significantly, the total capacity of vehicles varies somewhat differently (because standing passengers take up broadly only half the space of seated passengers). For a vehicle 20-25m long, one might expect a capacity of 80 seats in a fully-seated configuration, but only 40 seats in a longitudinally-arranged metro configuration, but the vehicle capacities might be 100 and 200 respectively. Typically, the number of doors per carriage would be 2 and 3-4 respectively, maintaining a ratio of 40-65 passengers per door.

However, that potentially gives a perversely-appearing set of indicators, with the number of passengers per door being greater, for inner-suburban stock. It might be preferable to assess appropriate door provision on the basis of the number of seats per door. In an outer-suburban vehicle with 80 seats and 20 standees, 2 doors gives 40 seats/door; in an inner-suburban vehicle with 50 seats and 100 standees, 2 doors gives the seemingly-more onerous 25 seats/door, but which should be sufficient in such a more open type of vehicle.

For a suburban rail vehicle, a door less than one every 10m of train length is unlikely to provide sufficient vehicle access/egress, whilst doors every 6m of train length or less are more appropriate for high-density urban operations. The adequacy of other stock types can be judged from the expected number of passenger movements at the critical door, and the time available at the busiest station in which to make these movements.

Doors which are widely-spaced increase the time it takes for boarding passengers to reach the door, and hence reduce the density of passenger flow. Vehicles designed for longer distances typically have end doors, thereby permitting an increase in comfort (air flow etc.), whilst those for suburban operations are better fitted with doors at 1/3 : 2/3 spacing. This typically reduces the inter-door distance from 3m & 21m to a more even 8m & 16m.

Seating Density

Passengers take up more space when sitting down (c. $0.5m^2$) than when they do standing up (c. $0.25m^2$). However, there is often pressure from (politicians acting on behalf of) longer-distance commuters to provide as many seats as possible, on the grounds that passengers do not like standing. Whilst this is true, it fails to recognise that increasing the number of seats in a railway carriage actually reduces its total capacity.

In addition, increased seating density reduces the area within a passenger vehicle in which one can move around, thereby reducing the speed at which one might do so. This then provides a second-tier (negative) impact on alighting and boarding rates.

Double-deck stock scores particularly badly on passenger alighting and boarding rates. Not only are there typically many seats per floor space, but the total door space per passenger is low, and vehicle construction usually means that these trains have end doors, increasing the spacing between doors.

This all suggests that Norske Tog might reasonably limit the seating density of acceptable designs, perhaps to those <1 seat/m^2.

Aisle Width

Conceptually, one might consider the width of the aisle of a train to be as much of a bottleneck as the train door itself, especially once boarding passengers wish to access the seating area itself; this can either be because (a) the vestibule is sufficiently full, or because (b) passengers really want a seat. In fact, preliminary analysis we have carried out suggests that the impact starts to become noticed immediately, and is not dependent upon (a). This supports learned best practice where aisles are widened at their vestibule end, providing a funnel-shaped aisle if high seating densities are required, since this encourages/facilitates boarding passengers moving into the seating area and away from the doors.

However, aisle width impinges most nearer the ground, not at shoulder height where humans are often widest. This means that an acceptable minimum for aisle width at waist height might be as low as 0.45m.

Other Features

Other in-vehicle features can also encourage quicker alighting and boarding – for instance, through the provision of external vehicle-mounted indicators (giving notification of destination, occupancy and features such as the location of wheelchair spaces), or internal vehicle-mounted indicators (giving notification of the direction of platform exits (stairs or lifts), connecting services etc.).

On the other hand, other features (which are nevertheless required in a train) are known to have a negative impact on passenger movement rates, so it is the positioning of these which matters. At stations only served by entrances/exits at platform ends, it may reasonably be foreseen that the critical door will be that end door (in contrast to stations served by entrances mid-way along the platforms, when passengers tend to spread themselves out amongst several doors). It is therefore sensible to avoid having capacity-reducing features (such as the ramps needed to assist wheelchair users) at the ends of trainsets, since this is likely to compromise station dwell times where the critical door is at one end of the train.

Impact of Features

Several of the features discussed above have had sufficient research done to be able to quantify them with statistical confidence, whilst the impact of others has not yet been proven (perhaps because of a correlation with other variables, or because results are not statistically-significant), or is only known by direction (i.e. a change makes things better). Evidence from both types of these is shown in Tables 1 & 2 below.

Factor	*Units*	*Change*	*Impact on rate/pass*
Vertical platform : train gap	M	+ 10 cms	-13%
Steps into/within the train	M	Removal	+ large
Door aperture width	M	+ 10 cms	+5%^
Standback width	M	+ 10 cms	+ small
Car area per door	m^2/m	- 6.5	+ small
Average inter-door spacing	M	+ 1m	-2%
Seating density	seats/m^2	+ 0.1/m^2	-1.6%
Aisle width	M	+ 10 cms	*+4%*
Interior indicators	yes/no	Addition	+ very small

Table 1. Summary of Rolling Stock Design Impacts on Passenger Alighting Rates

N.B. A change of + 6.5 m2/m car area per door is approximately that which results from moving from a 2-door carriage to one with 3 doors. This door excludes the benefit of reducing the *number* of passengers at the critical door.

^: non-linear relationship – see text. Values in *italics* estimated

Factor	*Units*	*Change*	*Impact on rate/pass*
Platform : train gap	m	+ 10 cms	- medium
Steps into/within the train	m	Removal	+49%
Door aperture width	m	+ 10 cms	+5%^
Standback width	m	+ 10 cms	+2.6%
Car area per door	m^2/m	- 6.5	+4%
Average inter-door spacing	m	+ 1m	- small
Seating density	seats/m^2	+ 0.1/m^2	- small
Aisle width	m	+ 10 cms	*+4%*
Exterior indicators	yes/no	Addition	+ very small

Table 2. Summary of Rolling Stock Design Impacts on Passenger Boarding Rates

N.B. A change of + 6.5 m2/m car area per door is approximately that which results from moving from a 2-door carriage to one with 3 doors. This door excludes the benefit of reducing the *number* of passengers at the critical door.

^: non-linear relationship – see text. Values in *italics* estimated

Specifying New Rolling Stock

There is a wide range of attributes to be considered when specifying new rolling stock, and these vary by the intended market for the trains concerned. For Norske Tog, excluding the specialist sleeper and airport access services, different potential markets include:

1. long distance (e.g. Oslo – Trondheim);
2. “inter city” (e.g. Oslo – Halden, Skien and Lillehammer);
3. outer-suburban (e.g. Kongsberg – Eidsvoll);
4. inner-suburban (e.g. Spikkestad – Lillestrøm)

However, whilst for each of these the balance between factors such as comfort, seating density and passenger movement varies, markets 2-4 all pass through the Oslo core tunnel and its bottleneck at Nationaltheatret. As a result, trains for all these markets do need to take significant account of passengers’ ability to alight and board easily. Although this factor is most important for market 4, what is less clear is the proportion of any total ‘score’ of a vehicle type which should be allocated to boarding & alighting, and how this might vary between the vehicle types.

However, within the score allocated for passenger movement, it would seem logical to allocate the most marks for those aspects of design which have the greatest impact. Table 2 shows that the biggest impact is the avoidance of steps upon entry, so they should be heavily penalised within any submitted design of rolling stock.

An alternative way of applying these criteria would be to specify the maximum time within which a given number of passenger movements had to take place. Given the need to maintain headways of 2.5 minutes or less, and the requirements for other functions (e.g. door opening & closing, platform reoccupation) also to take place, that maximum time might be set at 35s (with a target of nearer 30s). Data from Nationaltheatret shows that passenger flows are not balanced (there being more alighters than boarding passengers in the a.m. peak, and the opposite in the evening), and that appropriate targets might need to allow for 20 boarders and 10 alighters. An approach such as the modelling work carried out at Imperial College (2014a) could then be used to estimate the performance of suggested rolling stock, as part of a wider judgment of that rolling stock's acceptability.

Conclusions

The characteristics of rolling stock are a key element in the overall design of a railway, and directly affect the capacity which can be offered. In the Norwegian context, the design of suburban trains needs to fit with line capacity constraints through the Oslo tunnel, and in particular at Nationaltheatret.

Several criteria have emerged as worth stipulating for the Norwegian suburban rail context:

- A maximum car capacity of 40 seats/door;
- Doors to be at least 1.3m wide;
- Doors to comprise between 1/6 and 1/10 of the length of the train;
- Door spacing to be as equal as possible along the length of the train;
- Standbacks of at least 0.3m to be provided on at least one side of each door;
- The gap between platform and train to be minimised;
- Steps in the doorways of trains to be avoided;
- Seating densities to be a maximum of $1/m^2$; and
- Aisles to be at least 0.45m wide.

However, some of these criteria need to be amended for vehicles designed for inner-urban markets and having with a lower number of seats viz.

- doors to comprise between 1/6 and 1/8 of the length of the train;
- seating densities to be a maximum of $0.85/m^2$;
- aisles to be at least 0.5m wide

As a result of the importance of the Oslo tunnel bottleneck, Norske Tog is also encouraged to require suppliers of trains to ensure that expected flows of e.g. 20 boarders and 10 alighters can be accommodated within a given time (35s or less).

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