Norske Tog

Options for Metropolitan Area Railway Rolling Stock

FINAL REPORT

Updated February 2025

The Railway Consultancy Ltd

47 Burnhope Lane, Darlington. DL2 1FL. UK.
T: 020-8676-0395
W: www.railwayconsultancy.com

Options for Metropolitan Area Railway Rolling Stock

Executive Summary

E.1 The subject of the potential for double-deck trains in Norway has arisen again. Norske Tog, as rail leasing company, has asked the Railway Consultancy for an independent review of this, taking into account practice elsewhere in Europe, and estimating the impact on passenger movement times of different train types available in the market.

E.2 Passengers may be much concerned with getting a seat, but as the demand for rail travel in Norway has increased, some now cannot board trains at all. The expected level of passenger demand is therefore a key assumption. However, this is currently a difficult time to be estimating rail passenger demand; not only did the Covid pandemic affect traffic, but some of the underlying economic trends (e.g. the relationship between personal income and travel) were already showing signs of changing before this.

E.3 Any assessment of the impact of the capacity of different train types MUST take into account the wider elements of railway capacity (along a line, across a network) in a proper consideration of 'systems engineering'. Signalling systems, junction and timetable design all significantly impinge upon the capacity of a rail corridor, at least as much as rolling stock type, and all are affected by it (and vice versa).

E.4 Railway rolling stock capacity can be enhanced in various different ways, both within vehicles through differences in internal layout and (the focus of this report) the provision of extra floor-space. The latter may be achieved by having double-deck vehicles, longer fixed trainsets, long trains comprised of several shorter trainsets, or adding extra carriages. On the other hand, internal layouts with more seats actually *reduce* the total passenger-carrying capacity.

E.5 Using parameters derived from a peer-reviewed model, we have estimated the boarding and alighting times expected at the pinch-point station of Nationaltheatret in the cross-Oslo tunnel, for a range of different train types currently available for purchase. These results show that the single-deck N06 trains already in service in Norway would be expected to be at least 5 seconds quicker than any of the double-deck alternatives.

E.6 A comparison of other relevant countries demonstrates a range of approaches. However, what is clear is that, at the highest levels of demand, the generally-accepted solution is to have spacious single-deck trains. These can carry the greatest numbers of passengers and enable the operation of relatively-short station stops, which are essential, if line capacity, train frequency and journey times are to be maintained. More seats per train are not available without trade-offs with other negative consequences.

E.7 A consideration of the Norwegian situation notes that the Central Oslo tunnel is currently under pressure, but only from it having a combination of trains from different market segments passing through it. There are constraints elsewhere on the network (notably platform lengths) whilst, from an efficient operational and maintenance point of view, flexibility (and hence cost-effectiveness) is best achieved through having fewer different types of train. Purchasing more of the train types already on order would be the quickest way of increasing the rolling stock vehicle fleet.

E.8 Whilst one can identify a few train services in Norway for which double-deck trainsets might be appropriate, these are situations where there is not a capacity problem (e.g. Oslo – Halden, which does not traverse the Central area tunnel). It is also unclear if there is a market segment large enough to make it worthwhile having such trains. Given uncertainties about both future demand and capacity, solutions providing flexibility are to be preferred, which might indicate buying more of the existing train types until greater certainty is achieved (e.g. regarding the opening date of the second cross-Oslo tunnel).

Contents

Tables

Figures

Glossary

BMU	Bi-mode Multiple Unit: several permanently-coupled carriages with driving cabs at each end of the trainset, and two different power sources (e.g. diesel and electric)
DMU	Diesel Multiple Unit: several permanently-coupled carriages with diesel engines under one or more of the vehicles, and driving cabs at each end of the set
EMU	Electric Multiple Unit: several permanently-coupled carriages with electric traction motors under one or more of the vehicles, and driving cabs at each end of the set
headway	the time (or distance) between two successive trains
mppa	million passengers per annum (year)
pphpd	passengers per hour per direction
PRM TSI	Persons of Reduced Mobility Technical Standard for Inter-Operability (European standard)
saloon	that part of the train dedicated to seating/comfortable standing during transit
SDO	Selective Door Opening: controls fitted to train doors, to enable the driver or conductor to open some (but not all) of the doors of a train
tph	trains per hour
vestibule	that part of the train between the doors

Document control

Version: 1

	initials	date
Written:	NGH	18/02/25
Comments:	NT	
Updated:	NGH	
Authorised:	NGH	

1 Introduction

1.1 Background

From time to time, when discussing options for new trains in Norway, the use of double-deck trains is suggested. Further to a KVU (choice of concept report) on the future policy for railway rolling stock in 2022, this issue came to the fore again in early 2025. Norske Tog, as the country's rolling stock leasing company, was invited to provide input, and asked the Railway Consultancy Ltd for an independent review, sharing the concepts used in other countries but also making a pedestrian evaluation of the double-deck train options currently available in Europe.

The choice of rolling stock is a key problem for railway operators and Government sponsors alike. It is a significant capital item (only 7 trainsets at 150m NOK each is 1 bn NOK), which necessitates a formal decision-making process, preceded by appropriate analysis, as specified in Norwegian Government circular R108/19 (Norske Finansdepartementet, 2019). Since rolling stock should last at least 30 years, this decision arises only periodically, which creates further problems, such as a lack of experience. In Norway – as in many countries – this is also a decision into which politicians enter, asking key questions to which a substantive answer is required. One of these key questions is whether trains should be of single- or double-deck design.

This is a critical issue which affects not only rolling stock but also the capacity of rail infrastructure (including signalling headway and platform lengths). NSB produced a report on this in 2014 ("Toetasjerstog i Norge?") but the railway environment has changed since: a significant increase in patronage was recorded in the following 5 years after that report followed, of course, by the Covid pandemic which has changed travel patterns further. The Jernbanedirektoratet produced a report in 2021 about the potential lengthening of trains to 12 cars (c. 300m) in the Greater Oslo area, to accommodate expected traffic growth. That report started to set out some of the implications of such a strategy (for instance, on platform length), correctly noting that train lengthening was only one strategy for increasing railway capacity, another being the use of double-deck trains. The high infrastructure costs associated with platform lengthening led Jernbanedirektoratet to suggest that double-deck trains might be preferable, although more work was needed to understand the practicalities of such trains.

It is therefore an appropriate time in which to reconsider this issue in the context of the Norwegian railway. This report has been commissioned by Norske Tog, rolling stock lessor – and potential purchaser of new trains for Norway, whether of single- or double-deck. After a discussion of the wider problem of which trains are only a part (below), this updated report considers different ways in which rolling stock can contribute to the capacity of a railway (section 2), analysing in more detail than before the potential capacity available with different train types. It then (section 3) examines evidence from comparable and nearby countries to see what decisions they have taken, and why. Section 4 brings that material together, to see what might be most appropriate for the Norwegian context, whilst section 5 contains our conclusions.

1.2 Passenger Requirements

What do Passengers Want?

The key requirements of a passenger rail service are well-understood to reflect (in journey order) easy access to/from stations, reasonable fares, service frequencies and journey times, and no need to change trains en route. All of those may be considered the absolute basics. In terms of what passengers complain about for a given service, however, service unreliability and getting a seat are often mentioned.

One might therefore think that, when designing rail rolling stock, providing as many seats as possible was a key target parameter. That may particularly resonate with many Norwegians, used to a country and railway with lots of space. However, as population and demand increase in the Greater Oslo area, train services have been struggling to cope. With the Oslo tunnel nearing capacity in terms of the number of trains being run through it, passengers are now sometimes finding themselves unable to board a train at all.

At this point a different, "systems", view needs to be taken, a view which is explained in more detail in this report. In order to carry more people within a given railway infrastructure, one of the best options is to *remove* some seats, as this increases the passenger-carrying capacity, both physically and operationally, as is described in section 2 of this report. Passengers are rightly even more annoyed by an inability to board a train at all, rather than not getting a seat. Worse, delays at stations from inappropriate rolling stock can lead to a reduction in the train service frequency (and hence capacity) offered. In congested urban areas, therefore, considerations of the most appropriate type of train should not solely be about seat availability, but about serving passenger demand in a wider sense.

Future Passenger Demand

At first sight, it might appear beyond the scope of a report on rolling stock types to discuss demand forecasts. However, the overall level of demand is critical to the quantity and type of train service capacity required and hence is supremely relevant.

At the time of writing, railway demand in Norway has already substantially recovered from the impacts of Covid, but one needs to consider expected future trends. The Norwegian Government has a transport model for Eastern Norway which is used as a key part of the National Plan. That model forecasts that demand growth for rail transport is expected to arise both from increased population and from policy measures designed to manage economic growth sustainably. However, the link between economic growth and transport growth is weakening around the world (Metz, 2022, chapter 2) so the underlying assumptions may need to be challenged. This is especially the case for peak commuting travel, which is the key driver for the capacity increases sought here.

Because of its positive externalities[1], rail transport is seen to be a 'good thing', so there is an implicit assumption that demand should be satisfied at reasonable quality levels (rather than being priced away from the high peak or deterred through congestion). However, it is not entirely clear whether the train service frequencies set out in the Grunnrute tables are those thought to be required to provide the capacity expected to be needed (if so, every day, or only to cope with demand variability?), or those thought to be appropriate (marketing/policy-wise) for the expected level of demand (which may not be the same). A particular issue in Norway has been that of Flytoget services through the Oslo tunnel, where the policy-led train service frequency is considerably higher than the capacity-based need; reducing Flytoget services would enable other trains, with greater capacity, to run. As capacity constraints exist, there are also affordability constraints to these trade-offs.

Whilst there are wider economic agglomeration benefits from enabling the easy exchange of people between adjacent urban areas, technology may also enable a reduction in travel (as was seen from the increased amount of home-working and on-line meetings during the Covid pandemic).

Thus there are two important lessons we can draw from this. First, all railway planning work needs to be couched in context of the economy of the area, and changes in assumptions about that will feed through into the choice of appropriate policies for the railway. One concept that not discussed much

---

[1] Externalities are wider, usually-unpriced, social benefits arising from an activity such as operating a railway; a classic example of these benefits are their environmental impacts

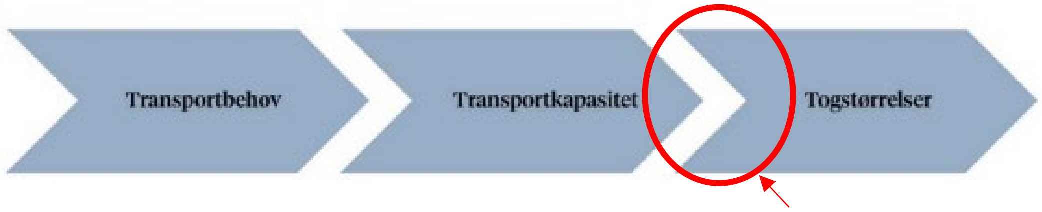
in Norwegian railway documents is that of demand management: whilst creating mixed land-use neighbourhoods to enable people to walk to work (rather than need to travel by train) is under consideration, a wider reduction in the dominance of Oslo might also be helpful. This could occur through the transfer of some offices out of the city centre to other locations within the region, either by Government direction, or as a result of market forces if city-centre rental prices get too high. In Norwegian rail planning documents, we see almost nothing said about the ability to use pricing to manage demand – either in absolute terms (pricing off demand completely), or (using the flexibility afforded by electronic ticketing) to spread the peak. London has a notably flatter peak period than cities such as Oslo because congestion has led to passengers choosing a wider range of travel times, but using pricing to achieve that is perhaps economically-preferable to using congestion.

Secondly, some of the options for addressing railway capacity have impacts on that level of demand: as well as affecting crowding, solutions involving *more* train services clearly increase demand by reducing waiting time. This is fundamental: there are many factors which determine the overall attractiveness of a train service, which is technically described through the concept of generalised cost (Harris et al, 2016). Within this index of travel difficulty, crowding and waiting are both valued more highly than journey time, so these apparently-second-order effects can be more important than might be thought. This is also exemplified by the tremendous increase in passengers caused by the new train service pattern introduced in the Oslo area from 2012.

As there is some uncertainty about much of the above, any solutions providing temporal or geographical flexibility instead of investment in fixed assets have an inherent advantage.

1.3 Maximising Capacity

The choice of type of train can easily be offered as a solution to a railway problem (e.g. excess demand) without considering what stakeholders are trying to achieve. Rolling stock is not an end in itself; rather, it is part of an overall transport solution. The normal problem it is suggested to address is that of capacity, but railway capacity is quite difficult to define. However, the diagram presented on page 19 of Jernbanedirektoratet (2021), whilst reproduced below, is inadequate, since it jumps directly from transport capacity to train size, which is incorrect.



Missing steps: line & network capacity

Figure 1. Transport Demand and Train Size
Source: Jernbanedirektoratet (2021), p19.

Train capacity is a function of the sum of the number of seats and standing places, a problem which can clearly be addressed by various rolling stock solutions (different seating configurations, adding more carriages, or using double-deck trains, for instance). The amount (quantity/duration) of crowding permitted is also relevant. However, train capacity is the wrong output, since nearly all railways need to run more than one train at once. We might therefore consider:

Line capacity, which is a function of the trainpaths that can be organised along a corridor. This is a function of the product of individual train capacity and its path along a line. It reminds us that the correct unit of capacity for a passenger railway is passengers per hour per direction (pphpd).

Scott’s formula gives us some guidance about this:

$$C = \frac{(24 - w) \times 60}{T + t}$$

equation 1.1

…where the capacity of a line, C, is primarily a function of T (the time taken for the slowest train on a route to traverse the critical line section) and t (any signal/route re-setting time). 24-hour capacity may be reduced by w, the white period during which a line may be closed for engineering maintenance. This is of particular relevance to Norway, which has many single-track rail lines, in which the possible number of trainpaths per hour may be quite low, especially where there are longer distances between passing places. This limits the possibility of increasing train service frequency as a policy for addressing current capacity shortfalls, although technological advances in signalling systems may reduce this problem a little.

However, line capacity is itself affected by various other factors. For instance, acceleration and braking rates, maximum speed, and station stop performance all affect T directly or indirectly, in their determination of the minimum signalled headway. That is also affected by details of the signalling system; for a line signalled with conventional 4-aspect equipment, the headway (defined as the time between successive trains) may be defined as

$H = S + 1.5D + O + L$ equation 1.2

where S = signal sighting distance
D = train braking distance
O = length of the safety overlap
L = length of the train

Unfortunately, the timetable operated (in terms of the ordering of trainpaths), the difference in time T between the slowest and fastest trains ($T_s – T_f$) and the capacity of terminus stations all also affect line capacity. Changes to stopping patterns and origin:destination pairs may also impact on line capacity and rolling stock decisions; we note that preventing some Østfold services from running through the Oslo tunnel would enable greater rolling stock flexibility in it. So line capacity is both difficult to define, and arguably not the correct measure either, because most railways have more than one line.

Network capacity is therefore even more complicated, not only being a function of all the factors already discussed, but depending on the number, location and type (i.e. flat or grade-separated) of junctions. Even the detail of the length of turnouts/points matters, because this will determine the speed at which trains may diverge. But it does mean that a particular rolling stock solution must form part of the solution to the problems of the whole network (or, at least in the case of Norway, the Oslo-area network) without exacerbating problems on other lines.

We also note that network considerations should also include its extent. Norway does not have a particularly-dense railway network (even in the Greater Oslo area). One possible solution to some line and network capacity issues would be to increase the extent of the network, thereby spreading the burden of providing capacity more widely. Consideration is already being given to a second cross-Oslo tunnel, and a direct line from Sandvika to Honefoss. However, these projects seem to be driven by capacity constraints and time savings respectively; we have not seen mention of two very significant passenger benefits of such an approach: (i) easier access to the network; (ii) greater network connectivity and hence ability to serve a wider range of potential trip patterns. A third potential benefit – of equalising congestion across parallel routes – does not occur in Norway outside the Oslo metro area, because almost no-one has a choice of railway routes.

All the above are important, as such measures might limit the need for a city of only c. 1m people to need to be served by 12-car trainsets of long vehicles (which would be unusual in a European context). Current plans even seem to be inconsistent about this: if there is to be a second cross-Oslo tunnel, then the capacity constraints on the current one will be reduced, and options for increasing rolling stock less important. Whilst understanding that there is a delay in the second tunnel project, its timescales are still not dissimilar to some of the rolling stock fleet replacement options considered in this report. 5 years' more planning, followed by 10 years of construction could still mean that the second cross-Oslo tunnel was available in 2040, when much existing rolling stock is still in service.

Cross-cutting issues: Railway capacity problems need to be considered in different time-spans. New lines take a long time to plan and build, so it is possible that rolling stock-based solutions (such as double-deck trains) might be helpful in the short- or medium-term whilst that new infrastructure is brought into use.

Lastly, all of the preceding definitions need to be taken in the context of the level of reliability (punctuality and cancellations) deemed to be acceptable. This is because there is an x^2-type relationship between railway punctuality and capacity utilisation, as shown in Figure 1.

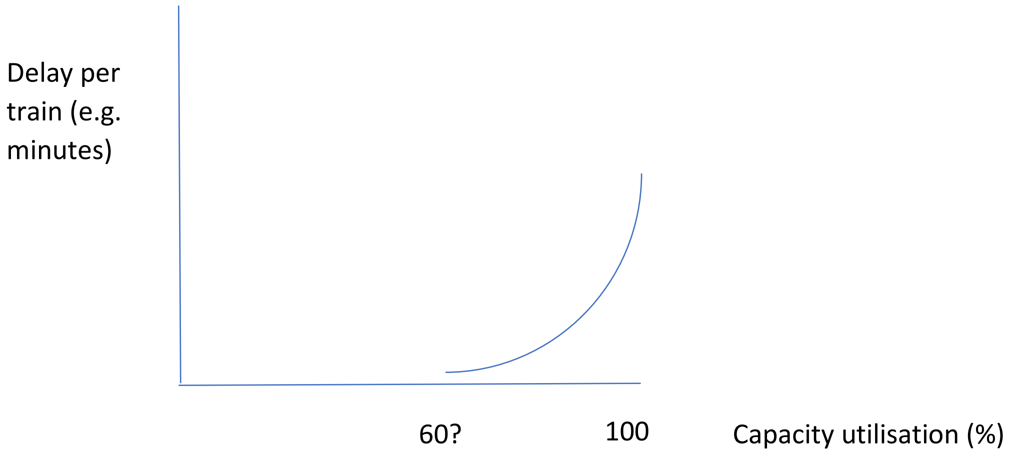


Figure 2. Illustrative Representation of Impact of Capacity Utilisation on Railway Performance

In summary, consideration of any type of rolling stock as the solution to a railway problem without considering the wider systems engineering impacts is flawed and can lead to unintended outcomes. In the next section, we therefore look at the wider implications of different types of rolling stock design solution.

2 Implications of Different Types of Rolling Stock Design

This report is not primarily concerned with the interior design of trains, although it is important to recognise the impact this can have on capacity. The provision of facilities (e.g. luggage space, toilets, or vending machines), the disaggregation of accommodation into different categories (e.g. Komfort class), and seating density (the number and arrangement of seats) all affect the carrying capacity of a given number of square metres of train. Importantly, as described in section 2.1 below, the relationship with seats is negative: the greater the number of seats, the lower the capacity.

The focus of this report is instead on the ways in which trains can be made larger, in terms of floor area. For completeness, we should note that it is theoretically-possible for the width of trains to vary. However, the railways of Norway use standard-gauge (1435mm) track and have a fixed loading gauge (NO1), which determines the width of trains under bridges, through tunnels etc. Having 5 seats across the train in a 3+2 formation is already possible (if not entirely comfortable), but NO1 prevents the use of further width as a solution for rolling stock capacity enhancements, and so this is not considered further.

In the sub-sections below, we therefore discuss the sorts of issues that are associated with different train type solutions. It should be noted that we do not refer to impacts which are readily-overcome technically, even if there may be a financial impact: for instance, trains with a larger profile take up a greater proportion of the cross-sectional area of a tunnel, which increases aerodynamic drag, but drawing extra power is usually possible to deal with this (albeit with increased energy costs).

2.1 Double Deck

Double-deck trains are able to accommodate more seats per train length. That may be a particular advantage for longer-distance commuters who might reasonably expect a seat, although that market segment is in decline after the Covid pandemic. However, because there are more seats, double-deck stock can offer *less* space for standees, luggage, prams, wheelchairs and bicycles. In fact, because a typical European takes up about 0.55m^2 of space when sitting down but might reasonably stand at a density of 4 pass/m (i.e. 0.25m^2 per person), it is possible for double-deck stock to *reduce* the capacity of a train of given floor area. Obviously, it compensates for that by having two levels, but since there needs to be at least one stairwell per carriage, and because 0.55 > 2 x 0.25, there is a significant impact on potential capacity, which therefore may not increase very much: NSB's calculations (see Table 1 below) suggest 21%.

Seated capacity		Standing room		Total capacity	
Single-deck	Double-deck	Single-deck	Double-deck	Single-deck	Double-deck
284	353	343	407	627	760

Table 1. Relative Capacities of Single- and Double-Deck Trains
Source: NSB (2014), Table 3

However, this increase in capacity may not be realised in practice, owing to the difficulty of passengers in finding all the possible seats in a 3+2 seating configuration, since the increased density makes sight along the carriage difficult. Given the relatively-cramped/uncomfortable nature of 3+2 seating,assengers may not be bothered to do this in the first place, especially for shorter journeys.

Nevertheless, even in what may appear reasonable loading gauges (e.g. the European standard), allowing more than 2m height for each deck can be difficult. This can prevent the easy provision of 3+2 seating, particularly in Norway, because the NO1 profile is not very wide, either below 1.2m or above 4m from rail level (see Figure 2). Moreover, there is a minimum aisle width of 450mm in the

PRM TSI, whilst Norway has generally adopted an even wider aisle width of at least 500mm, all of which makes 3+2 seating in double-deck trains in Norway almost impossible.

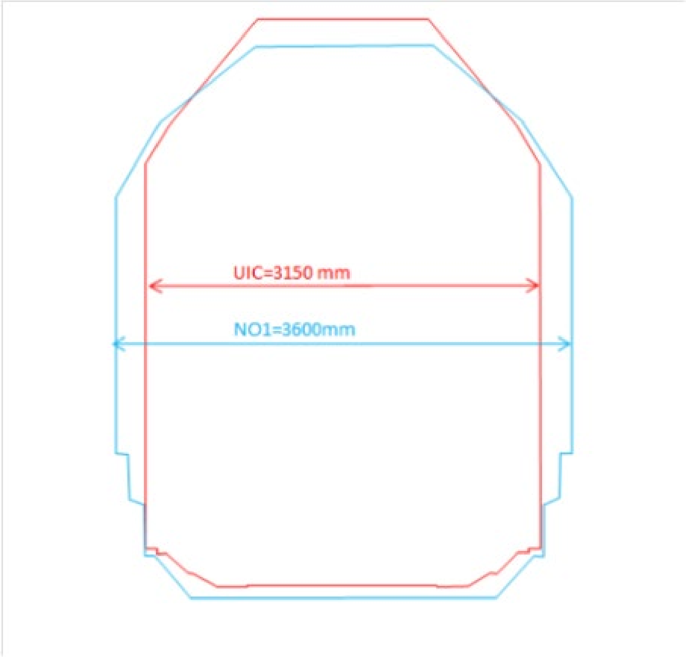


Figure 3. Norwegian and European Train Profiles
Source: NSB, 2014, Figure 1

In summary, whilst 3+2 seating is possible in Norway for single-deck stock (if not ideal), it is not practical on either level of double-deck trains. This constraint therefore works against the achievement of providing more seats/ train length, if providing a reasonable-quality environment for lower seating densities. Moreover, the lack of headroom for the window seats on the upper deck (and, depending upon the exact gauge and train profile, the lack of legroom for lower-level window seats) can be noticeable (see Figure 3). This is a potential problem for countries where people are taller than average (e.g. the Netherlands or Norway). Further, the reduced headroom eliminates the possibility of having overhead luggage racks, so space for alternative provision elsewhere in the train needs to be found.

Figure 4. Upstairs Interior of NS double-deck EMU 9575, Netherlands
Note restriction on height imposed by the loading gauge

Many double-deck train types therefore have lowered floors between the bogies. However, this means that both upper and lower decks may have to be accessed by stairs, leaving the car ends potentially the only places suitable for conveying those passengers with mobility problems (and the associated facilities e.g. wheelchair space, accessible toilet). Some Swedish stock (see Figure 4) has ramps into the lower saloon, but these also take up space.

Figure 5. Ramp into lower level of SJ double-deck EMU 3333, Sweden

The general necessity to have stairs between the vestibules and seating decks creates a potential safety hazard: stairs are a common-enough cause of slips, trips and falls in the station environment, where they are fixed; movement of the train is likely to make matters worse.

The lack of an aisle or walkway at consistent height along the length of a train makes it more difficult for passengers to move through the train to areas of lower passenger density. It can therefore be argued that double-deck stock exacerbates crowding. It is certainly the case that it adds considerable extra effort for staff, rendering ticket-checking more tiring, and making the use of a catering trolley almost impossible. Issues of poorer 'see-through' security can, to an extent, be addressed through the installation of more cameras.

Double-deck trains are relatively heavy, giving higher axle-loads than normal for passenger carriages. The extra weight causes notable extra track wear & tear, which is significant when considering the impact on the total railway. Moreover, there is a specific constraint in Norway, where the network (see Figure 4) largely has an 18-tonne axle-load. This means that double-deck trains may need to have shorter carriages and/or carriages made of aluminium, in order to remain well within weight limits when fully-loaded[2].

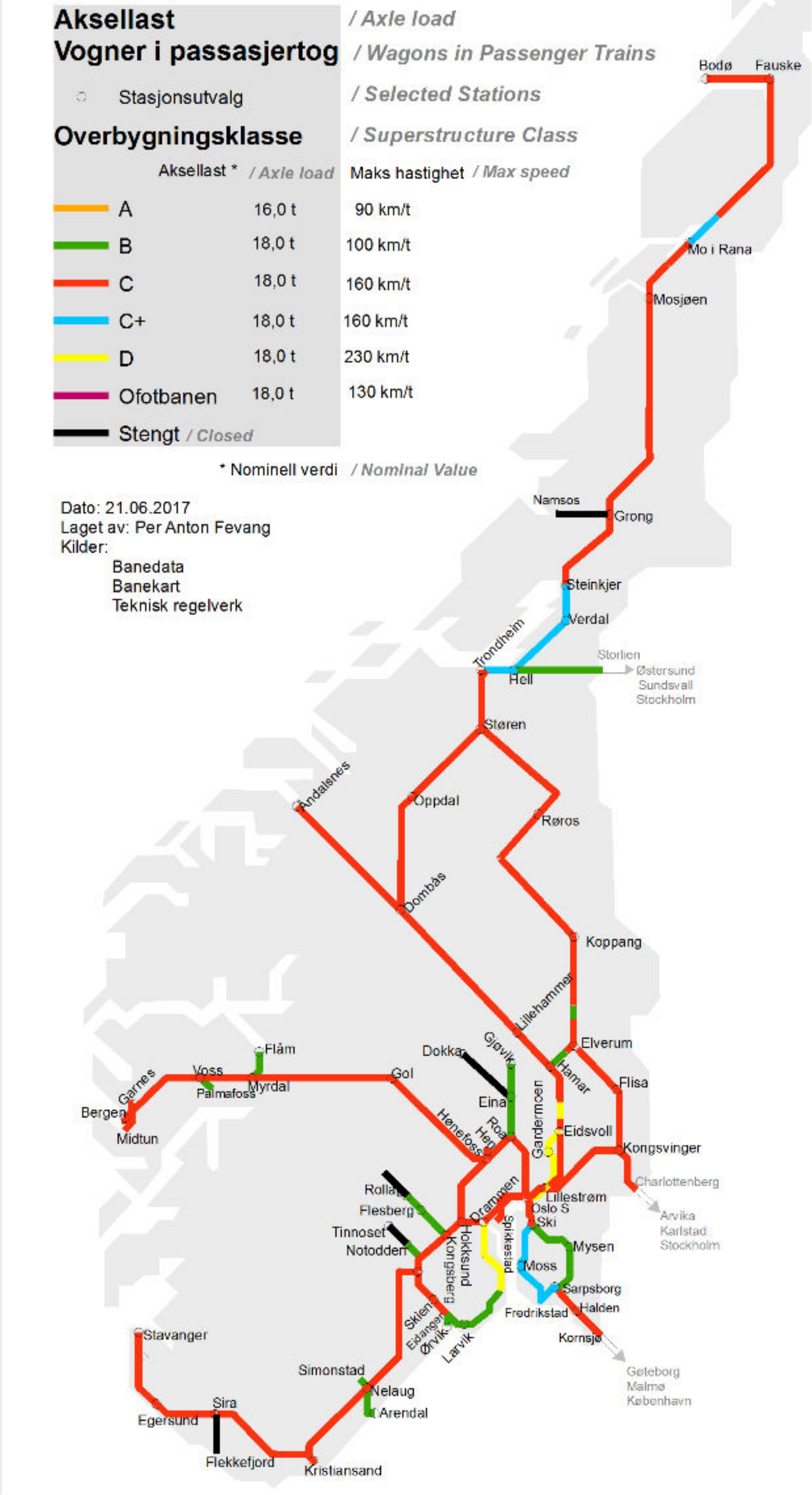


Figure 6. Weight Restrictions on Norwegian Railway Network
(source: BaneNOR)

Vestibules for double-deck trains need to be larger, to accommodate the larger on and off passenger flows, but these are of course areas of poor passenger facilities (e.g. few if any seats). An adequate

---

[2] Note that 100 adults with luggage can easily weigh 10 tonnes

vestibule for single-deck trains might be the 1.4m width of the doors plus a standback of 30cms on one side, whereas for double-deck trains wider doors (up to 1.7m) and standbacks on both sides of the door would be recommended. This increases the length of train by 0.6m per vestibule (1.2m per vehicle) to try to accommodate flows at stations, which therefore reduces the benefits of trying to provide more seats in such a train type. Note also that the provision of wider doors may be incompatible with the air pressures encountered at the highest speeds needing to be obtained (e.g. 200kph).

The biggest disadvantage of double-deck rolling stock, however, is in its impact on station stop times. In urban areas, the definition of signalled headway as set out in equation 1.2 above becomes less relevant, as it is the management of station stops which becomes critical. Broadly-speaking, the impact of station stops necessarily includes:

- braking during the run-in phase
- door opening and closing times
- passenger movement time
- despatch procedures and safety checks
- acceleration during the departure phase

Fruin identified at an early stage of his work (Fruin, 1971) that pedestrians moved at different speeds in different environments, and for understandable physiological reasons, free-flow walking speeds up or down stairs are rather less than on the flat (typically 0.5m/s, compared to >1m/s). This means that the per-person access times of boarders into the different saloons, and the egress times of alighters from them, are higher for double-deck stock than on single-deck trains.

This is compounded by the problem that the number of passengers trying to alight from each door is higher (reflecting saloon capacity at both higher and lower levels). In a single-deck train with 2 doors per car and a capacity of 100 passengers per car, each door is therefore required to be able to deal with an average of 50 passenger movements. For a double-deck vehicle with a capacity of 160 passengers per car, this obviously rises to 80 potential passenger movements per door.

So double-deck trains have more passengers per door, and at slower speeds (because of the steps involved in accessing the different saloons). Recent work by Harris et al (2022), using a large international dataset derived from railway consultancy and benchmarking work, was able to distinguish the effect of double-deckedness from that of steps in/out of the train. Obviously, one cannot have the former without the latter, but there are trains in service around the world which have steps to access single-deck rolling stock (e.g. Norway's recently-retired Classes 69 and 70). This analysis demonstrated that it is the presence of stairs which fundamentally affects passenger movement rates, typically reducing them by around 0.07 pass/s per step, or around 0.35 pass/s across the entire flight of stairs.

The above discussion has been entirely based on the movement of able-bodied passengers. However, in recent years there has been increased interest and effort in enabling the transport of the mobility-impaired. Irrespective of any moral or legal arguments about the need to provide for such groups, the above purely-quantitative arguments apply even more strongly to those needing level access for their wheelchair, pram, bicycle or other luggage.

The slower passenger movement rates of double-deck stock therefore lead to significantly-longer times. A typical example of this is given in Table 2 below. The difference in this example is 15 seconds for the same number of passengers and is per train: for an urban area with a 16tph service, this equates to 4 minutes lost per hour, typically equivalent to losing 1⅓ – 2 signalled headways, i.e. 1⅓ –

2 train paths. However, when we take into account the larger number of potential alighters and boarders at the critical door, the situation deteriorates further. If, in practice, double-deck stock has a 20% greater capacity than single-deck stock, then we should add 2 alighters and 3 boarders to the figures shown in Table 2, thereby adding a further 2+3=5 seconds per stop (i.e. losing another 1⅓ trainpaths per hour). A loss of 2 + 1⅓ trainpaths on a base of 16 is almost exactly the same as the theoretical gain from extra vehicle capacity.

For double-deck trains designed to travel at 200kph and therefore limited to 1.4m-width doors (i.e. those 0.4m narrower than ideal), coefficients derived from the analysis of Harris et al (2022) suggest that passenger movement rates would fall by 0.2 pass/s, so 25 passenger movements would take yet another 5s/train on top of this. That leads to a loss of a further 80-100s per hour, or another ½ - ¾ trainpath.

	Alighting rate (pass/s)	Alighters	Boarding rate (pass/s)	Boarders	Total Movement Time (s)
Single-deck rolling stock					
	1.3	10	1.3	10	15
Double-deck rolling stock					
	1.0	15	1.0	15	30

Table 2. Typical Passenger Movement Performance of Different Rolling Stock Types

Examples from international benchmarking work bear out the slower passenger movement rates achieved with double-deck stock in practice.

City	Alighting rate (pass/s)	Alighters	Boarding rate (pass/s)	Boarders	Weighted rate (pass/s)
Single-deck rolling stock					
Paris	1.25	23	1.05	14	1.17
Toronto	1.36	20	1.46	22	1.41
Double-deck rolling stock					
Paris	0.74	5	1.13	16	1.04
Sydney	1.19	24	0.9	20	1.06

Table 3. Comparison of Real-Life Passenger Movement Rates

However, Norway is not faced with the choice of using rolling stock already running on other railway systems. Instead, Norske Tog can only procure what railway manufacturers are currently offering. We have therefore developed a model based on the parameters derived from Harris et al (2022) to estimate the passenger movement time expected to be taken at Nationaltheatret station (the pinchpoint in the Oslo tunnel) with different types of double-deck train available today. Based on the information currently available to NT and RCL, our results are as set out in the Table below. These show the better station stop performance of trains designed for high-demand urban areas: single-deck trains with fewer seats and large vestibules. In contrast, features of double-deck trains such as stairs, more passengers per train length and greater distance to the doors have all been shown in research to reduce passenger movement times and therefore increase station stop times. *None* of the double-deck designs would be expected to perform as well as the N06 trains being introduced: indeed, all would be expected to have passenger movement times at least 5 seconds longer.

NEW MODEL			Rolling stock characteristics											Platform Conditions				Passenger Demand							
	Scenario	Rolling Stock Type	Vehicle Length (m)	Vehicle width (m)	Single (1) or double (1.5) deck?	Number of doors/car	Door width (m)	Usable standback depth (m)	Remaining vestibule depth (m)	Inter Door Distance (m)	Seats/car	Number of seats which are longi-tudinal	Steps in the door frame? (Y/N)	Vertical Step Distance (mm)	Horizontal Step Distance (mm)	Platform width (m)	Platform Screen Door Dummy (0=Nei, 1=Ja)	Number of Alighters	Number of Through Passengers in Vestibule	Number of Boarders	**Output (Alighting Passengers/ Second)**	**Output (alighting secs at NT)**	**Output (Boarding Passengers / Second)**	**Output (boarding secs at NT)**	**Total time at NT (secs)**
1	NT pm	N06	17.91	3.19	1	2	1.3	0.40	0.20	8.20	43.1	4	0	26	*20*	4.5	0	21.3	0	21.3	**1.43**	**14.90**	**1.44**	**14.77**	**29.67**
2	NT pm	Skoda VR dd coaches	26.40	3.3	1.5	2	0.8	0.00	0.00	11.93	113.0	0	0	200	*20*	4.5	0	21.3	0	21.3	**1.37**	**15.60**	**0.53**	**39.92**	**55.52**
3	NT pm	Skoda DB NIM	26.40	2.8	1.5	2	1.3	0.00	0.00	11.93	120	0	0	10	*20*	4.5	0	21.3	0	21.3	**1.36**	**15.60**	**1.02**	**20.90**	**36.51**
4	NT pm	Coradia Max BAWU 200	26.50	2.82	1.5	2	1.4	0.00	0.00	9.90	100	0	0	30	*20*	4.5	0	21.3	0	21.3	**1.40**	**15.21**	**1.10**	**19.41**	**34.62**
5	NT pm	Coradia Max MSW1	26.50	2.82	1.5	2	1.3	0.00	0.00	9.90	104.2	0	0	30	*20*	4.5	0	21.3	0	21.3	**1.40**	**15.21**	**1.05**	**20.33**	**35.54**
6	NT pm	ETR 421/521/621	27.20	2.81	1.5	2	1.5	0.17	0.00	11.58	103.4	0	1	170	*20*	4.5	0	21.3	0	21.3	**1.37**	**15.54**	**0.98**	**21.84**	**37.38**
7	NT pm	CAF	27.03	2.79	1.5	2	1.3	0.00	0.00	12.21	108.2	0	0	237	*20*	4.5	0	21.3	0	21.3	**1.36**	**15.66**	**1.00**	**21.20**	**36.87**
8	NT pm	Stadler KISS200 Sw	26.00	2.92	1.5	2	1.3	0.00	0.00	11.70	93.9	0	0	145	*20*	4.5	0	21.3	0	21.3	**1.37**	**15.56**	**1.02**	**20.91**	**36.46**
9	NT pm	Stadler KISS160 Hu	25.83	2.8	1.5	2	1.3	0.00	0.00	11.62	95.2	0	0	170	*20*	4.5	0	21.3	0	21.3	**1.37**	**15.54**	**1.03**	**20.60**	**36.14**
10	NT pm	Stadler KISS200 Au	25.00	2.8	1.5	2	1.4	0.00	0.00	11.10	87.2	0	0	180	*20*	4.5	0	21.3	0	21.3	**1.38**	**15.44**	**1.10**	**19.28**	**34.72**
11	NT pm	Siemens Desiro HC RRX	26.25	2.82	1.5	2	1.8	0.00	0.00	12.25	93.9	0	0	20	*20*	4.5	0	21.3	0	21.3	**1.36**	**15.67**	**1.22**	**17.39**	**33.06**
12	NT pm	Siemens Desire HC FST	26.21	2.82	1.5	2	1.4	0.00	0.00	12.25	109.3	0	0	20	*20*	4.5	0	21.3	0	21.3	**1.36**	**15.67**	**1.06**	**20.00**	**35.67**

Table 4. Estimated Station Stop Times for Double-deck Trains Currently Available

Comparison against N06 trains recently ordered by Norske Tog

Parameters from model from Harris et al (2022) and limited to those shown to be statistically-significant.

Some measurements averaged between vehicles whilst those values in red unavailable. However, the impact of increased vestibule sizes is only of the order of 1s, and the impact of the longitudinal seats even less.

So, whilst train seating capacity increases with double-deck rolling stock, total train capacity rises less steeply, whilst line capacity typically does not increase at all. Indeed, at the higher 20tph timetabled for the peak period through Nationaltheatret, line capacity *would actually fall*, and this would be exacerbated if the rolling stock was limited to having 1.4m-wide doors, in order to enable its operation at 200kph. Furthermore, the increased station stop time would lead to slightly-longer journey times, which would not be appreciated by passengers, especially as the extra time would be in unproductive time at stations. Very roughly, one might expect it to be possible to offer 20 double-deck trains per hour with 1000 seats each (20,000 pph in total) or 22 single-deck trains with 900 seats each (=19,800) but with more room for standees. It is therefore critically-important that stakeholders realise that providing more seats may lead to the ability to carry fewer passengers, and with longer journey times.

2.2 Longer Trains

All solutions involving longer trains need to take into account the length of the platforms at the stations where the trains will call. Historically, it was considered acceptable if trains were longer than the platforms, but this leads to safety concerns if passengers are able to alight from carriages which do not have a platform adjacent. When electric doors are fitted to trains, SDO (Selective Door Opening) enables drivers or conductors to manage this safety risk by controlling this, but a time and hence line capacity risk remains: information needs to be given to passengers to ensure that they have all gathered in the appropriate carriages, which can then become relatively full. Whilst this may not be important at the occasional smaller station, this is not a good general solution for busy rail corridors, where station stop times can be critical. Nevertheless, it should be taken into account when considering the value for money of specific station schemes.

That caveat stated, there are three generic solutions for longer trains, as set out below.

2.2a Fixed trainsets

This section describes one possible solution, of running longer trains. For the avoidance of doubt, however, there are two versions of this. One is to run individual trainsets with more carriages e.g. a fixed 10-car set. The other option is to run several trainsets together all the time, the use of several shorter trainsets (e.g. 3 x 5-cars, as has been suggested by Jernbanedirektoratet (2021)) being to enable piecewise fleet growth, and easier maintenance. The flexible hour-by-hour operation of shorter trainsets is discussed in section 2.2b.

Increasing the length of individual train-sets may be a reasonable response to increasing patronage when trains are initially relatively-short. For instance, reflecting general passenger demand growth in Britain, the typical EMU train-set in London has, in recent years, been of 5 cars, not the historic 4. If the base passenger load is consistently higher, this can be sensible, as running a 5-car set may reduce the need to run 2x4-car sets. In a more extreme version of this, replacements for the 3-car inner-suburban sets used out of London's Moorgate terminus have been 6-car sets. This has the advantage of reducing the space taken up by intermediate train-cabs, and the cost of the extra equipment within.

Increasing the length of trains directly leads to more floor-space, which can either be used for greater seating or greater standing space. However, especially as trains get longer (e.g. more than 4 or 5 carriages), it can be difficult in translating that to greater passenger carrying capacity, without careful consideration of the platform characteristics of stations along the relevant route. Unless different stations have entry/exit points at different places along the platform (e.g. front/middle/back), passengers will congregate in only part of the train, making it congested whilst other parts of the train are relatively empty. This is a particular risk with railways which run into terminus stations but can also happen when a holistic view is not taken of all the stations along a line.

Impact of Platform Entrances on Train Utilisation: Examples from London

Many train services from South East London and Kent run through London Bridge station to termini at Charing Cross and Cannon Street. This encourages commuters in the morning to travel at the front of the train, in order to minimise their egress time. Historically, this problem was exacerbated by the configuration of both the preceding London Bridge and Waterloo East stations, where the main egresses were also at the front. Crush loading was therefore common in car 1, whilst there could still be seats available in cars 10-12. Over the last few decades, this problem has been eliminated – if at very significant capital cost. Construction of the Jubilee line (which opened in 2000) provided a direct link between the rear of the platforms at Waterloo East station with a new tube station at Southwark. Reconstruction of London Bridge station in association with the Thameslink project (which opened in 2018) created a new main concourse with two egresses at 1/3 and 2/3 along the platform. However, the total cost of station works at those two locations was of the order of £1.5bn.

London Underground's Victoria line opened in stages between 1967 and 1974. It quickly became one of the busiest lines, offering huge time savings to around 100mppa, not least by providing cross-platform interchange with other lines. However, it had one major design flaw: 15 of the 16 stations along the route had their main entrance/exit at the South end of the platform. Passengers seeking to alight adjacent to their desired egress therefore had no incentive to move along the platform (or, indeed, walk through the train), and the high service frequencies (30tph+) gave them little time to do so anyway. Uneven train loading at Victoria became the determinant of line capacity, solved through the construction in 2017/18 of a new ticket hall, at a total cost of around £700m.

Whether by accident or design is unclear, but the suburban line from London Victoria to Crystal Palace has stations with entrances/egresses at various places along the platforms. On leaving Victoria (terminus, primary access obviously at the back), this systems engineering success passes through Battersea Park (egress at the front), Clapham Junction (front and middle), Wandsworth Common & Balham (both front), Streatham Hill (towards the front), West Norwood (right at the back) and Gipsy Hill (right at the front) before reaching Crystal Palace (right at the back). This ensures that evening peak trains load evenly throughout the train, minimising congestion and station stops whilst maximising the use of the rolling stock provided.

In summary, these examples highlight how the detailed physical arrangements at stations interact with train length and rolling stock type to determine line capacity.

Longer trains will, in general, require longer platforms, which it may or may not be easy to provide: there may be physical (either natural or human) obstructions which make platform lengthening exorbitantly-expensive. Stations in tunnelled sections of line are particularly problematic.

Similarly, running longer trains affects the facilities required for maintenance and storage in depots and yards. In particular, there need to be sufficiently-long sidings, whilst depot buildings may also need to be enlarged: there are currently only four tracks in Mantena's Lodalen trainshed that will accommodate a 300m-long train. Considerable expense may therefore be required in accommodating longer trains. This is a potential problem in Norway where depots in Stavanger, Bergen and Trondheim are too short to accommodate longer trains, without upgrade works[3].

The inability to use the full length of the train at stations with short platforms is another instance where the extra length of the train may not offer full value, a problem likely to be even worse when considered in investment terms, since full-length trains are only likely to be justified in peak periods which, by definition, do not occur all the time. Outside peak periods, the operation of long trains creates unnecessary cost – for instance in energy consumption, rolling stock maintenance and track wear & tear. This is a major disadvantage of the fixed 12-car formations introduced on Britain's Thameslink route which runs North – South through London: trains of such size were never needed for the overnight services to Gatwick Airport and, during the Covid pandemic, were not needed for any services at all!

However, there are also some other, more technical, operating consequences of running longer trains. Equation 1.1 showed that the length of a train directly impacts on line capacity, because longer trains take longer to pass over any given section of track – including bottlenecks or constraints, such as Nationaltheatret station. The number of trains which can be run therefore falls slightly as they get longer, so line capacity does not go up quite proportionately with train length.

2.2b Multiple Part-trains

The combination of several shorter trainsets is relatively easy to achieve with DMUs or EMUs, or even fixed sets of trailer vehicles. The flexibility offered enables operators to match capacity to the expected demand, thereby minimising any excess operating costs. Unfortunately, those savings can be more than exceeded by the increase in cost caused by the greater complexity of operations (for instance, in train drivers) and maintenance (e.g. of coupling equipment). That coupling and uncoupling is also a potential source of train service unreliability. However, it can enable some part-trains to be released for maintenance, enabling that to be undertaken more cheaply throughout more of the 24-hour day than would otherwise occur with fixed trainsets.

Multiple part-trains, however, come into their own in networks reaching capacity. Here, several part-trains can be coupled together to create high-capacity trainsets in the busiest line sections, then being uncoupled to provide a wider range of destinations with through services (eliminating interchange, a key deterrent of travel for some passenger market segments). This is a widely-used practice in Britain, where the rail network is at capacity in and around many of the larger cities.

---

[3] Depots in Stavanger and Bergen were built for 5-car Class 73s and Flirts respectively; that in Trondheim was built for the type 76 BMU, which consists of 5 full-length carriages and a shorter diesel power pack only. Without expansion, none of these depots could therefore accommodate trains of 6 full-length carriages.

Figure 7. Uncoupling of Loaded Trainsets in Service, Haywards Heath, Britain

There have been some interesting examples of this technique across Europe. Swiss railways operate fixed trainsets of locomotive + 5 carriages, with another set of 5 carriages added to the other side of the locomotive during peak periods.

Figure 8. Locomotive in Centre of Peak-Lengthened Train, Brig, Switzerland

When British Rail electrified the main line out of London Waterloo in 1967, the limit of electrification was at Bournemouth. Train services from London were formed of a high-powered 4-car EMU (REP) in the centre of a 12-car formation, there being a 4-car trailer (TC) set on either side. Upon arrival at Bournemouth, a diesel locomotive took the front TC set on to Weymouth, whilst the REP and rear TC terminated, and acquired a new TC set from Weymouth, to return to London. This practice ceased in 1990 when the line to Weymouth was electrified throughout.

However, this strategy of using multiple part-trains cannot currently be applied in Norway. Safety rules introduced in recent years by BaneNOR (presumably to reduce risk) do not permit a loaded trainset in service to be coupled up to another trainset. This is because it is currently not permitted to plan to run a second train into an occupied train section as a signalled train movement, but only as a shunt, and legislation does not allow passengers to be carried on a shunting train movement. In practice, loaded trains are sometimes coupled up to other trainsets in service when the train service is disrupted; we also note that these train movements were permitted historically, so it may be worthwhile challenging the current regulations.

2.2c Adding Extra Carriages

When trains are crowded, it is not uncommon to hear passengers asking why train companies do not “simply add some more carriages”. However, train operators will recognise a variety of issues that this strategy causes. Foremost may be an investment/asset utilisation problem: in the 1970s British Rail had some trains of carriages which were reportedly only used 18 times per year (chiefly for Summer weekend service strengthening); that was possible whilst the trains were surplus from service reductions elsewhere, but those train services largely disappeared as soon as the older trains could not be kept traffic-worthy. However, there are costs associated with keeping even life-expired rolling stock available for service: minimum maintenance must still be undertaken, whilst space is needed for storage.

The general problem of shunting, and requiring a second locomotive to ‘release’ an incoming locomotive trapped at the buffer stops of a terminus station, was a key factor in the general movement of railways away from operation with locomotives and carriages, especially for shorter-distance operation, where this was disproportionately awkward. A common solution was the creation of driving trailer carriages: ‘ordinary’ carriages in which a driving compartment was installed in one end, with cabling along the train enabling the locomotive to be controlled from the other end of the train. Although British Rail went through a phase of this prior to the more widespread of multiple units, other railways (e. g. Deutsche Bahn) continue to find this an appropriate operating solution.

Figure 9. German double-deck trainset at Heilbronn

Nevertheless, rather than the addition of complete trainsets, many people understand the concept of adding individual carriages. That, however, requires labour (driver and shunter) and some form of locomotive for shunting. When railways were mixed-traffic affairs with wagonload freight, some of which might have been loaded/unloaded in or adjacent to major stations, it was possible to amend the length of passenger trains using marginal resources: those shunters were required for the freight traffic anyway. Now that nearly all countries except Switzerland have withdrawn from wagonload freight operation, the possibility of adding the odd extra carriage has receded into the unacceptably-expensive.

3 What do Other Railways Do?

This section of the report considers the solutions adopted by countries and systems with broadly-similar characteristics to the national/suburban railways of the Greater Oslo area. We have therefore excluded from this analysis Asian cities, where population densities are far greater than in Norway, and so where a more metro-type train is appropriate for a different culture and circumstances.

3.1 Europe

Norway

Before considering other countries, however, it is first worth noting that Oslo metro replaced its entire fleet about 10 years ago. Short trainsets are used, to minimise track occupation times, as a high-frequency service is necessary through Jernbanetorget, in order to serve all the different branches at a reasonable frequency. However, because journeys are typically short, the provision of seats is not very important, and the vehicles are designed to have considerable multi-use space.

Figure 10. Interior of Oslo Metro train

Sweden

Suburban services in Stockholm followed the Norwegian example of being re-routed under the city centre in a new tunnel, but not until 2017. However, with longer-distance services excluded from this route, that led to the standardisation of rolling stock, with all trains now operated by the Alstom Coradia X60 type. Sweden has therefore avoided the Norwegian problem of trying to run all train services with a mix of rolling stock types along one line. X60s are 6-car articulated sets 107m long, with an interior design comprising 2+2 seating in a walk-through train. Given the width of the Swedish loading gauge, that enables a reasonable amount of standing, which is acceptable for suburban traffic. SJ does operate double-deck stock on outer-suburban services, but trains from further out are not put into the tunnel.

Figure 11. SJ single-deck suburban EMU 6039 enters Stockholm C

Figure 12. Interior of SJ X60 trainset

Source: Wikipedia

Figure 13. SJ double-deck set 3727 leaves Stockholm C

Denmark

The rolling stock solution chosen for the Danish capital is unusual. Copenhagen S-Tog trains are formed of short but very wide and open cars, enabling the carriage of bicycles in one vehicle. The bulbous nature of the profile is evident from Figure 14 below, but the seats are not quite wide enough to permit three adults to sit side-by-side.

Figure 14. Kobenhavn S-tog 9125 at Glostrup

Figure 15. Interior of Kobenhavn S-Tog trainset

Germany

The suburban railways of Germany (their S-Bahn services) display several quite-different solutions. Where the population is organised into several adjacent cities or large towns (classically in the Ruhrgebiet, but also around Dresden, and Karlsruhe/Mannheim), DB has adopted push-pull operation using fixed sets of electrically-hauled double-deck coaches.[4] Note, however, that most of the cities/towns involved are significantly larger than their Norwegian equivalents.

In some cases, where services are of slightly-longer duration and lines not electrified, there are push-pull services using fixed sets of single-deck coaches with diesel locomotives. However, this is only a solution where capacity is not under pressure.

---

[4] The same solution has also been adopted in Northern Italy, which has a similar geographic distribution of larger cities within the same region. The double-deck rolling stock used was built at the same time and place as NT's Class 72 single-deck fleet, but has only c. 8% more seats.

Figure 16. Electric loco 146232 on double-deck stock at Appenweier

Figure 17. Diesel loco 218490 on the rear of a push-pull single-deck trainset at München Pasing

In the largest cities, however (e.g. Berlin/Hamburg/München), DB has adopted longer trains of single-deck open EMUs, generally formed of several 4-car trainsets.

The flexibility of multiple part-trains is used, not only to reflect different demand levels at different times of day, but also to reflect geographical peakiness (where demand falls off from the city centre), applied where lines are branched and/or reverse en route. For instance, München S-bahn's S7 route reverses at Ostbahnhof, where an extra train-set can be added or detached.

Trains are generally of more open vehicles, with relatively-fewer seats (at most 2+2). Such designs are continuing to be replicated and improved, emphasising the need for large vestibules, wide aisles and plenty of multi-user space (for prams, bicycles etc.), as the impact of all these on critical station stop times is understood.

Figure 18. Class 423732, operating as a single 4-car set, arrives at München Pasing

Figure 19. Interior of Refurbished Class 423 EMU, Germany

France

The Paris RER system bears some similarity to the rail network of South East Norway, with a series of cross-city suburban rail lines. As Paris has a comprehensive city-centre metro system, the RER is designed to address a market of commuting from new towns built some way out. The type of operation is inconsistent, with some single-deck, and some double-deck services. However, station stop times at the key interchange of Chatelet-les-Halles limit the actual number of trains operated in the peak hour: the timetabled 24tph is rarely achieved, with trains just getting later through the peak period. We have observed only 20tph being managed to run during the peak hour, with the remainder being ‘left over’ to the following peak shoulder period. This emphasises the disadvantage of trying to provide maximum seating for rail services which go through capacity-constrained city centre routes.

Figure 20. Double-deck EMU 401 at Versailles Chantiers, Paris

Britain

London is clearly the part of Britain where rail services are under greatest pressure. Several different operating solutions can be found, depending on the other constraints of the network. However, an important policy change in recent decades has reflected the understanding that capacity is *not* best provided by maximising the number of seats in a train (driven by an inappropriate Government Value-for-Money objective of minimising capital expenditure per seat); latest designs of suburban trains are generally of more open designs, maximising overall capacity (as well as enabling the carriage of wheelchairs, prams, bicycles, luggage etc.). 3+2 seating is therefore generally being replaced by 2+2 in newer train builds, not least because the British loading gauge is relatively limited, with vehicles only 2.8m wide at seat level. The cramped interiors of some 1990s trains (e.g. Class 465 'Networkers') led to excessive station stop times (e.g. at Woolwich, Lewisham, London Bridge) and their subsequent replacement by designs with fewer seats.

Figure 21. Cramped Interior of Class 465 'Networker', London

Many radial main lines run 4- or 5-car EMUs, in multiple during the peaks to form 8/10/12-car formations; very few suburban stations have platforms capable of taking trains longer than this. 5-car trainsets are generally more recent, reflecting the higher underlying demand of the immediately pre-Covid period. Selective Door Opening does occur at some smaller intermediate stations, but is not encouraged, for reasons of passenger safety, information and usability.

On the capacity-constrained line South through East Croydon and Gatwick Airport, the number of branch lines with passengers all desiring through services to London has led to the operation of 3x4=12-car EMU formations, with trains being split/joined at Haywards Heath to provide through services to all destinations. Similar operations occur (or have recently taken place) at Ashford and Faversham (Kent), Horsham (Sussex), Colchester and Kirby Cross (Essex).

Figure 22. Class 375 at Faversham, a location for train splitting/joining

Some routes have services which drop off carriages at intermediate stations (e.g. Northampton), but this leads to uneven loadings between the vehicles providing service for the whole route, and those only for part of it. This is somewhat mitigated by having the short-working carriages at the busier London end of the train, which encourages their use in and out of London's terminal stations.

Some vehicles of trains between London and King's Lynn are dropped off/re-connected at Cambridge. However, this is not just because Cambridge is the largest settlement on the route, with demand tailing off North thereof. Beyond Ely, electrification in 1991 was undertaken 'on the cheap', and there has until recently been insufficient traction power supply to provide for 8-car trainsets.

Because the recent upgrade project was focussed on line capacity (especially in Central London), Thameslink services are run with fixed 8- and 12-car formations. Whilst helpful for maintaining low station stop times whilst coping with the high demands of the London peaks, this inevitably leads to low train loads at the geographical extremities of the network (e.g. between Stevenage and Peterborough) and at times of low demand (e.g. overnight). This weakness was highlighted during the Covid pandemic, when demand fell by as much as 95%, and 8-car trainsets were being used to carry only 50 people. However, in a departure from historic British practice, these trains have a 2+2 seating interior with wider aisles and 'walk-through' gangways from one carriage to the next, enabling the carriage of well over 1000 passengers per train in the peaks.

Figure 23. Fixed 12-car set 700108 passes Brockley (South London) on a Thameslink working

Figure 24. Spacious interior of Class 700 Thameslink train

The Crossrail project (which opened in May 2022) has been designed to address the historic capacity limitations of the London Underground system, exacerbated by significant recent increases in the population of London. Everything has therefore been designed to be larger. Trains are formed of fixed 9-car sets of longer[5] single-deck vehicles with 3 doors/car but relatively-few seats per vehicle (some transverse, some longitudinal).

Figure 25. Interior of Class 345 train for Crossrail, London

As part of the overall planned design, all Crossrail stations in the centre of London are double-ended, to ensure use of the whole length of train (and to maximise the catchment area of the stations). This demonstrates the need to undertake 'systems engineering' to reflect the inter-actions between rolling stock and other elements of the railway.

However, what has become apparent over the years is that there is a degree of choice between radial routes for some passengers wishing to travel in and out of London. This means that routes which are congested can shed traffic to nearby quieter lines – or be encouraged to do so, through promotion and/or differences in fares. Examples of this include the Brighton main line and the parallel but quieter Uckfield branch.

On orbital routes (some of which are shared with freight), demand can still be at significant levels. Services of between 4 and 16tph are run by London Overground, using short (4/5-car trains) of very open stock with only longitudinal seating, thereby maximising the space available for standing.

---

[5] 23m, not the 20m which is standard for British suburban EMUs

Figure 26. 'Open' interior of Class 378 London Overground train

Overall demand levels in London are also periodically reduced by the dispersal of economic activity out of the capital – either of Government offices to economically-disadvantaged areas, or by the private-sector, if Central London property values are deemed to be too high.

In other areas (including Scotland), levels of demand are lower (so perhaps more akin to the Norwegian context), but operating solutions have almost all veered towards the operation of fixed-set EMUs, with sets being coupled together where necessary to provide more capacity. Services in Birmingham, Manchester and Glasgow (including those running through the Central area, at frequencies of up to 14tph) are mostly operated by 3-car EMUs, run as 6-car formations in the peaks. Pending full system electrification, services in the Edinburgh area include some still operated by DMUs, but again the philosophy is of multiple part-trains (several multiple unit sets coupled together).

3.2 Other Comparable Environments

The range of countries which are strictly comparable with Norway is limited, but some of the Australian cities share a similar rail network geography to Oslo, and have not dissimilar populations.

Australia

Melbourne and Brisbane: both cities use single-deck EMUs, the latter on the narrower gauge used in Queensland. Both cities have high-frequency (16tph+) corridors in their central areas, and need short station stops in order to manage capacity. However, interiors have historically been fitted with quite a few seats, and demand pressure in Melbourne is leading to a reduction in the numbers of seats per car, to enable greater capacity (if through standing).

Figure 27. Alstom Xtrapolis trainset 122 at Richmond, Melbourne

Figure 28. Queensland Rail EMU 105 at Sherwood, Brisbane

Sydney: double-deck rolling stock is standard across the Sydney Trains fleet, for suburban services covering up to 100kms from the CBD. Despite the large loading gauge, it is not possible to stand up in the window seats upstairs, whilst the (loss of space/difficulty in movement) impacts of the stairs up/down to the saloons are obvious.

Figure 29. Upper Deck of Waratah stock, Sydney, Australia

Figure 30. Vestibule area of Waratah stock, Sydney, Australia

However, in a significant policy change, the metro now under construction (conversion of the busiest Bankstown line plus a new underground section) has chosen to have single-deck trains of an open design.

Summary

From the above examples we can see that, at the highest traffic loads, single-deck trains of an open design (i.e. with few seats) are almost universally preferred, especially where railways traverse city centres. Recognising the impact on station stop times, other countries have generally tried to avoid the situation in which longer-distance trains with denser seating configurations run through city-centre tunnels.

4 What is Appropriate for Norway?

4.1 Quantity of Demand

Norway is not a populous country, and total annual rail demand for the whole country is only c. 80mppa. Few lines have more than 4tph, although the busiest corridor (the tunnel between Oslo S and Skøyen) has a maximum combined service of c. 24tph serving around 10,000 pphpd in the peak hours. The wider core route between Drammen and Eidsvoll is the only operating route where provision of higher-capacity trains might be justified (possibly only for peak Ekstratog); it also has the advantage of serving relatively-few stations, so infrastructure works would be relatively few in number.

4.2 Market Segments

Rolling stock needs to be matched to the appropriate market conditions, where in Norway one might identify four:

1 Lokaltog – all stations e.g. Spikkestad – Lillestrøm

2 Regional (services currently provided by the same fleet (Flirts))

    A Outer-suburban: e.g. Drammen - Eidsvoll

    B InterCity: e.g. Skien – Lillehammer

3 Long-distance: e.g. Oslo – Stavanger & Bergen

Sections 2 and 3 of this report have clearly identified that double-deck trains would *not* be appropriate for LokalTog services, for which Class 77s have recently been ordered anyway. Long-distance services in Norway are under less capacity pressure, and of relatively-low frequency anyway, suggesting that frequency increases would be of greater benefit to passengers than train lengthening.

Because of the way in which services in South East Norway operate (with outer-suburban and most InterCity services also traversing the congested Oslo tunnel), these market segments are also generally not ideally-suited to double-deck stock either. However, there are some exceptions, most notably the Oslo S – Halden route which does not enter the tunnel. This market segment (and hence the potential for double-deck stock) is currently very limited, but could be enhanced by minor service changes, for instance in any peak extra services on the Moss route terminating at Oslo S, thereby keeping clear of the central area tunnel.

4.3 Route Constraints

The Norwegian rail network is relatively-poor in physical quality, on a range of different variables. Much (possibly over 90%) of the Norwegian network is curved, limiting the potential speeds of 'fast' trains – and hence the value in having rolling stock capable of those higher speeds. At around 20t, axle-loads are at the lower range of European practice, which could affect the use of some train types. However, train weight on any system impacts on infrastructure maintenance costs, even if there are not actually any weak structures preventing the operation of a given type of train.

Apart from the Drammen – Hamar and Oslo – Ski corridors, the majority of routes are only single-track, which places limitations on line capacity and timetable construction. Even some of the cross-Oslo routes (e.g. to Kongsvinger) have single-track sections, which can affect punctuality, which is not ideal for services which subsequently have to merge into a high-frequency core. That core (the Oslo tunnel) is double-track with island platforms at Nationaltheatret but, with a peak service frequency of up to 24tph, under pressure. As already noted, station stops there are therefore critical to overall system performance.

4.4 Flexibility

Norway has a relatively-small amount of railway rolling stock, within which economies of scale do not apply. It is not cost-effective to have small incompatible train fleets, since the proportion of spare parts and trainsets needed is relatively greater (as can be seen from Flytoget's acquisition of "non-standard" trains). Norske Tog is already trying to standardise its fleets to become more efficient and enable this greater (operational and maintenance) flexibility, a trend which some rolling stock options would prejudice.

The coupling/uncoupling solutions widely used in Britain and Germany could be difficult to operate in Norway, given the colder temperatures, and the need to keep plastic bags over train coupling equipment, to avoid undue ingress of snow. Experience in Norway also showed that coupling/uncoupling was a major source of delay. Whilst these processes could be manageable in depots, the time taken for traincrew to deal with this could be a significant timetabling and hence cost constraint if attempted during normal traffic. However, recent operating restrictions limiting the coupling-up of loaded trainsets may be more of a constraint to this type of solution.

4.5 Timescales

Norske Tog is already procuring trains of Types 77 and 79. It would therefore be very easy to acquire further trainsets of the same types, by extending current orders. Depending upon the quantities required and the method of financing, extra trains of the same type could be available within 2-3 years. They could facilitate either enhanced frequencies (where line capacity exists) or longer train formations (where platform lengths or SDO permits).

The other train type solutions would take longer – and might cost more – to implement. Even though there are potential train types already on the market, invitations to their manufacturers for a new rolling stock type for Norway would have to be preceded by development of a specification, and then a full competitive procurement process would be required. Judging from recent experience, the whole process might take 5 years. Acquiring different train types would also have implications for physical infrastructure (e.g. stations, sidings, depots). Given planning legislation and the need to fit in with other planned railway expenditure, that could take at least as long.

More importantly, though, longer fixed trainsets and double-deck stock, as different technical solutions, would only be expected to replace existing trainsets upon their life expiry (it would not be cost-effective to do so before then). However, the Flirt trains are currently broadly 10 years old, but with another 25 years' life in them, meaning that large-scale fleet replacement by a different type would not be complete before c. 2045. The only trains with potential for early replacement are the Type 71s (the early Flytoget fleet), but that fleet is relatively small, is not generally subject to demand pressure nor of great impact to the Central Oslo tunnel, but also completely unsuited to double-deck operation given the quantity of luggage carried to/from Gardermoen airport.

So, even if solutions about other train types were deemed preferable (a conclusion which does not emerge from our analysis), now is the wrong time to make that decision.

5 Conclusions and Recommendations

The potential acquisition of double-deck trains is an issue which has recently arisen again in Norway. However, this is not an issue which is only about the fleet itself: the choice of rolling stock for a railway is a key strategic decision which affect infrastructure and train service levels too. It therefore appropriately attracts attention from politicians and formal government appraisal processes, whilst passengers may just worry about there being enough seats. However, the understanding of a railway as a system emphasises that this decision needs to take into account many other factors; it should only be a sub-set of a wider consideration of how best to deliver total passenger rail capacity across a network of routes.

The underlying demand forecasting assumptions merit being challenged, if cost-effective investments are to be achieved on behalf of the Norwegian tax-payer, as the apparent levels of assumed growth seem high, and the value of some future peak trips unclear. There also appear to be several under-used policy initiatives which could be taken which would reduce the scale of the overall rail capacity problem, including reducing overall demand through land-use planning measures, and increasing the extent of the rail network itself. The latter would reduce the pressure on any individual corridor, and therefore reduce the pressure on rolling stock capacity. The 'need' for some train services (e.g. all of the Flytoget frequency) is also unclear, whilst the rigid adherence to services running between specific origins and destinations (e.g. all trains from Moss running through to Lysaker) is an artificially-imposed constraint. Earlier delivery of a second cross-Oslo tunnel would also provide a wider range of service and rolling stock options, if at significant cost.

If extra railway rolling stock capacity is genuinely-needed, there are several possible strategies for achieving it. These include longer fixed trainsets, using multiple part-trains, adding extra carriages, and using double-deck vehicles. Each of these solutions has its own advantages and disadvantages; for instance, longer trains can require significant investment in platform lengthening. Contrary to what might be thought, however, double-deck trains do not necessarily increase line capacity; indeed, on busy lines, their poor performance during station stops is likely actually to *reduce* the number of trains which can be run, entirely negating their higher per-train load. Our analysis of double-deck train types currently available for purchase shows that all would require at least 5 seconds longer passenger movement time at Nationaltheatret, and therefore increase journey times and reduce line capacity.

Railways in similar countries elsewhere (e.g. in Europe) variously use a range of different rolling stock strategies. However, those systems under the greatest demand pressure have nearly all adopted an approach using single-deck open vehicles, with wide doors, big vestibules and lots of multi-user space. This is especially the case where railways traverse city centres. Recognising the impact on station stop times, other countries have generally tried to avoid the situation in which longer-distance trains with denser seating configurations run through city-centre tunnels.

Double-deck rolling stock is theoretically OK for longer-distance services where seating provision is important, but with relatively-few people, no pressure on signalled capacity or track occupancy, and where stations have short platforms i.e. in situations where there is no capacity problem. In Norway, that might (for instance) apply to services between Oslo S and Halden. However, double-deck stock does not function at all well in a denser urban environment, where these requirements do not apply. As our calculations show that the use of such trains through the Oslo tunnel would actually reduce line capacity, this is definitely not recommended.

Given the uncertainties associated with demand forecasting and railway development, solutions offering flexibility in their timing are to be preferred over those requiring significant capital investment. Purchasing further part-trains of conventional stock therefore seems to be a more robust solution, even if current operating practices do not enable them to be coupled up when loaded; the latter should be challenged.

References

Finansdepartementet (Norwegian Ministry of Finance) (2019) “Statens Prosjektmodell”, Rundskriv R-108/19, 8th March.

Fruin, J J (1971) “Pedestrian Planning and Design”. Updated in Bowman, B L et al (1989) “Handbook on Planning, Design and Maintenance of Pedestrian Facilities”, US Department of Transportation, Virginia, USA.

Harris, N G, Haugland, H, Olsson, N O E & Veiseth, M (2016) “An Introduction to Railway Operations Planning”, A & N Harris, London (243pp).

Harris, N G, de Simone, F & Condry, B (2022) “A Comprehensive Analysis of Passenger Alighting and Boarding Rates”, Urban Rail Transit 8, pp. 67-98. Doi.org/10.1007/s40864-021-00161-8

Jernbanedirektoratet (2018) “Toglengdestrategi for Regionaltrafikk pa Ostlandet og Tilbringertjenester til Oslo”, projektsnummer 21007113, 13th April.

Metz, D (2022) “Good to Go? Decarbonising Travel after the Pandemic”, London Publishing Partnership (224pp.)

NSB (2014) “Toetasjerstog i Norge?: en studie av mulighetsrommet”, Sak 14/830