Green train
Basis for a Scandinavian high-speed train concept

FINAL REPORT, PART A

Oskar Fröidh

KTH Railway Group, publication 12-01

Gröna Tåget

Trains for tomorrow's travellers

Gröna Tåget
Trains for tomorrow's travellers

www.gronataget.se
www.railwaygroup.kth.se

Printed in Stockholm 2012

Green Train
Basis for a Scandinavian high-speed train concept

Final report, Part A

Oskar Fröidh

Stockholm 2012

KTH Railway Group
Publication 12-01

ISBN 978-91-7501-232-2

English translation: Ian Hutchinson

All illustrations, if otherwise not mentioned: Oskar Fröidh

Contact the author:
Div. of Transport and Logistics
Royal Institute of Technology (KTH)
SE-100 44 Stockholm
Sweden
oskar.froidh@abe.kth.se

KTH Railway Group
Sebastian Stichel
stichel@kth.se
Phone: +46 8 790 60 00
www.railwaygroup.kth.se

Foreword

The Green Train (in Swedish "Gröna Tåget") is rather unique as a research and development programme since it brings together both institutes of higher education and infrastructure managers and railway companies and train manufacturers in a common programme. Since its inception in 2005 the objective has been to develop a concept proposal for a new, attractive high-speed train adapted to Nordic conditions that is flexible for several different tasks on the railway and interoperable in the Scandinavian countries.

The concept proposal can act as a bank of ideas, recommendations and technical solutions for railway companies, track managers and the manufacturing industry. It is an open source, which means that it is accessible to all conceivable stakeholders.

The research programme has already attracted the interest of the industry both in Sweden and other countries during the years we have been working on it. We do not, however, have a finished train to show, but the results of the programme are presented primarily in two final reports that are based on a large number of research reports.

Final report A, which is this one, deals with the travel market, traffic, economy and the bases of the Gröna Tåget train concept. The report gives a background to the environment for which the train concept is intended and focuses on how the users, the travellers and the train operators can derive the greatest possible benefits.

Final Report B [1] deals with the recommendations that the Gröna Tåget concept proposal constitutes on a more technical level. This part also briefly describes the context and the lines where the train is intended to operate.

Finally, the author would like in particular to thank Tohmmy Bustad at the Swedish Transport Administration for his support throughout the research programme, and Evert Andersson, programme coordinator at KTH, for his excellent cooperation. I would also like to wish all participants good luck in their future activities with all the knowledge generated in Gröna Tåget.

Stockholm, January 2012

Oskar Fröidh

---

[1] Andersson, E., 2012: Green Train. Concept proposal for a Scandinavian high-speed train. Final report, part B. KTH Railway Group Publication 12-02, Stockholm

Acknowledgements

The author wishes to acknowledge the following participants in the programme for a rewarding and developing cooperation:

Trafikverket ***The Swedish Transport Administration***

Tohmmy Bustad, *responsible for the programme*
Nils Edström, Malcolm Lundgren and Björn Svahn
Johan Öberg, Nicolas Renard and Bengt B. Johansson

Bombardier Transportation, Sweden

Henrik Tengstrand, Regina 250 coordinator
Johan Palm, Christer Högström and Jakob Wingren
Richard Schneider (CH), Åsa Sandberg and Ben Diedrichs
Astrid Herbst, Anders Frid, Ulf Orrenius and Christina Larsson

Operators

Peder Wadman, Tågoperatörerna
Susanne Rymell, SJ AB
Björn Asplund, Transitio

Vinnova, institutes and consultants

Carl Naumburg, Vinnova (funding)
Olle Lundberg, LundbergDesign
Joakim Jörgensen, Lars Andersson and Per Gullers, Interfleet Technology
Per Leander, Lennart Kloow and Mattias Jenstav, Transrail
Björn Kufver, Ferroplan
Lena Kecklund and Marcus Dimgård, MTO Safety
Jennifer Warg, Vectura
Björn Blissing, Lars Eriksson, Selina Mårdh, Lena Nilsson and Jerker Sundström, VTI

Universities (except KTH)

Daniel Eriksson and Martin Ranvinge, Konstfack
Sinisa Krajnovič, Chalmers
Anders Jansson, Uppsala Universitet

Royal Institute of Technology (KTH)

Evert Andersson, *programme coordinator*
Bo-Lennart Nelldal, Hans Sipilä and Karl Kottenhoff
Rickard Persson (also VTI and Bombardier Transportation)
Ulf Carlsson, Shaffiq Khan and Kent Lindgren

Anneli Orvnäs, Sebastian Stichel and Piotr Lukaszewicz
Tomas Karis and Mikael Sjöholm
Tomas Muld and Gunilla Efraimsson
Juliette Soulard and Stefan Östlund

Contents

Figure 1. Vision of Gröna Tåget (LundbergDesign; Gröna Tåget, 2010)

Abstract

The Green Train (in Swedish ”Gröna Tåget”) is a high-speed train concept, that is economical, environmentally friendly and attractive to travellers. It is suited to specific Nordic conditions with a harsh winter climate, often varying demand and mixed passenger and freight operations on non-perfect track. The main proposal is a train for speeds up to 250 km/h equipped with carbody tilt for short travelling times on electrified mainlines. The concept is intended to be a flexible platform for long-distance and fast regional passenger trains, interoperable in Scandinavia, i.e. Denmark, Norway and Sweden.

The Gröna Tåget programme delivers a collection of ideas, proposals and technical solutions for rail operators, infrastructure managers and industry. This is part A of the final report, dealing with market, economy and service aspects, with an emphasis on the areas where research has been done within the Gröna Tåget research and development programme.

Passenger valuations and economy in train traffic exposed to competition are controlling factors in the design of the train concept. One important measure to achieve better economy in the train traffic with 15% lower total costs and the possibility to reduce fares is to use wide-bodied trains that can accommodate more seats with good comfort. Travel on some studied routes in Sweden may increase by 30% compared to today’s express trains through shorter travelling times, lower fares and more direct connections, which are possible with shorter, flexible trainsets.

Gröna Tåget will be designed to give good punctuality even during peak load periods. Doors, interior design, luggage handling and vestibules with lifts for disabled travellers must be dimensioned for full trains. A well-considered design reduces dwell times and delays.

Capacity utilisation on the lines increases with greater speed differences between express trains and slower trains in mixed traffic. Punctual stops and skip-stop operation for regional trains are a few of the measures that compensate for the increase in capacity utilisation and reduce disruptions.

Green Train. Basis for a Scandinavian high-speed train concept. Final report, part A (Fröidh, O., 2012)

Summary

Introduction

Gröna Tåget delivers a collection of ideas, proposals and technical solutions for rail operators, infrastructure managers and industry. The purpose of the research and development programme is to define an attractive, efficient and economic high-speed train concept based on passengers' valuations and technical possibilities. Intended to be interoperable in Scandinavia, Gröna Tåget serve as a flexible standard platform that is adaptable to different needs. Increased train travel on the expense of car driving and air travel is an important ”green” quality, even lower energy consumption than present high-speed trains another.

Travel market

An analysis of the travel markets for long-distance passenger traffic shows that high-speed trains will have good prerequisites also in the future, provided that:

- Journey times are short and attractive, in particular in the business travel market
- Fares are low, in particular in the private travel market
- Frequency of service is high, in particular on short and medium-length routes
- Good comfort and service can be offered.

It is thus these demands that must apply to a new high-speed train like Gröna Tåget.

Increases in travel with Gröna Tåget

Line	***Western Main Line***	***Southern Main Line***	***West Coast Line***	***E Coast & Bothnia Line***	***Mälar & Svealand Line***
Forecast 2020	*Stockholm–Gothenburg*	*Stockholm–Malmö*	*Gothenburg–Malmö*	*Stockholm–Umeå*	*Stockholm–Örebro*
Increase in travelling (millions pkm/yr)	+31%	+30%	+28%	+26%	+8%

Examples of possible journey times in Sweden

	No. of stops	**Poss. journey time today, express trains** *(X 2000)*	**Poss. journey time with upgraded track and Gröna Tåget**
Stockholm–Gothenburg (455 km)	0	02:45	02:30
Stockholm–Malmö (614 km)	2	04:00	03:35
with the planned Eastern Link	*2*		*03:15*
Gothenburg–Malmö (305 km)	3	02:30	02:15
Stockholm–Sundsvall (402 km)	5	03:20	03:05
Stockholm–Umeå (737 km)	10	05:40	05:05

Remarks: Speed increase on existing line without curve straightening. Journey times assume that capacity additions to running times will be the same as today or less.

With Gröna Tåget in express train traffic, increases in travel of around 30% compared to today's supply in the basic forecast for 2020 are estimated as a result of shorter journey times, often also lower fares and in some cases fewer changes and higher frequency of service.

If the relative travelling time gains are greater than the examples from Sweden, travel may increase even more with Gröna Tåget.

Traffic

An important objective of Gröna Tåget is to produce a standard train which is flexible to be able to perform a variety of tasks and interoperable in Scandinavia. It can also be adapted for traffic in neighbouring countries with broad gauge or a continental body width.

Short train-sets allow interesting operational possibilities that generate higher revenues and in some cases lower costs, particularly when the degree of utilisation can be increased. A prerequisite is that coupling and decoupling can be done quickly and easily even in winter weather.

The most important conclusion is nonetheless that short train-sets are interesting from the point of view of operating economy as long as demand (travel) is considered. Revenues often increase more than costs when the supply is improved, which is possible with short train-sets.

A generally usable train unit for long-distance traffic in Sweden and the Nordic area has 300 seats. The trains will need to be run as multiple units on many departures. Even a smallish unit with 230 seats is useful for reinforcing capacity during both peak and off-peak periods. A larger unit with approx. 400 seats has also been considered but it has less flexible application on the lines and when passenger numbers are fewer.

Economy

Three factors stand out as particularly important for achieving good economic efficiency in train operation:

- High occupancy
- Good space utilisation
- High average speed, including dwell time.

Gröna Tåget is a proposed concept, the aim of which is to improve all these points compared to existing train concepts. Space utilisation is increased with a wide body that accommodates more seats in the same car. The wide carbody allows a 2+3 seating arrangement in economy class and 2+2 in 1st class, which reduces the total cost per seat kilometre by 15% compared to a normal or continental body profile.

A high average speed can be achieved through good acceleration and tilting. Tilting at higher speeds in curves is profitable on routes with smaller curve radii, in particular if it can shorten the circulation times and thus save trainsets. Shorter dwell times also give lower costs, and in particular at stations with high capacity utilisation they can contribute to better resource utilisation.

Train concept prerequisites

The Gröna Tåget train concept is proposed to be a single-decker train to allow tilting with a wide carbody. The train can be designed in a conventional manner with long carbodies and bogies at the ends or with shorter carbodies in articulated concepts.

For operation in Scandinavia, Gröna Tåget can be executed with a wide body that is between 3.45 and 3.54 metres wide at its widest point 1.7-1.8 metres above top of rail provided that the vehicle profile is designed appropriately and includes a Hold-off device (HOD) and modified lateral suspension (ALS). The dimensioning area to achieve Scandinavian interoperability is Denmark where Gröna Tåget is intended for traffic over the Öresund Link to Copenhagen and possibly beyond. Continued investigation of track distances and obstacles is necessary to determine the greatest possible carbody width. A preliminary vehicle profile suggests 3.54 m carbody width, which can also be equipped with tilting, but switched off on Danish rails however.

The platform lengths on electrified lines vary in the Nordic countries between 125 and 410 m depending on the lines and stations in question. The generally most practical train length is approximately 108 m with four long carbodies, which suits many different platform lengths by adding and detaching units.

Punctual and fast

Gröna Tåget must be designed for punctual train traffic. This means that the train concept must be dimensioned for peak loading when the train is full. Boarding and alighting must take place within very tight margins, which means that doors, entrances, luggage racks and the train's central aisle must be in well considered locations and correctly dimensioned.

There should be two single doors on the side of each car located according to the so-called quarter model, i.e. ¼ and ¾ of the way along the car for the shortest boarding and alighting times. Other solutions with doors at the ends of the car or in the middle of the car mean longer distances to walk on the train. Disabled passengers can board at a special entrance equipped with a lift that is faster than many of today's solutions.

Luggage racks for heavy luggage need to be able to accommodate more items than many trains today and also have room for prams in order to increase safety and improve the working environment in cases of extensive leisure-time travel. There must be a space under each seat for overnight bags and hand luggage and a shelf above the windows.

Seating comfort must be dimensioned for journey times up to 5 hours. The possibility for flexible furnishing where economy class seats can be turned into plus standard or first class seats for business travellers should be considered in order to increase the degree of utilisation. This assumes that the middle seat in rows of three and the aisle seat in rows of two can be converted into extra tables.

Car layouts on Gröna Tåget

A wide train accommodates 25% more seats in the same carbody compared to normal width or the continental car profile. It is possible to accommodate just under 300 seats in a wide-bodied train with three cars dimensioned for punctual traffic and good comfort or 2.7 seats per metre of train length. The corresponding number of seats in cars of continental width requires five cars and gives 2.2 seats per metre.

A lower degree of comfort, fewer luggage racks and fewer doors would, in the same way as a smaller buffet area, make room for more seats, but this would at the same time reduce travellers' willingness to pay and increase the risk of delayed trains.

Track for higher speeds

Top speed

A suitable speed to shorten journey times by express train on conventional main lines in Sweden is 250 km/h. Tilting trains give substantial journey time gains. On track that has been built since the 1990s, even higher speeds are possible, in some cases up to 275 km/h where the track geometry permits this. The high-speed lines that are now being planned will allow trains to be operated at 320 km/h without tilting.

A suitable installed output for a train for general use is 15-20 kW/ton of train weight for a maximum speed of up to 250 km/h, and 20-25 kW/ton for 280-320 km/h. Output requirements increase with more stops and steeper slopes. Higher output is also desirable to obtain more effective electric braking, which gives greater energy recovery.

Capacity

In order to increase speeds on lines with mixed traffic, capacity needs to be reviewed. On single-track lines, shorter run times are an advantage for reducing the number of crossings between trains, while overtaking with freight trains will increase in the same way as on double-track lines. Commuter traffic often leads to a limit to the number of train paths for other trains and slightly delayed express trains become even more delayed but this problem already exists today.

Measures that has proven to be effective for improving the capacity utilisation is to introduce skip-stop traffic with commuter- or regional trains to increase the average speed of slower trains and thus reduce the speed differences. Shorter distances between crossing loops (on single-track lines) and overtaking possibilities increases the capacity and has positive influence on punctuality.

Simulation of the Southern Main Line in Sweden shows that reduced dwell time delays as can be achieved with the Gröna Tåget train concept compared to present express trains, may be sufficient to compensate for the poorer punctuality that might be a consequence of raising the speed.

Mixed traffic with large speed differences consume more capacity and the system becomes sensitive to disruptions. It is possible to reduce the disturbances through different measures but the basic problem still remains. In a longer perspective with increasing traffic, substantial capacity increases will be needed.

Lines for express trains

The measures that may be necessary for an engineering upgrade for higher speeds are higher cant (both executed and cant deficiency), and for speeds over

200 km/h elimination of level crossings, a new signalling system (ERTMS), replacement of track and switches where older types still remain, and perhaps also catenary conversion, geotechnical measures, measures on certain bridges, and measures to increase safety when passing platforms.

Socio-economically profitable

The socio-economic calculation shows that, generally speaking, it is profitable to shorten journey times by increasing the speed of express trains to 250 km/h in Sweden. The most profitable measure is to increase speeds according to planned reinvestments where the new equipment have such high performance that no further measures to increase speeds are needed. Extensive capacity measures and if many grade separated crossings need to be built are expensive measures that reduce the socio-economic return. Shorter travelling times may on the other hand justify introduction of ERTMS.

What does Gröna Tåget need?

Gröna Tåget needs such characteristics that it fulfils the objectives of being an attractive, economically viable and environmentally friendly express train, interoperable in long-distance traffic and regional express traffic in Scandinavia. This concerns both developed technology and the implementation of various solutions that allow the objectives of the train concept to be attained. What Gröna Tåget need could be found in Chapter 8.3 (page 187).

1. Gröna Tåget – an introduction

The Green Train (in Swedish "Gröna Tåget") research and development programme was initiated in response to the need for development of passenger traffic in the increasingly fragmented railway sector. The old corporate structure of a state-owned railway administration that cooperated with a "court purveyor" is not viable in a deregulated situation with competition in both procurement and traffic operation. What is needed is instead are broader, more open collaborations with shared risk-taking that also involve universities and other institutes of higher education in order to take development further and strengthen the railway's competitiveness.

Gröna Tåget is the railway sector's response to the five vehicle research programmes, of which "Gröna bilen" (Green car) is one, that the Swedish Government has supported the automotive industry with over the same period (PFF, 2011).

1.1 What is Gröna Tåget?

Concept proposal for express trains

The Gröna Tåget research and development programme is to result in a concept proposal for the next generation of express trains.

Gröna Tåget aims at the Nordic markets with a train concept that is reliable in winter climates, is also flexible for routes with fewer travellers, and is track-friendly, attractive and cost-effective. There is also an ambition that travellers with a large amount of luggage, a pram or some disability will have an easier train journey. The objective is that Gröna Tåget will be able to constitute a new standard train for interregional traffic in Scandinavia.

Gröna Tåget is a collection of well-motivated ideas, proposals and technical solutions but no prototype will be produced that is fully in line with our proposals. The knowledge that has been acquired and the solutions that are proposed can be used in part or in full. A railway company that wishes to purchase a new train decides itself what it will ultimately look like. In order to produce a functioning train, however, continued research is needed on many subsystems and components. A train manufacturer may adopt one proposed detailed solution as standard while another will perhaps choose a different solution.

Figure 2. A train manufacturer may adopt one proposed detailed solution as standard while another will perhaps choose a different solution. (Fröidh/LundbergDesign)

The purposes of the Gröna Tåget programme are:

- To develop train concepts and technology that will give attractive, efficient, climate-friendly train traffic on medium-distance and longer journeys
- To influence the development of European standards and train concepts for Nordic conditions
- To further strengthen competence to develop trains in Sweden.

In many ways it is a question partly of developing train concepts better suited to users in the Nordic countries than many other concepts can be expected to and partly of paving the way for profitable exports of trains and expertise to other markets (Ökad spårtrafik utvecklar Sverige, *Increased track-bound traffic develops Sweden*, 2009).

Characteristics of a Green train

Earlier research identified the most important characteristics for train traffic's attractiveness in the travel market (see for example Nelldal et al., 1996; Effektiva tågsystem, *Efficient Train Systems*, 1997). A journey by train can mainly be made more attractive by means of:

- Shorter travelling times
- Lower costs, enabling both lower fares and increased profitability
- An attractive, functional passenger environment with high comfort
- Greater reliability, even in the Nordic winter climate.

More attractive train traffic increases the train's market share, which in itself is possibly the most important "green" effect. Fossil-fuelled car, bus and air traffic can decrease or stagnate at the same time as today's train travellers gain greater benefit from an improved supply of electrically powered train traffic.

In addition to transfers to train travel, Gröna Tåget will have direct financial and environmental consequences that reinforce the green profile. The following are of particular importance to railway companies and track managers and in some cases also third parties:

- Track-friendliness, for good performance and low wear to the tracks
- Lower energy consumption
- Less noise.

All in all, Gröna Tåget provides possibilities to increase productivity in the railway sector and efficiency in the transport sector. By extension this will affect society in a green, more environmentally friendly, direction, in particular as regards anthropogenic emissions of climate-impacting gases, i.e. greenhouse gases.

1.2 About the research programme

Cooperation in the railway sector

The Gröna Tåget research programme engages large parts of the Swedish railway sector: the Swedish Transport Administration[2], Bombardier Transportation, the train operators, institutes of higher education, research institutes and consultants. The programme was conducted between 2005 and 2012. Several different sub-projects are summarised in the final reports, and this part, Part A, includes six projects in the areas of market, traffic and train concepts. Part B (Andersson, 2012) summarises a large number of projects of a predominantly vehicle engineering nature.

[2] On 1 April 2010, the Swedish Transport Administration (Trafikverket) took over the responsibility for administration of Sweden's state-owned track installations from the National Rail Administration (Banverket). Both agencies' names will be found in the report.

Sub-projects concerning market, traffic and train concepts

An attractive passenger environment

One of the major sub-projects is *An attractive passenger environment*, a collaborative project between Bombardier, Konstfack and KTH. The aim was to work with the train's interior and furniture from a traveller perspective. Some of the solutions studied in the project have been implemented in SJ's X55 express train.

Kottenhoff, K. and Andersson, E., 2009. Attractive and efficient train interiors. KTH Railway Group, Publication 0903. Stockholm

Lundberg, O., Eriksson, D. and Ranvinge, M., 2010. Design and innovation for rail vehicles. Konstfack (University college of arts, crafts and design), Stockholm

Wide-bodied trains in Denmark

The carbody widths that can be permitted in Denmark are being studied in collaboration with Rail Net Denmark (Banedanmark). The sub-project at KTH will be concluded during 2012, but preliminary results are included in this final report.

Fröidh, O. and Persson, R., 2011. Säkerhetsmarginal för trafik med breda tåg i Danmark (in Swedish). *(Safety margins for traffic with wide-bodied trains in Denmark)* PM 2011-06-21, not published

Gröna Tåget – driver's cab

The Swedish National Road and Transport Research Institute (VTI) conducted the *Gröna Tåget - driver's cab* sub-project to produce bases for designing future driver's cabs on high-speed trains with regard to information and safety systems. VTI has also developed a train simulator that can be used for research and education.

Mårdh, S. et al. (i.e. Eriksson, L., Blissing, B., Nilsson, L. and Sundström, J.), 2010. Gröna Tåget – förarplats (in Swedish) *(Gröna Tåget - driver's cab)*. Slutrapport. VTI, Linköping

Capacity for Gröna Tåget

Express trains in mixed traffic lead to significant speed differences between the different types of trains, which may cause capacity problems. A report is planned for publication in 2012.

Sipilä, H. and Warg, J. (planned 2012). Kapacitetsanalys av Södra stambanan (in Swedish) *(Capacity analyses of the Southern Main Line)*. KTH, Stockholm

Market and traffic

The Market and traffic sub-project at KTH analysed the market prerequisites and calculated the financial consequences of various overall solutions for traffic and train concepts. The report "Resande och trafik med Gröna Tåget" *(Travel and traffic with Gröna Tåget)* is at the same time the basis of the present final report, Part A.

Fröidh, O., 2010. Resande och trafik med Gröna Tåget (in Swedish, includes an English summary). KTH Railway Group, Publication 1001. Stockholm

Sipilä, H., 2008. Körtidsberäkningar för Gröna Tåget (in Swedish) *(Running time calculations for Gröna Tåget)*. KTH Railway Group, Publication 0802. Stockholm

Support systems in train driver environments and experiences from a train project

Two small sub-projects have inventoried today's and tomorrow's support systems for train drivers and experiences from the purchase and delivery of a series of regional trains.

Dimgård, M., Jansson, A. and Kecklund, L., 2009. Dagens och morgondagens stödsystem i tågförarmiljöer (in Swedish) *(Today's and tomorrow's support systems in train driver environments)*. Report. MTO Safety, Stockholm

Dimgård, M., and Kecklund, L., 2010. Erfarenheter av ett tågprojekt (in Swedish) *(Experiences from a train project)*. Report. MTO Safety, Stockholm

1.3 Summary

Gröna Tåget delivers a collection of ideas, proposals and technical solutions for rail operators, infrastructure managers and industry. The purpose of the research and development programme is to define an attractive, efficient and economic high-speed train concept based on passengers' valuations and technical possibilities. Intended to be interoperable in Scandinavia, Gröna Tåget serve as a flexible standard platform that is adaptable to different needs. Increased train travel on the expense of car driving and air travel is an important "green" quality, even lower energy consumption than present high-speed trains another.

2. The travel market for high-speed train traffic

Future travel by high-speed-train is dependent on both the future car, bus and air supply and how attractive the Gröna Tåget supply can be made. Shorter journey times are the single most important supply factor as regards long-distance traffic but lower fares, frequency of service and comfort are also important for attractiveness.

2.1 Introduction

High-speed trains are a developed form of the railway's supply of opportunities for fast travel. New high-speed lines have been built and high-speed trains operate on many lines in Europe and Asia, benefiting society with greater accessibility. There is also a need to shorten travelling times on existing lines where the passenger base is limited and insufficient to justify new lines. Tilting high-speed-trains like the X2 (X 2000) and the Pendolino that can maintain higher speeds on curves can achieve fairly high speeds and with their preconditions have succeeded well in the market.

The Gröna Tåget research programme is intended to draw up a proposal for how a future high-speed-train can be designed on the basis of market needs in Sweden and the other Nordic countries. Gröna Tåget must be able to give short travelling times on curvy lines just like the X 2000 but in addition also be able to achieve high speeds on newly constructed links. The Gröna Tåget train is thus a development of the notion of high-speed-trains. An attractive train concept and good overall economy are the two most important objectives.

There is some uncertainty as to how the market for fast long-distance train traffic will develop in the future. In Gröna Tåget's future market segment, long-distance journeys of one to four hours or distances of 150-600 km, it is in stiff competition with the car, in particular in the lower part of the interval where the train's frequency of service is relatively low, and with air transport in the upper part of the interval. Coach services can also compete with low prices and relatively advantageous travelling times on motorways compared to slow trains. Price pressure in the air sector is strong and ticket prices fall over time, which is particularly noticeable in the case of low cost carriers[3].

[3] The term *low cost carriers* is used here (instead of "low-fare companies") since their average costs/fares are lower than those of full service companies, but not necessarily all fares.

Train traffic consequently needs to be developed with both low prices, shorter travelling times and higher frequency of service to be able to cope with competition from other transport modes.

2.2 The long-distance travel market

Market segments

The long-distance travel market, i.e. journeys over 100 km, primarily comprises official business journeys and leisure time trips. Commuting is not normally included, even if people also commute over long distances on express train routes. Long-distance journeys may take place regularly but most are more infrequent and require more extensive planning (booking tickets, etc) and perhaps overnight stays.

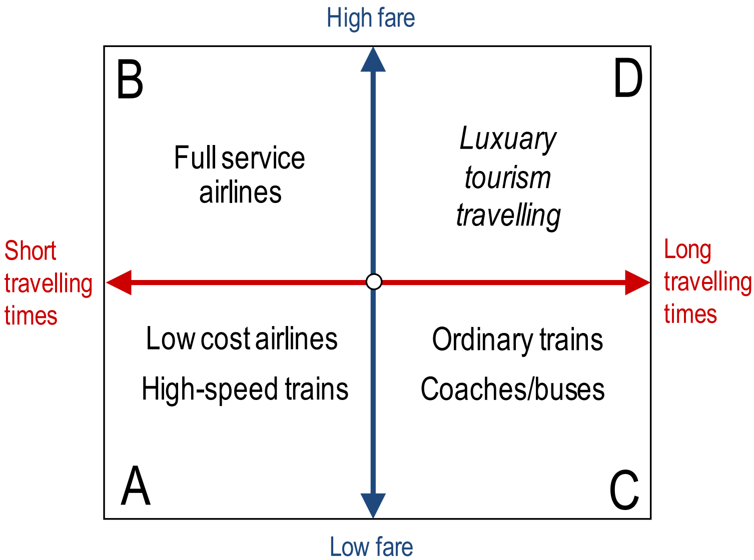


Figure 3. The long-distance travel market divided by market segment depending on fares and travelling times. Gröna Tåget is intended to compete in the expanding segment A, with short travelling times and low fares. Source: Fröidh, 2008

The long-distance travel market is primarily sensitive to the travelling times, the fares and frequency of service but also to comfort and service. Individual travellers value the supply factors differently depending on the reason for their journey, their time budget and their economy. Leisure-time travellers who pay for their tickets themselves are for example in general more sensitive to the price than a person travelling on official business. But the most important long-term factor in the market is the travelling times, given that fares and frequency of service are acceptable.

The long-distance travel market can be divided into market segments depending on travelling times and fares. Before express trains and high-speed-trains existed, the train supply was mainly in sector C, with relatively long travelling times but in general low fares. Air traffic existed before the low cost carriers' time in sector B, i.e. fast and expensive.

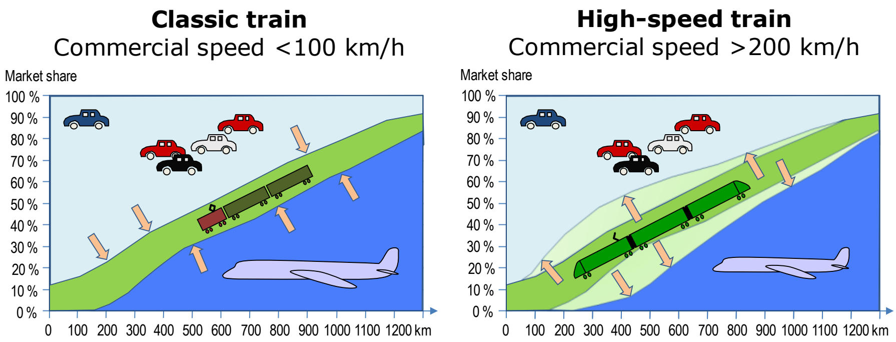


Figure 4. Competitive pressure as a function of the train's average speed. Gröna Tåget can achieve average speeds of 150-170 km/h on upgraded lines, giving them a market potential somewhere between what is possible with conventional trains and new high-speed lines.

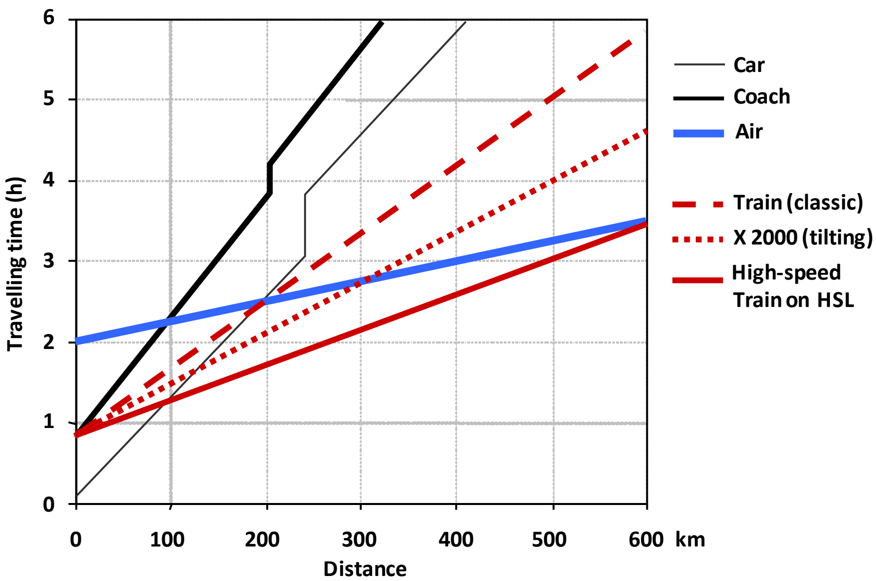


Figure 5. The schematic showing travelling time door-to-door with different modes of transport, including connecting journeys, changes, and in the case of car and coach also breaks. The X2 (X 2000 express train) is the fastest mode of transport from about 100 km up to 300 km, in some cases even further. Source: Modified from Nelldal, 1998

Low-cost air travel has made flying cheaper and express trains and high-speed trains have made the train faster. Both modes now compete in many cases in the same market segment (A). This is a market segment that is expanding as it leads the market in terms of both travelling times and fares. Other factors, such as comfort and service, provide some scope for a supply also in sector B, where travellers view the journey as a goal in itself and do not demand short travelling times (Fröidh, 2008).

Sector C thus has a limited customer base of people in the lower income bracket and it is often here that society needs to make supporting purchases of traffic that is not economically profitable from a business point of view.

Journey time

As stated earlier, travelling time is the single most important supply factor, given that frequency of service and fares are acceptable. Short travelling times give good accessibility and accessibility is the transport system's principal "product". Good accessibility is a prerequisite for many businesses, which also explains why it is valued highly.

Short travelling times on upgraded lines are one explanation why the X 2000 has led to so many more people in Sweden choosing the train for long-distance journeys and why short-distance journeys by air and feeder traffic by air within a 400 km radius of Stockholm have declined substantially in recent decades (Nelldal, 2005a). Other factors, like the construction of more motorways, which makes car journeys shorter, and high costs for low-demand minor air routes that cannot be covered by surpluses from other routes after the deregulation of air traffic, have also contributed to the marked reduction in airlines' feeder traffic.

Fares

Fares are an important ingredient in the attractiveness of the supply. Most airlines and also SJ AB have introduced a concept called yield management. Based on a simple principle of benefit, it aims to minimise the consumer surplus by means of statistical analyses of demand. One characteristic of yield management is a varying but limited number of extremely cheap tickets in order to sell empty seats (cf SJ's offering of train tickets for 95 SEK).

Properly executed, yield management can increase both demand and revenues (see the figure; Doganis, 2002). Innovative pricing is an important factor behind the increase in travel by train in Great Britain since 1990 (Wardman, 2006). If DB were to introduce yield management in train traffic in Germany, the company would be much more competitive against the low-cost airlines than without such fares (Eisenkopf, 2005).

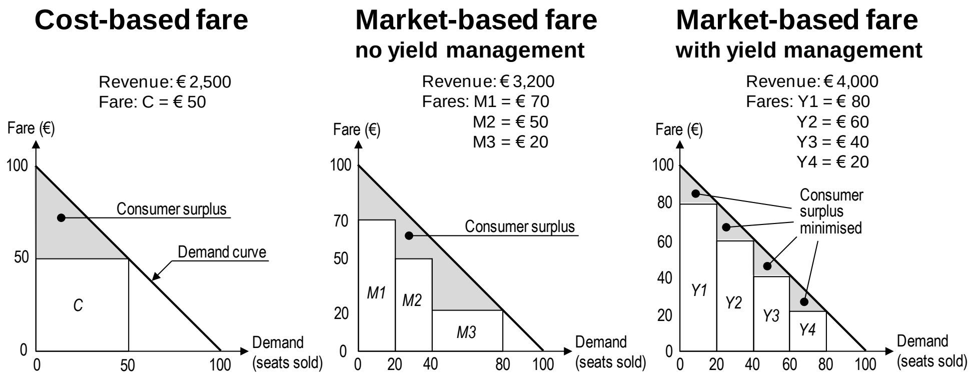


Figure 6. Flat rate based on production cost (left) generates revenues of 2,500 EUR for one departure, but only half the seats are sold when the price is 50 EUR. A market-based price and yield management, which minimises the consumer surplus, result in revenues of 4,000 EUR and 80% seats sold in the example furthest to the right. Source: Doganis, 2002

Road traffic

Car

Over longer distances, the car is relatively slow compared to air and express trains. The travelling times are considerable for many possible journeys, especially a return journey the same day, and under these prerequisites the car is not the first choice when there is a faster public transport alternative. On the other hand, the reasons for choosing the car for long journeys are that it is cheaper for a family, there is a lot of luggage to be transported, and the car is needed at the destination, or other reasons that are often connected to leisure-time journeys.

Over shortish and medium distances, the difference in travelling time compared to the train is smaller, one of the main reasons being that roads are in an increasing number of places being converted to motorways. The importance of frequency of service is also greater when it comes to shorter distances since waiting time constitutes a growing proportion of the time sacrifice for the whole journey. Connecting journeys and changes make public transport both relatively slow and often more expensive. The train therefore has difficulty competing with the car when connecting journeys are required and frequency of service is not high enough.

The future development of car travel is to a great degree dependent on the availability of cheap energy and the environmental issues. The development of motoring over the past century was based on the availability of cheap oil and other raw materials but the consequence has been environmental problems, including the greenhouse effect. Emissions of greenhouse gases must be cut if we are to have a transport sector that is sustainable in the long term (Åkerman and Höjer, 2006).

Good opportunities may, however, exist to attract motorists with a good supply of train traffic. Short travelling times, high frequency of service, low fares, good comfort and service are attractive to most travellers who can choose their mode of transport, as many surveys and studies have shown (for example, The Svealand Line; Fröidh 2003). The train's possibilities vary depending on the reason for the journey and market segment, but there is good reason to regard car travellers as the train's greatest market potential.

Long-distance coach travel

A study of parallel train and coach supply in Intercity traffic in Ireland shows that most people prefer (value more highly) to travel by coach. But the situation in Ireland is that train traffic is often operated with old trains (the average age of the rolling stock was 25 years at the time of the most recent survey) and on outdated track. The coaches are in general modern, clean and well-maintained and the travelling times are shorter and the fares lower. The conclusion is that the supply in itself is more important than the mode of transport (Ahern and Tapley, 2008).

The study of the regional train traffic on the Svealand Line (Fröidh, 2003), however, shows that car-drivers value fast-train traffic on X2 trains considerably higher than coach traffic – in the latter case, there is consequently a "track factor" that can not only be explained by supply factors in the form of travelling times, fares and frequency of service.

Travellers on the Blekinge Coastal Line have shown in a study that they prefer the train to the coach for interregional journeys (over 100 km). The introduction of through Öresund trains between Copenhagen and Karlskrona after electrification of the line has led to more travellers and a larger catchment area around the stations than the previous railbus traffic had, despite the fares and travelling times remaining unchanged (Fröidh and Kottenhoff, 2009).

If the train faces competition from long-distance coach traffic with low fares, the train operator is forced to reduce the fares to be competitive against the coach traffic. In practice, train fares have become more differentiated through yield management than coach fares. When train and coach fares are comparable, the train has a considerably higher market share as long as travelling times are shorter and comfort better on the train than on the coach (Nelldal and Troche, 2010).

Air traffic

In the immediate post-war period and especially from 1970, air traffic saw strong growth as an exclusive, fast way to travel. National airlines built up the route networks around their respective hubs in most European countries. Since the 1990s, deregulation and subjection to competition, in addition to new motorways, express trains and high-speed lines, have forced the air transport sector into substantial restructuring. We are still in a period where the earlier networks are being broken up and replaced by low cost carriers that are more focused on new direct routes with low fares. Short feeder routes are disappearing as they become unprofitable and more and more really long-distance routes are appearing as a consequence of the globalisation of tourism and trade and industry.

Fares and revenues are showing a sharp downward trend for the airlines, who have to reduce their costs in order to be successful (Doganis, 2001). The low cost carriers use a variety of strategies to reduce their costs. Examples include only selling tickets for point-to-point journeys, thus avoiding responsibility for transfers, using small airports for their lower airport charges, using the Internet as a sales channel, charging for all kinds of extra service and working with supporting revenues, and maintaining a modern, uniform aircraft fleet, but mainly by producing more efficiently with a minimum of administration (Franke, 2004).

In Europe, the low cost carriers have focused on short-to-medium distance routes of 634 km on average, where 70% are shorter than 1,000 km (Dobruszkes, 2006). It is often a matter of giving air connections to towns and cities alongside the high-speed networks or the traditional airlines' routes. This might indicate that one success factor for the low cost carriers would be to develop new geographical markets through high accessibility to new areas.

One experience from Germany is that the established airlines have lost more travellers to the low cost carriers than train traffic has (Eisenkopf, 2005).

2.3 Production costs for trains and air transport

Trains and air transport have different production costs. Fares, however, are set according to other premises than those applied by operators who use yield management, as stated earlier. The operator's profit, on the other hand, is the difference between average revenues and costs. The production costs thus give a picture of the average costs even if distribution over different categories of traveller varies.

Examples from the airlines are that low-cost carrier Ryanair's average production costs in 2004/2005 were 0.039 EUR (0.35 SEK [4]) per seat-km, while SAS's were 0.078 EUR (0.71 SEK), or double the amount (Fröidh, 2008). However, the cost is highly dependent on how production takes place and, in addition to obvious differences in personnel costs and administration, aircraft size (type), network and route length also have an impact on the total cost.

In domestic air traffic, costs can be calculated using a model that the Swedish Civil Aviation Administration, now part of the Swedish Transport Agency developed together with Cranfield University (Hofton, 2006). The model has been adapted to Swedish conditions and the version used here is for 2005.

By comparing the results from the domestic model with Gröna Tåget's cost model (see the next section) it is possible to calculate the cost structure in competition with the train and air transport.

There is a distinct decline in total costs per seat-km the longer the air route, which is also supported by other sources (Pavaux, 1991; Babikian et al., 2001; and also Mayer, 2005). The reason is that a high proportion of air traffic's costs are associated with take-off, landing and terminal handling.

Larger aircraft also give significantly lower costs per seat-km than smaller aircraft (Doganis, 2002). The examples in the model are the smallish Saab 340A with 34 seats with higher costs per seat-km compared to the larger Boeing 737-800 with 179 seats (the full service carrier) or 189 seats (the low cost carrier).

Train traffic's costs per seat-km decline only slightly with distance, mainly because terminal time represents only a small proportion of the total circulation time.

The results show that train traffic can be produced with lower costs per seat-km than domestic air traffic. Ryanair's average value in international traffic has a break-point with the X2 (X 2000 express train) at 800 km. Ryanair and other low cost carriers, however, can not achieve as low costs in domestic traffic, among other things because the airports have a different cost structure in Sweden and feeder traffic to the airports would constitute such a high share of the total travelling time and travel cost. On domestic routes, the cost break-point per seat-km is on such long routes that it is outside all major domestic routes in Sweden.[5] The train consequently has lower costs in domestic long-distance traffic than air transport.

---

[4] Exchange rate in the example: 1 EUR = 9.1 SEK (November 2004)

[5] Pavaux (1991; in Mayer 2005) puts the break-point for equal costs per seat-km , feeder flight/high-speed train somewhere between 1,200 and 3,000 km.

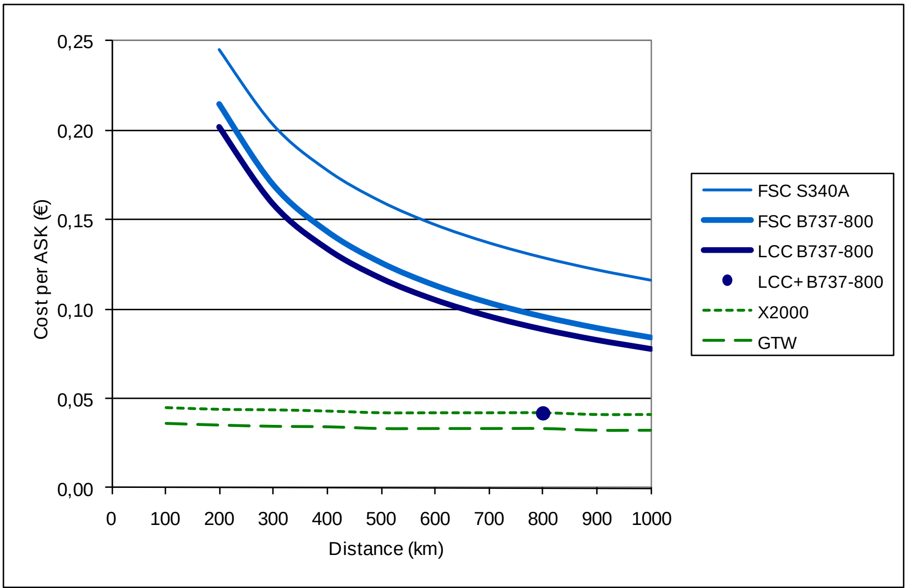


Figure 7. Model-calculated costs for domestic air and train traffic in Sweden, per seat-km (ASK) in EUR (2005 values). FSC (Full Service Carrier). LCC (Low Cost Carrier), where LCC+ by way of comparison shows Ryanair's average in international traffic. The aircraft types are the (Saab) S340A and the (Boeing) B737-800. GTW: Gröna Tåget Wide. Source: Fröidh, 2008

A number of factors affecting the result should be borne in mind however:

- Occupancy
- Cost development
- Distribution of costs (yield management)

Occupancy is often significantly better in the air sector than for train traffic. A low cost carrier flying point-to-point generally has a degree of occupancy (cabin factor) of 75-80% while the best long-distance rail routes have about 70% and SJ 54% on average (SJ AB annual report 2010). The reason for the lower average degrees of occupancy on trains is the fact that the intermediate markets make it difficult to achieve optimum seat occupancy and the large diurnal variations in work-related travel. This affects the break-point for the cost per seat-km (and the fare) to air transport's advantage.

Costs in the air transport sector show a distinct decline over time, mainly due to stiff competition and price pressure in the sector (Doganis, 2001). Equivalent circumstances have not existed in the railway sector. This may, however, change as a result of procurement in regional and deregulation of long-distance passenger traffic.

The distribution of costs over traveller categories varies and a large proportion of trips on official business also allows more cheap tickets to be offered to the private travel market. Short travelling times attract a business traveller base with great ability to pay and it is necessary to use yield management for an attractive supply from the point of view of price. The train (SJ in Sweden) competes successfully today with air transport over distances up to 400 km and also in the slightly longer Stockholm–Gothenburg end-point market, but the train also needs to have a more attractive supply on other routes in order to be able to keep and take more market share in the long run.

2.4 Express trains in the travel market

The most important supply factors

Express trains, and in particular high-speed trains, have shown that modern train traffic with high speeds have great market potential and on many lines train traffic has increased substantially thanks to the short travelling times. Travelling times are the single most important supply factor, but fares, frequency of service, comfort and service are also important.

Lower average fares are possible through lower production costs. But it is also necessary to distribute the costs on strictly business lines by differentiating fares, which can be accomplished by means of yield management. Through these mainstays private travellers can be offered a larger proportion of cheap tickets. But the shorter travelling times that attract business travellers with spending power to the train are still an important prerequisite.

More travellers expand the passenger base and frequency of service can be increased. This in turn further increases demand, known as the Mohring effect (Mohring, 1972; also described for example in Small, 1992). It is also possible to build up a market by offering more departures, exemplified by the Blekinge Coastal Line and the Svealand Line (Fröidh, 2003; Fröidh, 2005; Fröidh and Kottenhoff, 2009). In order to also maintain a high frequency of service on lines with fewer travellers, however, smaller train units with good economy are required.

Comfort is important for attractiveness and many travellers compare the train to their own car. The train must be more comfortable and be perceived as well designed to be able to attract more travellers. The need and willingness to pay for service varies widely with the reason for travelling, socio-economics and individual needs, but a new type of train must enable more flexibility in the service supply, such as refreshments and meals and information provision (Internet connections, journey information, etc.)

All in all, express trains and high-speed trains will continue to have good prerequisites in the travel markets in the future, provided that:

- Travelling times are short and attractive, in particular in the business travel market
- Fares are low, in particular in the private travel market
- Frequency of service is high, in particular on short and medium-length routes
- Good comfort and service can be offered.

It is thus these demands that must apply to a new express train like Gröna Tåget.

Demand elasticity

A better, more attractive, supply of train services will lead to an increase in travel. Demand elasticity allows a rough estimate to be made of this increase in demand.

Elasticity calculations can only be used where changes in supply are marginal. Substantial changes in supply and many interacting factors mean that demand elasticity is not able to reflect the actual change in demand and under these circumstances a (good) forecasting model gives better results.

Elasticity must always be viewed in its context, both as regards the interval to which it refers (which in itself is an approximation since it is the derivative of a function), and under what preconditions it was calculated (starting point of the supply as regards travelling time, market share, with or without competition from air travel, etc). There are threshold values at which elasticity peaks distinctly such as when the travellers' time budget for a minor change enables daily commuting for example (Nelldal, 2005b).

Demand elasticities of less than 1 are called inelastic, while values above 1 are elastic and mean greater percentage increases in demand than changes in supply.

The summary overview shows that travelling time elasticity is often significant and elastic with values of around 2 or more. The precondition is that travelling time is critical as regards accessibility (threshold values) or in competition with air travel and therefore crucial to the choice of travel mode. Under other circumstances, travelling time elasticity may be inelastic, i.e. the travellers who have already discarded the train as an option do not consider shorter travelling time to be quite as crucial as regards the choice of travel mode.

Table 1. Examples of demand elasticities for train supply

Supply factors	***Interval***	***Elasticity***	***Source:***
Travelling time	Travelling time 2-4 hrs (peak at 2.5-3 hrs travelling time where competition from air exists)	−1.5 to −2,0	Nelldal, 2005b
	Model-calculated for high-speed trains in Spain	−2.4 to −2,6	Bel, 1997; Martín & Nombela, 2007
	Travelling time approx. 1 h on long-distance regional journeys on the Svealand Line	−1.7 to −2,4	Fröidh, 2003
	Sweden, distance-dependent, primary competition from car Mean journey length 600 km 400 km 200 km	 −1,7 to −1,9 [1] −1,0 to −1,1 [1] −0,4 to −0,5 [1]	Calculation guide, 2009
	IC trains in Great Britain 1996	−0.9	Seabright, 2003 (Wardman)
	IC trains in Great Britain 1991	−0.6 to −0,7	Seabright, 2003 (Macket&Nash)
Price	TGV Sud-Est and TGV Atlantique 2005 (higher on longer routes)	−0.9 to −1.8	SNCF (not published)
	Transfer to airport in Great Britain in 1990s	−0.6 to −0.8	Lythgoe&Wardman, 2002
	IC trains in Great Britain 1996	−0.6	Seabright, 2003 (Wardman)
	IC trains in Great Britain 1992	−0.6 short term −1.1 long term	Seabright, 2003 (Goodwin et al.)
Frequency of service	Sweden, ASEK 4 (in general)	0.5	Calculation guide, 2009
	10-20% change in frequency of service, Great Britain	0.3 to 0.4	DfT National Traffic Model (2002)

[1] Depending on distribution between private and business journeys

The elasticity applied in elasticity calculations in Sweden is based on the assumption that the new travellers come mainly from the car (Beräkningshandledning, 2009), which means lower elasticity figures than if they come from air travel. When the travellers come from air travel, this in turn means a reduced supply of air routes that contribute to increase travelling time elasticity for the train, i.e. a Mohring effect (Mohring, 1972; Small, 1992).

In most studies, price elasticity is inelastic, but there are exceptions. Experience from the TGV in France shows clearly elastic values of up to −1.8 on longer TGV routes. It is also worth noting that one source shows that elasticity is considerably higher in the long term than in the short term – it consequently takes time to build up demand. Some examples of changes that take place over periods of some years before a new equilibrium is reached are the individuals' choice of workplace and car ownership (Fröidh, 2003).

Frequency of service elasticity is as a rule between 0.3 and 0.5 and therefore inelastic. As with all demand elasticities, it is, however, the initial status that is important, and higher elasticity can be expected at the threshold values. One conceivable threshold value is that a frequency of service of 2 hours is perceived as not good enough for commuting to work while 1 hour can be accepted, as indicated in the valuation of frequency of service in a study conducted on the Svealand Line (Fröidh, 2003).

In the case of long-distance traffic with Gröna Tåget, the demand elasticities listed below are used in calculations of changes in travel.

Table 2. Demand elasticity in calculations for Gröna Tåget

Supply factors	***Elasticity***	***Interval***
Journey time	−1.5 −0.9	2-4 h travelling time by fast rain Other express train markets
Price	−0.8	Long-distance train journeys with approx. 70% private travellers
Frequency of service (waiting time)	0.3 0.4 0.5	Up to 10% change 10-30% change Over 30% change

Where there is a need to change trains, an empiric frequency of service elasticity of −0.2 is used, i.e. changing reduces elasticity by 20%.

2.5 Demand calculations

Examples of Gröna Tåget in Sweden

Forecast for comparison

Analyses from five Swedish railway lines are presented here as examples of possible increases in demand with more attractive train traffic. The reference is the so-called Base Forecast 2020 that the then National Rail Administration developed while drawing up the National Transport Plan for 2010-2021. The Base Forecast 2020 (Base 2020) covers traffic in the Swedish railway network in 2020, where decided and on-going infrastructure projects have been completed but without the new projects analysed in the plan (National Plan, 2009). The point of departure for calculations of travel and revenues is transport production, the number of passenger-kilometres per year, in Base 2020.

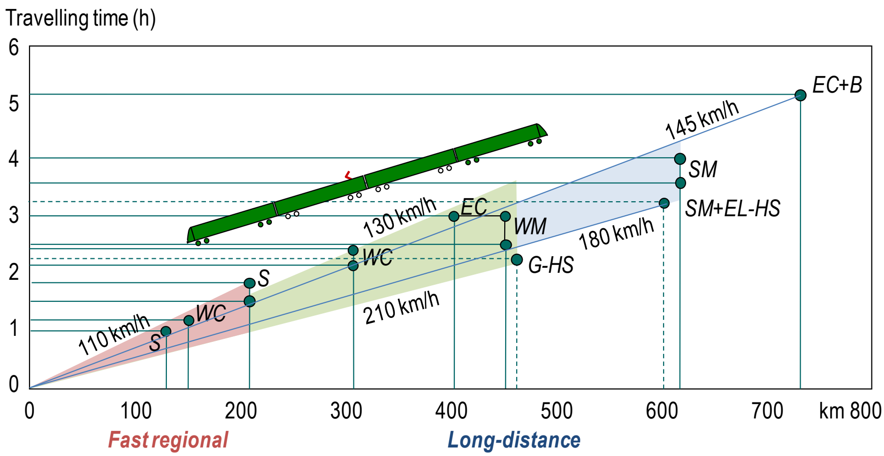


Figure 8. Examples of commercial speeds of routes with travelling times of 1-5 hrs and distances of 100-700 km in Sweden on which Gröna Tåget can operate.

B: Bothnia Line, EC: East Coast Line, EL-HS: Eastern Link High-Speed Line (planned), G-HS: Götaland High-Speed Line (proposed), S: Svealand Line, SM: Southern Main Line, WC: West Coast Line, VM: Western Main Line.

The Gröna Tåget 2020 forecast is based on Base 2020, but with the difference that it includes investments for higher speeds up to 250 km/h, together with some extension of capacity, on the five existing lines in the analysis. The routes are also operated with Gröna Tåget instead of the base forecast's Type 2 trains, which are equivalent to an older express train (X2) with tilting carbodies and with a maximum permitted speed of 200 km/h. Travelling times, frequency of service and fares are thus different in the new scenario.

Future travel on Gröna Tåget is calculated using demand elasticities for every route. The effects on the whole network (the railway network) are thus not included, nor are the synergies of several combined improvements that often give significantly greater effects than an individual factor, for example better marketing or such a big improvement in supply that households manage with fewer cars (Fröidh, 2005; Nelldal, 2005b).

Supply factors

The most important supply factors for train traffic in the forecasts are travelling time, fares and frequency of service (waiting time).

The travelling times stated are average travelling times for all express trains in the traffic design and include stopping patterns and certain timetable supplements. The travelling time gains with Gröna Tåget are based on a speed increase up to 250 km/h on existing track where possible, compared to 200 km/h in Base 2020 (Sipilä, 2008).

The average revenue for express trains in the initial situation is set at 1.10 SEK/pkm (passenger kilometre) on the Western Main Line, the Southern Main Line, and the East Coast Line and the Bothnia Line and for the X 2000 in another comparable forecast (Höghastighetsbanor i Sverige, 2010). On the Mälar Line and the Svealand Line, it has been set at 0.80 SEK/pkm, which is the same revenue as for SJ's Intercity trains (Höghastighetsbanor i Sverige, 2010). In the latter case, regional travel with increased commuting and competitive pressure from car journeys motivate different average revenues. On the West Coast Line, a value has been set that lies between the two, i.e. 0.99 SEK/pkm. This is motivated by the fact that an increase in the proportion of travel by express train with an improved supply can give higher revenues than normal Intercity traffic because the supply is improved.

Gröna Tåget trains can achieve roughly 20% lower total costs than the X2 (X 2000). On the base forecast's express train lines, it is assumed that half the cost reduction with Gröna Tåget will be passed on to the consumer and the other half to the producer, i.e. the traffic operator on the Western Main Line, the Southern Main Line, and the East Coast Line and the Bothnia Line. This means that the average revenue will fall by 10% to 0.99 SEK/pkm with an equal distribution of the cost reduction to the producer and the consumers.

On the other hand, Gröna Tåget may lead to more long-distance travellers on lines with a regional character, such as the West Coast Line, the Mälar Line and the Svealand Line, through a greater number of long-distance routes. It has been assumed here that the Intercity rate of 0.80 SEK/pkm and the rate on the West Coast Line of 0.99 SEK/pkm remain unchanged in the Gröna Tåget alternative.

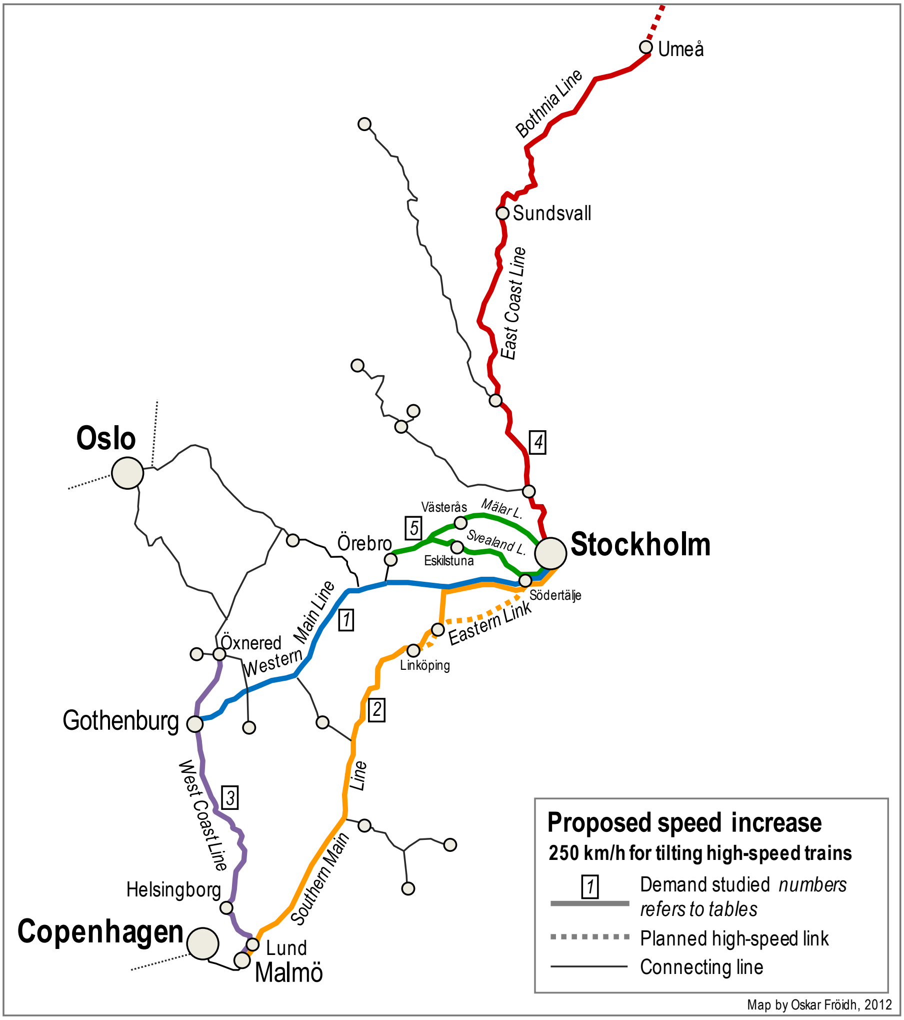


Figure 9. Lines studied for demand calculations. The Eastern Link is a planned 155 km high-speed link on the Southern Main Line which would boost the demand above the 30% increase by Gröna Tåget.

The number of trains a day refers to weekdays and journeys in both directions (train pairs). The waiting time between departures is calculated in the forecasts by dividing the period from kl 06:00 to 21:59 (16 hours or 960 minutes) by the number of express train departures.

The Gröna Tåget 2020 scenario includes slightly more services than Base 2020 between Stockholm and Gothenburg (Western Main Line) and between Stockholm and Malmö (Southern Main Line), where there is assumed to be room for a marginally increased supply as a consequence of the increase in demand.

Table 3. Supply factors for express trains

Line	Base 2020	Gröna Tåget 2020
1. Western Main Line ***Stockholm–Gothenburg***		
Train pairs per day	20	24
Waiting time (mean)	48 min	40 min (−17%)
Travelling time (mean)	187 min	170 min (−9%)
Revenue (mean)	1.10 SEK/pkm	0.99 SEK/pkm (−10%)
2. Southern Main Line ***Stockholm–Malmö***		
Train pairs per day	16	22
Waiting time (mean)	60 min	44 min (−27%)
Travelling time (mean)	275 min	251 min (−9%)
Revenue (mean)	1.10 SEK/pkm	0.99 SEK/pkm (−10%)
3. West Coast Line, (Öxnered–) ***Gothenburg–Malmö–Copenhagen***		
Train pairs per day	7 (+8) [1]	16
Waiting time (mean)	64 min	60 min (−6%)
Travelling time (mean)	148 min	130 min (−12%)[2]
Revenue (mean)	0.99 SEK/pkm	0.99 SEK/pkm
4. East Coast and Bothnia Lines ***Stockholm–Sundsvall–Umeå***		
Train pairs per day	14	14
Waiting time (mean)	69 min	69 min
Travelling time (mean)	235 min	212 min (−10%)
Revenue (mean)	1.10 SEK/pkm	0.99 SEK/pkm (−10%)
5. Mälar Line and Svealand Line, ***Stockholm–Örebro***		
Train pairs per day	32	32
Waiting time (mean)	30 min	30 min
Travelling time (mean)	110 min	100 min (−9%)
Revenue (mean)	0.80 SEK/pkm	0.80 SEK/pkm

[1] 7 long-distance train pairs in the base forecast, +8 train pairs (out of a total of 32) with regional trains (Öresund Trains) which are assumed to be predominantly long-distance journeys for comparability between the scenarios

[2] 14% for Gothenburg–Copenhagen and 5% for Gothenburg–Öxnered

Between Gothenburg and Malmö/Copenhagen, 8 of the 32 Öresund Train services are transformed into Gröna Tåget services and take on a more distinct long-distance traffic character rather than a regional character though Gröna Tåget's enhanced attractiveness.

Between Stockholm, Sundsvall and Umeå, the available single-line capacity limits the number of services, but this also means that the trains on this route are as a rule longer. The customer base is in fact sufficiently large to increase the number of services, if there were only sufficient capacity.

Between Stockholm and Örebro there are two alternative routes, one via Västerås and the other via Eskilstuna, that are assumed to each have 16 train pairs, making a total of 32 services between Stockholm and Örebro in 2020 in both scenarios.

Fröidh (2010) contains a more detailed description of the supply.

Travel calculation summary

Table 4. Demand for journeys by express train, by line

Line	***1. Western Main Line***	***2. Southern Main Line***	***3. West Coast Line***	***4. E Coast & Bothnia Line***	***5. Mälar & Svealand Line***
	Stockholm–Gothenburg	*Stockholm–Malmö*	*Gothenburg–Malmö*	*Stockholm–Umeå*	*Stockholm–Örebro*
Passenger volume (millions pkm/yr)					
Base 2020	1,261	1,759	520	1,174	608
GT 2020	1,656	2,284	666	1,484	659
Difference	395	525	146	310	51
Change	*+31%*	*+30%*	*+28%*	*+26%*	*+8%*
Number of journeys (millions/year)					
Base 2020	3.06	4.41	3.01	2.98	7.43
GT 2020	3.92	5.52	3.84	3.73	8.05
Difference	*0.86*	*1.11*	*0.83*	*0.75*	*0.62*

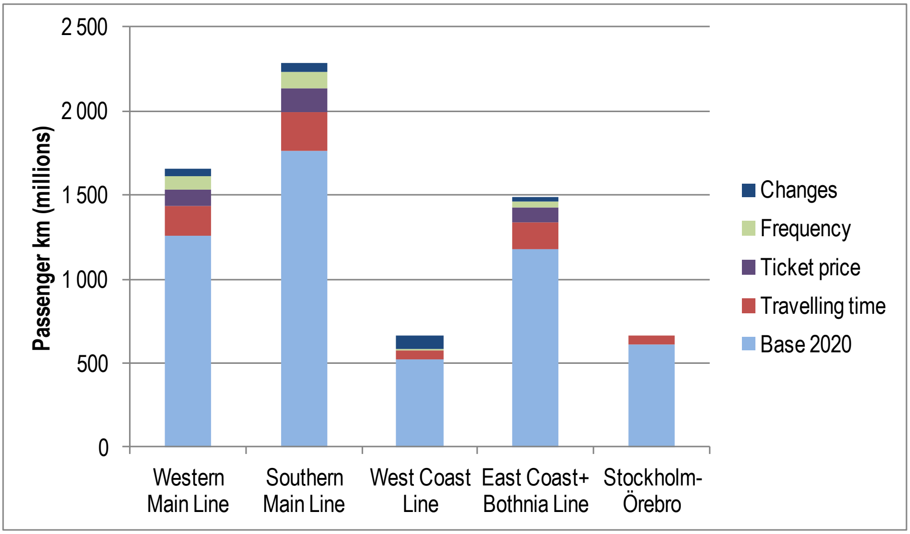


Figure 10. Travel by express train (millions of pkm) according to Banverket's base forecast for 2020 (Base 2020) and increases calculated using demand elasticities for fewer changes, higher frequency of service, lower fares and shorter travelling times with Gröna Tåget.

On the lines studied, long-distance travel by express train increases by 26-31% when Gröna Tåget is introduced, measured in passenger-kilometres.

Increases are effects of an improved supply with shorter travelling times, lower fares, higher frequency of service and somewhat fewer changes on some new direct lines.

The revenues for the traffic operators from Gröna Tåget increase by 14-25% in the examples with the approach that the consumers and the producer share the cost reduction.

Long-distance travel between Stockholm and Örebro both via Västerås (Mälar Line) and via Eskilstuna (Svealand Line) are estimated to increase by 8% through shorter travelling times, but on the other hand the same fares and frequency of service are assumed for Gröna Tåget as for the previous scenario. The increased revenues from the traffic will therefore be of the same magnitude.

2.6 Summary

An analysis of the travel markets for long-distance passenger traffic shows that high-speed trains will have good prerequisites also in the future, provided that:

- Journey times are short and attractive, in particular in the business travel market

- Fares are low, in particular in the private travel market
- Frequency of service is high, in particular on short and medium-length routes
- Good comfort and service can be offered.

It is thus these demands that must apply to a new high-speed train like Gröna Tåget.

Table 5. Examples of possible journey times in Sweden

	No. of stops	***Poss. journey time today, express trains (X 2000)***	***Poss. journey time with upgraded track and Gröna Tåget***
Stockholm–Gothenburg (455 km)	0	02:45	02:30
Stockholm–Malmö (614 km)	2	04:00	03:35
with the planned Eastern Link	*2*		*03:15*
Gothenburg–Malmö (305 km)	3	02:30	02:15
Stockholm–Sundsvall (402 km)	5	03:20	03:05
Stockholm–Umeå (737 km)	10	05:40	05:05

Remarks: Speed increase on existing line without curve straightening. Journey times assume that capacity additions to running times will be the same as today or less.

With Gröna Tåget in express train traffic, increases in travel of around 30% compared to today's supply in the basic forecast for 2020 are estimated as a result of shorter journey times, often also lower fares and in some cases fewer changes and higher frequency of service.

Table 6. Increases in travel with Gröna Tåget

Line	***Western Main Line***	***Southern Main Line***	***West Coast Line***	***E Coast & Bothnia Line***	***Mälar & Svealand Line***
Forecast 2020	*Stockholm–Gothenburg*	*Stockholm–Malmö*	*Gothenburg–Malmö*	*Stockholm–Umeå*	*Stockholm–Örebro*
Increase in travelling (millions pkm/yr)	+31%	+30%	+28%	+26%	+8%

If the relative travelling time gains are greater than the examples from Sweden, travel may increase even more with Gröna Tåget.

3. Traffic with Gröna Tåget

The markets and lines where Gröna Tåget will operate are controlling factors in the design of the train concept. The goal is an interoperable express train for Scandinavia, but Gröna Tåget can also be of interest for neighbouring countries. Flexibility for different traffic designs and adaptation to demand till are important for operating economy.

3.1 Scandinavia and neighbouring countries

Main technical data

In the Gröna Tåget programme, the ambition is to design a concept that allows interoperability in Scandinavia, i.e. Sweden, Norway and Denmark. For practical reasons, most analyses in the Gröna Tåget programme have been made for Swedish conditions. There are, however, more countries where Gröna Tåget is no less suitable, as the following review will show.

Table 7. Main data for the railways in and around Scandinavia

Country	*Reference profile*	*Gauge*	*Electrical system*
Sweden	Wide	1,435 mm	15 kV, 16 2/3 Hz
Norway	Wide	1,435 mm	15 kV, 16 2/3 Hz
Denmark	Wide (restricted)	1,435 mm	25 kV, 50 Hz
Finland	Wide	1,524 mm	25 kV, 50 Hz
Baltic States & Russia	Wide	1,520 mm	3 kV DC and 25 kV, 50 Hz
Germany	Continental	1,435 mm	15 kV, 16.7 Hz

The railways in Scandinavia have many common prerequisites. Germany also has standard gauge (1,435 mm), while Finland, the Baltic states and Russia have broad gauge. A broad vehicle gauge is a possibility that has yet to be utilised in many areas with a wide reference profile but which improves economy in train traffic. Most main lines are electrified, but with some exceptions with regard to Denmark.

The climate in northern Europe with cold winters with abundant snow, in maritime areas with alternating milder and more humid periods, puts special demands on both track and vehicles. The risk of colliding with large wild animals such as elks and deers is another factor that must be taken into consideration when designing new train concepts.

National prerequisites

Sweden

The vehicles that Gröna Tåget can replace and supplement over the next decade are mainly locomotives and passenger cars from the 1980s and the X2 express train from the 1990s. On many conventional lines, it is possible to increase speeds up to 250 km/h, which gives shorter travelling times.

A possible expansion of high-speed lines means that a large proportion of today's express train traffic on the main lines would be replaced by high-speed trains on the proposed Götaland Line (Stockholm–Gothenburg via Jönköping) and Europa Line (Jönköping–Malmö/Copenhagen). Gröna Tåget as a concept is suitable for higher speeds and can to advantage also be used in traffic where trains operate on both new high-speed lines and the conventional network (Höghastighetsbanor, 2009). The new lines increase track capacity significantly but in order to be able to properly exploit this capacity and not hinder high-speed trains with few stops, the interregional trains operating on the high-speed lines need to achieve a top speed of 280-320 km/h and have good acceleration.

Norway

Conditions in Norway are on a par with those in Sweden. One difference, however, is that the track network has a higher proportion of sharp bends and single track, which tangibly reduces average speeds and makes it more difficult to compete with the car and air transport. The railway network is being modernised and new links with a standard for up to 250 km/h are being built on the Intercity routes, i.e. the routes in the more densely populated corridors around the country's capital of Oslo with travelling times of at most a couple of hours.

NSB acquired a series of modern multiple unit trains (BM73) around the turn of the century that are to be followed by a series of multiple unit trains for short- and long-distance regional traffic (BM74 and BM75), to be delivered between 2010 and 2013, which can replace older rolling stock. New lines that generate more travel may, however, lead to a need for more trainsets than the relatively weak long-distance traffic in Norway uses today.

With its wide carbodies, Gröna Tåget also gives better economy than the BM73, which means that increased competition might be able to lead to wide trains quickly finding a place on Norwegian tracks.

New high-speed lines are also being investigated in Norway (Samferdseldepartementet, 19/2/2010). The Gröna Tåget concept would also suit these tracks very well.

Figure 11. Possible lines for Gröna Tåget in the Nordic countries. In addition to shortening travelling times in the conventional railway network Gröna Tåget can also run on high-speed lines, giving fast direct connections to places outside the actual high-speed network.

Denmark

There are today two circumstances that limit the possibilities to propose Gröna Tåget for traffic in Denmark. One is the more restrictive vehicle gauge which means that wide trains can not at present operate on Danish lines other than under special conditions. The Öresund link constitutes an exception in this respect. The Gröna Tåget programme therefore contains a study conducted in cooperation with the Danish Rail Administration to determine whether an extended vehicle gauge can be permitted from Sweden to Copenhagen and on to Helsingör.

The second is that only certain Danish long-distance lines are electrified. It is possible, however, that Denmark will electrify more lines. Gröna Tåget holds considerable advantages for these lines that permit fast, wide-bodied, electrically powered trains, and in a harsh climate.

Denmark has decided to build a new high-speed line for 250 km/h to strengthen capacity on the Copenhagen–Ringsted route. The line will be completed in 2018 and will be the first line in an upgraded network that will be suitable for Gröna Tåget (Banedanmark, 2011).

Finland

Wide-bodied trains for broad-gauge track should be able to operate in the Finnish railway network. The Finnish reference profile also permits comfortable, spacious double-decker cars which also give good operating economy. However, travelling times are longer without tilting and only a limited number of lines have at present been adapted to express trains. Over the next decade many of the older cars will be phased out. Gröna Tåget could to advantage replace many loco-hauled trains, mainly on medium-distance lines.

Germany and continental Europe

Wide-bodied trains are not generally possible since the gauges are too small on the continent. Gröna Tåget can however be manufactured with a continental width, which enables direct connections between for example Oslo and Berlin or Stockholm and Hamburg when the fixed Fehmarn Belt link is completed in 2020 (Banedanmark, 2011). A concept with convertible day and night trains might also be possible to increase the degree of utilisation (Troche, 1999) but has not been studied in the Gröna Tåget research programme.

On those lines where ICE services operate in Germany, a somewhat wider reference profile (DE1) is permitted than on other lines and in central and southern Europe (G1 and G2). The extra width can be used to improve comfort on the trains (EN 15273-2:2010 Railway applications – Gauges – Part 2: Rolling stock gauges).

Market opening and competition on the tracks

The process of separating the railway's infrastructure and traffic movements has been driven along in the European Union, as has deregulation of long-distance passenger traffic. In favourable cases, this may increase the supply of long-distance traffic on the main lines. In general, opening up a market leads to low-fares for consumers through increased competition. Where demand for long-distance journeys is high, more operators will want to operate train traffic, while society must support train traffic that is not profitable on many other lines.

Opening up the market consequently affects train traffic supply, in the form of both numbers of seats (i.e. frequency of service and train sizes) and fares. The railway companies must reduce their costs and enhance the attractiveness of the supply. One example is that SJ has achieved high occupancies of 70% or more in express train traffic in their monopoly situation. In case of competition with other operators, it can be assumed that the total supply will increase more than demand, which will lead to lower fares and a further increase in demand. Occupancy will probably decline and the operators' profits will fall compared to when they had a monopoly. In the prerequisites for Gröna Tåget, an average occupancy of 60% is assumed to be financially sustainable in the long term and a realistic level for the future. Better adaptation of the supply through coupling and decoupling of trainsets as demand varies may on the other hand increase occupancy and 65% average occupancy may then be realistic in certain situations.

The railway market has the characteristic of requiring much capital and thus long-term financial undertakings. Which companies own the rolling stock and operate the services is dependent on the market and the railway companies' investments. The intention is that Gröna Tåget, which gives lower traffic operation costs in Scandinavia, will give a competitive edge compared to many other train concepts.

3.2 Traffic design

Flexibility for different traffic designs

There are differences of principle between long and short trainsets.

Earlier calculations show that short trainsets are cheaper in service than longer trainsets on a certain demand curve in long-distance regional traffic. The reasons are that the supply of seats can vary with demand and that the greater flexibility in vehicle usage with short trainsets allows higher frequency of service. If the short trainsets can also be fitted with passages between the units, such as for example on the Danish IC/3 (the Flexliner concept) and the Öresund trains (OTU), the crew can work more efficiently and fewer conductors and cafeteria staff are needed. This would save another 6-8% of the operating costs (Kottenhoff 1999; Effektiva tågsystem, 1997).

The differences in principle between short and long trainsets in certain traffic designs with Gröna Tåget's cost model are analysed in the following.

Trainsets and frequency of service to meet variations in demand

In principle there are two ways to meet variations in travel for diurnal, weekly and seasonal variations: Frequency of service and train length. Where variations in demand are substantial, as for example in regional train traffic, both methods are normally used.

One consequence of using long trainsets that are dimensioned for peak loads is that average occupancy decreases.

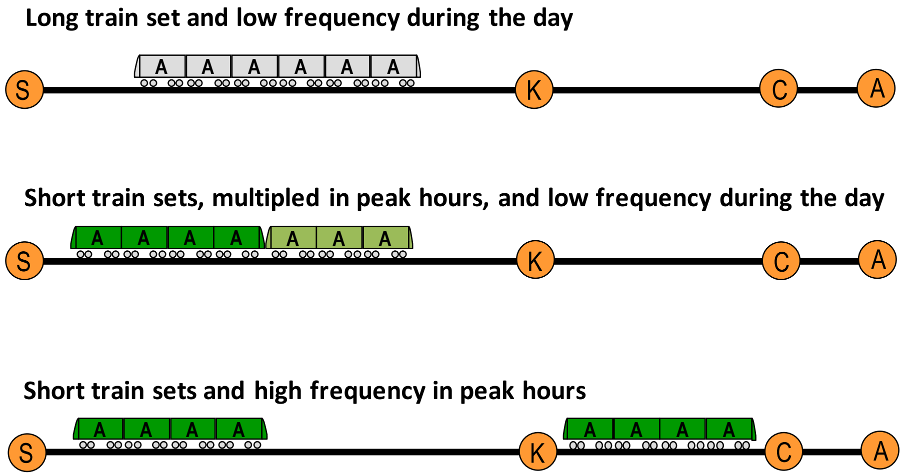


Figure 12. Operating principles to meet variations in demand over the day, week and season. Higher frequency of service increases demand and shorter trains give lower costs in off-peak traffic.

Higher frequency of service gives more travellers and in the example with doubled frequency of service in morning and afternoon peak traffic, a 15% increase in travel is assumed, calculated on travel over the whole day since business travel, journeys to work and commuting to school are relatively sensitive to the frequency of service. This means that revenues will increase more than the cost of improving the frequency of service. Higher frequency of service also assumes that there is free track capacity during peak periods.

Table 8. Train operation for variations in demand

	Long trainsets Low frequency of service	***Short trainsets****, multiple-coupled in peak traffic* Low frequency of service	***Short trainsets*** High frequency of service
Number of services	15	15, of which 6 in multiple	21, 6 of which are extra trains in peak traffic
Number of seats/day	6,900	5,820	6,300
Number of journeys/day	4,100	4,100	4,700
Occupancy (mean)	60%	70%	75%
Total costs (index)	100	96	105
Revenues (index)	100	100	115
Result (index diff.)	**0**	**+4**	**+10**

[1] In one direction with GTW with train sizes according to the figure

The additional costs resulting from short trainsets include among other things parking trains during off-peak periods. Drivers who can perform coupling and decoupling and parking are also needed. On the other hand, these trainsets can be cleaned and maintenance carried out on them between tours of duty, preferably during the day. The long trainsets instead need care and maintenance during the night or through use of the reserve coaches during the day, which also involves additional costs.

Differentiated supply

Higher frequency of service can be arranged in two ways that differ in principle: all trains stop according to the same pattern or with different (differentiated) stopping patterns. The value of higher frequency of service at intermediate stations must then be compared to the value of shorter travelling time between the end-points without stopping, or the stations where the faster trains also stop.

Low frequency of service uses less track capacity than high frequency of service and having some non-stopping trains can also mean put capacity under more pressure.

In the example calculation, travel is assumed to increase by 25% with doubled frequency of service except in off-peak periods, such as late evening, from 15 to 27 trains in both directions. In the example with differentiated supply, the shorter travelling times in the end-point market increases the average journey distance and thereby the load factor and the revenues more than is lost in the intermediate markets in the alternative where all trains stop at all stations. This is consequently a question of the number of stops and what demand they give and can be gained from shorter travelling times in the end-point market.

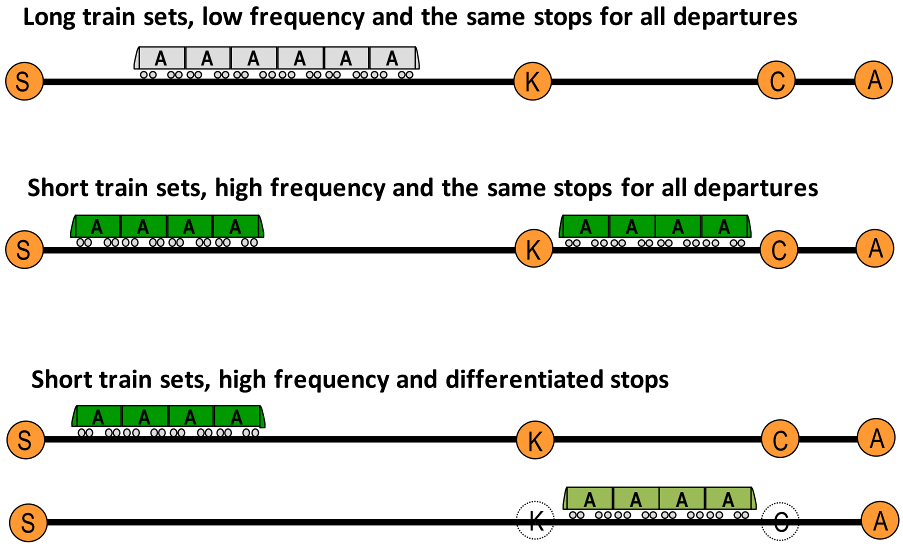


Figure 13. Fixed stopping pattern or differentiated supply with different stopping patterns that give different travelling times.

Table 9. Frequency of service

	Long trainsets *Low frequency of service*	***Short trainsets*** *High frequency of service*	***Short trainsets*** *High frequency of service, different-iated supply*
Number of services	15	27	15 stopping and 12 non-stopping
Number of seats/day	6,900	8,100	8,100
Number of journeys/day	4,100	5,100	5,300
Occupancy (mean)	60%	63%	65%
Total costs (index)	100	126	122
Revenues (index)	100	125	132
Result (index diff.)	**0**	**−1**	**+10**

[1] In one direction with GTW with train sizes according to the figure

The result shows that the cost of higher frequency of service in principle balances the increased revenues. The total costs increase less if the traffic design is differentiated, but the greatest gain comes from the increased revenues in the end-point markets, which give a clear positive net gain under these prerequisites.

Direct route compared to route with changes

Two trainsets can be uncoupled at a junction where each trainset can then continue to its destination. The advantage of this is one less change for the passengers, who can travel directly even to minor destinations. It is here assumed that direct connections give about 20% more passengers than if they have to change. Unaccustomed private travellers value direct trains highest because they can relax and do not have to worry or carry luggage. The frequency of service and conditions for changing are also important.

The results show that direct trains are profitable when travel between the destinations is as good as equal. On routes of roughly equal size, the additional direct connection generates enough new travel to give a net profit. In other cases, the increased operating costs can hardly outweigh the increase in revenue from increased travel on direct trains because longer trainsets can (as here) also mean lower occupancy on some sections. The key issue is to improve occupancy on the trains and the conclusions may be more positive with an optimised traffic supply where the train is the same size on the service with a change as on the direct connection.

In order for the traffic design with coupling and uncoupling to work, it must be possible to couple and uncouple units quickly even in winter conditions with snow and ice formation and the train services must be punctual with few disruptions.

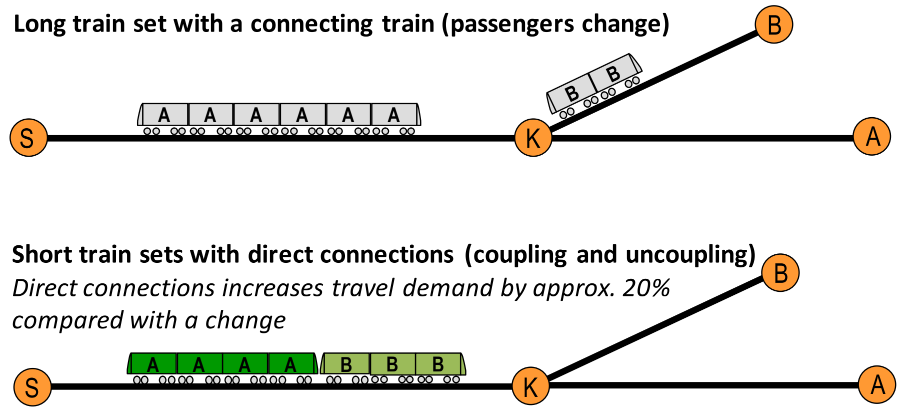


Figure 14. Passenger changing or direct with coupling and uncoupling.

Table 10. Direct routes

	Change	**Direct routes** *Dest. B 33% of total demand*	*Dest. B 50% of total demand*
Number of services	8	8	8
Number of journeys/day		A: Unchanged B: 33% × 1.2	A: Unchanged B: 50% × 1.2
Total costs (index)	100	112	109
Revenues (index)	100	107	110
Result (index diff.)	**0**	**−5**	**+1**

It might also be an alternative for capacity reasons to couple together two trains on a more loaded route, which are then uncoupled and continue to separate destinations, instead of operating the trains in separate train paths.

3.3 Demand variations in the traffic

Controlling demand

Demand can be influenced by using yield management. High fares when trains begin to become fully booked and low fares when there are unoccupied seats cause travellers who are price-sensitive but not so time-sensitive, often leisure-time travellers, to choose less crowded departures. There therefore exists a possibility to even out the demand between peak and off-peak traffic. In more long-term planning, however, the objective is to adapt the supply of seats, within reasonable limits, to the demand at any given time.

The variations in demand that occur with uncontrolled demand are greater than with controlled demand but the same principles apply in both cases.

Variations over time

A time-dependent variation in demand occurs per season, week and day (Rosenlind, Lind and Troche, 2001). The variations in travel arise out of the variation in people's different activities. A seasonal variation is for example that few people travel to work or on official business during the holiday period but all the more make leisure-time trips. Similar fluctuations also occur per week and per day. For the railways, it is thus people's working life that affects travel to a great extent.

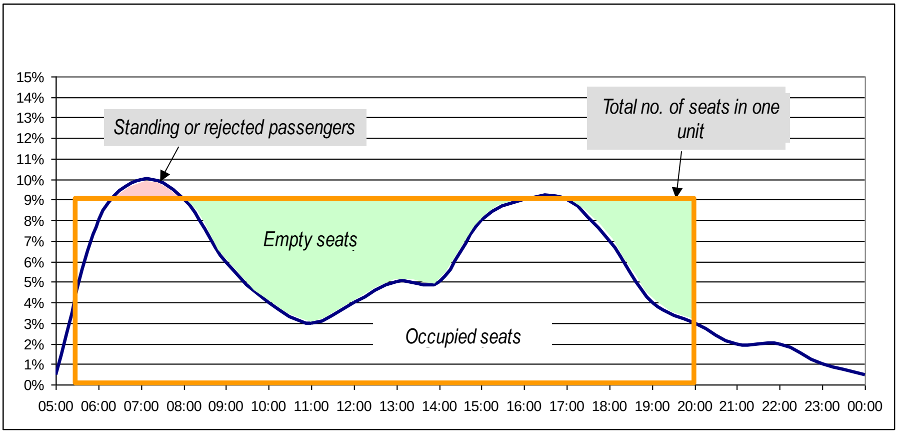


Figure 15. Traffic with a fixed trainset over a day of traffic operation. The diurnal variations in demand are typical for work-related travel on weekdays but may vary in magnitude.

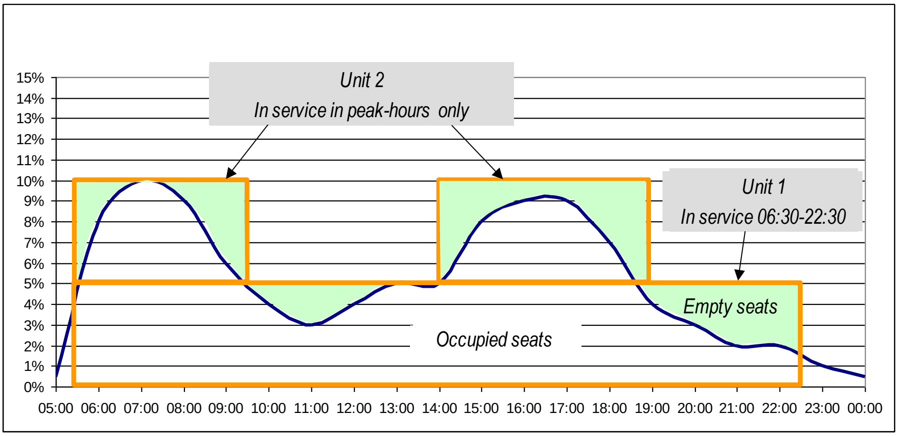


Figure 16. The same demand curve as in the figure above but for traffic with two trainsets. Trainset 2 can either be multiple-coupled or used to increase the frequency of service in rush-hour traffic if there is free track capacity. Occupancy increases compared to traffic with one trainset, despite more evening services.

The difference in loading varies with the reason for travelling and the length of the journey, but as regards Gröna Tåget it should be reasonable to expect 2-3 times higher loading in peak traffic than in off-peak traffic, with the exception of late evening and night services, where demand is even lower. Work-related travel (business trips and commuting to work) gives distinct peaks in the morning and afternoon from Monday to Friday, while long-distance leisure-time travel has distinct peaks in the afternoon-evening on Friday and Sunday.

Several short trainsets can be used to increase frequency of service compared to one long trainset provided that there is free track capacity. Higher frequency of service gives more travellers when the supply is changed, which means that the demand curves in actual fact look different depending on the frequency of service.

Shorter trainsets have another advantage: flexibility. As regards both technical maintenance and different tasks over the life of the train, shorter units can be utilised better than one long trainset.

Variations on routes

Train capacity assessments are based on the elasticity calculations for travel by express train in Sweden (see chapter 2). On the basis of these prerequisites, the number of travellers per departure on different routes around the country can be calculated.

In the first step, the number of travellers on average per the most loaded section for each trip is calculated. The number of trips is calculated on the basis of the average annual daily traffic divided by the number of departures. An estimated factor (0.7-0.9) for the proportion of travellers on the most loaded section compensates for people boarding the train along the route who can use the same seat that a person leaving the train has vacated.

Table 11. Load on the trains without diurnal, weekly and seasonal variation

GT Forecast 2020	**No. of journeys per service** *Entire route*	**Proportion of travellers** *on most loaded section*	**Travellers per service** *Most loaded section*
Western Main line	255	0.9	230
Southern Main Line	390	0.8	310
West Coast Line	285	0.8	230
East Coast Line	415	0.8	330
Mälar Line Svealand Line	395	0.7	275

In the next step, three levels of travel are calculated: off-peak, normal and peak traffic. Off-peak traffic is assumed to be all evenings, Saturday afternoons and Sunday mornings. Peak traffic is Monday to Friday mornings and afternoons and Sunday afternoons, but not during holiday periods when among other things school vacations determine the peak periods instead. Normal service refers all other times of the operating day and thus includes diurnal, weekly and seasonal variation. The number of passengers in off-peak periods is assumed to be 50% of the number in normal traffic operation and in peak traffic 150% of the number in normal traffic. In practice, these figures vary depending on the distribution between leisure-time travel and business trips and in regional services also commuting to work, and how yield management is used to control demand by means of the fares.

Train sizes in terms of number of seats are in turn also dependent on the degree of occupancy. Generally speaking, a high number of end-point journeys in long-distance traffic give a high degree of occupancy. For express train traffic with good economy the goal might be an average occupancy of at least 60% (Beräkningshandledning, 2009). In practice, occupancy on express trains in Sweden achieved over 70%, which means more than 90% occupancy in peak traffic.

A great amount of especially unidirectional commuting to work in long-distance regional train traffic gives lower occupancy due to the larger variations in demand with a distinct rush-hour. The Calculation Guide (Beräkningshandledning, 2009) prescribes an occupancy of 40-50% for regional traffic on empirical basis.

On the basis of Gröna Tåget's forecast for 2020 and the assumed degrees of occupancy, intervals for appropriate train sizes for traffic in Sweden can be calculated. The degree of occupancy has here been set at 50% for off-peak traffic, 70% for normal and 90% for peak traffic.

Table 12. Train sizes calculated according to loading

GT Forecast 2020	***Low traffic*** *50% of average travellers per service* *50% occupancy*	***Normal traffic*** *100%* *70% occupancy*	***Peak traffic*** *150% of average travellers per service* *90% occupancy*
Western Main Line	230	330	385
Southern Main Line	310	445	515
West Coast Line	230	330	385
East Coast Line	330	470	550
Mälar Line Svealand Line	275	395	460

According to these calculations, the smallest trainsets would have an economic size of 230 seats, both for traffic during off-peak periods on the Western Main Line and the West Coast Line and for extra capacity (multiple-coupling) in peak traffic on those lines. A medium-sized trainset of 300-330 seats would however be more generally useful in long-distance traffic.

Primarily on the East Coast Line but also on the Southern Main Line, the number of travellers per express train journey is estimated to be substantial. A large proportion of the trains will need to be multiple-coupled if the train size is

300 seats and large trainsets of around 400 seats might possibly be considered. The disadvantages are that flexibility is reduced and if it were to be possible to run several services in addition to those in the forecast, 400 seats will be too large a trainset for normal traffic. Such a situation might for example arise if two railway companies begin to compete on the same route. For this reason, it is recommended that the base in normal traffic be a medium-sized trainset with 300 seats.

These train sizes apply provided that the railway company makes an active effort to adapt the train size to the demand and also uses yield management as an instrument to even out demand over different periods. Otherwise, the average occupancy will fall and the need for more seats on the trains will increase. The need for more seats on the trains applies in general if the demand for train travel should suddenly increase as a result of some external event, for example drastically increased petrol prices or cuts in air services.

In summary, the analysis shows the importance of flexibility in the train concept. In addition to fast coupling and uncoupling being necessary, the trainsets should also be able to be extended and shortened semi-permanently by purchasing intermediate cars for existing trainsets or removing intermediate cars and reconfiguring the vehicle fleet.

3.4 Summary

An important objective of Gröna Tåget is to produce a standard train which is flexible to be able to perform a variety of tasks and interoperable in Scandinavia. It can also be adapted for traffic in neighbouring countries with broad gauge or a continental body width.

Short train-sets allow interesting operational possibilities that generate higher revenues and in some cases lower costs, particularly when the degree of utilisation can be increased. A prerequisite is that coupling and decoupling can be done quickly and easily even in winter weather.

The most important conclusion is nonetheless that short train-sets are interesting from the point of view of operating economy as long as demand (travel) is considered. Revenues often increase more than costs when the supply is improved, which is possible with short train-sets.

A generally usable train unit for long-distance traffic in Sweden and the Nordic area has 300 seats. The trains will need to be run as multiple units on many departures. Even a smallish unit with 230 seats is useful for reinforcing capacity during both peak and off-peak periods. A larger unit with approx. 400 seats has also been considered but it has less flexible application on the lines and when passenger numbers are fewer.

4. Economy in the train concepts

Business-economic calculations of the train traffic's costs are important in order to be able to design the train concept for economically viable traffic. A cost model was developed within the project to be able to make general analyses of concept proposals and different traffic designs for Gröna Tåget.

4.1 The cost model

Costs in train traffic

Train traffic's costs are largely fixed or slow-varying and time-dependent. Profitable train traffic is consequently based on generating as high revenues as possible once the investments have been made.

The total costs can be divided into capital costs, time- and route-dependent costs, and overhead costs (administration and sales). In Gröna Tåget's cost model, however, all costs are converted into route-dependent costs depending on the traffic design. The same train type can consequently give different results depending on the traffic design that the analysis concerns.

The table (below) represents an attempt to generalise the costs although there are exceptions to the main rule.

Consumption-related costs as a rule concern standardised ”consumables”, such as water for washing and comfort on the trains, electricity for train operation, and train paths and track access charges. In principle, these costs arise immediately in conjunction with consumption.

Personnel-related costs change more slowly. This is mainly due to the personnel needing to have certain competencies, which requires education. Security of employment also means that the labour force cannot be downsized without a period of notice or further education. Personnel agreements can be designed in different ways but the railway company's aims during a certain planning period (up to a year) must function as planned. The possibility often exists to rent vehicles and/or hire personnel for short periods but the availability of suitable trains and competent personnel is as a rule limited to covering marginal changes. The marginal costs are also generally higher for rented production resources than one's own when conditions are stable.

Maintenance costs have here been classified as mainly personnel-related since maintenance presupposes competent personnel, but there are also varying proportions that are consumption-related or investment-related.

Table 13. Nature of train operation costs

Costs' nature	***Cost item***	***Unit***
Consumption-related ***Direct costs,*** *arise immediately*	Terminal costs	SEK/timetable hour and vehicle *f* (vehicle characteristics, traffic design)
	Energy costs	SEK/train-km *f* (vehicle, traffic)
	Track access charges	SEK/train-km *f* (vehicle, traffic)
Personnel-related ***Semi-variable costs,*** *up to 1 year's horizon/one train plan*	Personnel costs (on-board personnel)	SEK/timetable hour and train *f* (vehicle, traffic)
	Administration and planning (personnel and premises)	Prop. of all other costs exclusive of selling costs (SEK/train-km)
	Selling costs (personnel, ticketing systems and premises)	SEK/passenger-km *f* (occupancy)
	Maintenance costs (personnel, workshops and components)	SEK/train-km *f* (vehicle, traffic)
Investment-related ***Slow-varying costs*** *over longer period than 1 year*	Capital costs for vehicles (acquisition and divestment)	SEK/timetable hour and train *f* (vehicle, traffic)
	Any fixed facilities (not included in the model)	

Investment-related costs generally require planning and undertakings with a time horizon of several years. Railway vehicles are made to order and in addition to the actual vehicle also include documentation for its use and maintenance and training of personnel. As a rule it takes 2-5 years to get new vehicles into service once they have been ordered, longer in the case of a first order and long series. It can also take time to divest vehicles. The vehicles are thus of particularly great strategic importance and entail slow-varying costs over longer periods than one year. Major components for repairs and maintenance also need to be ordered and manufactured with extensive forward planning.

The model's structure

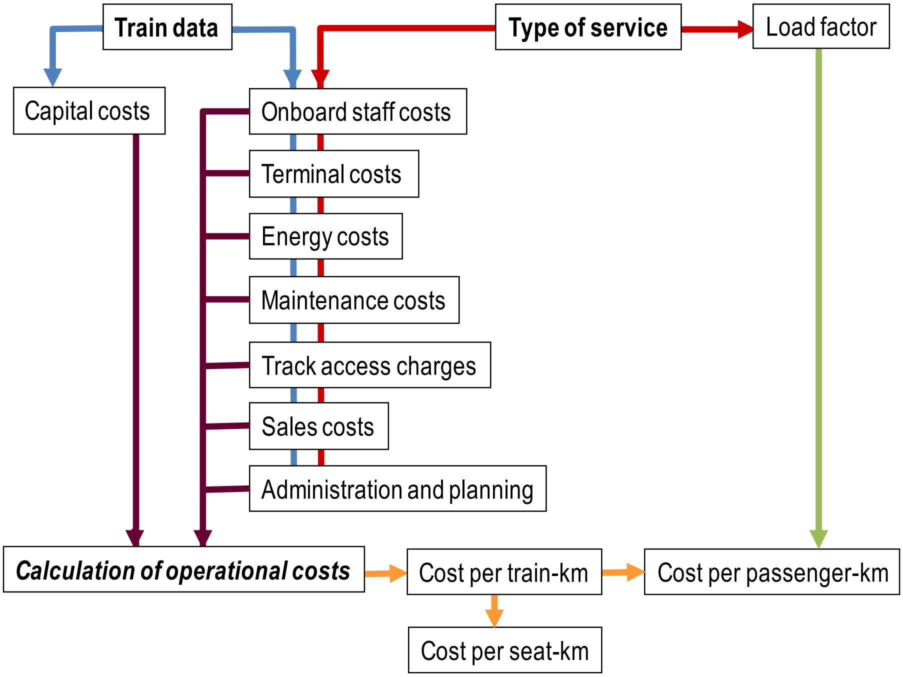


Figure 17. Structure of Gröna Tåget's cost model

Gröna Tåget's cost model calculates total costs for passenger train traffic in the form of general costs per train-kilometre (train-km). Since the services and degree of occupancy are included, specific total costs such as cost per seat-kilometre (seat-km) and passenger-kilometre (passenger-km) can also be calculated for special traffic designs.

The first version of the model is based on data collected between 2005 and 2007 from train operators, the National Rail Administration (Banverket) and a number of other experts in Sweden. Unofficial, commercially sensitive figures, however, are approximate. The cost level has then been adjusted to 2010.

The cost model has however not been fully validated due to the lack of independent external data; the results should therefore be viewed with caution. In Gröna Tåget's cost model, differences between different factors can be expected to be more accurate than absolute figures. One source is Kottenhoff's (1999) model Tåganalys *(Train Analysis)*, which gives equivalent results.

Regarding regional passenger traffic on the railways, there are significant differences in costs through different types of traffic production and design, demand over time and administration and sales, but calibration against

Upplands lokaltrafik's (UL) costs for its Upptåget trains shows that conditions in regional traffic can be recreated relatively well.

The total costs must be weighed against the revenues when comparing the economy of traffic designs. In many analyses, costs and revenues correlate, i.e. a cheaper alternative gives fewer travellers and thus lower ticket revenues. Every analysis is accompanied by a description of how the comparisons were made.

Values in the 2010 model

Cost of capital

The depreciation period for vehicles in the analyses is 20 years, i.e. the same that SJ applies for express trains. Business-economic effective interest is assumed to be 6.5% (Samhällsekonomiska principer *Socio-economic principles*, 2008).

Table 14. General standardised prices (2010) for passenger train rolling stock

Vehicle type	***Max. permitted speed 200-240 km/h***	***Max. permitted speed 250-280 km/h***
Basic design	(SEK millions)	(SEK millions)
Electric loco or power unit	40	
Intermediate car without propulsion equipment or passenger car	19	24
EMU (with propulsion)	25	30
Additional per driver's cab in multiple unit train/control car	5	5
Additional to basic design		
Tilting equipment	5%	5%
Wide body incl. interior fittings	5%	5%

Standardised acquisition prices have been used for passenger train rolling stock. They were developed from figures in the trade press and apply at an exchange rate of about SEK 9.55 = 1 EUR (average for 2010; Oanda, 2011). The basic design includes vehicles adapted to the Nordic climate and disabled travellers. Two different speed categories are presented; 200-240 km/h (vehicle category Class 2 according to the TSI) and 250-280 km/h (Class 1). As a rule the higher speed range may include pressure-proof design for better comfort when passing through tunnels, adapted running gear, better braking capability and higher output. The threshold between Class 1 and Class 2, i.e. the differences between design for 240 and design for 250 km/h is, however, small. On the other hand, the cost-driving differences are not precisely defined and must be considered approximate between the two columns in the table (below).

Gröna Tåget may be designed in several different ways, but the concept calculated here has long carbodies and either a wide body (GTW) or a continental gauge suitable for traffic south of Copenhagen (GTC). An articulated concept with shorter carbodies and Jacobs bogies (GTA) has not been calculated to date but is also conceivable.

Table 15. Standardised prices for train types

2010 prices	***No. of cars in trainset*** *Total*	*Driven*	*Power unit*	***Additional to basic design*** *Tilting*	*Wide body*	***Standardised trainset price*** *(SEK millions)*
Gröna Tåget *250-280 km/h*						
GTW-3	3	2	No	Yes (+5%)	Yes (+5%)	105
GTW-4	4	2	No	Yes (+5%)	Yes (+5%)	130
GTC-4	4	2	No	Yes (+5%)	No	125
GTC-5	5	3	No	Yes (+5%)	No	155
Other train types *200-220 km/h*						
NSB BM73 (A)	4	3	No	Yes (+5%)	No	110
SJ X55 *Regina*	4	3	No	No	Yes (+5%)	110
SJ X2 *X 2000*	6	0	1	Yes (+5%)	No	165
VR Sm3 *Pendolino*	6	4	No	Yes (+5%)	No	155

GTW: Gröna Tåget Wide; GTC: Gröna Tåget Continental

In the calculation of standardised prices, different interior standards and equipment options have been disregarded. Experience tells us that the series size and distribution of development costs have a greater impact on the price than different equipment alternatives.

The prices used apply roughly in serial manufacture of around 40-80 train units. Smaller series can have a significantly higher unit price, while larger series give a lower unit price.

Personnel costs

Salaries for on-board personnel are time-dependent (SEK/h), but have been converted to distance-dependent costs (SEK/train-km) by calculating for a special traffic design. Monthly salaries are adjusted upwards with social contributions (60%) and then personnel administration costs (15%) to obtain the salary cost. There is also an additional factor, effective work time, which is that part of the annual 1,440 working hours (including absence regardless of reason) that is scheduled on trains and consequently includes work outside the train's timetable for starting up and parking and overnight stays.

Table 16. Costs for on-board personnel

Category	***Monthly pay***	***Effective work time***	***Personal cost** (per timetable hour)*
Driver	32,000 SEK	60%	818 SEK/h
Chief conductor	26,500 SEK	70%	580 SEK/h
Other service personnel	21,500 SEK	90%	366 SEK/h

As standard, the calculations include one driver on every train, one conductor per (commenced) 200 seats, and one other person in small cafeterias and two in large cafeterias or bistros. On some departures with many travellers and at appropriate meal times, demand for refreshments is so high that it would over the cost of the cafeteria staff but this does not apply generally (Mägi, 8/3/2010). Included here are thus the full personnel costs involved to be able to offer a defined service for travellers in each traffic design while the net revenues from sales will vary. In practice it is also possible for the chief conductor to help out in the cafeteria at certain times but this does not change the salary costs.

Terminal costs

Terminal costs are costs for service such as washing the outside, cleaning the inside, filling up with water and emptying toilets. Costs for track rental and heating to get the trainset ready for the next departure in traffic designs with coupling and uncoupling are also included. A value of SEK 150/vehicle hour, i.e. per scheduled hour and vehicle, is used here.

Energy costs

Energy consumption is calculated by calculating the train's running resistance, which depends on the train's composition, aerodynamics and speed. Also included in the cost model are energy for acceleration after stops at stations and the effect of energy recovery. Gröna Tåget with eco-driving and high output to the electric brake can achiever 25% recovery of the electrical intake (Sjöholm, 2011; Andersson, 2012).

Energy consumption for comfort equipment such as air conditioning with heating/cooling, lighting, etc is included at a standardised value, in general 0.3-

0.5 kWh/vehicle-km with the lowest values for faster trains since the comfort energy is actually time-dependent.

Gröna Tåget's cost model has been calibrated here against both measured values and model-calculated energy consumption with ERTSim for the X2 and Gröna Tåget under comparable conditions (Andersson and Lukaszewicz, 2006; Lukaszewicz and Andersson, 2009).

Energy consumption for an X2 train with a power unit and six cars with 309 seats and a maximum speed of 200 km/h is 71 Wh/passenger-km at 60% occupancy and two stops on the Western Main Line between Stockholm and Gothenburg. Gröna Tåget with 300 seats in four wide-bodied cars and a maximum speed of 250 km/h on the same line consumes 49 Wh/passenger-km. The 31% lower energy consumption is achieved despite higher speeds through better aerodynamics and shorter trains which have lower running resistance, more than double the recovery of braking energy from 11% to 25%, and in the example also a higher degree of occupancy from 60% to 60-65% as a consequence of increased demand and better adaptation of the train size with Gröna Tåget.

A further developed version of Gröna Tåget for high-speed traffic at 320 km/h is estimated to consume 60 Wh/passenger-km on average on the proposed Götaland Line between Stockholm and Gothenburg, which is lower than today's X 2000 on the Western Main Line (Lukaszewicz och Andersson, 2009; Andersson, 2012).

The cost of electricity at the train's pantograph including tax, network charges and electricity certificates is assumed to be 0.72 SEK/kWh for 2010/2011.

Maintenance costs

Maintenance costs are divided into four different parts: light maintenance (weekly), heavy maintenance (train taken out of service), insurance costs for damage and a cost for modernisation and refurbishment halfway through the train's life. The maintenance costs are partly speed-dependent and increase as the vehicle's maximum permitted speeds increases since higher speeds often require more complicated designs and lower tolerances.

In the cost model, it is assumed that light, weekly maintenance costs SEK 4/vehicle-km for locomotives/power units and multiple units with propulsion equipment and SEK 2.50/vehicle-km for intermediate cars or passenger cars without propulsion equipment.

The maintenance costs are those costs that are judged to have the greatest uncertainty in the cost model. Of the model-calculated total costs for train traffic, maintenance (the sum of light and heavy maintenance, damage and modernisation) as a rule accounts for 20-25%. Of this, light maintenance accounts for about 60%. Maintenance and refurbishment halfway through the train's life, or after about 10 years, are estimated to cost 10% of the acquisition price.

Track access charges

The Swedish track access charges consist of four components. The train path charge is intended to apply on the major main lines, but exclusive of the peak-traffic charge for the major cities. Additional charges include an accident charge of SEK 0.81/train-km, a track wear charge of SEK 0.0036/gross ton-km and a special extra charge of SEK 0.0081/gross ton-km (Network Statement 2011).

It is possible to count in track access charges according to track forces, which would be to the advantage of vehicles that cause less damage to the track, mainly through lower axle loads and soft bogies. This model (DeCAySys), however, is not used at present by the Swedish Transport Administration or in the model calculations.

Administration and planning

Administration and planning costs are set at 15% of the operating costs, i.e. all the other costs except selling costs.

Selling costs

In the model it is assumed that selling costs (ticket selling and marketing) in long-distance traffic amount to SEK 0.11/passenger-km with a reserved seat, which is assumed to be the rule in long-distance traffic. This cost is consequently dependent on the traffic design and the number of travellers on the trains. In the long-term, the sales channels will influence the outcome and greater use of the Internet and mobile phone tickets instead of manual sales and paper tickets will reduce the costs. The total also includes the railway companies' costs for public areas at the stations.

Traffic design

Traffic design includes route, number of stops, travelling time (timetable time) and dwell time at the end-station before the next departure and frequency of service. The model then calculates the total number of train-kilometres and the required number of trainsets to operate the services including 12% of the reserve vehicles. The assumed utilisation of each vehicle is estimated on the basis of an average long-distance traffic design, not including reserve vehicles, to be 290 days per year and 14 hours per day but that could be adapted for different conditions.

The degree of utilisation can be varied as desired. A level that is used in the analyses of long-distance traffic and judged to be economically viable in the long term is 60% on average, which also agrees with socio-economic calculations (Beräkningshandledning, *Calculation Guide*, 2009).

With shorter trainsets and active coupling and uncoupling, it may in many cases be possible to achieve a higher theoretical degree of occupancy than with fixed, long trainsets. In practice, there are many factors that make this an uncertain assumption, for example increased off-peak traffic as a consequence of lower vehicle costs, a future deregulation with competing supplies and the fact that demand is influenced to varying degrees by means of yield management.

4.2 General analyses

Average speed

Average speed is important for both the production costs and the total costs. The example assumes the same train type, the same frequency of service and the same terminal time regardless of average speed. As average speed increases, the number of trainsets needed to maintain traffic decreases, i.e. the circulation time becomes shorter. Here we disregard the fact that a lower top speed may mean cheaper trains since a low average speed may also be a consequence of (partly) poor track or capacity problems.

As a rule train types are used that are adapted for higher speeds through lower running resistance, which eliminates the effect of speed increases on energy consumption.

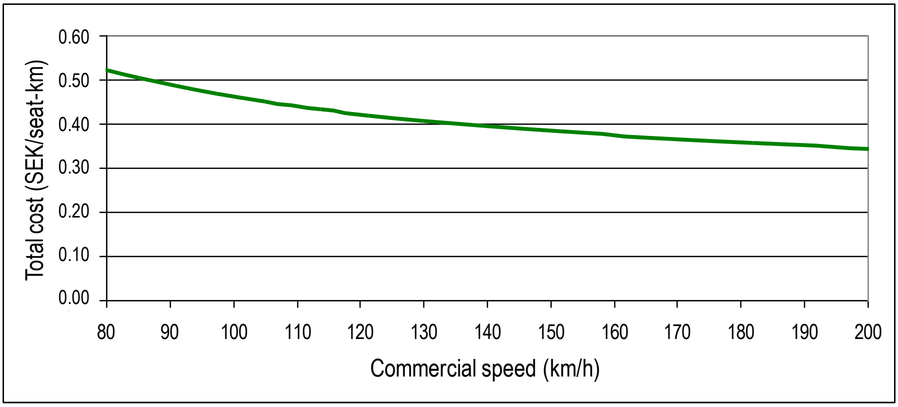


Figure 18. Total costs (SEK/seat-km) as a function of the train's average speed

Total costs decrease with increasing average speed through higher productivity. Cost elasticity at 80 km/h is 0.56, i.e. 10% shorter travelling times reduce costs (SEK/seat-km) by 5.6%. At 100 km/h, elasticity is 0.5, at 150 km/h 0.38 and at 200 km/h 0.34.

Higher average speeds, i.e. shorter journey times, are consequently an effective way of reducing costs. However, increased revenues as a result of a more attractive supply generally have an even greater effect on income. Shorter travelling times are therefore a measure that affects both costs and revenues and should always be considered.

Space utilisation

Good space utilisation, i.e. many seats per metre of train length, can reduce the total cost per seat. Typical values for European multiple unit trains with a continental car body profile and comfort for long-distance traffic are 2-2.2 seats per metre of train length. Trains with only first class furnishing and fittings have lower values. Double-deckers or wide-bodied trains usually have 2.7-3.0 seats per metre. The wide Shinkansen trains in Japan have 3.3 seats per metre. The Japanese Shinkansen JR East E1 and E4 Max trains, designed for long-distance regional traffic and that have two decks and wide bodies, have the best figure; over 4 seats per metre of train length.

There is a clear linkage between space utilisation and total cost per seat-km. Between 2.0 and 3.0 seats per metre of train length, space elasticity is about −0.55 with continuous adjustment of personnel costs. This means that in this interval 50% better space utilisation reduces the total cost by 27% per seat-km. Earlier research showed similar results with a space elasticity of −0.5 (Kottenhoff, 1999).

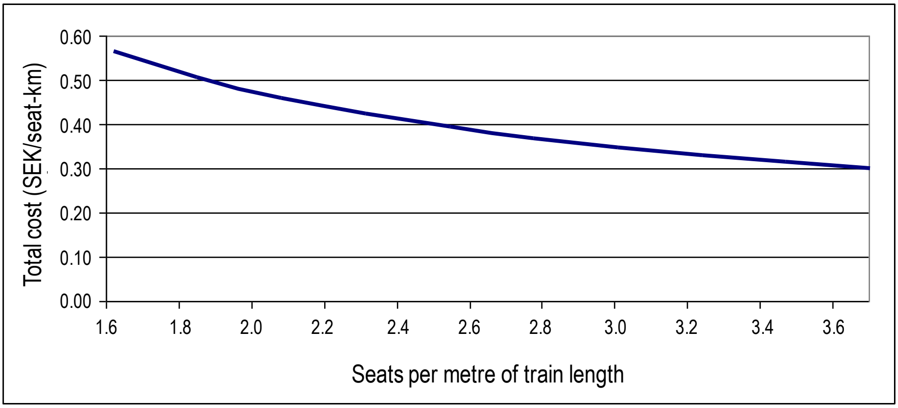


Figure 19. Total cost depending on space utilisation on the train measured in seats per metre of train length.

(Degree of) occupancy

The number of travellers per available number of seats on the train, or the occupancy, is of great importance when it comes to calculating the cost per trip. Occupancy is 100% when a train is full and all the seats are occupied by travellers, but most trains have several unoccupied seats, at least for part of the way. The average occupancy over the day, week, season or year and for each route is very important for a railway company's economic viability.

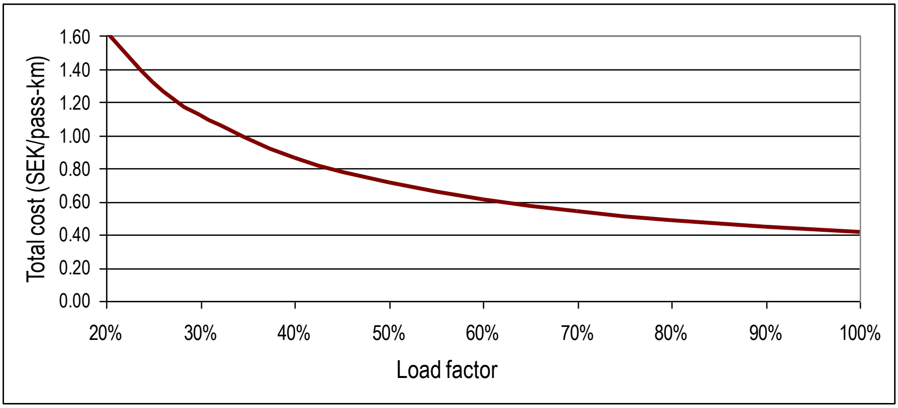


Figure 20. Total cost in SEK/passenger-km as a function of occupancy.

In this analysis the train has the same number of crew regardless of occupancy. In reality, an operator can try to reduce his personnel costs if there are few travellers, but if occupancy varies there will nonetheless be some routes/sections where a full crew is needed for reasons of crew scheduling.

The analysis shows that the cost per passenger-km (or per trip) can be halved if the average occupancy increases from 30% to 70%. The marginal cost of transporting another traveller consequently decreases.

One conclusion from this analysis is that it is expensive to operate trains with empty seats. Good finances in railway traffic require high occupancy. But occupancy can be impacted by adapting the supply (i.e. adding or removing cars or changing the number of departures) or by affecting the demand. Yield management is an effective instrument for affecting the demand by selling unoccupied seats at a (lower) marginal cost.

4.3 Analyses of train concepts

Loco-hauled or multiple unit trains?

A loco-hauled train has propulsion equipment concentrated to a locomotive or a power unit that has no space for passengers. Several locomotives can be coupled together in the same train and be multiple-operated. A multiple unit train has propulsion equipment distributed over cars with varying numbers of driven units (wheel axles) and undriven units in the train. In concept, the Swedish X2 express trains (X 2000) are in actual fact loco-hauled trains, as are high-speed trains like the TGV Duplex and ICE1 and ICE2, but because they are cohesive train units with a uniform design they are classified as multiple unit trains in other contexts.

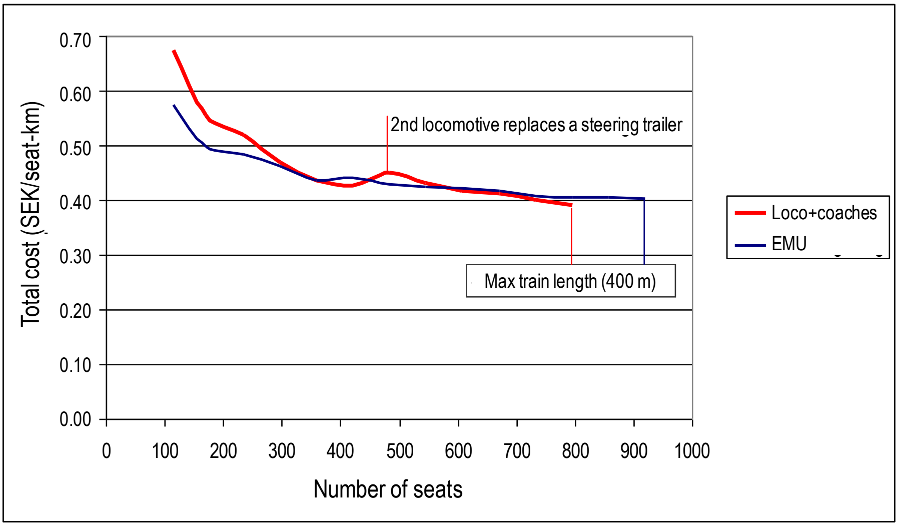


Figure 21. Comparison of total costs between loco-hauled and multiple unit trains. Both types have the continental body width, the same seat layout and do not have tilting, which gives the same journey times.

A comparable loco-hauled train and multiple unit train have the same number of seats in each car and the same comfort and level of service. In the following analysis, any differences in travelling times have been eliminated and the example is based on long-distance traffic between Stockholm and Gothenburg (455 km) with 60% occupancy and comparable characteristics in other respects. The comparison refers only to the train concept as such.

The analysis was made for train lengths up to 400 metres, which is in line with the European platform norm for high-speed lines.

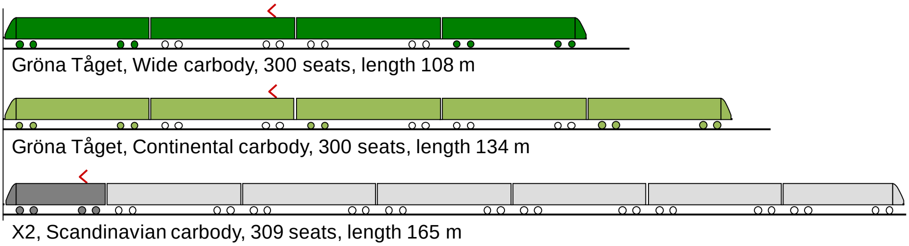


Figure 22. Differences in space utilisation measured as number of seats per metre of train length mean that the train lengths and costs vary considerably.

Loco-hauled trains are assumed to have a minimum of 2 and a maximum of 7 cars (including a control car) per locomotive or power car. A greater number of cars per locomotive would give even lower costs and is possible in the case of slower trains. On the other hand, there are technical limitations to producing sufficient tractive power for high speeds. Loco-hauled trains with 8-13 cars instead have 2 locomotives in order to achieve acceptable journey times. Multiple unit trains are assumed to have at least 50% driven axles and can have up to 15 cars with long bodies in the trainset for a given train length.

The loco-hauled train concept is best from an economic point of view with a relatively large number of cars per locomotive. The locomotives, however, take up space that could be used for seats and a full-length loco-hauled train has as many seats as a multiple unit train of the same length.

At train sizes of up to 5 cars (in the example, 300 seats with continental body width) a multiple unit train gives significantly (1-15%) lower total costs than a loco-hauled train. Over the whole length range, multiple unit trains on average give 3% lower costs. Multiple unit trains also have greater maximum capacity since more of the train length is used for passenger areas. Another factor is the better acceleration and regenerative braking ability with distributed power on multiple units.

Multiple unit trains can therefore be recommended, and definitely for shorter trains and for trains that need maximum capacity within a given train length.

Wide-bodied trains or continental profile?

Wide-bodied trains allow a 2+3 seating arrangement (the '+' represents the centre aisle) in economy class and 2+2 in business class with the same comfort as a narrower train with a continental profile. Seats on the continental-profile train are arranged 2+2 in economy class and 1+2 in business class. The wide-bodied train can accommodate 25% more seats per car according to studies of seating arrangement.

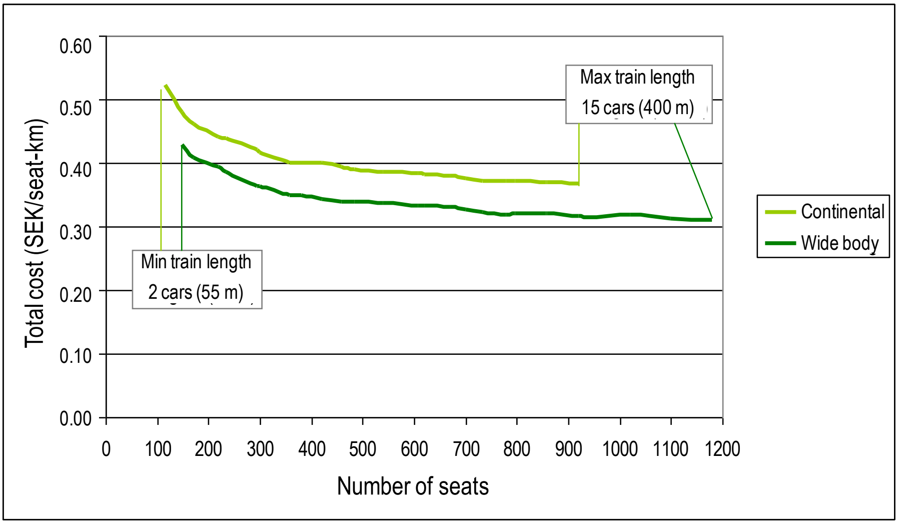


Figure 23. Comparison of total costs between a multiple unit train with a continental profile and one with wide carbodies but which is otherwise identical. The wide-bodied train has on average 25% lower total costs per seat-km.

The example includes a cafeteria the area of which is proportional to the number of seats, with the exception of the smallest and largest trains, which have less cafeteria space per seat. The cafeteria is also more spacious on a wider train. Wider trains also have more seats for a given train length, which is an advantage if the train length is limited by the available platform length.

In the example it is also assumed the acquisition cost of each car is 5% higher for the wider train compared to the continental one since the wider train contains a little more material in the carbody and has more seats. The train's cars are also assumed to be 5% heavier, which has an effect on both track access charges and energy consumption per car.

The analysis covers long-distance traffic with 60% occupancy in both cases, with everything else identical between the train types.

The results of the analysis show that the wide train on average gives 15% lower total costs for a given number of seats as an effect of the wide train being able to be made shorter (fewer cars). In the example, the cost elasticity for space utilisation on multiple unit trains is −0.5 (25% more seats gives 12.5% lower costs), which is in agreement with earlier research (Kottenhoff, 1999).

If the lower costs are fully passed on in the form of cheaper rates, fares on wide-bodied trains can be lowered by up to 15%, or alternatively increased profitability for the railway company. Wide-bodied trains are therefore recommended as a way to reduce costs through increased productivity with maintained comfort.

Double-decker trains can also be expected to give similar positive effects but have not been analysed in this project since the point of departure is that they can not be equipped with tilting and thus give longer travelling times.

Tilting or non-tilting?

Tilting trains shorten travelling times on conventional lines with many curves by allowing higher speeds in the curves. The system's function and effects are described in more detail in Andersson (2012) and Persson (2011).

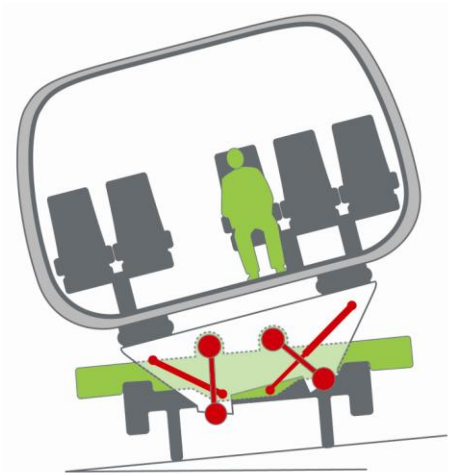


Figure 24. The principle of an active hydraulic tilting mechanism with sliding linkages. Image from the Gröna Tåget folder, 2010 (LundbergDesign).

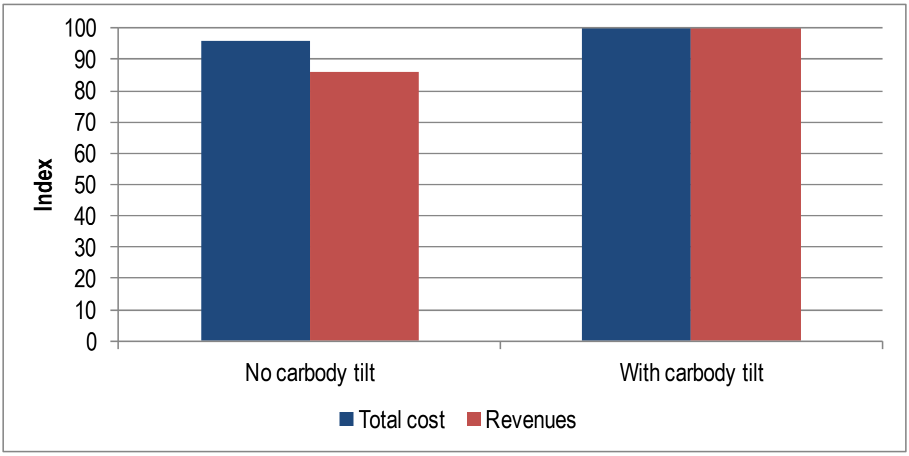


Figure 25. Examples of total costs and revenues for a tilting and a non-tilting train.

Approximately 6% of the travellers, but a larger proportion of women, experience travel sickness on the X2 (Förstberg, 1996). The proportion varies with how the tilting functions. Methods to reduce travel sickness are tilting according to pre-programmed track data instead of accelerometer control and reducing the lateral compensation compared to today's values (Persson, 2011).

After upgrading the track for 250 km/h, a tilting train can cover the distance between Stockholm and Gothenburg in 2 hours and 45 minutes on the section in the example. A similar train but without tilting takes 17 minutes longer (Sipilä, 2008). In this case, it is possible to reduce the circulation time from 8 to 7 hours, saving a trainset in hourly traffic.

The shorter journey times generate more trips. If travelling time elasticity is set at −1.5 (Nelldal, 2005b), a roughly 9% saving in travelling time means a 14% increase in travel and ticket revenues since the supply is more attractive as a consequence of the shorter travelling times with the tilting trains. Operating costs also increase when more seats are needed on the trains as a result of the increase in demand, but this is not included in the example.

The extra cost of tilting in the form of increased acquisition price and maintenance costs is about 5%. Tilting gives lower total costs as it contributes to fewer trains in circulation. The most important effect, however, is that it gives higher revenues. Tilting can therefore be recommended provided that the track can cope with higher speed in curves.

Costs of different train concepts

Different train concepts can be analysed using the cost model. The example includes four different multiple unit train concepts that exist in the Nordic countries. These are the Finnish VR Sm3 Pendolino, the Swedish SJ X2 (X 2000) with 6 cars and a power unit, and the SJ X55 Regina and the long-distance variant (A) of the Norwegian NSB BM73. The exterior carbody width of the trains is 3.0-3.2 metres, except for the X55 where it is 3.45 metres with a 2+2 seating arrangement in economy class. Two possible multiple unit concepts for Gröna Tåget have also been included as comparisons, one with a continental carbody width (GTC) and 5 cars and one with wide carbodies (GTW) and 4 cars. The acquisition costs are the standardised price for 2010, i.e. a probable average price if the trains were ordered new.

The total costs and the marginal costs both include an assumption as regards the train crew (whole persons), which means that some train sizes are more advantageous than others.

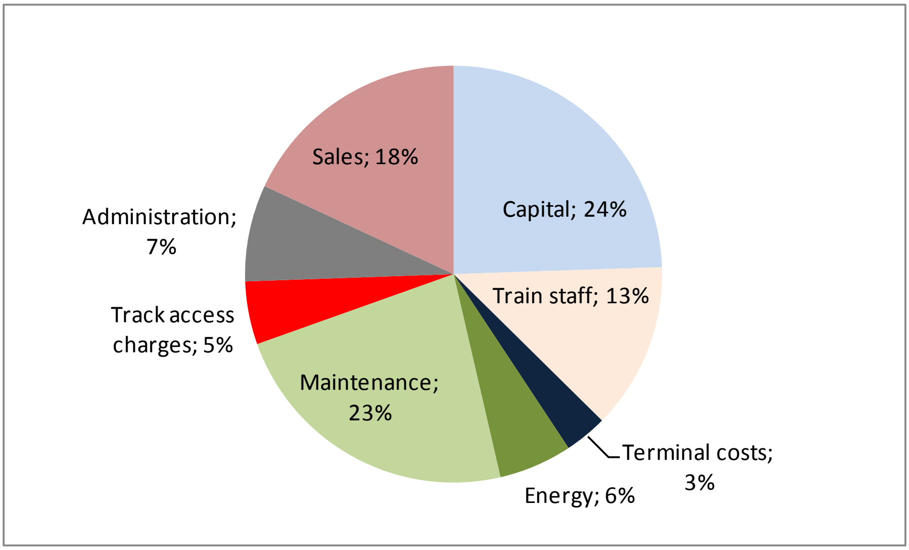


Figure 26. Distribution of total costs for Gröna Tåget with four cars and wide bodies (GTW-4) calculated with Gröna Tåget's cost model, 2010 values.

Table 17. Examples of train concepts

	VR Sm3 Pendolino	***SJ X2 X 2000***	***SJ X55 Regina***	***NSB BM73(A)***	***Gröna Tåget GTC***	***Gröna Tåget GTW***
Concept	EMU	Loco	EMU	EMU	EMU	EMU *Wide*
Composition	6 cars, 4 driven	1 power unit, 6 c.	4 cars, 3 driven	4 cars, 3 driven	5 cars, 3 driven	4 cars, 2 driven
Std price(2010)	SEK 155m	SEK 165m	SEK 110m	SEK 110m	SEK 155m	SEK 130m
No. of seats	309	309	245	204	300	300
Price per seat	*SEK 502k*	*SEK 534k*	*SEK 449k*	*SEK 539k*	*SEK 517k*	*SEK 433k*
Tilting	Yes	Yes	No	Yes	Yes	Yes
Top speed (permitted)	220 km/h	200 km/h	200 km/h	210 km/h	250 km/h	250 km/h
Average speed[1]	156 km/h	150 km/h	137 km/h	154 km/h	165 km/h	165 km/h
Total costs						
SEK/train-km	136	140	107	95	126	110
SEK/seat-km	0.44	0.45	0.44	0.46	0.42	0.37
Marginal cost (SEK/seat-km)						
Another car [2]	0.34	0.44	0.28	0.44	0.30	0.30
Multiple trainset	0.42	0.43	0.41	0.43	0.40	0.35

[1] Calculated for Stockholm–Gothenburg (455 km) with four stops and upgraded line

[2] Driven/undriven car depending on train concept, a further power unit for the X2

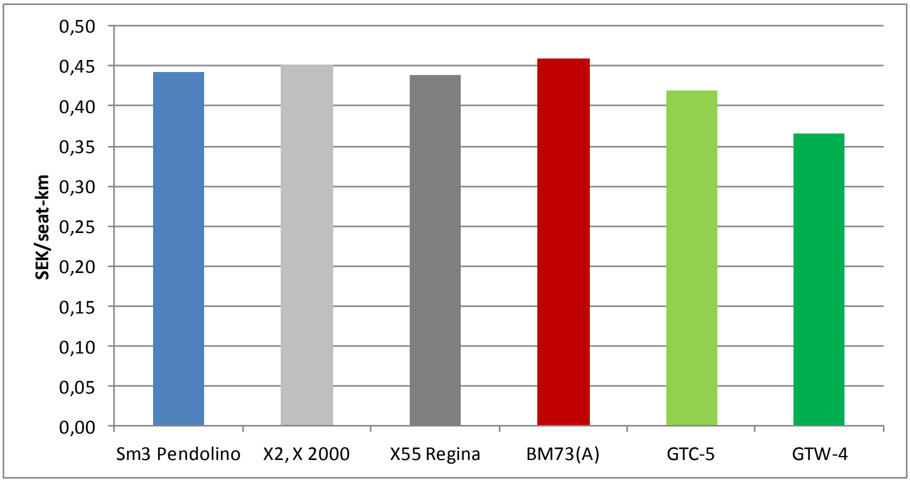


Figure 27. Total costs per seat-kilometre for four existing train concepts and two possible Gröna Tåget train concepts.

All the train concepts have been calculated for long-distance traffic, here the Stockholm–Gothenburg route, with different average speeds depending on tilting and top speed. The line is assumed to be adapted to trains with a new maximum permitted speed of up to 250 km/h.

Gröna Tåget is estimated to have lower total costs than the three existing train concepts counted per seat-km and in particular the wide-body alternative gives a cost saving.

The marginal cost of another seat on the train, calculated as an extra car, is considerably higher for the X2 than for the multiple unit concepts. This is because the SJ X2 with 6 cars already has the maximum number of cars per locomotive/power unit in order to achieve the required tractive power and another locomotive is needed if a further car is attached. On the other hand, the marginal cost decreases for subsequent cars that are attached when the train has two locomotives. The calculation also assumes that all multiple unit trains can easily be extended by one car, which can be said to disadvantage the loco-hauled trains, but this inflexibility is a result of the endeavour to achieve as good economy as possible in the loco-hauled train concepts (maximum number of cars per locomotive). When the marginal cost is instead calculated for a multiple unit train of the same type, the differences between loco-hauled train concepts and multiple unit concepts are significantly smaller.

4.4 Financial key ratios

Revenues from more seats

Table 18. Long-distance and regional operator's yield

2010	***DSB long-distance and regional***	***NSB AS (incl commuter trains)***	***SJ AB***	***VR long-distance***
Travel (pass.-km millions)	4,270	(2,733)	6,774	3,073
Average trip length[1]	98 km	(53 km)	179 km	228 km
Revenues of operations (*Currency* millions)	DKK 4,380	(NOK 4,871)	SEK 8,627	EUR 422
2010 average exchange rate to SEK	1.28	1.21	(1.00)	9.55
Yield per pass.-km (SEK/pass.-km)	1.31	(2.12)	1.27	1.31

[1] Operators have different mixes of long-distance and regional journeys
Sources: Annual reports 2010 for DSB, NSB AS, SJ AB and VR Group; Oanda, 2011

In 2010, the state train operators DSB, SJ and VR in the Nordic countries had revenues from long-distance traffic and regional train traffic, not including commuter trains, of approximately SEK 1.30 per passenger-km. There was competition between transport modes but little or no competition between different operators in this train traffic segment. With noticeable competition on the tracks, it can be assumed that the average revenues will fall.

In an example with a traffic design with hourly traffic and single trainsets on every departure between Stockholm and Gothenburg (455 km) each fast trainset runs 400,000 km a year, including a vehicle reserve of 12%. The figure may vary, for example due to how large the demand variations are over the day.

At 60% average occupancy, the revenue from another seat can thus be calculated to be SEK (440,000 × 1.30 × 0.60 =) 343,200 per year and trainset, assuming that demand is as great in the margin. If the extra seat were to assume a lower fare to achieve 60% occupancy, the benefit is less.
SEK 0.65/passenger-km as the average revenue, or only 30% occupancy for the extra seat, then generates ticket revenues of SEK 171,600 per year, seat and trainset.

The Stockholm–Gothenburg traffic design described above requires 9 trainsets. If the trainsets are furnished efficiently and each contains 10 extra seats compared to what would otherwise be the case, the total revenue from tickets thus increases by SEK 15-30 million a year.

The value of shorter stops

The running time value

The purpose of the following example calculation is to indicate the importance of short dwell times and as a result be able to weigh the number of doors, the train's interior design with aisles and luggage space, technical dwell time and the value of extra seats on the train against each other.

The dwell time at stations is included in the running time value, which is calculated in the socio-economic calculation. A general business economic value for a traffic design in Sweden is SEK 4.7 million per minute of running time and year, or SEK 51 million per minute of running time capitalised over the vehicle's economic life (see Section 7.5).

An example of a traffic design where the dwell times at 10 intermediate stations can be reduced from 120 s to 90 s gives a total gain of 5 minutes' running time per train. This is equivalent to a business economic value of SEK 23.5 million/year or SEK 255 million discounted over the vehicle's economic life (20 years). In other words, it is profitable to build the vehicle so that it shortens the dwell times by 30 s if the extra acquisition and maintenance costs are at most SEK 255 million for the entire vehicle fleet in the traffic design. If the number of seats is affected, the changed revenues must also be considered.

The infrastructure

Long dwell times for boarding and alighting at the stations can be assumed to be a problem at major stations with many travellers and where the available time at the platform is limited for capacity reasons. The dimensioning time is the passenger traffic's peak traffic periods when both the number of trains and the number of travellers on every train is highest.

Provided that no further investments are made in more platform tracks at the most loaded stations, the dwell times for a new express train should be limited to 2-3 minutes in peak traffic, which must also allow travellers with large amounts of luggage or disabilities time to board or alight from the train. There is thus a relationship between installation costs and dwell times. The socio-economic value of short dwell times, both in terms of travellers' time gains and installation costs in the infrastructure, is greater than the business-economic gains for the railway company.

The weight of the train

An analysis has been made of how the train's mass (service weight) affects the total cost of a wide-bodied multiple unit train in long-distance traffic. The results of the analysis indicate that the mass has very little importance with a cost elasticity of 0.04. It is then only energy consumption and track access charges that it is possible to affect.

If the output were adapted to the mass so that the weight/output ratio is constant, a lighter train with fewer traction motors gives a cost elasticity of 0.2. This means that a 20% lighter train has a 4% lower total cost in respect of not only energy consumption and track access charges but also lower capital expenditure and lower maintenance costs. The alternative with the same number of, but less powerful, traction motors in a lighter train probably has a cost elasticity of closer to 0.04 than 0.2.

A low tare thus gives no appreciable cost saving potential in long-distance traffic with few stops. On the other hand, axle loads and track forces set a limit for how much a vehicle can weigh. There may be cost savings for acquisition and maintenance, for example in the form of fewer bogies per given train length in articulated train concepts, and in some cases this requires a light carbody and light technical equipment in order not to exceed the permitted axle load.

Track access charges based on track forces would however increase the railway company's benefit from lower tare.

4.5 Summary

Three factors stand out as particularly important for achieving good economic efficiency in train operation:

- High occupancy
- Good space utilisation
- High average speed, including dwell time.

Gröna Tåget is a proposed concept, the aim of which is to improve all these points compared to existing train concepts. Space utilisation is increased with a wide body that accommodates more seats in the same car. The wide carbody allows a 2+3 seating arrangement in economy class and 2+2 in 1st class, which reduces the total cost per seat kilometre by 15% compared to a normal or continental body profile.

A high average speed can be achieved through good acceleration and tilting. Tilting at higher speeds in curves is profitable on routes with smaller curve radii, in particular if it can shorten the circulation times and thus save trainsets. Shorter dwell times also give lower costs, and in particular at stations with high capacity utilisation they can contribute to better resource utilisation.

5. Prerequisites for express trains

The frameworks to which Gröna Tåget must adhere are defined by the infrastructure. Vehicle profiles and platform lengths are two factors that physically determine the design of the train concept. Safety aspects and how the personnel use the equipment are also important as regards operation.

5.1 Safety

Risk assessment

Like any other train, Gröna Tåget must have a high level of safety for both the crew, the travellers, maintenance personnel and other people along the railway. This section will briefly touch upon some design issues that have an impact on the consequences of a possible accident.

The probability of an accident occurring must not be higher for Gröna Tåget than for other trains and the probability is already very small. There are greater risks in everyday life than when travelling by train. On the other hand, the train must be designed with safety in mind.

The safety effort can be divided into two main areas of focus (Brabie, 2007);

- Active safety; methods that reduce the probability of an accident, such as signalling systems, automatic train control (ATC/ETCS), inspection of wheels and track, etc.
- Passive safety; methods that aim to mitigate the consequences when an incident or accident occurs.

The accident risk is usually defined as the product of the probability of and the consequences of an accident. Society's and individual valuations of the accident risks can on the other hand be skewed and the consequences are often assigned more importance than the probability. Train accidents are rare but when they nonetheless do occur, they can in some cases be very serious, i.e. low probability and minor to severe consequences. By comparison, air accidents are as a rule serious (low probability but extremely severe consequences) while most road accidents are less serious (high probability but minor consequences).

In safety-critical applications in industry and in the railway sector, risk assessment is used, where both probabilities and consequences are identified and valued with the purpose of changing the design of something or how it is used in order to reduce the risks.

Accident risks

The line

Level crossings with roads involve significant risk in railway traffic. Most accidents at level crossings occur as a result of a car driver making a mistake but the consequences may affect both road-users and travellers and personnel on the trains. In Sweden, level crossings are accepted on lines where the speed of the trains is 200 km/h maximum but are not permitted where speeds are higher. According to European norms, the carbodies must always be designed to withstand collisions with objects like cars, but a collision at high speed with a heavy truck risks having major consequences (Effektiva tågsystem, *Efficient Train Systems*, 1997).

Since the lines on which Gröna Tåget will operate are in general equipped with both remote-controlled signalling systems and safety systems, the risk of colliding with another train is negligible. On the other hand, there may be some risk of a collision if another train has derailed and is in a position where it causes an obstruction before other traffic past the scene of the accident can be stopped.

Track defects such as buckling, undermined embankments or obstacles on the line from track work, accidents or sabotage, can cause derailment, as can foreign objects on the track or other track faults. Gröna Tåget does not affect the risk but a good design can mitigate the consequences of a possible accident.

The vehicles

Serious technical faults in the train's running gear like axle fractures, material defects in the wheels and bearing breakdown, or parts falling off the train, can occur and in unfavourable circumstances may cause derailment. It is possible, however, to mitigate the consequences of an incident or accident by designing the train appropriately. The most important thing appears to be that the train stops in an upright position on the track and does not turn over or leave the track completely. Brabie (2007) has shown that it is important for the bogie to be designed so that it follows the track by being able to slide along and be steered by the track in the event of a derailment. Damping of movements (stiffness) in the bogies, between bogie and carbody, and between the carbodies are also important for the train's behaviour in the event of a derailment.

Antagonistic threats

Antagonistic threats are the risk of terrorist activities. It is difficult to prevent different terrorist activities in an open system. In train traffic, with the exception of systems with barriers and some form of access control, travellers can move freely at stations and on the trains. There are generally no luggage inspections, neither of size, amount or content.

The alternative is a closed system at different levels where ticket control at a barrier is combined with scanning of luggage as a first level. This exists on high-speed trains in Spain and on the Eurostar between London and Paris/Brussels. Passenger control and luggage check-in like today for air travel are the next level. This would however lead to disadvantages for travellers such as poorer accessibility (it takes significantly longer) and higher costs.

A preliminary assessment is that antagonistic threats mainly affect station design. A closed system with passenger control must probably be introduced if the risk of terrorist attack is judged to be imminent, even if an efficient intelligence service is probably the best counter-measure. On the other hand, the consequences of terrorist attacks, accidents and fires can be minimised with a well-considered train design.

No easily accessible sources on this matter have however been found and the material that does exist is in part not generally accessible either. The question of designing the train to withstand antagonistic threats is not dealt with further in Gröna Tåget since it is an issue of general safety in the transport system.

Design of Gröna Tåget

It is necessary to design the train such that both accidents and fires are prevented and consequences of accidents minimised. The extent of such measures can not however be determined at this stage of the train concept; it is an issue that must be studied in detail, among other things by means of risk assessment.

The interior of the train should be designed in such a way as to minimise the consequences of an accident or a fire. In the event of a fire, it is important that the train can be sectioned off to be able to continue to a suitable place for rescue operations.

A follow-up of an accident involving an express train shows that interior furnishings such as seats, tables, lamps, mouldings and cupboards, caused the most, and the most serious, injuries from travellers being struck by them. Furnishings have also in some cases become detached and crushed people under the combined pressure instead of absorbing it. Luggage and broken glass from windows then flew around, risking causing injury. Luggage that had landed in the centre aisle also made it difficult to evacuate the train (Holgersson, Forsberg and Saveman, 2012).

To reduce the risk of injury on Gröna Tåget, it is proposed that:

- Interior furnishings be made of yielding materials that reduce the risk of injury, and with soft shapes, yet that remain firmly secured even under extreme loading in case of accidents
- Luggage shall be secured by means of lockers, doors or nets as far as possible and no heavy luggage is to be placed on high racks
- Long saloons are to be partitioned to catch luggage and other objects that can turn into projectiles during strong acceleration.

Experience from earlier accidents shows that it is important to keep people in the cars so that they do not fall out of windows at the time of the accident and that they must be able to be easily evacuated after the accident. This indicates that the windows must be able to withstand an accident without breaking and be able to be removed for evacuation purposes.

5.2 Train driver's environment

The train driver's support systems

High speeds on conventional lines increase the requirements concerning the support systems that train drivers need to be able to drive the train. The introduction of ERTMS/ETCS level 2 means that the safety-critical information is presented in the driver's cab instead of by means of trackside signals. There are also a number of other support systems for the driver, who is responsible for the train being operated in a safe manner. These include detection and indication of the train's status and if inappropriately designed such systems can divert the driver's attention away from information that is important from a safety point of view.

Within the Gröna Tåget programme, an inventory has been made of research in the field and it indicates the importance of systematic data analysis in system development, assuming that the system including the user can in itself constitute a source of error, and collaborating with the end-users throughout the design process, and the importance of experiments (Dimgård, Jansson and Kecklund, 2009).

The design of the driver's cab must satisfy several different requirements regarding a good working environment. Within the EU, research and standardisation efforts are being conducted in order to develop driver's cabs that satisfy these requirements and establish a European standard. The objective for Gröna Tåget's driver's cab must be clear information at the right time (Literature review, p. 17, in Mårdh et al. 2010).

In one of Gröna Tåget's research projects, VTI has developed a train simulator that can be used for both research purposes and educating drivers of express trains.

Ordering and delivery of new trains

An evaluation of a train project, in this case the acquisition and commissioning of Skånetrafiken's X61 Pågatåg trains, also shows that the users must be involved throughout the process to achieve success. The Man – Technology – Organisation (MTO) perspective must also be present at all times. The evaluation of the train project also showed that with three participating organisations, Skånetrafiken (the client), Arriva (the operator) and Alstom (the supplier), all the parties involved must work closely together to be able to realise the project in time. Skånetrafiken's justifiable position that the trains must be quality-assured before formal handover, i.e. free from the usual teething troubles, led to delivery delays and the manufacturer has been unable to rectify the problems in time (Dimgård and Kecklund, 2010).

5.3 The train's width

Vehicle profiles in Europe

Most infrastructure managers in Europe use reference profile G1 or G2, or GA or GB and in new installations GC, which are more generous in the upper parts. These profiles do not permit wide-bodied trains. The reference profiles also require longer carbodies to be made narrower than shorter carbodies since a large part of the curve deflection lies in the vehicle, not the track. The dimensioning factor in the reference profile is often the distance between parallel running tracks on lines and in yards, in combination with curves.

Kinematic reference profiles contain most of the car's movements while under way, and dynamic reference profiles must include all vehicle movements.

Gauges

On the continent, gauges are as a rule considerably narrower than in the Nordic countries. The gauge on adjacent tracks on older lines is often between 3.5 and 4.0 m. An even greater bottleneck is the older St Gotthard tunnel in Switzerland. When it was built, the tracks were laid 3.4 m apart on the straight through the tunnel and 3.5 m apart on the ramps with curve radii down to 280 m. The G1 reference profile is dimensioned according to this section, and both G1 and G2 allow a kinematic width, i.e. including certain vehicle movements, of 3.29 m.

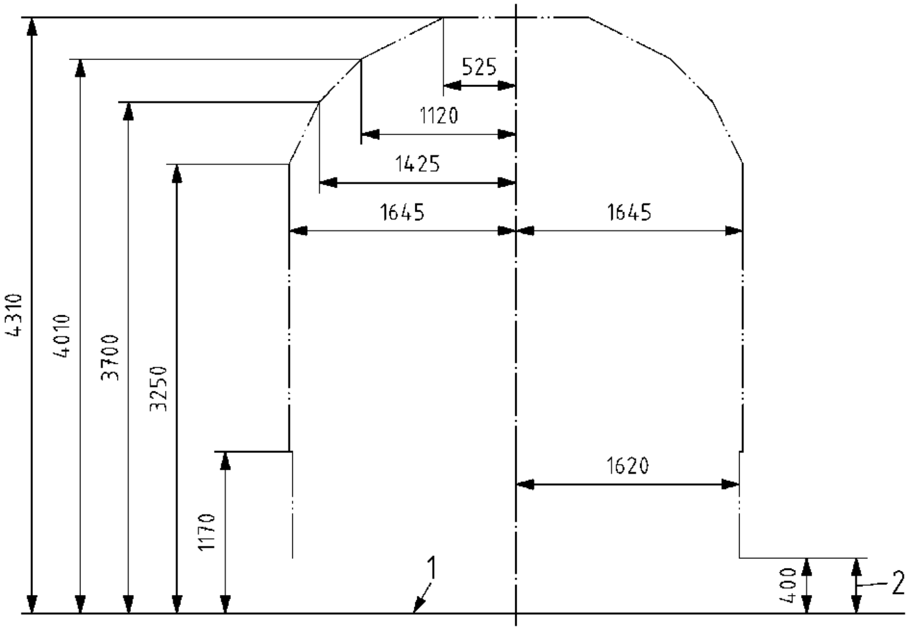


Figure 28. Kinematic reference profile G1. Dimensions in the lower area (2) above top of rail (1) can be found in the detailed dimension diagram in the source material. Source: EN 15273-2:2010 Railway applications – Gauges – Part 2: Rolling stock gauges

Table 19. Track gauges on main lines in some European countries

Country	*Standard on new and converted lines (except HSL*)*	*Minimum gauge*	*Reference profile (maximum width)*
Denmark	4.25 m[1]	4.00 m[1]	DK (K*3,778 m)[1]
Germany	4.00 m	Straights: 3.50 m Curves (R=250 m): 3.62 m[3]	DE1 (K*3,418 m)[4, 5]
Switzerland	V≤140 km/h: 3.60 m V≤160 km/h: 3.80 m V≤250 km/h: 4.20 m	*St. Gotthard Line:* Straights 3.40 m; curves (R=280 m) 3.50 m[5]	G1 (K*3.29 m)[4]
Sweden	4.50 m	4.00 m (Hässleholm-Lund)[2]	SEa (D*3.70 m)[4]

D*: Dynamic vehicle profile; K*: Kinematic vehicle profile (see EN 15273-2:2010)
HSL*: High-Speed Lines; for high-speed line (V ≥ 250 km/h) TSI applies

1 Banenorm (Track norm) BN1-154-2 (Marts 2008)
2 Inventoried by Swedish Transport Administration, 2011
3 Eisenbahn-Bau- und Betriebsordnung (EBO)Anlage 4 EBO(Verordnung) Gleisabstand
4 EN 15273-2:2010 Railway applications – Gauges – Part 2: Rolling stock gauges
5 DE1 applies in the ICE network, otherwise width as for G1
6 Hauenstein, Bernhard. SBB

When it opened in a few years' time, the new Gotthard basis tunnel will however make the older St Gotthard tunnel an exception.

A vehicle with small suspension movements can be made slightly wider or higher than a vehicle with large suspension movements since the vehicle movements are included in the kinematic and dynamic reference profiles. This can be exploited in Gröna Tåget through a Hold-off device (HOD) and active lateral suspension that reduces the vehicle's maximum sideways movements. With a smaller curve deflection, 9 cm wider carbodies can be allowed than for vehicles without HOD and modified lateral suspension.

Reference profiles in the Nordic countries

Interoperability in Scandinavia

For traffic in Scandinavia, it is essential that long-distance trains can operate to Copenhagen, which is an important market for travel to and from Sweden, both for neighbouring Skåne and longer routes such as to Stockholm and Gothenburg. A wide-bodied train should consequently have the capability to operate on the Öresund Link and stop at both Copenhagen Central Station and Norreport station. For capacity reasons, it should also be able to operate to Österport to turn round. Gröna Tåget in a regional configuration might also be of use in Öresund train traffic, which means that the Coastal Line between Copenhagen and Helsingör is also of interest.

All four Nordic countries with railways apply more free space and a larger reference profile than is usual on the continent. The limitations are as a rule the height of the profile in Norway and in Denmark its width. In Sweden, the reference profiles have been changed and implemented in the European Norm (EN) to allow wide-bodied trains in the track network.

Carbody widths

In the Nordic countries there a number of trains with wide carbodies, for example Copenhagen's S-train. The precondition is that the S-trains' carbodies are extremely short and thus give significantly less curve deflection than a conventional passenger car. Sweden has the multiple unit Regina train on long-distance routes and also on some services to Oslo. Extra-wide freight containers, SECU boxes, are also transported from several Swedish paper mills to the Port of Gothenburg.

Table 20. Examples of carbody widths in the Nordic countries

Train type	***Traffic in***	***Ext. width (b)***	***Bogie centre distance (a)***	***Remarks***
X 2000 (X2)	Denmark, Norway, Sweden	3.08 m	17.7 m	Tilting
Regina (X50-X55)	Sweden, Norway	3.45 m	19.0 m	
SECU-box (freight)	Sweden	3.60 m	approx.10 m	SEc profile
IC3 (MFA-FF-MFB)	Denmark, Sweden, Germany	3.10 m	17.73 m	Jacobs bogies
IC4 (MG-FH-FG-MG)	Denmark	3.15 m	19.1 m	Jacobs bogies
S-tog (SA/SE)	Copenhagen	3.60 m	(approx.10 m)	Single-axles

Trains with wide carbodies can contribute to improve economy in train traffic and increase capacity since they have more seats for a given train length than the normal (continental) carbody width has, with maintained comfort. Wide carbodies can accommodate 2+3 seats abreast in economy class and 2+2 in first class. The interior carbody width in a wide train should therefore be 3.3 m at seated travellers' elbow height. With a wall thickness of 10 cm, this would mean an exterior carbody width of 3.5 m.

The Swedish Transport Administration and the Norwegian National Rail Administration have been working systematically to widen the vehicle profile to suit wishes expressed by both freight and passenger traffic operators. It is thus often possible to operate wider vehicles than stated as the maximum in the reference profiles since a few rare obstacles may remain that dimension the general vehicle.

Sweden

In Sweden there are two reference profiles for vehicles: SEa, which is general, and SEc, which has been introduced for freight traffic on certain routes. The wide-bodied Regina with 3.45 m exterior carbody width can operate on all lines with SEa or SEc. Loading tracks, however, constitute an exception since loading platforms restrict the area below 1.2 m above top of rail (see the figure). The obstacle clearance limit, i.e. the point at which the train can stand unhindered on tracks that converge at switches, also need to be moved on some lines. Given these measures, Gröna Tåget with a 3.54 m-wide carbody, HOD and a smaller suspension movement can operate on all lines.

SEa and SEc have been entered as standard in the TSI through European Norms (EN). The intention is that the SEa and SEc gauges will also be entered in the TSI for future high-speed lines in Sweden (Sollander, 4/11/2009).

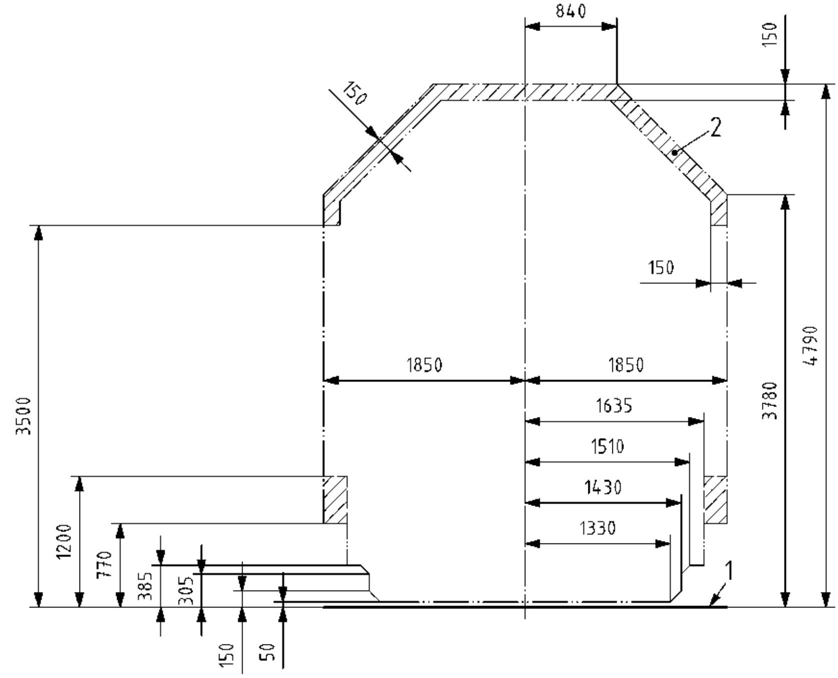


Figure 29. The dynamic reference profile SEa which applies generally in Sweden. The hashed area in the lower part can be used for wide-bodied trains except at loading platforms. Source: EN 15273-2:2010 Railway applications – Gauges – Part 2: Rolling stock gauges

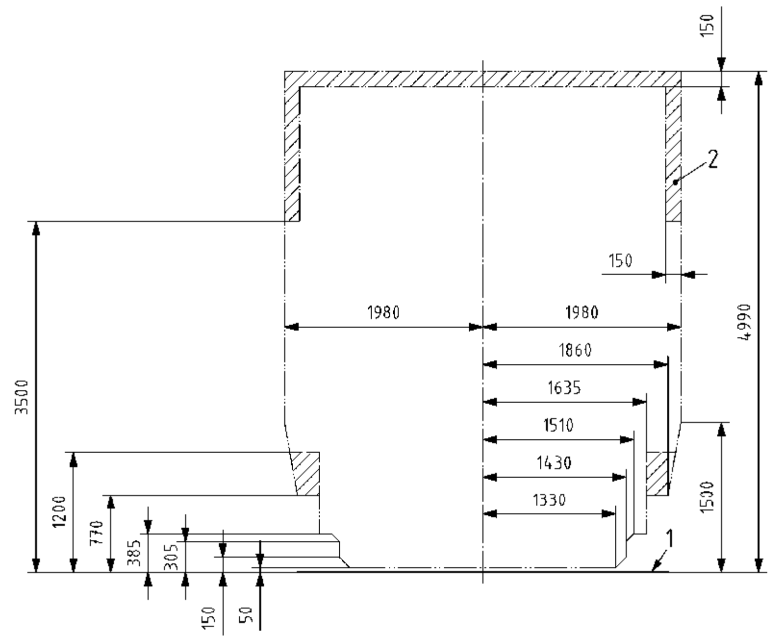


Figure 30. The dynamic reference profile SEc which applies on adapted lines in Sweden. Source: EN 15273-2:2010 Railway applications – Gauges – Part 2: Rolling stock gauges

Norway

Wide-bodied trains are also possible in Norway with roughly the same reservations as in Sweden, but the general width is a little smaller. The NO1 dynamic reference profile is 3.6 m wide, i.e. 0.1 m narrower than in Sweden (Network Statement 2013). There are however restrictions at heights below 1.2 m where loading platforms for freight traffic exist. To be able to take advantage of the possibilities offered by wide-bodied trains, the vehicle width needs to be greater in this area, which as a rule can be allowed except on loading tracks.

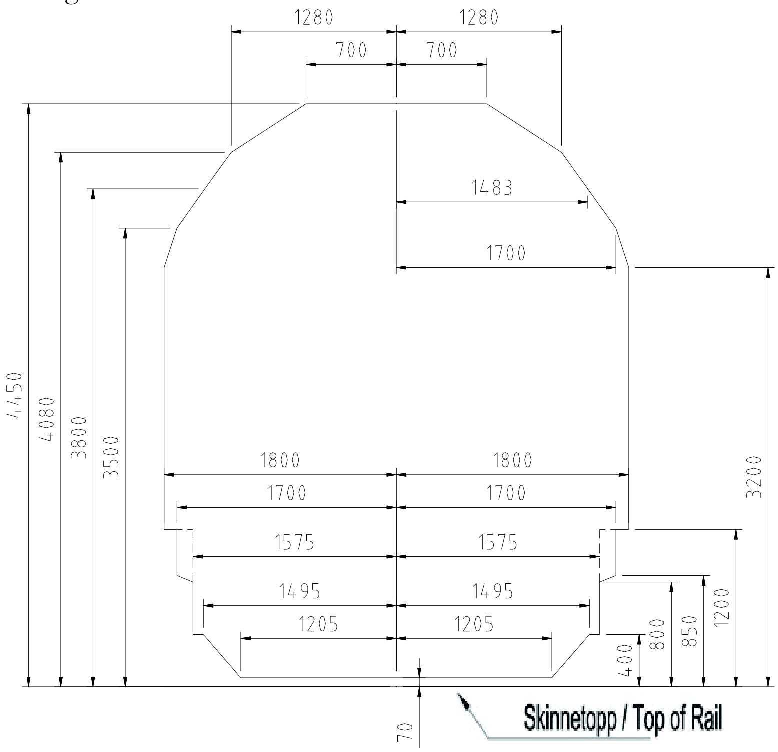


Figure 31. Reference profile NO1 applies throughout Norway. NO1 is dynamic, meaning that the vehicle's movements while under way must also remain within the profile. Source: Norwegian National Rail Administration's Network Statement 2013

The Norwegian National Rail Administration has simulated traffic with a wide-bodied Regina train with a carbody width of 3.45 m and established that most main lines allow wide-bodied trains without the need for any measures. There are however exceptions, for example the Gjøvik Line and the Haugastøl–Myrdal–Bergen section on the Bergen Line. It is, however, possible to eliminate many of the remaining obstacles by rebuilding the line. With a carbody width up to 3.54 m and HOD, Gröna Tåget can in all probability be interoperable on most lines in Norway.

Denmark

Banedanmark's (Rail Net Denmark) kinematic "reference profile for rolling stock on long-distance lines" (Rail Net Denmark's Network Statement 2012) is smaller than the equivalent reference profiles in Sweden and Norway.

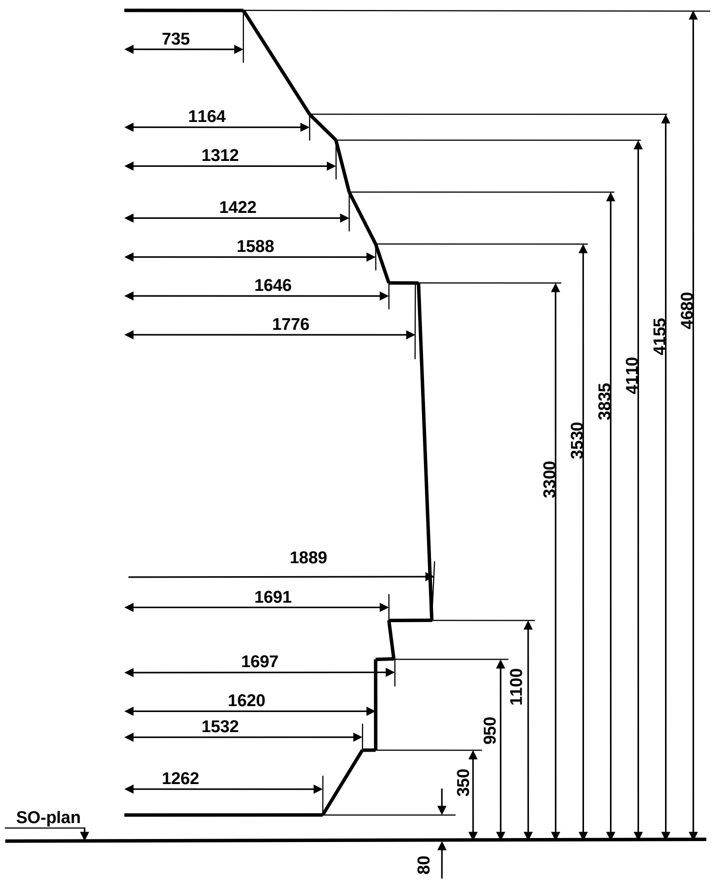


Figure 32. Rail Net Denmark's reference profile for rolling stock on main lines. The reference profile is kinematic. Source: Banedanmark's Netredegørelse (Network Statement) 2012

In Denmark (and on the continent) a rather small profile extension is applied in curves, unlike Sweden and Norway. This makes Denmark's reference profile dimensioning for a wide-bodied train that is interoperable in Scandinavia. Restrictions regarding wide-bodied trains are mainly in the area between platform height (76 cm) and service platforms (up to 1.1 m above top of rail) and the vehicles' upper corners. The reference profile does not allow sufficiently wide carbodies to give the comfort aimed for in Gröna Tåget.

The free space that dimensions room along the line does, however, permit wide-bodied trains. The vehicle profile needs to be narrower across the roof (above the windows) than today's Regina carbody to reduce conflicts with immovable objects.

According to an earlier notification from Rail Net Denmark (see further in Fröidh, 2010), certain possibilities exist to operate traffic on the lines with wide-bodied trains as a special transport mode. Normal traffic requires a general permit that applies independently of other traffic, i.e. the vehicles must be able to be operated on double-track lines without needing to take traffic on the other line into account. This requires both surveying of gauges and any other obstacles to be able to dimension a suitable vehicle profile and testing of the safety level (margin) that has hitherto applied regarding the distance between vehicles coming from opposing directions.

A review of the prerequisites for wide-bodied trains on Danish lines shows that the current margin, defined as the difference between gauge and the largest possible vehicle width, plus the extra margin that the European Norm (EN) recommends that the infrastructure contain, is larger in Denmark than for example in Switzerland and Germany at the critical height for wide-bodied trains of 1.7-1.8 m above top of rail. One conclusion is that it should be possible to reduce the margin in Denmark from 106 mm to the same value as in Switzerland and Germany, i.e. 29 mm, to allow a generally increased (77 mm) carbody width (Fröidh and Persson, 2011).

Local conditions on the route where wide-bodied trains can come to be used should also be able to determine the possible carbody width. Some examples show that the carbody's exterior width on 4.0 m gauge lines according to the reference profile in question may be 3.30 m but it should be possible to be widened to 3.54 m within the free space. The wider carbodies can be accomplished by means of HOD and modified lateral suspension, surveying and more accurate calculations. A limiting factor for carbody widths over 3.45 m is the 4.0 m dimensioning gauge in combination with the existing curve radii. Gauges, curve radii and certain obstacles are currently being surveyed and inventoried within the Gröna Tåget programme in collaboration with Rail Net Denmark and the Swedish Transport Agency and this is due to be completed during 2012. Formal approval is also needed for normal traffic with wide-bodied trains.

In the event that Gröna Tåget can not be designed with shorter carbodies with Jacobs bogies or in a semi-trailer concept, the carbody width can at any rate be increased compared to long carbodies. With a bogie centre distance of 15 m, compared to 19 m with a dimensioning curve radius of 250 m, the carbody can for example be made 136 mm wider with the same curve deflection.

Finland

The reference profile in Finland allows 3.4 m wide vehicles. The typical clearance section for the free space, however, is 5.0 m wide (Finnish Network Statement 2012). No special investigations have been made but it is here assumed that it is technically possible to operate wide-bodied trains to the same extent as in Norway and Sweden after surveying and taking any necessary measures in the infrastructure.

Carbody width

There are in principle two categories of carbody width that are of interest for a future Gröna Tåget: wide body and continental width. Intermediate widths between the wide body and the continental width are less interesting in an economic perspective as long as they do not accommodate more seats. Trains that are slightly wider than continental width are however by tradition used in all the Nordic countries to improve comfort. This width gives more elbow room and a few centimetres wider seats. If carbodies are to be standardised in the European market, it is probably a continental profile that is closest to hand. For Gröna Tåget, however, comfort should be improved by taking advantage of the possibilities to have a few centimetres wider reference profile than G1/G2 in Germany.

Table 21. Carbody width

Variant	*Maximum interior width*	*Maximum exterior width with 10 cm wall thickness*	*Areas (some measures poss. required in the infrastructure)*	*Seating*
Wide	3.25-3.34 m	3.45-3.54 m	Sweden, Norway, Denmark[1], Finland	First class 2+2 with good comfort Economy class 2+3 with good comfort
Continental	2.6-2.8 m	2.8-3.0 m	Continental Europe[2]	First class 1+2 with good comfort Economy class 2+2 with good comfort

[1] Denmark requires the free space to be fully utilised and restrictions apply regarding which routes services can be operated on. Shorter bogie centre distances (for example 15-17 m) allow wider carbodies

[2] In Germany, slightly wider vehicle widths than in southern Europe are permitted (reference gauge DE1)

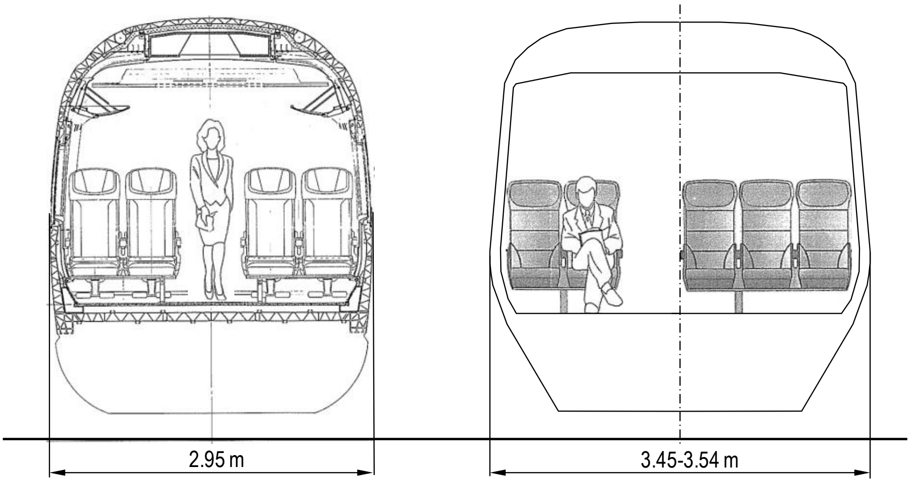


Figure 33. Continental carbody width (illustrated by the first series of the German ICE3 high-speed train with 17.375 m bogie centre distance) and Gröna Tåget with wide carbody and Hold-off device (HOD) with modified lateral suspension.

Studies of the reference profiles in Sweden, Denmark and Norway have shown that Gröna Tåget with long carbodies can be made at least 3.5 m wide but probably another few centimetres wider on the line from Sweden to Copenhagen Central and on to Österport. An upper limit of 3.54 m exterior carbody width is assumed here, on condition that the vehicles are equipped with HOD and modified lateral suspension, which will reduce movements while running.

For the concept of wide-bodied trains to be attractive to travellers and operators on long-distance routes, good comfort is needed – and the wider the trains the greater the seating comfort. To increase interior width it should be possible to build trains with thinner walls of about 10 cm thickness while fulfilling requirements concerning for example crash safety and heat and sound insulation. This means an interior width of between 3.25 and 3.34 m.

Compared to the Scandinavian width such as on the X2, Gröna Tåget can be made 50-60 cm wider inside and compared to the continental profile 60-70 cm wider, which is fully equivalent to the width of a seat with individual armrests. One proposed carbody profile for Gröna Tåget with an exterior carbody width of 3.54 m would with 10 cm walls mean an interior width at its widest point (1.7-1.8 m above top of rail) of 3.34 m. This gives good comfort for all travellers.

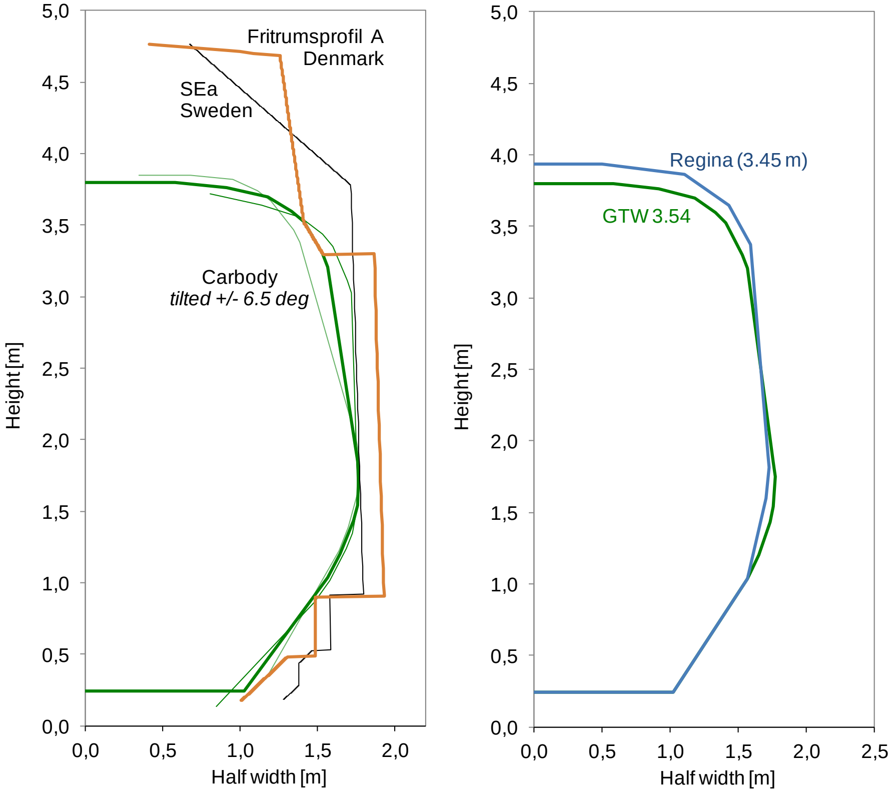


Figure 34. Proposed carbody profile GTW 3.54 for Gröna Tåget with 3.54 m exterior width which is possible with modified lateral suspension and Hold-off device (HOD). Tilting is accommodated within the SEa vehicle profile in Sweden but must be turned off in Denmark.[6]

Tilting can be used in Sweden and Norway according to the proposed vehicle profile, while in Denmark it would be in conflict with objects along the line. The 3.54 m wide carbody therefore presupposes that tilting be turned off in Denmark.

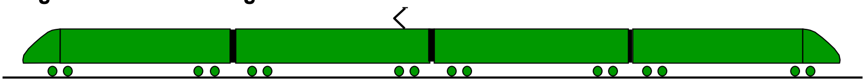
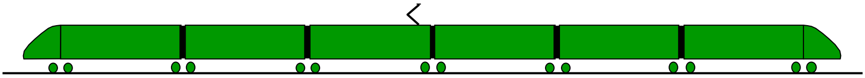
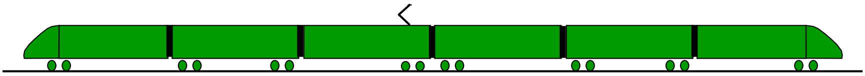
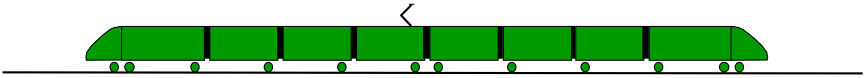
[6] The investigation of gauges and obstacles in Denmark had not been completed at the time of writing and may lead to changes in the vehicle profile.

5.4 Train configuration and train length

Train configurations

If Gröna Tåget were to be built without tilting, a double-decker concept could also be considered. Presented here are four different principle solutions for single-decker trains that can be equipped with tilting, i.e. the express train that Gröna Tåget is primarily intended to be.

Table 22. Train configurations for multiple unit trains

	Long carbodies with bogies at the ends
L	
	Examples: Regina, the Zefiro and Velaro high-speed trains, and others
	Articulated, short carbodies with Jacobs bogies
A	
	Examples: X60 and ET423 commuter trains, the AGV high-speed train
	Semi-trailer, articulated with short carbodies
S	
	Examples: C20 metro train, the X'trapolis regional train concept
	Extremely short carbodies with single-axle bogies
E	
	Examples: Similar to the S-train in Copenhagen and the Talgo high-speed train

In general the train's economy could be improved with longer carbodies and with fewer bogies. When the number of bogies is reduced, this also means that the axle loads are increased to the maximum permitted, which may lead to higher track access charges and higher track maintenance costs. The bogie centre distance that is possible on wide-bodied trains in Denmark may, however, limit the length of the carbodies and it will then be a question of weighing the benefits of wide-bodied trains against the possible extra cost of shorter carbodies against each other.

Train length

Train length should be chosen partly according to the demand (number of travellers per departure) and partly according to standardised platform lengths.

Table 23. Advantages and disadvantages of the train concepts

Train configuration	Advantages	Disadvantages
L Long carbodies	• Tried and tested • Few passages between the cars	• Possibly limited width for use in Denmark • Relatively simple to couple and uncouple cars
A Articulated with Jacobs bogies	• Tried and tested • Somewhat fewer bogies gives lower costs • Can be made wider for use in Denmark	• Several passages between the cars affect the passenger environment and space utilisation • Axle loads may be high • Troublesome to couple and uncouple cars
S Semi-trailer	• Can be made wider for use in Denmark • Possibly fewer bogies, if so lower costs	• Several passages between the cars affect the passenger environment and space utilisation • Not tested for high speeds • Axle loads may be high • Troublesome to couple and uncouple cars
E Single-axle bogies	• Single-axle bogies (lighter and cheaper) • Can be made considerably wider for use in Denmark	• Even more passages between the cars affect the passenger environment and space utilisation • Not tested for high speeds (with the exception of Talgo) • Requires active steering • Slightly lower ride comfort • Troublesome to couple and uncouple cars

To also maintain a reasonable frequency of service during off-peak periods with good economy the smallest train unit must be relatively small. On the other hand, the available track capacity often limits frequency of service during peak traffic periods. The difference in load between off-peak and peak traffic can then be accommodated by adding and detaching units where frequency of service is not increased. Short trainsets allow both degrees of freedom to be used to adapt the supply.

Trainset lengths

For Gröna Tåget as a conceivable train principally for long- and medium-distance traffic a number of practical train lengths have been identified. The shortest trainset length has been assumed to be 80 m, which is a result of the fact that the costs per seat-km increase with shorter trainsets. It is also advantageous from a technical point of view, mainly for braking and current collection, to not have too short trainsets at higher speeds.

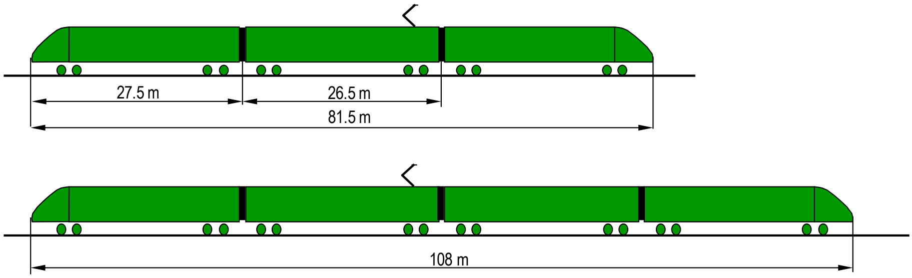


Figure 35. Conceivable trainsets (L) with three and four long carbodies.

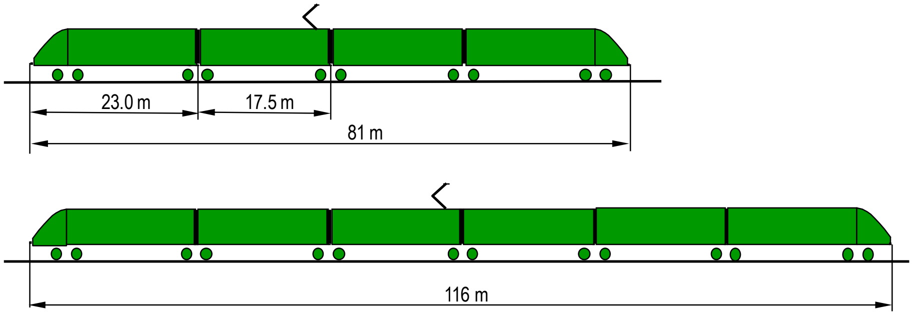


Figure 36. Conceivable articulated (A) trainsets with four and six short carbodies with Jacobs bogies.

Two principle train concepts are shown here. One has long carbodies with a module length of 26.5 m for the intermediate cars and 27.5 m for the leading and trailing cars, and with bogies at the car-ends with a bogie centre distance of 19.0 m.

The second concept is an articulated concept with shorter carbodies and Jacobs bogies, i.e. the bogie centre lies in the middle between the car-ends, except in the leading and trailing cars whose outermost bogie. The bogie centre distance and the module length in the intermediate cars in the example is in both cases 17.5 m and the leading and trailing cars are 23 m long between the couplings' shock planes. The bogie centre distance on other types of train with Jacobs bogies is for example 16 m on the X60 commuter train and 17.3 m on the AGV high-speed train, and a train concept with shorter carbodies than this would thus entail somewhat higher costs than the best applications.

In an international perspective, adaptation to the TSI for high-speed trains can be considered. This means that the units' length should be multiples that give a train 400 m long, which is the maximum train length. Depending on traffic tasks and technical prerequisites, practicable train units can then be 80 m, 100 m, 133 m or 200 m long. Platform lengths, however, vary and in practice determine which train lengths give good capacity utilisation.

Platform lengths

There are several different platform lengths in the Nordic countries. The most important ones are shown in the table (below). Note that at many stations only a few tracks have a platform length that conforms to the standard, while others may have shorter platforms.

Table 24. Platform standards and train lengths

Platform length		***Long carbodies (L)***		***Short carbodies (A)***	
		Unit comb.	*Train length*	*Unit comb.*	*Train length*
125 m	SE: Certain lines in Sweden	4	108 m	6	116 m
210 m	NO: Certain stations EU: Half-module acc. to TSI[1]	3+4 7	190 m 188 m	5+5 11*	197 m 204 m
225 m	SE: Minimum length (TSI)[1] on high-speed lines in Sweden	4+4	216 m		
250-255 m	NO: Several lines SE: Several lines	3+3+3	244 m	4+4+4 6+6	243 m 232 m
320 m	DK: Standard i Denmark FIN: Certain stations in Finland	4+4+4 5+5	295 m 269 m	5+5+5 8+8	296 m 302 m
330-340 m	DK: Tracks 3-4 at Copenhagen Central SE: Malmö C lower	3+3+3+3 4+4+4 6+6	326 m 324 m 323 m	4+4+4+4	324 m
355 m	NO: Certain lines in Norway DK: Tracks 5-6 at Copenhagen Central SE: Several main lines	3+5+5	350 m	6+6+6	348 m
410 m	FIN: Several main lines EU: 1 full or 2 half-module high-speed trains according to TSI[1]	5+5+5 7+7	404 m 375 m	5+5+5+5 11[2]+11[2]	394 m 407 m

1 TSI HS INS, 2008

2 Or 10 carbodies with expansion module in the middle of the unit for 200 m trainset length

Given that the platform lengths must be used to maximum extent with short multi-coupled trainsets, trainsets with four long cars and a unit length of 180 m can be used in all the Nordic countries. In Norway and Sweden, three long carbodies with a unit length of 81 m can also be used and in Finland and Denmark five long carbodies with a unit length of 134 m. Trainsets with shorter carbodies can to advantage be made up of four, five or six cars, i.e. trainset lengths of approximately 81, 98 or 116 m.

If the trains are only rarely multiple-coupled or the longest platform lengths do not normally need to be used, other, longer, trainsets may be of interest to the traffic companies.

Table 25. Most practical trainset lengths for multi-coupled trains

	Long carbodies	***Short carbodies***
Denmark (DK)	4, 5	4, 5, 6
Finland (FIN)	4, 5	5
Norway (NO)	3, 4	4, 6
Sweden (SE)	3, 4	4, 6
TSI high-speed (EU)[1]	*5, 7*	*5, 11[2]*

[1] TSI HS INS, 2008

[2] Or 10 carbodies with expansion module in the middle of the unit for 200 m trainset length

5.5 Summary

The Gröna Tåget train concept is proposed to be a single-decker train to allow tilting with a wide carbody. The train can be designed in a conventional manner with long carbodies and bogies at the ends or with shorter carbodies in articulated concepts.

For operation in Scandinavia, Gröna Tåget can be executed with a wide body that is between 3.45 and 3.54 metres wide at its widest point 1.7-1.8 metres above top of rail provided that the vehicle profile is designed appropriately and includes a Hold-off device (HOD) and modified lateral suspension (ALS). The dimensioning area to achieve Scandinavian interoperability is Denmark where Gröna Tåget is intended for traffic over the Öresund Link to Copenhagen and possibly beyond. Continued investigation of track distances and obstacles is necessary to determine the greatest possible carbody width. A preliminary vehicle profile suggests 3.54 m carbody width, which can also be equipped with tilting, but switched off on Danish rails however.

The platform lengths on electrified lines vary in the Nordic countries between 125 and 410 m depending on the lines and stations in question. The generally most practical train length is approximately 108 m with four long carbodies, which suits many different platform lengths by adding and detaching units.

6. Train concepts

Gröna Tåget is to be an attractive express train for both business and leisure-time travellers in all weathers. One fundamental idea is the wide carbody, which gives 15% lower total costs for train traffic than a carbody with a normal profile. Another principle is that Gröna Tåget must be designed to allow punctual station stops also during periods of peak load.

6.1 The travellers are the target group

Inroduction

In the Gröna Tåget research programme the objective is to develop and attractive train concept in the form of a concept proposal based on business economic and socio-economic assessments. As has been shown in previous chapters, Gröna Tåget is intended for Interoperability in Scandinavia, principally operating in fast long-distance regional traffic and long-distance traffic during the daytime. One basic idea is to meet the stiff competition from other modes of transport with an attractive supply for business and leisure-time travellers alike. In other words, Gröna Tåget can be considered an everyday train that functions in all weathers. Much of Gröna Tåget's attractiveness is in its economy, where both short travelling times and good space utilisation give lower costs and higher revenues.

Of the prerequisites that are important as regards the train's attractiveness and economy the following stand out in particular:

- Carbody width (load gauges, carbody length, bogie centre distances)
- Train configuration (short or long carbodies, train length)

These exterior prerequisites have been dealt with in previous chapters.

- Activities during the journey (service, market concept)
- Interior and furnishing (function, principal dimensions, disposition, comfort)

An attractive train concept must be both economically viable for the railway company and valued highly by the travellers.

Activity approach for the train's design

Travellers can choose to fill their travelling time with activities, in addition to the journey itself. Making use of the time on board can make the train journey more attractive. The activity approach involves describing and valuing the travellers' various activities during the journey. On the basis of this assessment, the train concept for Gröna Tåget can be designed (Fröidh, 2009).

The travellers' activities can be divided into different categories. Depending on the purpose of their trip, age, interests and companion(s), travellers constitute a heterogeneous group with different desires and needs. A baby for example has entirely different needs to a business traveller during the journey, and a group of people travelling will often devote their time to being together (socialising with each other) while a person travelling alone may choose to watch a film. Some people like to be active (talk, walk), others passive (rest), which are conflicting interests when it comes to noise/sound volume and lighting for example.

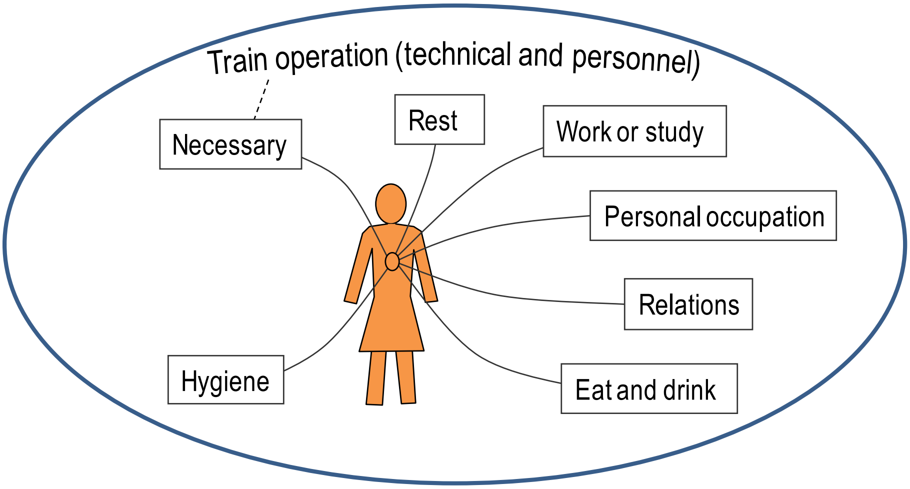


Figure 37. Travellers' conceivable activities during their journey.

The most important activities during the journey are:

- Those necessary for the journey (boarding and alighting, information, ticket handling)
- Rest (relax, sleep, think – noise sensitive)
- Work or study (use the journey time to read, write, communicate using computer and phone)
- Personal occupation (read, watch a film, play games, listen to the radio or music)
- Relations (chat to other passengers, play, play games with other people)
- Eat and drink (own food/drink brought along or served at one's seat or in the train's cafeteria)
- Hygiene (toilet, sanitary).

One general conclusion from this is that it is important to provide for travellers' individual choices, i.e. several activities (including rest) should be possible and the train should be designed for flexibility to suit different desires. These desires can often be translated into a value through the travellers' willingness to pay and it is consequently possible to weigh cost against benefit for the railway company.

Activities that demand a relatively large amount of space, for example a shop with room for customers and stock, exercise activities, a large restaurant or that otherwise that take up a large area in addition to normal seats are not of any interest as regards Gröna Tåget. Energy consumption and the price of the journey would increase if such activities were introduced. This does not conform to Gröna Tåget's profile but may in certain cases be of interest as regards other train products.

The design of Gröna Tåget is dealt with in the parallel project Attraktiv passagerarmiljö, *An attractive Passenger Environment*, (see Kottenhoff och Andersson, 2009; Lundberg, Eriksson och Ranvinge, 2010) and valuation studies of a large number of factors in Kottenhoff and Byström (2010).

Disabled travellers

Many travellers have a disability of some kind.

A summarising definition of handicap can be found in Heinz and Kottenhoff (2001): "When the surroundings' demands are greater than physical ability, a handicap arises". Since the transport system is to be accessible to everyone, the function in the train concept, interaction with stations and infrastructure and possibilities to obtain information and service need to be taken into consideration from the outset.

The disabilities that must be taken into account when designing a new train concept according to European norms can be found in TSI "Persons with reduced mobility" (TSI HS PRM, 2008). They concern travellers in wheelchairs, travellers with other physical disabilities, travellers with impaired hearing or vision, travellers with impaired mental or communicative ability and travellers of short stature. These definitions consequently cover a large group of travellers. Traditionally, certain disabled travellers are considered to be handicapped in a physically inappropriate environment, but this extended definition also includes for example travellers with large amounts of luggage, travellers with prams, pregnant travellers, children, and also visitors who do not speak the country's language and thus cannot understand written or spoken information.

Accessibility in Gröna Tåget is treated in the following as an integral part of the train concept and the aspects that are important as regards the function are described as appropriate throughout the text.

6.2 Design for punctual stops

Delays at stops

Punctuality

Punctuality is one of the most important quality factors in train traffic. Punctuality is dependent on many different factors; travellers, weather, vehicles, timetable, track and not least organisation, rules and routines (Claesson and Lindh, 1992; Olsson, Sætermo and Røstad, 2002; Fahlén and Jonsson, 2005; Olsson and Veiseth, 2011). The Gröna Tåget train concept must be designed so as to enable punctual train traffic. Station stops stand out as particularly important and critical events with regard to punctuality. Experience shows that station stops take time, and often a longer time than the traffic company planned for when drawing up timetables.

Dwell time at small stations is 1 minute in the timetable and 2 minutes at larger stations. The figure shows that the excess time at the stop (i.e. the delay at the stop) varies. Number of passengers, occupancy on the train and departure punctuality at the point of origin have the strongest correlation with punctuality (Olsson och Haugland, 2004). Many passengers means that passenger interchange takes longer. If 90% of the trains are to keep to the scheduled stop without any additional delay, the dwell time at a station with only boarding or alighting passengers should, according to curve "Low", be 100 s while at a larger station, according to curve "High", it should be 190 s or a little more than three minutes. There is also an observation from Norrköping Central Station, which has more boarding and alighting passengers than the stations measured in the figure. It shows even longer delays and the 90% target requires a scheduled stop of 4-5 minutes there (Fröidh and Jansson, 2005).

The excess stop times have relatively long tails, i.e. the standard deviation is large. In other words, it is difficult to predict whether the train will manage the stop within the time stated in the timetable. The stops with the X2 are in actual fact a source of delay which can only sometimes be made up along the line (see also the section on capacity in Chapter 7). Vestibules and the interior on the X2 have been designed in such a way that a relatively long time is required at station stops. One of the reasons is that the dimensioning door on the train, the control car's door, lengthens the stop times for the whole train (Heinz, 2003).

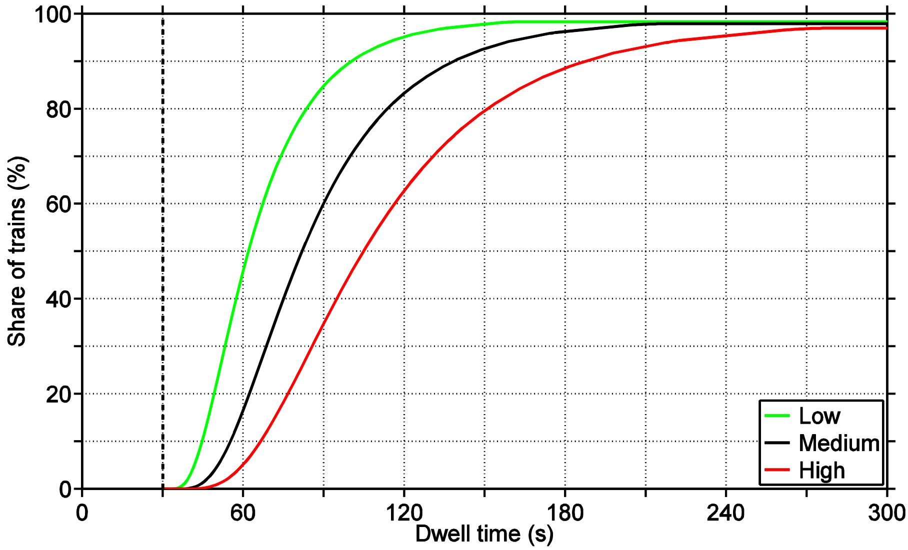


Figure 38. Dwell times for SJ's X2 express train in three categories, measured in 2007 on the Western Main Line. The shortest measurable stop is 30 s. The larger the station with several boarding and alighting travellers, the longer the stop and the greater the standard deviation. Source: SJ AB, from Sipilä and Warg, planned 2012

Causes of delay at stops

The passengers must alight and board during the dwell time, while the technical time is additional. Any deviations over and above the ideal case will under these preconditions result in delays. Possible deviations include:

- One or more passengers have wheelchairs, prams or very cumbersome luggage
- Unusually large number of travellers with heavy luggage, for example during the longer public holidays
- More passengers than were thought at the stations
- Uneven distribution of travellers boarding and alighting through the doors of the train
- A fixed interval (clock) timetable that is dimensioned for normal and not peak traffic
- Technical problems with one or more door or other systems
- Other causes (personnel exchange, to do with train operation).

In practice, this means that many situations outside of normal train traffic risk causing delays. The higher the train's loading, the more the problems with too long stops will increase. For economic reasons, high occupancy is a necessity during periods of high demand.

There are several design factors that can improve punctuality and reduce the stop times, as we will see in this section.

Distribution of the stop times

The train's total dwell time consists partly of technical time and partly of the travellers' boarding and alighting time.

Technical time includes time to close the doors, signal all-clear before departure, etc.

Boarding and alighting time is dependent on the dimensioning door, i.e. the door on the train that is the last to get all the passengers off who are to pass through it.

If we disregard the distribution of travellers along the platform during boarding, the following train-related parameters are identified (Heinz, 2003):

1. Technical time (s)
2. Number of travellers through the dimensioning door (number of doors)
3. Door width (m)
4. Number of steps / height difference between platform and the floor of the train (m)
5. Passenger flow on the train (physical design, orientability).

Doors for boarding and alighting

Number of doors on the train

The number of doors on the train can vary with its task – many stops motivate more doors than few stops. In long-distance traffic, there are as a rule fewer stops during the journey. The total dwell time is therefore relatively short. On the other hand, travellers as a rule have large amounts of luggage that require time and space to handle when getting on and off the train. Shorter stop times are of greater interest in long-distance regional traffic, but travellers as a rule have less luggage and are relatively mobile.

If the train is to be used in several different kinds of traffic, it needs to be dimensioned according to the needs of the most demanding kind of traffic when it comes to boarding and alighting. Too few doors will contribute to cause passenger jams, leading to long stops and the risk of delays. There is consequently a connection between the flow of travellers on the train and the number of doors. The most important thing is to assess the need according to the desired dwell time for passenger interchange at the stations. In many long-distance railway cars about 40 seats per single entrance door is usual.

Boarding and alighting times can be shortened with better-designed entrances, vestibules and interiors. The number of seats per entrance door could be increased if the train were designed in the right way:

- Entry at platform level or at most 1-2 steps up to the floor of the train
- 90 cm free door width with single doors
- Split passenger flows through the car (quarter model or centre model)
- A wide centre aisle or the possibility to pass in the aisle
- Luggage can be stowed quickly and out of the way of the flow of other passengers
- Passengers with hindrances to movement such as a wheelchair or pram or other bulky luggage are to board or alight through less congested doors.

Under favourable conditions as described in the points above, a single door would probably be able to cope with up to 60 seats with stop times unchanged compared to today's X2. However, ideal conditions are seldom possible for financial reasons. A general recommendation is therefore to plan for a maximum of 40-50 seats per single door.

The risk of technical faults in the doors and the need to evacuate the train indicate that more doors is preferable to fewer doors. The doors are sensitive to disruptions and must be designed for winter weather, including sand for slippery platforms, and be carefully maintained.

Location of doors on the train

There are three main alternatives as regards the location of the doors on a carbody.

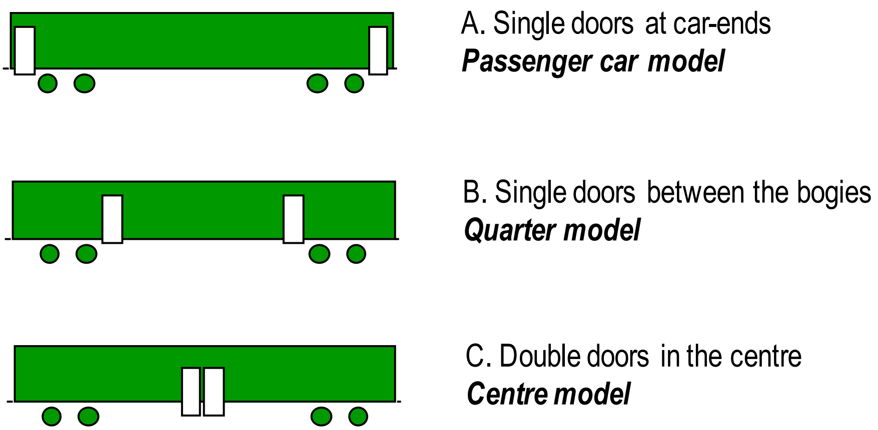


Figure 39. Door location in three different models.

In addition to technical characteristics like the carbody structure and possibilities for flexibility as regards seat arrangement, the location of the doors is also important for dwell times (for boarding and alighting) and comfort in seats in different places in the car.

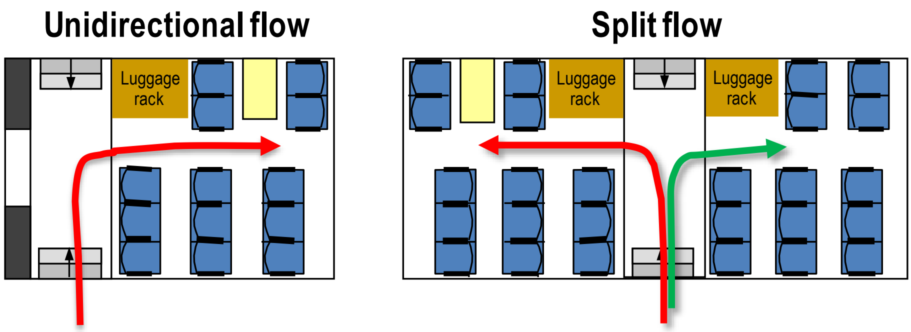


Figure 40. Traveller flow in a passenger car.

Split flows that are achieved in the quarter and centre models, i.e. travellers can move right and left from the entrance door, reduce boarding times compared to single-direction flows as in the passenger car model (Tuna, 2008).

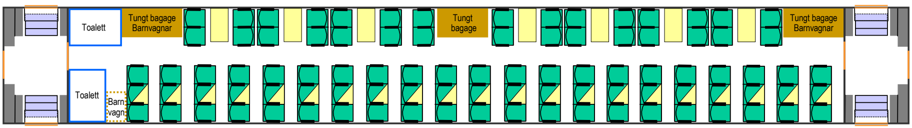


Figure 41. The passenger car model with single doors. Intermediate car with one long saloon with 93 seats.

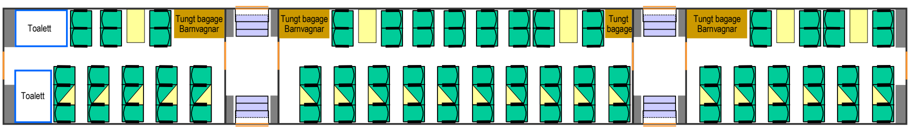


Figure 42. The quarter model with single doors. Intermediate car with three saloons and 93 seats.

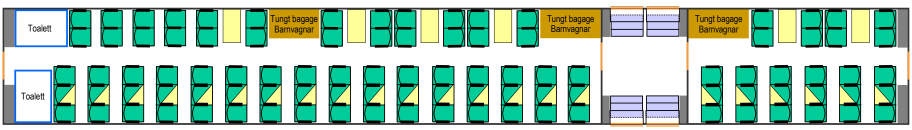


Figure 43. The centre model with asymmetrically placed double entrance doors. One long and one short saloon, and since the vestibule takes up less room than the two vestibules in the two other models there is room for another row of seats, making a total of 98.

The centre model can also be placed asymmetrically closer to one of the bogies as in the layout diagram, but one drawback is that jams (queues) occur easily in the longer saloon when many travellers want to board or alight, making dwell times longer.

Further factors to consider are the technical possibilities to accommodate appliances and electrical equipment below the floor in combination with tilting when the cars have low floors and entrances.

Table 26. Advantages and disadvantages of different door locations

	Comfort and convenience	***Passenger flow***	***Accessibility for disabled travellers***	***Carbody structure***
A Passenger car model	Less noise and draughts for seated travellers	Unidirectional flows – easy to find one's way, greater risk of queues	High floor with lift for disabled travellers. Low entrance not possible	Entrance (and crumple zones) at car-ends an advantage One long saloon makes optimal seat arrangement simple
B Quarter model	Risk of somewhat more noise and draughts for seated travellers	Split flows – slightly more difficult to find one's way, less risk of queues	High floor with lift or low entrance for disabled travellers	High floor minor problems; low entrance entails cost increase Three short saloons make optimal seat arrangement more difficult
C Centre model	Less noise and draughts for seated travellers	Split flows – slightly more difficult to find one's way, less risk of queues	High floor with lift or low entrance for disabled travellers	High floor minor problems; low entrance entails cost increase

The evaluation shows that with the same prerequisites, somewhat more seats can be accommodated in a car with the centre model due to the wider vestibule for two single doors taking less room than two narrower vestibules.

The quarter model gives the most even passenger loading and least risk of jams during boarding and alighting and thus constant dwell times and less risk of delays at stops.

The passenger car model has technical advantage in that it gives an advantageous carbody structure and also a large saloon where it is easy to achieve an optimum seat arrangement, which not only applies to new trains but also for example to trains converted for operation in other types of traffic.

The choice of solution is therefore dependent on the prerequisites and requirements, in particular as regards dwell times for boarding and alighting and also to a certain extent accessibility for disabled travellers.

Door widths

The doors should permit simple, unhindered passage for a traveller with luggage. With 90 cm free door opening, a traveller can as a rule carry a suitcase in both hands. Above 90 cm, however, the benefit of wider doors is less since the passenger flow is often restricted by travellers queuing on the platform Two narrow doors are consequently more efficient than one wide door (Heinz, 2003).

Single doors should therefore have a free width of approximately 90 cm. Smaller widths are a hindrance to travellers with large amounts of luggage and wider doors can rarely be used (Heinz, 2003; Rüger, 2006; Rüger, 2007). The TSI (TSI HS PRM, 2008) stipulates the smallest permitted door width of both exterior and interior doors on the train to be 80 cm where accessibility by wheelchair is required.

A double-door, without a pole in the middle, does not give the same high capacity as two single doors placed next to each other with a pole in the middle. This is partly due to the fact that double doors often have a maximum width of 130-140 cm which is far too narrow for two passengers with luggage. But it is also due to the fact that not all travellers walk in two lines. Some choose to walk in the centre and passengers alighting are often forced into a single line by travellers waiting on the platform. A centre pole, in effect two single doors next to each other, on the other hand, divides passengers into two parallel flows. Another reason is that it is simpler to accomplish a pressure-proof carbody with single doors that close against a centre pole.

Passenger flow on the train

Location of luggage racks

The possibility to stow luggage is crucial to the passenger flows during boarding and alighting, in part for convenience, comfort and safety during the journey.

Heavy luggage should be placed on or close to the floor to avoid heavy lifting that takes time and partly blocks the aisle and which from an ergonomic point of view should be avoided. Luggage racks on the floor are thus better than racks above the windows for heavy luggage. Travellers also want to be able to watch their luggage during the journey to reduce their worry and the risk of luggage thefts on the train.

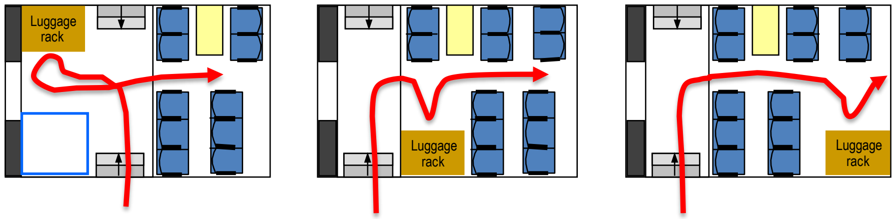


Figure 44. Three principles for locating luggage racks in a passenger car.

Table 27. Characteristics of different locations of luggage racks

Principle	*Passenger flow*	*View of luggage*
Luggage rack in the vestibule	Jams and conflicts in the vestibule	Poor or none
Luggage rack at end of saloon	Jams at end of car	Some or poor
Luggage racks in saloon	Little room to drag large items in the centre aisle. Jams or returning passengers (opposing flows) in the aisle	Some or good

Of the luggage rack locations studied, it is an advantage to place several luggage racks in the saloon to avoid jams and allow travellers a better view of their luggage. The emphasis should however be on the racks closest to the entrance doors, where especially large and heavy items and (folded) prams can be left since they can not freely be transported along the aisle, particularly if the aisle is less than 60 cm wide.

Models of passenger flows

Heinz (2003) among things estimated simple linear models for boarding and alighting passengers. The models cannot, however, be used in situations that give a wide spread in the dwell times including travellers with prams and travellers with physical disabilities or large amounts of cumbersome luggage. Nor has the passenger flow inside the car been considered, i.e. the risk of jams or queues of passengers, and this might constitute a bottleneck at the luggage rack, for example, which in practice restricts the passenger flow.

Tuna (2008) also estimated models on the basis of observations in Germany, Austria and Switzerland. The models also give relevant results for passenger jams, but they are based on some factors that differ from Swedish conditions as regards entry and platform height and the seating arrangement in the car (see the following section on aisles).

Table 28. Time required by boarding passengers

Number of passengers per door:	***10 passengers*** *[min:s]*	***30 passengers*** *[min:s]*	***50 passengers*** *[min:s]*
Face-to-face seating, long-distance train (Tuna, 2008)	1:00	4:20	7:30
Face-to-back seating, long-distance train (Tuna, 2008)	0:50	3:00	5:40
IC2000, long-distance train (Tuna, 2008)	0:30	1:20	2:10
Long-distance train (Heinz, 2003)	0:30	1:30	2:30

Sources: Heinz, 2003: Linear model for travellers with luggage, 90 cm door opening and platform-train floor height difference 57 cm (in-car passenger flow not considered).
Tuna, 2008: Model based on observations from Austrian and German long-distance cars and Swiss double-decker IC2000 cars.

The observations presented in the table show the importance of designing the train so that passengers do not cause jams when boarding. The Swiss double-decker IC2000 cars have a level entry, wide doors with large vestibules and travellers can turn right or left as they choose, or go up to the top floor (split flows). This gives exemplarily short boarding times.

As a rule, long-distance cars have the entrance at the end of the car (unidirectional flow), steps and narrow passages to negotiate with luggage. Travellers are expected to divest themselves of their luggage along the way. A narrow aisle prevents other travellers from passing when one traveller may also need to ask another sitting in the aisle seat to stand up to allow them to reach the window seat. The problem becomes even worse when many travellers board through every door.

The width of the centre aisle

The width of the centre aisle is of importance as regards boarding and alighting times when large numbers of travellers must board or alight at the same time and jams (queues) of travellers occur. A study conducted in Germany, Austria and Switzerland shows that boarding times can be shortened by approximately 24% if the centre aisle is more than 60 cm wide compared to the standard width (slightly more than 50 cm) since it allows passengers with luggage to meet and pass each other in the centre aisle (Tuna, 2008).

The same study also shows that the boarding times when jams occur are shorter if people sit facing each other rather than in the same direction. The explanation for this is that the fixed tables between the seats in the types of car studied are fairly small and do not go all the way to the aisle. This allows people to meet and move out of the way when other passengers are stowing their luggage but reduces comfort in the aisle seats.

The effect of too little room to meet in the aisle is very long boarding and alighting times, mainly at the station of origin. It is also a well-known phenomenon in commercial air traffic.

The socio-economic effects of jams and slow boarding at the station of origin (and the equivalent) at the destination) are distributed over three parties:

- The traffic company, which is forced to have the train at the platform 5-10 minutes before departure, which extends the circulation time without any additional revenues and moreover involves a risk of delays
- The travellers, who suffer queues (time losses, irritation) and a risk of delays
- The infrastructure manager, who sees capacity reduced at often already heavily loaded stations.

The centre aisle should consequently be so designed to provide room for travellers to move out of the way, for example to deal with their luggage. The fixed tables in face-to-face seating compartments should be dimensioned to allow room for people to meet in the centre aisle (60-70 cm wide) but this must always be weighed against the value of also having tables at the aisle seats, which increases comfort.

Platform heights

The height difference between the platform and the floor of the train is of great importance for the dwell times. The height differences are also crucial to accessibility for disabled travellers. From all points of view it would be desirable to have the platforms at the same height as the floor of the train to make things easier for travellers with disabilities and shorten dwell times for the train. For historical reasons, however, there is no universal common standard on the railways.

European norms (TSI) permit two standard heights of platforms: 55 cm (intermediate) and 76 cm (high) above top of rail with a tolerance of (-3.5 cm/+0). The Swedish Transport Administration has a national Swedish exemption from the European norms and uses 58 cm for intermediate and 73 cm for high platforms with a tolerance of ±3 cm.

Table 29. Platform heights in the Nordic countries

	Std according to TSI *Height above top of rail*	**Other similar standards in the Nordic countries** *Height above top of rail*
Low platform		26 cm (FIN), 35 cm (NO)
Intermediate height platform	55 cm (DK, FIN)	50-60 cm (NO), 58 cm (SE)
High platform	76 cm (DK, NO)	70 cm (NO), 73 cm (SE)
On level with high floor		92-120 cm

High platforms are better than intermediate for increasing accessibility to single-decker trains because of the lower height difference between the platform and the floor of the train. On the other hand, it is an advantage for double-decker trains if the entrance is at the same level as the floor on the bottom floor. In 2008, the Norwegian National Rail Administration decided to use the high platform's 76 cm as the new universal standard height for accessibility at Norwegian stations (Norwegian National Rail Administration, 2008). Denmark, Finland and Sweden use 55 (58) cm platform height on long-distance train platforms.

Gröna Tåget should consequently be designed to cope with platform heights of both 55 and 76 cm and other heights in the 50-76 cm interval with present platform heights in the Nordic countries.

Entry

Floor height on single-decker trains

On most trains the floor height is between 1.10 and 1.25 m above top of rail, except in different kinds of low-floor designs where the floor of the car can be located at the same height as the platform. The reason for floor heights of over a metre is to be able to accommodate wheels and technical equipment below the floor. To take advantage of the possibility to have wide-bodied trains, it is also necessary that the height of the floor be above the narrow part at the platform height in the vehicle profile.

The wheel diameter on Gröna Tåget needs to be at least 920 mm. Smaller wheels would be desirable but the combination of small wheels and high speeds causes technical problems with increased wear to the wheel's tread. Above the bogies, with a 920 mm wheel diameter the lowest possible floor height is 1.18-1.20 m above top of rail. At entrances and perhaps also between the bogies, the floor might possibly be a few centimetres lower to accomplish a more comfortable step up to the floor of the train.

Steps

An entry design with a maximum of two steps is to be preferred so that travellers with large amounts of luggage will not lose a disproportionate amount of time when boarding and alighting (Heinz, 2003; Rüger, 2006; Rüger, 2007). Tuna (2008) draws the conclusion that already two steps noticeably increases alighting times for above all small children and elderly and disabled travellers, but in these studies there were many situations where the platform was 76 cm in height and the train's steps were made for a platform height of 55 cm, producing a gap to negotiate between the platform and the train's top step.

The height of steps in staircases should not be more than 18 cm to allow them to be climbed and descended comfortably, but in practice is often higher on railway vehicles (Heinz, 2003). TSI stipulates 20 cm as the maximum permitted step height and 24 cm as the minimum depth for steps on a train (TSI HS PRM, 2008).

In the Nordic countries, the platform heights that the train should be able to handle lie between 50 and 76 cm. If all the height difference were to be covered by steps, 2-3 steps each a step height of 20 cm and with floor height at the entry of approx. 1.15 m, also a small ramp in the centre aisle would be necessary to reach a height of 1.18-1.20 m above the train's bogies.

Entry for disabled passengers

Gröna Tåget prescribes solution with a high floor throughout the train, without interior steps. A car with a special low-floor section on a level with the platform would be one possibility but has been rejected during the course of the discussions. The reasons are that the low-floor section cannot suit more than one platform height and that the surface of the floor would be narrower than the width that would otherwise be able to be used higher in the vehicle profile. For those travellers with severe physical disabilities, mobility would also be restricted to the low-floor section of the train. For a commuter train with more frequent stops than in long-distance traffic, for example, the assessment might be a different one.

The approach in Gröna Tåget is instead to lift physically disabled travellers to the train's floor level. One idea that was looked at in the Attractive passenger environment project is an entry lift in the form of a vertically adjustable floor at a special entrance. The entry lift can raise the travellers up to or down from the train's floor height and automatically set itself to the platform height. Once on the train, travellers can move freely without height differences.

Figure 45. Manually fitted wheelchair ramps on NSB's BM73 multiple unit train. Handling a wheelchair at an intermediate station leads unfailingly to delays because of the complicated procedure.

The entry lift needs to be developed technically to meet the demands for fast boarding and alighting and good functionality even in cold winter conditions, and sand and salt to prevent people slipping on the platforms. Compared to many other conceivable solutions like a lifting table, a manual ramp or a truck on the platform, the entry lift has the best prerequisites to shorten boarding and alighting times, including the standard deviations in the dwell times, and thus contribute to more punctual train traffic.

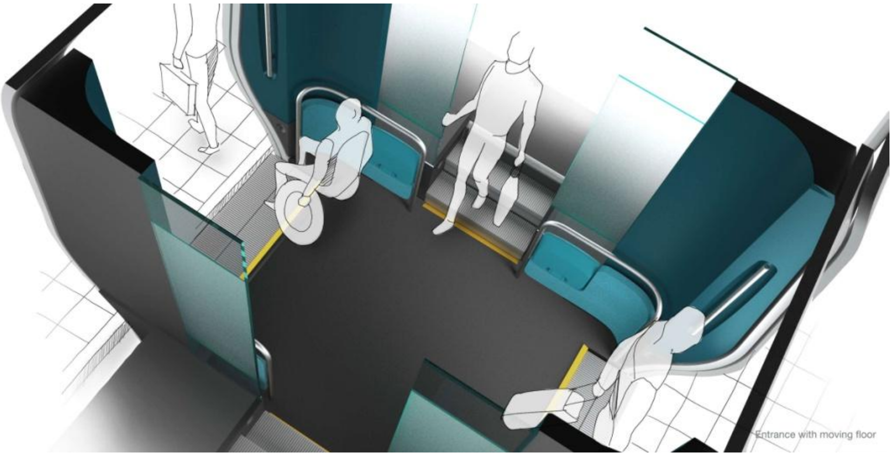


Figure 46. For Gröna Tåget an entry for disabled travellers is proposed with a lift in the form of a vertically adjustable floor. Illustration by Lundberg, Eriksson och Ranvinge, 2010

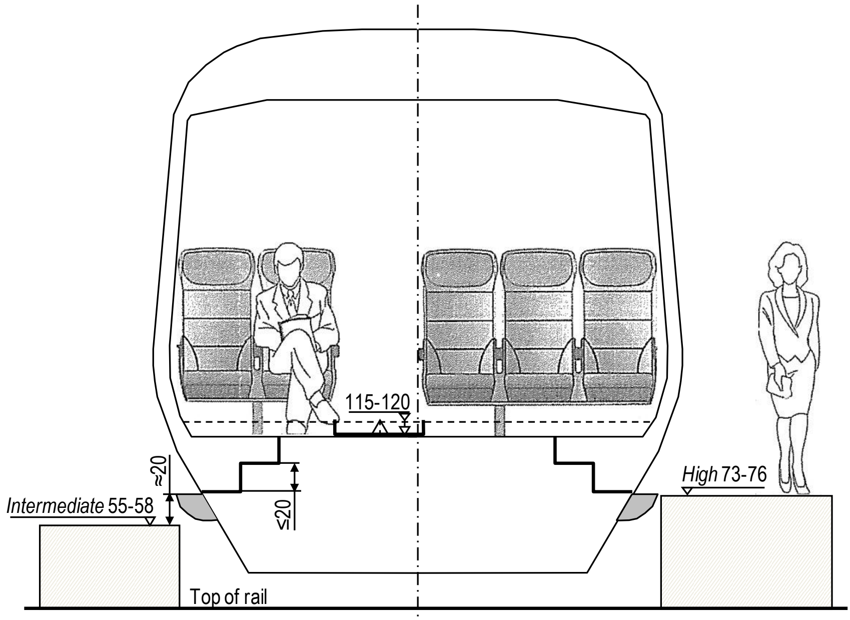


Figure 47. Principles for entry (measured in cm) with top of rail (TOR) as reference. Three 18-20 cm high steps from an intermediate height platform and two steps from a high platform. A shorter ramp in the centre aisle may be necessary where the height of the steps is insufficient.

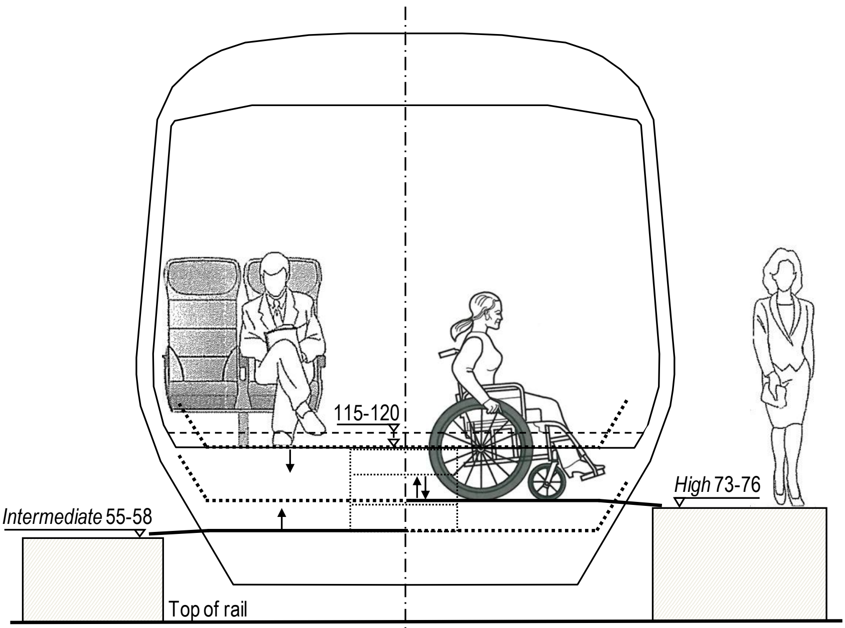


Figure 48. Entry lift (vertically adjustable floor with bridging devices) at at least one entrance on the trainset (measured in cm). Physically disabled travellers have a level entry regardless of platform height.

Other measures to shorten dwell times

Where on the platform does the train's door stop?

Without information, travellers must often walk long distances along the train when it has stopped to find their car; this takes time. The longer the train and the greater the number of unaccustomed travellers, the longer the dwell time (Pettersson, 2011).

Markings showing where the train's cars stop must be clear and the information can be given on the ticket in the same way as seat number and car are given; "car stop A" or something similar. Platforms should have dynamic signs that clearly show the positions of the cars. These are also simple to change so that they show the right positions regardless of in which direction the trainset is pointing.

Spread reservations

If seats can be reserved, travellers can be spread evenly over the train to avoid jams at a dimensioning door. This applies at all stations along the route. A good example is that the ticket booking system distributes for example 60 travellers alighting in Norrköping equally over four cars and does the same with travellers alighting at the station.

Another aspect is to handle passengers who are known to take considerable time to board and alight appropriately from the time of booking. This mainly applies to physically disabled people, i.e. travellers with wheelchairs, prams or large amounts of luggage who need more time and compensating for this by reducing the number of travellers at the doors in question.

Adapted timetable

Under periods of high load, such as major public holidays and other occasions with many travellers, the timetable could be adjusted as regards dwell times at stations. A large number of travellers means longer dwell times. In traffic according to a fixed interval timetable, good punctuality requires dwell times to be dimensioned according to the peak load.

Summary: Design for punctual stops

By designing Gröna Tåget for short dwell times for boarding and alighting with many travellers at peak loading times, travelling times can be shortened, in turn shortening the circulation times. The delays at stops can be reduced as regards both mean value and standard deviation and thus contribute to more punctual train traffic.

- Two single doors give shorter dwell times than one double door (without a pole in the middle)
- Travellers should be distributed in two directions from each door (split flows); the doors should therefore preferably be placed ¼ and ¾ of the way along the car (quarter model) rather than at the ends of the car
- Large saloons and a long way to the closest entrance door along the aisle easily lead to jams (queues) of travellers, resulting in longer dwell times for boarding and alighting
- A level entry between the platform and the floor of the train is to be preferred but is often not possible, especially not with wide-bodied trains (floor height 1.18-1.20 m) with standardised platform heights (55 and 76 cm) respectively
- 1-2 steps at the entrance give shorter stops than 3 or more steps
- For physically disabled travellers a spacious entry lift is required to overcome the height difference between train floor and platform and allow fast boarding and alighting
- The dimensioning door is of crucial importance with regard to dwell times. An even load over the whole train is to be striven for through appropriate train design, traveller information and distribution using the booking system
- A single door should be dimensioned for 40-50 seats but this can be increased by booking faster travellers with little luggage and adapting entry, entrance and interior for fast boarding and alighting
- The free door opening at a single door should be 90 cm, and definitely not narrower than 80 cm, while a wider opening than 90 cm has little effect
- The centre aisle should allow travellers to meet and pass by giving it a width of 60-70 cm, for example by means of slightly shorter fixed tables in face-to-face seating arrangements.

6.3 Luggage on trains

Simple and safe

Luggage without check-in

In studies, many people give a lot of luggage as one reason for not going by train and a great many train travellers also consider handling luggage to be troublesome (Rüger, 2004).

Handling luggage is also important as regards travelling times since the train must generally allow boarding without checking in, which is a competitive advantage against the airlines. Slow boarding and alighting with heavy luggage delays stops at stations and prolong travelling times. Finally, handling and stowing luggage on board is important in a safety context since hazardous goods may not be taken on board and personnel may be injured by luggage that is in the way or falls down while the train is in motion.

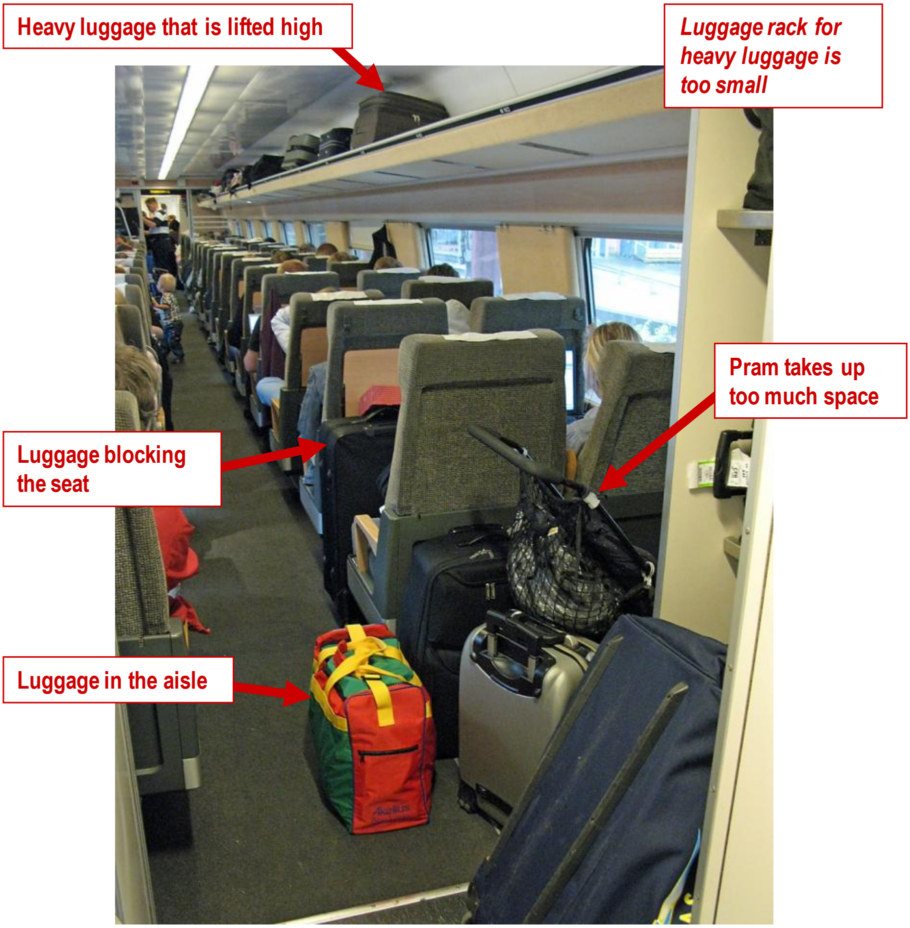


Figure 49. Examples of undesirable yet typical placing of luggage on the X 2000 as a result of insufficient luggage racks for heavy luggage. At peak loading times, travellers have even more luggage, making the problem worse.

Security against theft

It happens that luggage is stolen on trains. When thefts occur, they are often committed by people boarding at a stop and taking selected items of luggage. Measures to limit unauthorised people's access to platforms and trains are blunt – there is no control of people when they purchase tickets – and would mean barriers for travellers, just as they would make it impossible for people to meet travellers off the train or wave them off when leaving on their journey.

One solution might be to equip cars with locking devices for luggage, for example a metal wire with a lock or a separate locker for every case to make theft more difficult. The lock could be activated by means of a smart card or a phone app that the traveller also uses as a ticket, but this presupposes that the railway company introduces such a ticket system.

Many travellers consequently say that they want to be able to see their luggage from their seat. The luggage racks at the entrance do not often satisfy this requirement. Changing the location of the luggage racks may also give travellers a better view of their luggage.

Safety from injury

From the railway company's point of view, an economically advantageous location for luggage racks is above the windows with a traditional luggage rack running along the car. The rack does not encroach upon seating space and travellers can also keep an eye on their luggage. Luggage can also cause injury in certain cases, in particular when heavy luggage is stowed on the luggage rack above the windows.

- The luggage may fall on people if the train sways and jerks extensively, for example when tilting is turned off or in case of severe track faults
- If the train derails or other types of accident occur, luggage may fall off the racks or fly around and injure many travellers
- It requires such great effort to lift luggage onto the racks above the windows that many travellers risk back-strain and others cannot manage it all
- Travellers and personnel passing through the train risk falling over luggage that has been placed in aisles when the luggage racks are full. It may also prolong an evacuation in the event of a fire or accident.

The probability of a traveller being injured by luggage must be considered low, i.e. most journeys take place without personal injury. In spite of everything, there is nonetheless a risk and it can hardly be considered a good solution for disabled travellers to have to stow heavy luggage on the luggage racks above the windows.

Luggage on board today

Location in today's car types

The distribution of travellers' luggage over different locations on board is dependent on the train's degree of occupancy and the cars' design. Two comparable car types with saloons and a relatively high proportion of face-to-back seating in long-distance traffic are the cars in the X2 trainsets and a German (DB) saloon car where the distribution of items of luggage between different locations is shown in the figure. Travellers place their luggage differently depending on the train's physical layout and on trains with a high proportion of face-to-back seating like the Danish IC/3 Flexliner concept some luggage is also stowed in the space behind/between the seats (Khan and Sundberg, 2002).

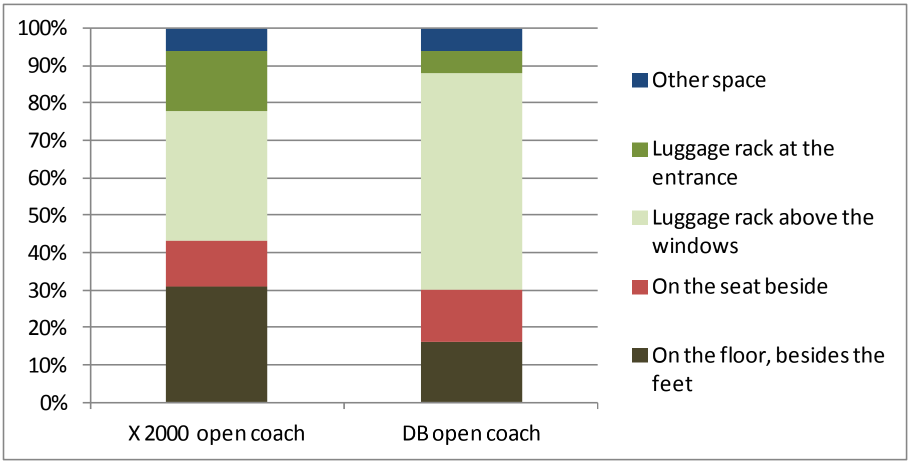


Figure 50. Distribution of travellers' luggage on board the X 2000 in Sweden (Kahn och Sundberg, 2002) and a DB saloon car on Austria (Rüger, 2004). "Other space" includes pram spaces, behind a seat or in the aisle.

Amount of luggage per traveller

The amount of luggage per traveller differs significantly depending on route, time and season, and travellers' purpose with their journeys. Travellers who travel over a day, i.e. a large proportion of business journeys and commuting to work, as a rule have little heavy luggage, while travellers on private journeys and holiday trips with overnight stays carry considerably more heavy luggage.

The various studies do not measure precisely the same amount due to different definitions of heavy luggage, i.e. large items of luggage. Hand luggage is smaller items regardless of type. Rüger (2004) set a maximum limit 40 litres' volume for suitcases, 45 litres for a soft bag and 30 litres for a backpack.

Other luggage is defined as cumbersome or heavy items, for example skis and prams, that do not belong in either the heavy luggage or hand luggage categories. On planes these items must often be checked in as special luggage. Prams are most common with private travellers. In the Swedish study, 100 long-distance travellers had 3-4 prams with them (Khan och Sundberg, 2002).

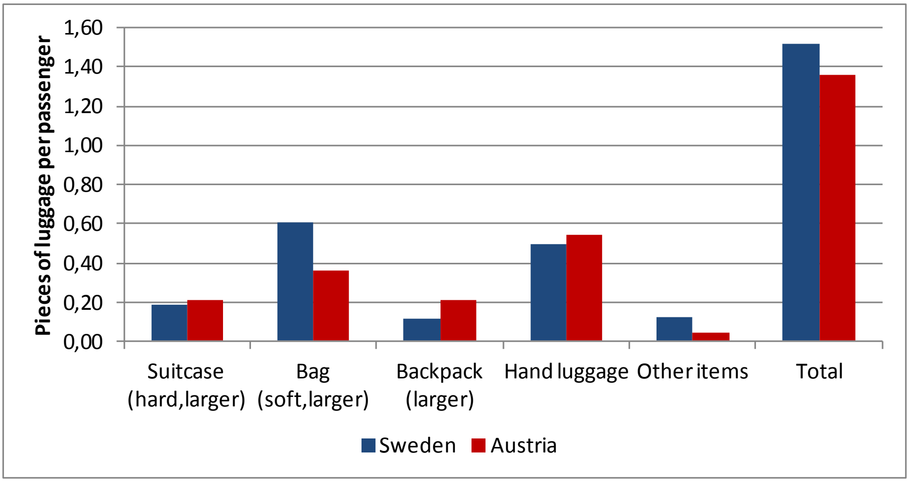


Figure 51. Items of luggage per traveller on long-distance trains. Heavy luggage is a subset of the suitcases, the bags, the backpacks and other things. Sources: For Sweden: Khan och Sundberg, 2002; for Austria: Rüger, 2004

Table 30. Other luggage

No. of items per 100 travellers	***Sweden, long-distance trains***	***Austria***
Pram	3-4	0.2
Wheelchair		0.02
Bicycle		0.2
Skis	0.6	2.4

Sources: Khan and Sundberg, 2002; for Austria: Rüger, 2004

The tendency to take a bicycle along has to do with accessibility to the whole railway system and what alternatives there are. Bicycles were for example not permitted on the long-distance trains studied in Sweden. Better accessibility for people in wheelchairs and perhaps allowing bicycles to be transported on long-distance trains can therefore be expected to increase the number of bicycles and wheelchairs on board. For Gröna Tåget to be able to be used in different kinds of traffic, a flexible luggage compartment to be able to also transport bicycles and skis when necessary would be useful.

Dimensioning of luggage racks

Heavy luggage on board

To be able to dimension the luggage racks for heavy luggage, the heavy luggage must be defined as regards size. In this regard the criterion is that luggage that must be checked in for a journey by air is definitely heavy luggage. Medium-sized luggage of the cabin luggage type is in a grey zone, but luggage that its owner is not strong enough to lift onto the luggage rack above the windows or is too big to be placed under the seat can be considered to be heavy luggage.

Rüger (2004) and Kahn och Sundberg (2002) use another definition in their censuses that all include a great deal of medium-sized luggage. According to that definition, the number of pieces of heavy and medium-sized luggage may be 1.1 per traveller for private travellers but only 0.35 for business travellers making their journey over the day. Business trips with overnight stays mean more luggage and the value of 0.8 pieces of heavy and medium-sized luggage is in agreement with the average for all travellers. In the summer and during other periods with many holiday travellers, the number of items per passenger increases.

The number of items of hand luggage per traveller is roughly the same in Sweden as in Austria; 0.5 items on average. Observations on Swedish trains in July and August 2008 (Fröidh and Andersson, not published) showed that the number of heavy items can amount to 45-70% of the number of travellers. This means that at peak loading on for example travelling days around major public holidays and during holiday periods, the train will be full and about half the travellers will have heavy luggage with them.

Luggage racks on Gröna Tåget

One possibility that has been studied in the *Attractive Passenger Environment* project is to have a flexible compartment that can be used for heavy luggage under peak load conditions with many leisure-time trips and for seats when there are many business travellers and commuters. The conclusion, however, is nonetheless that if the luggage situation on trains is to be improved, fair-sized racks are needed (Lundberg, Eriksson and Ranvinge, 2010).

As regards Gröna Tåget, it is proposed that it be dimensioned for 0.4-0.5 pieces of heavy luggage per traveller. This is substantially more than in the example with the X2 and will cover most kinds of traffic. On a very small number of the departures with exceptionally large amounts of luggage, the problem cannot be resolved in any other way than by blocking certain seats in the booking system and using them to store luggage, The luggage racks should also be dimensioned for one pram for every 25 travellers. Prams of the standard type are approximately 65 cm wide but can also be turned on their side if they are folded, with the same width.

If the heavy item is 25 cm deep, it will require 10-12.5 cm per seat of rack space at 0.4-0.5 items per traveller with the case standing on its end. Including space for prams, 12.5-15 cm per seat are required on the rack for heavy luggage. Ten seats thus require 1.2-1.5 metres of space on the luggage rack.

The luggage racks for heavy luggage are proposed to have three shelves, where the bottom one has most free height for very large cases and prams.

Cabin luggage and hand luggage is assumed as now to be placed on luggage racks above the windows, or with more space-efficient seats below the seat in front.

Exceptions can be made from the proposed dimensions if a larger number of travellers making journeys only over the day are expected, first and foremost commuters and business travellers who do not then carry as much luggage. A flexible train that can also be used for leisure-time trips, however, must be dimensioned for peak loads.

Summary: Design for simple luggage handling

When designing the train concept, the starting point must be that during peak periods in long-distance traffic (holiday trips and during major public holidays) there will be many travellers who have a large amount of luggage with them. Commuters and business travellers who are often the most common travellers in everyday peak traffic, on the other hand do not have the same amount of luggage and it is not the dimensioning period.

- Travellers prefer to be able keep an eye on their luggage. Luggage racks for heavy luggage and prams should therefore be located in the saloon, provided that the aisle allows people to pass each other.
- Luggage racks for heavy luggage should be dimensioned for 0.4-0.5 items per traveller on full trains and also one pram for every 25 travellers. In all, 1.2-1.5 metres of luggage rack per ten seats are required.
- The luggage racks above the windows are suitable for cabin luggage and hand luggage but not for heavy luggage. They must not be placed too high; about 1.60-1.75 m off the floor is acceptable.
- Space-efficient seats with thinner cushions allow a free height of 30-35 cm between the floor of the car and the seat and cabin luggage and hand luggage can then be placed below the seat in front.

6.4 Seating comfort

Space for long-distance journeys

The space for each seat varies widely between different modes of transport. Generally speaking, the space is on the small side in cars and on coaches/buses and planes, but is by tradition more generous on trains, in particular on trains in long-distance traffic.

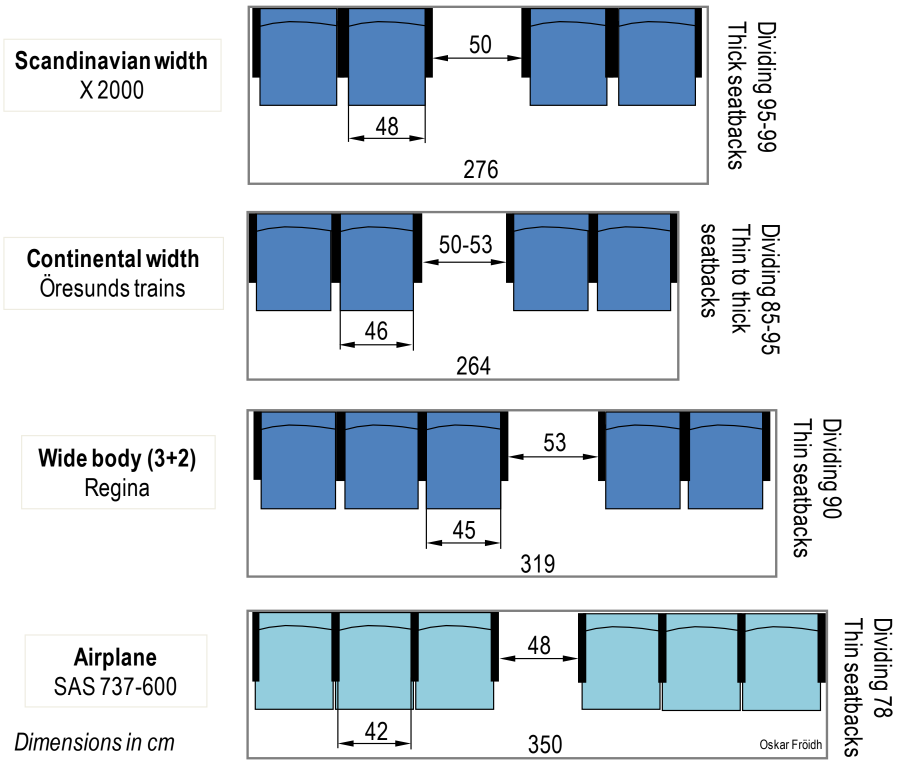


Figure 52. Space for seats (cm) in economy class on some different train types and on a commercial airliner.

When designing the train, a good standard should be chosen that is suitable for long-distance journeys of up to 5 hours even if most journeys will be 1-3 hours long. Travellers who spend a great deal of their time every week on the train, for example regional commuters and business travellers have high demands as regards comfort (Kottenhoff and Byström, 2010).

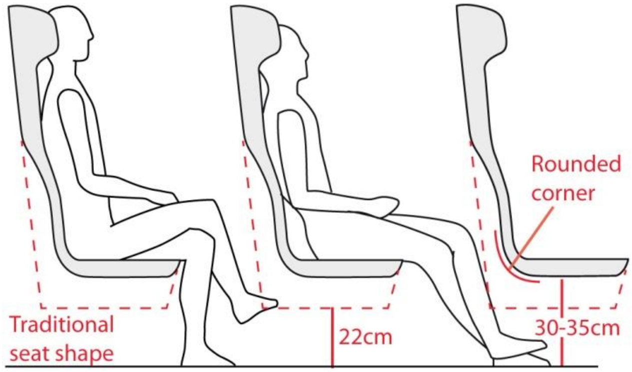


Figure 53. A space-efficient seat type with a thin, rounded seatback and space for the legs and feet below the seat in front gives the same valuation as a 10-15 cm greater spacing dimension. Illustration from Kottenhoff and Andersson, 2009

Spacing dimensions

Seats can be designed to save space by:

- Making the back thin in critical places (knee height)
- Providing space for the legs and feet under the seat in front
- Having the reclining mechanism push the seat cushion forward at the same time, thus reducing the intrusion of a reclined seatback into the place behind.

Given that these conditions can be satisfied, an economic spacing dimension can be determined. With a 6 cm thick seatback, space between the floor and the underside of the seat cushion of at least 30 cm and an efficient reclining mechanism, seat spacing dimensions of 86 cm in rows with two seats in a face-to-back arrangement and 89-91 cm for rows with three seats are recommended. This is also sufficient to accommodate a laptop on the seat's table (Kottenhoff and Andersson, 2009).

If the space under the seat in front is used for cabin luggage and hand luggage, as on aeroplanes, not all the extra space can be counted as extra legroom – but there are also luggage racks above the windows as an alternative.

The study on which the recommended 86-91 cm spacing dimension is based was not, however, focused on the inconvenience of reaching and leaving the window seat. The travellers' valuations show that the important remaining space between the knee and the back of the seat in front must be 20 cm or greater also for tall people when seated for the legroom to be perceived as good (Kottenhoff och Andersson, 2009). There is also a willingness to pay for better comfort, which means that more legroom and possibly thicker cushions can be considered. Valuation studies have shown 4-7% for 10 cm more legroom, to be compared with increased train operation costs per traveller of 5-8% for a 10-15 cm greater spacing dimension between the rows of seats.

Valuation studies have also shown that travellers' negative value of sitting three abreast (on average 2% of the fare) can be compensated with either more legroom or a slightly wider middle seat. A spacing dimension in face-to-back seating that is 5-10 cm longer in rows with three seats than rows with two is therefore of utmost importance.

Facing sears are perceived as cramped as regards legroom, which justifies the addition of approximately 10% more legroom to the spacing dimension in face-to-face seating. In rows with three seats, only face-to-back seating is assumed here since it is more difficult to reach the window seat with fixed tables.

Table 31. Spacing dimensions for seats with space-efficient seats

	First class	**Economy class**	
		Comfort	*Capacity*
Face-to-back; 2-seat	100 cm	90 cm	86 cm
Face-to-back; 3-seat	*n/a*	97.5 cm	91 cm
Face to face with fixed table, 2-seat	210 cm	200 cm	190 cm
Face to face with fixed table, 3-seat	*n/a*	*n/a*	*n/a*

The car sketches presented in this report have the spacing dimensions shown in the table (above). In economy class, the comfort values are normally used but a variant is shown with a capacity arrangement with smaller spacing dimensions according to Kottenhoff and Andersson (2009), which should be considered a minimum.

Seats in harmony with the windows

In interviews on board trains in Sweden, travellers have expressed dissatisfaction with the fact that certain wall seats lack windows and travellers in those seats have no view, despite having booked a window seat. Many Swedish trains have carbodies with wider wall sections between the windows, and since the carbodies must often suit several different spacing dimensions and types of interior, some seats will be located next to a wall section. It is probable that there is a significant willingness to pay for a window seat with a view, even if there are travellers who do not value it particularly highly.

Reversible seats so that travellers are always facing in the direction of travel are unusual in Sweden. One study showed that travellers in Norway, where older cars have reversible seats, preferred to sit facing forward to reduce travel sickness, while the opposite was true in Sweden where reversible seats did not exist (Förstberg, 2000). Travellers' valuation of reversible seats and how they affect the frequency of incidence of travel sickness is consequently unclear. There are, however, clear indications that people should sit facing in the train's longitudinal direction while crosswise seats in a bistro for example give more travel sickness symptoms.

Japan's Shinkansen trains for example as a rule have both reversible seats and windows that harmonise with the spacing dimension, which seems to indicate that there is a willingness to pay for this comfort.

Wide-bodied trains with 2+3 seating

Research shows that the negative value of 2+3 seating is on average 2% of the fare compared to continental-style seating with 2+2, and it does not switch from negative to positive until the next full train with more than 80% occupancy (Kottenhoff and Andersson, 2009). Since wide-bodied trains on the other hand have 15% lower total costs, this gives scope for a fare reduction that attracts many more travellers than possibly forgo travel by train due to the risk of sitting in a middle seat.

Individual travellers may on the other hand have both a preference for three abreast, for example a family of a group of three travelling together and a strong aversion to the middle seat despite it having individual armrests and good comfort. As regards the latter, there exists an opportunity to choose first class where wide-bodied trains with 2+2 seating give an even greater percentage improvement in seat occupancy than in economy class compared to 1+2 seating.

Width of the seat

The width of the seat space is more important than the fact that three people sit abreast when the train is full. Comfort, especially in the middle seat with three seats abreast (2+3 seating), therefore needs to be improved according to studies of travellers' willingness to pay. In addition to a solution with a wider cushion, travellers' valuation can be increased with individual, hinged armrests on all seats. Here it is proposed that seats have individual armrests and that the seat cushion is made 46 cm wide, which presupposes an inner width of approximately 3.3 m at elbow height.

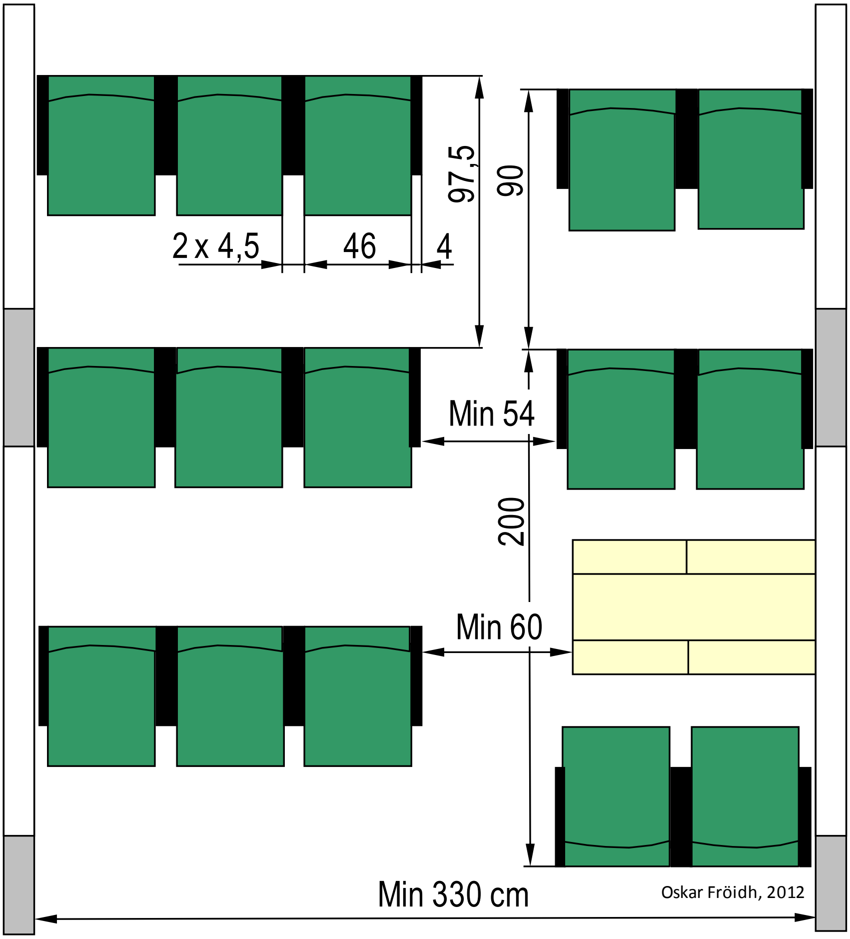


Figure 54. Standard dimensions (cm) in car sketches on Gröna Tåget with wide carbody and good comfort. The dimensions assume space-efficient seats with thin cushions.

In first class, a larger spacing dimension of 100 cm is assumed in first class than in economy class, which gives more legroom in order to increase travellers' willingness to pay. The width of the seat, however, is identical in both first and second class. The reason for this is findings from studies that show that first class passengers principally pay for room and peace and quiet to work, followed by comfort, such as more legroom, and a wider seat (Kottenhoff, 2002).

The width in second class is compensated for in first class by extra tables beside the seats, which generally gives more elbow and territorial space. A new valuation study would clarify whether travellers prefer the extra table or would rather have a wider seat. A survey has shown that a 5 cm wider seat is valued at 4% of the fare (Kottenhoff and Andersson, 2009).

Flexibility

In order to increase legroom it is assumed that some areas are flexible between economy class, plus-standard and first class. This means that these areas are in principle arranged as 2+3, but where the middle seat and the aisle seat have seatbacks that are also folding tables. The first-class area is increased as necessary at the expense of the economy-class area by turning middle seats and possibly aisle seats into tables in one simple operation, i.e. changing plus-standard into first-class standard.

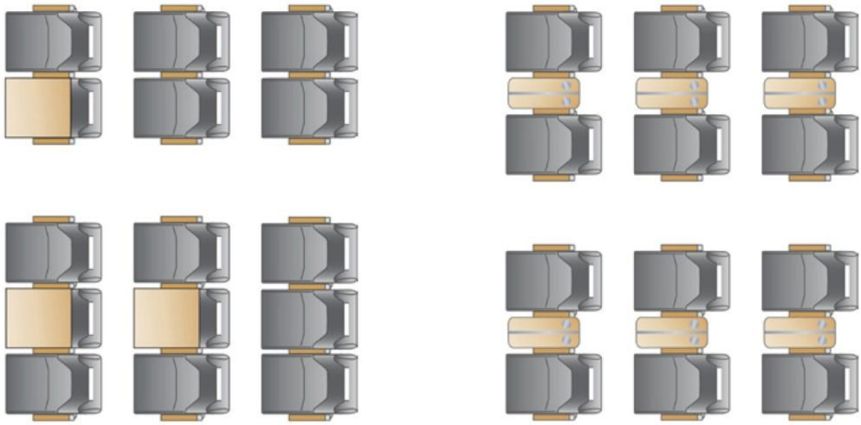


Figure 55. Flexible seats with 2+3 seating in 2nd class can be converted into plus-standard (2nd class+) or first class by folding the back to make a table. Illustration from Kottenhoff and Andersson, 2009

In the case of plus-standard, the middle seat in a row of three is turned into a table by folding down the seatback, which has a firm, flat rear side, transforming the seating arrangement into 2+1+1. In flexing in first class, the aisle seat's back/table in two-seat rows is also folded down, turning the seating arrangement into 1+1+1. Practical experience has shown that it is important to screen the view from behind between the backs of the seats to prevent unauthorised people from seeing possible sensitive information that the traveller in front is reading.

All seats must have tables for both refreshments and work: in face-to-back seating arrangements, foldable tables that are fixed to the seat in front, preferably steady and with some form of vibration damping, and in face-to-face seating arrangements with fixed tables with foldable edges.

Wheelchair places

Trains less than 205 m long must have at least two places for wheelchairs (TSI HS PRM, 2008). The actual number should be assessed according to calculated demand for journeys with wheelchairs. There is on the other hand no requirement that larger disablement aids such as motorised invalid carriages should be able to be taken along on trains.

Wheelchair places must be able to be reached by wheelchair without steps inside the train and have access to a handicap toilet. The minimum width of doors for wheelchair passage is 80 cm. If people in wheelchairs are to be able to move around the train on their own, the free width of the corridor must be at least 100 cm, but a wheelchair can cope with narrower passages of 80 cm. Access to service such as a cafeteria without steps is desirable but not a requirement.

6.5 Refreshments

On-board refreshments

Travellers' demand (willingness to pay) for food and drink should be equivalent to the cost of serving food/refreshments on board trains for it to be of interest for a traffic operator to offer the service. This means that refreshment services need not be profitable in themselves but that together with the added value to the traveller of having food and drink available it must show a positive result in the form of increased ticket revenues.

With fewer travellers on the train, shorter travelling times and at certain times of the day there is little call for a refreshment service. A solution must then be found that gives a basic supply at low cost and with high quality to be able to compete with the refreshment offerings at the stations.

When journey times exceed more than two hours on board, demand for food/refreshments like sandwiches and hot meals increases. One solution is the bistros on the SJ express trains X2 and X55 where items are displayed in a refrigerated self-service counter. This makes it easy for the customer to inspect items before purchase and contributes to increased sales but takes up a fairly large amount of space. Vending machines in the same car as the bistro might be a complement when the bistro is closed or when there is a queue in the cafeteria.

Refrigeration and heating arrangements will then be necessary, preferably in the form of a galley close by.

Stocking and food handling

The endeavour must be to minimise picking, stock-taking and other work on board in order to give better service and utilise the personnel optimally. A systems of carts (a box on wheels) is used today that is a system borrowed from the aeroplane. The goods are lifted from the carts to the shelf in the refrigerated display on trays. There is a desire to get things ready faster, for example if it could be made possible to display the items directly from the carts without needing to lift them onto the shelf.

One possibility might be a system with modules that are slotted into place from the outside. Stocking (loading items) and unstocking (removing unsold items) are accomplished by exchanging modules from the outside of the car. Similar systems are already in use for many technical components on the train on its visits to the workshop.

Food must be handled in an unbroken refrigerated chain to avoid it needing to be thrown away after a certain time in non-refrigerated conditions. Food must also be well-packed to avoid having to test the personnel for contagious diseases, i.e. if it is to be possible to use the crew in the cafeteria. Where food is handled, a separated personnel toilet is also required.

6.6 Design for long-distance traffic

Dimensions

The car layouts in the following section show a number of possible interior layouts on Gröna Tåget and what capacity the train can have. The intention is to exemplify how the proposed train concept can be translated into design. Since Gröna Tåget is intended to be a generally usable train, it is highly important to choose solutions that are adaptable to different markets and that it is flexible in order to allow changes and redesign during the lifetime of the train.

The fundamental idea of Gröna Tåget is a wide-bodied train that allows 2+3 seats abreast in economy class and 2+2 in first class, with technical equipment stowed under the floor. The train must be able to be equipped with tilting, which places special demands on the design of the carbody.

The carbody in the long-bodied variants in the following sketches have an interior dimension, i.e. furnishable area including entrances, of 25 m. The end cars have 4-metre tapering nose sections with driver's cab, giving an interior dimension of the passenger compartment of 22 m. The maximum interior carbody width, at the elbow height of seated passengers, on the wide-bodied train (GTW) is 3.30 m and on the continental-width train (GTC) 2.70 m.

As the main alternative, the doors are drawn as single doors according to the quarter model, located ¼ and ¾ of the car's length between the bogies. This gives the shortest boarding and alighting times. A capacity variant with double single doors according to the centre model is also shown since it accommodates 5% more seats, but prolongs dwell times.

An articulated version with short carbodies and Jacobs bogies (GTA) is presented by way of comparison with the same interior carbody width as GTW. The furnishable length is in this case 16 m in the intermediate cars and 17.5 m in the end cars.

Interior furnishing

The proportion of first class seats in the sketches is 22-23%. This is insufficient on the main lines during mornings and afternoons when there is a high proportion of business travellers. The wide-bodied train here has flex capabilities, which means that the middle seat in a row of three abreast can be converted into a table in one simple operation. The same applies to the aisle seat in a two-seat row. This means that a 2+3 arrangement can also be sold as either 2+1+1 or 1+1+1. The need for more first-class seats is consequently covered with flexible seating at the expense of the number of economy seats.

On trains with continental carbody width, the first-class section would need to be extended at the expense of the economy class section, which reduces the number of seats slightly, Here, however, only a layout where the proportion of fixed first-class seats is roughly the same as on the wide-bodied train is shown.

In the sketch, the cafeteria is 7.5 m long in the M1 intermediate car, which is the same as on the comparable X55 train. In the capacity version it is even shorter. The idea behind a compact cafeteria is that demand for refreshments has decreased slightly with the shorter travelling times, even if many travellers will still expect food to be available at normal mealtimes. The small saloon next to the cafeteria can be used as a dining area if the seats are left unreserved at mealtimes. The idea is also to offer as many first-class passengers as possible refreshments at their seats. It is, however, possible that an operator might prefer a larger cafeteria and this will then affect both cost and energy consumption per seat-kilometre.

The car layouts are shown with the reservation that the detailed layout may need to be changed with regard to appliances and other technical equipment in the furnishable area, and detailed studies of designs for physically disabled passengers, luggage and cafeteria services. The main principle is that the furnishable area shall be reserved for seats to the greatest possible extent and every reduction in the number of seats must be justifiable economically or for safety reasons.

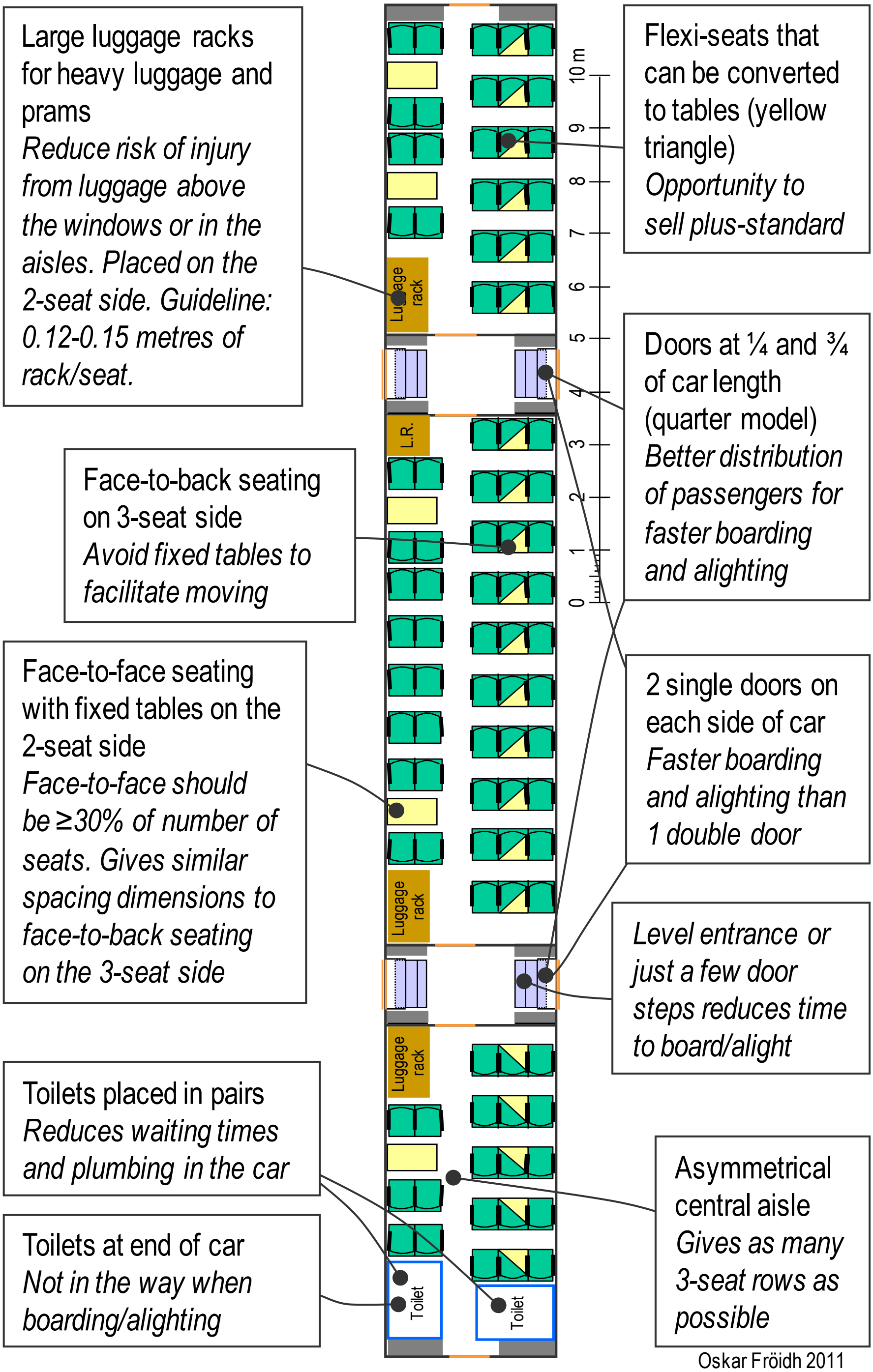
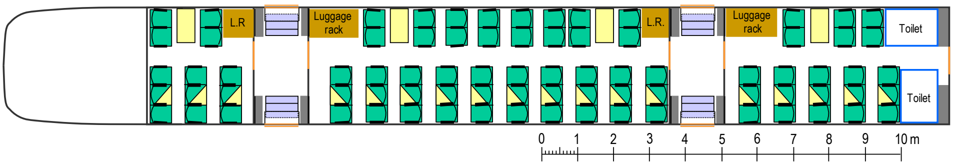


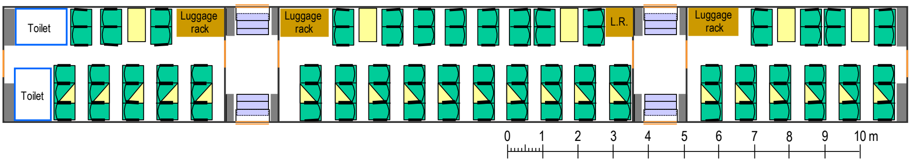
Figure 56. Design principles for the car layouts.

Wide-bodied train (GTW) with good comfort

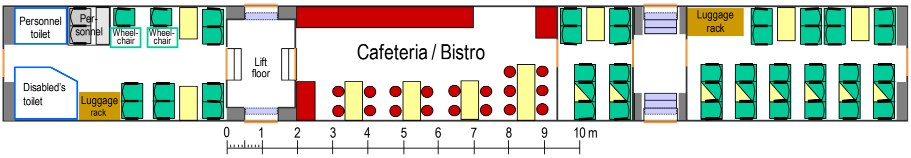
In long-distance traffic in Sweden, a train size of 300 seats is practical and the variant sketched here has 285 bookable seats distributed over four cars with good comfort and generous luggage space.



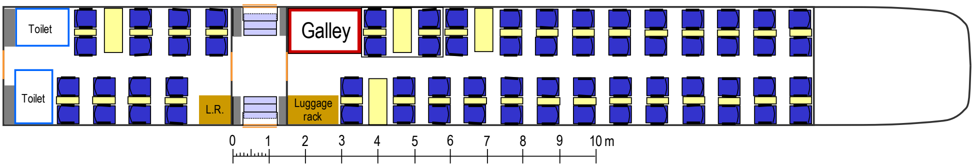
GTW end-car B. 80 seats in economy class (2+3) with flex capabilities.



GTW intermediate car M3. 93 seats in economy class (2+3) with flex capabilities.



GTW intermediate car M3. 93 seats in economy class (2+3) with flex capabilities.



GTW end-car A. 66 seats in economy class (2+2) with galley.

Figure 57. Wide body, comfort, 285 seats

Table 32. Potential for additional seats

GTW, 4 cars, comfort	Seats *1st class*	*Econ.*	*Total*	*Remarks*
Layout as in sketch	66 (23%)	219	**285**	Cafeteria 2 wheelchair places
Potential for additional seats				***Consequences***
Double single doors as in centre model instead of quarter model		10		Longer dwell times
Half as much space for heavy luggage and prams	2	10		Increased risk of injury from luggage in aisles and on the racks above the windows
No cafeteria service and no personnel toilet		38		Poorer service
Restaurant, ¾ car		*(-36)*		*Better service*
No personnel compartment		2		Poorer work environment
5-7% less legroom	4	10		Poorer comfort, not plus standard
1 toilet per car instead of 2	2	6		Queues, poorer comfort
Total incl. potential	*76*	*285*	*361*	

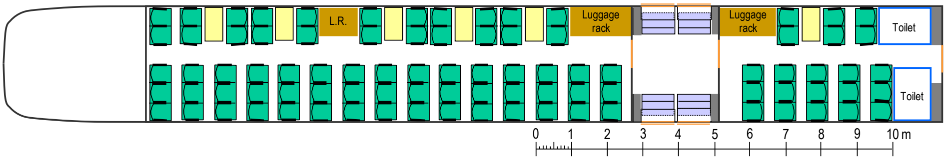
Table 33. Key figures for doors, luggage racks and toilets

GTW, 4 cars, comfort	*Mean value*	*Max. value*	*Remarks*
No. of seats per entrance door	41	49 (economy); 66 (1st class)	
Space on luggage racks for heavy luggage and prams	16 cm		Per seat
No. of seats per toilet	41	55	

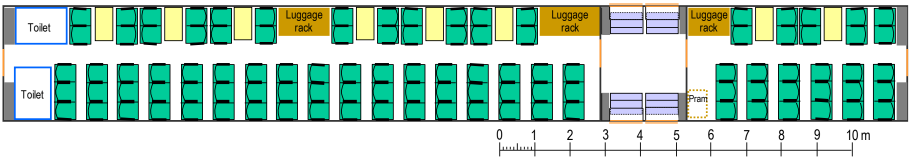
In this version of the GTW, the mean values of the key figures for both doors and toilets are relatively low and there is sufficient space for heavy luggage and prams. Distribution is relatively good in economy class but the maximum loading will be in the first-class section of end-car A. One possible variant is to also have two single doors in end-car A, which would reduce the number of first-class seats by 8, but on the other hand gives greater flexibility for other kinds of traffic.

Wide-bodied train (GTW), capacity version

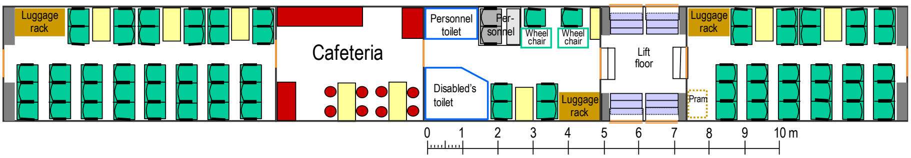
A study of a version with many seats gave an idea of the potential for an economic, energy-efficient train. The smaller spacing dimension has been used here, together with double single doors according to the centre model instead of the quarter model's two single doors, with the purpose of obtaining more seats on the train. There is no first class but in end-car A the seats are flexible, which allows plus-standard to be sold. In all, there are 335 economy class seats in the sketched layout.



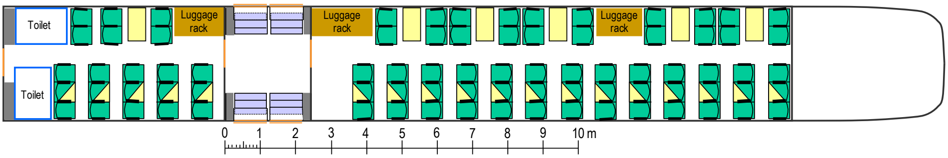
GTW end-car B. 88 seats in economy class (2+3).



GTW intermediate car M3. 103 seats in economy class (2+3).



GTW intermediate car M1. 64 seats in economy class (2+3) and 2 wheelchair places, and a small cafeteria.



GTW end-car A. 80 seats in economy class (2+3) with flex capabilities.

Figure 58. Wide body, capacity version, 335 seats

Table 34. Potential for additional seats

GTW, 4 cars, capacity	**Seats** *1st class*	*Econ.*	*Total*	*Remarks*
Layout as in sketch		335	**335**	Small cafeteria 2 wheelchair places
Potential for additional seats				***Consequences***
Half as much space for heavy luggage and pram		14		Increased risk of injury from luggage in aisles and on the racks above the windows
No cafeteria service and no personnel toilet		20		Poorer service
No personnel compartment		2		Poorer work environment
1 toilet per car instead of 2		8		Queue, poorer comfort
Total incl. potential		*379*	*379*	

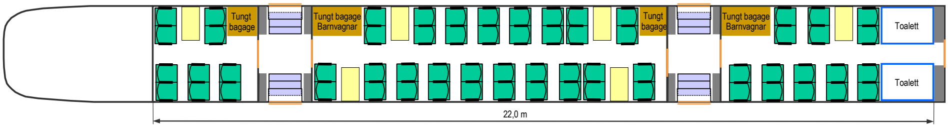
Table 35. Key figures for doors, luggage racks and toilets

GTW, 4 cars, capacity	*Mean value*	*Max. value*	*Remarks*
No. of seats per entrance door	84	140	Double single doors
Space on luggage racks for heavy luggage and prams	16 cm		Per seat
No. of seats per toilet	48	70	

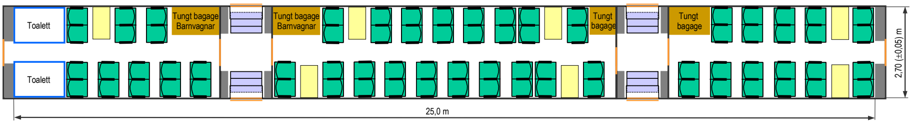
The capacity version of GTW has more seats per door and longer aisles, which means that boarding and alighting times will be relatively long with a clear risk of jams under peak loading conditions. In the layout shown, there is also a saloon that has no direct contact with the entrance door in intermediate car B. The capacity version can however be improved in these respects, with the result that slightly fewer seats can be accommodated. The lack of a first class section gives more seats, which can, however, be converted to plus-standard with flexible seats, which will mean 18 fewer seats on the three-seat side of end-car A.

Continental width (GTC) with good comfort

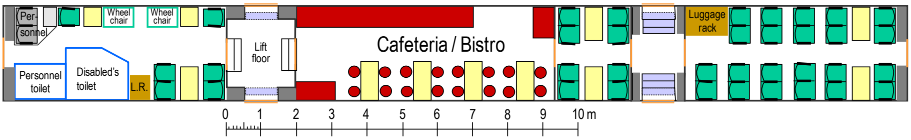
Gröna Tåget with a continental carbody width, five cars and 288 bookable seats is comparable to GTW with a wide carbody and four cars.



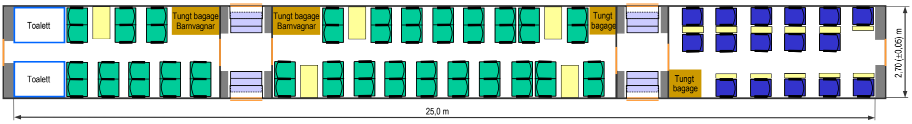
GTC end-car B. 62 seats in economy class (2+2).



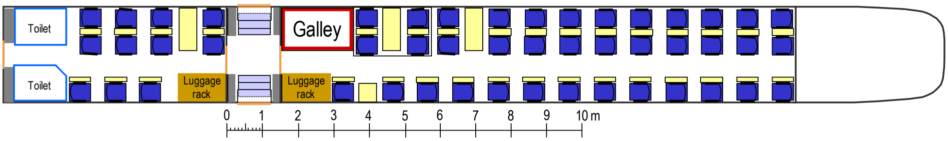
GTC intermediate car M3. 74 seats in economy class (2+2).



GTC intermediate car M1. 36 seats in economy class (2+2) and 2 wheelchair places and a cafeteria.



GTC intermediate car M4. 52 seats in economy class (2+2) and 16 seats in first class (1+2).



GTC end-car A. 48 seats in first class (1+2) with galley.

Figure 59. Continental body, comfort, 288 seats.

Tabell 36. Potential for additional seats

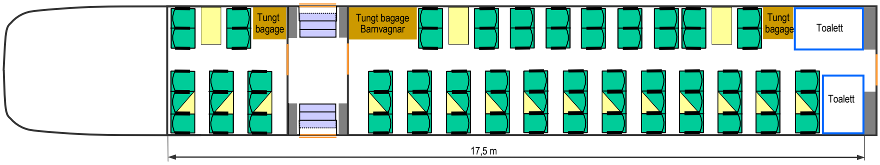
GTC, 5 cars, comfort	Seats *1st class*	*Econ.*	*Total*	*Remarks*
Layout as in sketch	64 (22%)	222	**288**	Cafeteria 2 wheelchair places
Potential for additional seats				***Consequences***
Double single doors as in centre model instead of quarter model		16		Longer dwell times
Half as much space for heavy luggage and prams	1	10		Increased risk of injury from luggage in aisles and on the racks above the windows
No cafeteria service and no personnel toilet		32		Poorer service
Restaurant, ¾ car		*(-30)*		*Better service*
No personnel compartment		2		Poorer work environment
5-7% less legroom	3	12		Poorer comfort
1 toilet per car instead of 2	1	6		Queues, poorer comfort
Total incl. potential	*69*	*300*	*369*	

Table 37. Key figures for doors, luggage racks and toilets

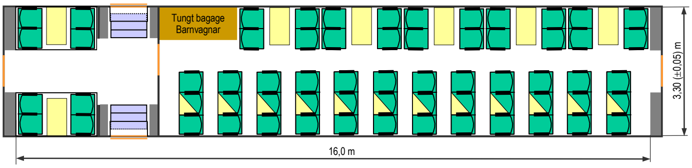
GTC, 5 cars, comfort	*Mean value*	*Max. value*	*Remarks*
No. of seats per entrance door	32	40 (economy); 48 (1st class)	
Space on luggage racks for heavy luggage and prams	19 cm		Per seat
No. of seats per toilet	32	43	

As stated earlier, the first-class section should really be larger for some kinds of traffic, but the plan here is comparable to the wide-bodied GTW train with four cars as regards the proportion of fixed seats in first class. It is also possible to increase seating space slightly at the expense of the number of doors, luggage racks and toilets to make it fully comparable to GTW. In the configuration shown here, GTC has somewhat better performance as regards dwell times.

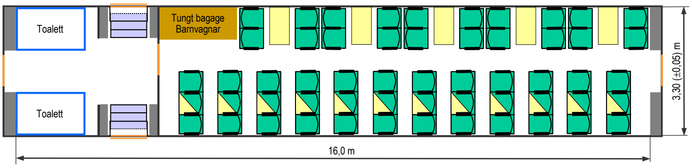
Articulated with good comfort (GTA)



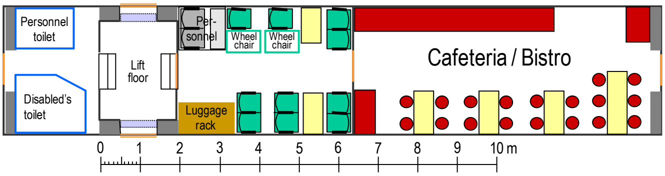
GTA end-car B. 67 seats in economy class (2+3) with flex capabilities.



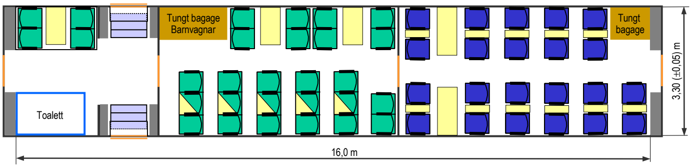
GTA intermediate car M3. 64 seats in economy class (2+3) with flex capabilities.



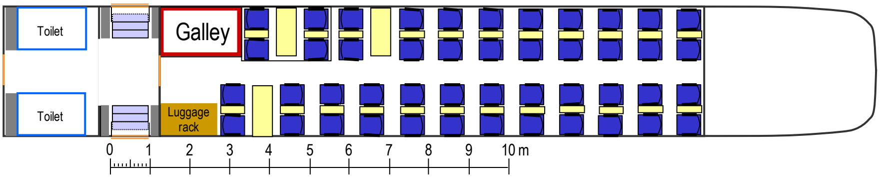
GTA intermediate car M2. 56 seats in economy class (2+3) with flex capabilities.



GTA intermediate car M1. 10 seats (2+2), 2 wheelchair places and cafeteria.



GTA intermediate car M4. 22 seats in first class (2+2) and 29 seats in economy class (2+3) with flex capabilities.



GTA end-car A. 46 seats in first class (2+2) with galley.

Figure 60. Wide body, articulated, comfort, 294 seats.

An articulated train concept (GTA) with six short carbodies and Jacobs bogies between the cars accommodates 294 bookable seats with good comfort.

Table 38. Potential for additional seats

GTA, 6 cars, comfort	Seats 1st class	Econ.	Total	Remarks
Layout as in sketch	68 (23%)	226	**294**	Cafeteria 2 wheelchair places
Potential for additional seats				***Consequences***
Half as much space for heavy luggage and prams	1	10		Increased risk of injury from luggage in aisles and on the racks above the windows
No cafeteria service and no personnel toilet		40		Poorer service
No personnel compartment		2		Poorer working environment
5-7% less legroom	2	12		Poorer comfort
Total incl. potential	*73*	*290*	*363*	

Table 39. Key figures for doors, luggage racks and toilets

GTA, 6 cars, comfort	*Mean value*	*Max. value*	*Remarks*
No. of seats per entrance door	49	67 (economy); 46 (1st class)	
Space on luggage racks for heavy luggage and prams	13 cm		Per seat
No. of seats per toilet	37	50	

The articulated train concept gives somewhat higher loading at doors and on luggage racks than GTW in the configuration shown here. The loading is however still considered acceptable. Double single doors might possibly be considered instead of one single door on each side of the car to reduce dwell times.

Differences between the train concepts

Wide-bodied trains or continental carbody width

A comparison between wide-bodied (GTW) and continental-width (GTC) trainsets shows that wide-bodied trains accommodate 25% more seats in an otherwise comparable design thanks to better space utilisation.

Expressed in another way, four wide-bodied cars have the same number of seats as five continental-width cars. GTW has 2.64 seats per metre of train length as opposed to 2.15 on the GTC with good comfort and designed for fast boarding and alighting.

Depending on the degree of space optimisation and the distribution between first and economy class, 25% more seats is an average figure. In first class, the gain from 2+2 compared to 1+2 is greater. The width in itself makes it easier to also arrange the train for all other functions besides seating, for example cafeteria service and toilets.

The wide-bodied train is also assumed to have flexible seating distribution so that seats in economy class can be converted to plus-standard or first class, which increase the degree of occupancy. A larger proportion of fixed first class accommodation would mean poorer space utilisation.

Articulated train with short carbodies

The version with six wide carbodies is about 8 m longer than a train with four long carbodies with the same number of seats. This means 2.53 seats per metre of train length compared to 2.64 on GTW, The pivoting joints take up space and make it somewhat more difficult to arrange the seats.

In return, the number of bogies is reduced from 8 to 7, which has a positive impact on costs.

Capacity version

By choosing shorter seat spacing dimensions, it is possible to fit in more seats per metre of train length. Double single doors according to the centre model give a saving compared to the quarter model since two vestibules are replaced with one. In the sketched train, 3.10 seats are accommodated per metre of train length.

The door arrangement, however, has a substantial impact on boarding and alighting times and one must ensure that it gives reasonable times as regards stops at the most loaded stations. The capacity version outlined here was produced with the intention of indicating the potential for an economic, energy-efficient train and can be improved, but at the expense of seat numbers.

6.7 Summary

Punctual and fast

Gröna Tåget must be designed for punctual train traffic. This means that the train concept must be dimensioned for peak loading when the train is full. Boarding and alighting must take place within very tight margins, which means that doors, entrances, luggage racks and the train's central aisle must be in well considered locations and correctly dimensioned.

There should be two single doors on the side of each car located according to the so-called quarter model, i.e. ¼ and ¾ of the way along the car for the shortest boarding and alighting times. Other solutions with doors at the ends of the car or in the middle of the car mean longer distances to walk on the train. Disabled passengers can board at a special entrance equipped with a lift that is faster than many of today's solutions.

Luggage racks for heavy luggage need to be able to accommodate more items than many trains today and also have room for prams in order to increase safety and improve the working environment in cases of extensive leisure-time travel. There must be a space under each seat for overnight bags and hand luggage and a shelf above the windows.

Seating comfort must be dimensioned for journey times up to 5 hours. The possibility for flexible furnishing where economy class seats can be turned into plus standard or first class seats for business travellers should be considered in order to increase the degree of utilisation. This assumes that the middle seat in rows of three and the aisle seat in rows of two can be converted into extra tables.

Car layouts on Gröna Tåget

A wide train accommodates 25% more seats in the same carbody compared to normal width or the continental car profile. It is possible to accommodate just under 300 seats in a wide-bodied train with three cars dimensioned for punctual traffic and good comfort or 2.7 seats per metre of train length. The corresponding number of seats in cars of continental width requires five cars and gives 2.2 seats per metre.

A lower degree of comfort, fewer luggage racks and fewer doors would, in the same way as a smaller buffet area, make room for more seats, but this would at the same time reduce travellers' willingness to pay and increase the risk of delayed trains.

7. Track for higher speeds

To be able to raise speeds for Gröna Tåget, the track must be upgraded. Gröna Tåget's characteristics should be chosen such that it is a generally usable train for different tracks and different kinds of traffic.

7.1 Objectives for speed increase

Shorter travelling times an urgent issue

Shorter travelling times give both increased travel since the train is more attractive and reduces the cost of train traffic. A variety of measures can be considered to achieve shorter travelling times, such as higher top speeds, more powerful acceleration, a higher threshold speed in curves and shorter stops at stations for passenger interchange. These measures are all considered in the Gröna Tåget programme. Gröna Tåget shall also lead to greater punctuality through a good design for peak loading during peak traffic periods.

An important prerequisite for short travelling times is that the track permits high speeds. Gröna Tåget shall also be electrically powered, which assumes electrified lines fed by electricity generated with low CO_2 emissions.

Table 40. Top speeds in the Nordic countries

	Top speed 2012	*Planned (built) new links*	*Studied high-speed lines*
Finland	220 km/h	n/a	n/a
Norway	210 km/h	250 km/h	330 km/h
Sweden	200 km/h	250 km/h	320 km/h
Denmark	180 km/h	250 km/h	n/a

Sources: Railway network statements 2012, various reports

What top speed should be the target?

There is an optimum as regards the costs and benefits of higher train speeds. This optimum is not however clear-cut but varies with different prerequisites on different lines. Since Gröna Tåget is a concept proposal that must allow interoperability in Scandinavia, it needs to allow flexibility in its design and be presented in general terms. The following sections analyse the prerequisites in Sweden. The prerequisites are similar in the other Nordic countries, even if they differ as regards technical details and the track geometry is different in parts.

7.2 Track geometry and train characteristics

Track geometry

The track geometry is a crucial factor for top speed and, by extension, travelling times. A high top speed presupposes large curve radii. Sharper curves can to some extent be compensated by carbody tilting and bogies with good running characteristics, which is one of the basic ideas behind express trains like Gröna Tåget.

For trains in category B, i.e. all passenger trains without tilting, the currently permitted cant deficiency (I), which is a measure of the resulting lateral acceleration (centrifugal force) in curves, measured in the track plane, is 150 mm. For the X2 with tilt, I=245 mm measured in the track plane is permitted, i.e. passengers are compensated for a large part of this lateral acceleration by means of the tilt.

According to European norms upon which the new pan-European signalling system ERTMS/ETCS is based, higher lateral acceleration can be permitted. For non-tilting trains I=165 mm can be permitted and for trains with tilt 300 mm, even if 275 mm is normal for express trains in Europe. This only affects comfort and is generally considered to give an acceptable centrifugal force in the train's passenger compartments given active carbody tilting.

In addition to this, the cant (D) is also important. In Sweden, 150 mm is used, but a planned increase to 160 mm means that somewhat higher speeds can be permitted in curves without any problem.

For Gröna Tåget, speeds in curves need to be reviewed with the purpose of shortening travelling times. The diagram shows four different alternatives with different cant, including cant deficiency (D+I). Speed profile P4 with D+I=325 mm means that D=160 mm and I=165 mm, i.e. a train without tilt but somewhat higher speeds in curves than today's category B trains.

Speed profiles P5, P6 and P7 are tilting trains, with D=160 mm in all cases. P5 means that I=245 mm, P6 I=275 mm and P7 I=300 mm.

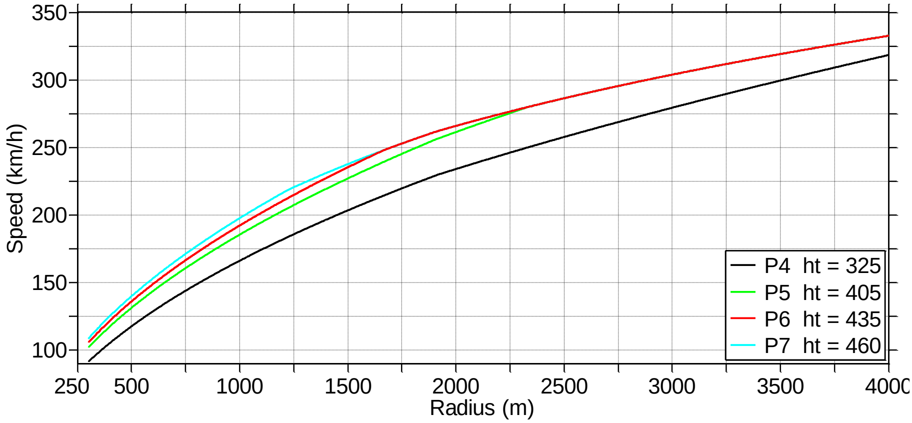


Figure 61. Diagram of maximum permitted speed (km/h) as a function of curve radius (m). The four different curves (P4-P7) represent different applied cant (ht=D+I) including cant deficiency. Source: Sipilä, 2008

At higher speeds the permitted cant deficiency is limited according to the norms, which means that tilting trains in particular have a decreasing benefit in traffic on lines with large curve radii. At speeds above approximately 275 km/h (curve radii above 2,247 m), there is no difference between tilting trains with different permitted cant deficiency either. The maximum permitted speed is however always rounded down to the nearest 5 km/h in running time calculations.

In the running time calculations presented for Gröna Tåget, speed profile P6 is generally used, i.e. an applied cant of 160 mm and a cant deficiency of 275 mm (D+I=435 mm) which is judged to be most realistic among other things with regard to travel sickness.

The following diagrams show today's speed profiles (B-trains and S-trains) on some selected lines and the calculated speed profiles without (P4) and with tilt (P6). Today's track includes on-going construction projects but no other re-routing. For a more detailed description, the reader is referred to Sipilä (2008).

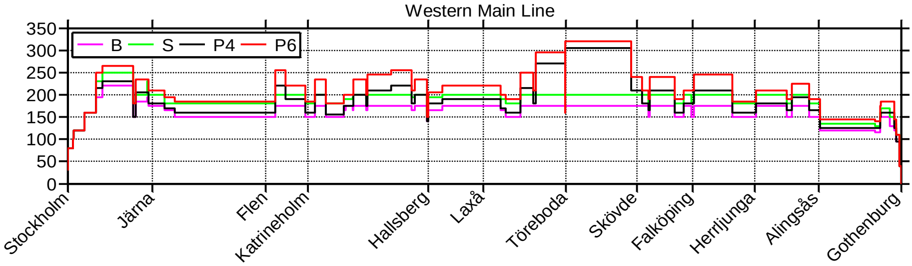


Figure 62. Possible speed profile Stockholm–Gothenburg taking the track geometry into account. The profile shows that today's S-train, i.e. the X2, has a relatively even speed profile for 200 km/h (green line). A future high-speed-train (P6) can touch 250 km/h on several short sections and 300 km/h on the Västgöta plain between Töreboda and Skövde. Source: Sipilä, 2008

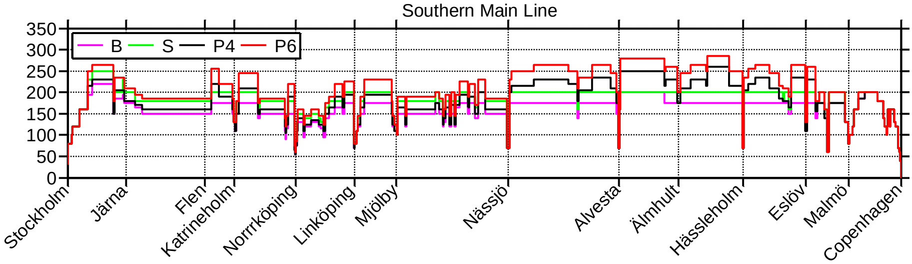


Figure 63. Possible speed profile Stockholm–Copenhagen via Katrineholm and Malmö taking the track geometry into account. On the section between Nässjö and Örtofta south of Eslöv, the Southern Main Line is relatively straight and high-speed-trains can run at at least 250 km/h with the exception of a few speed reductions here and there. Source: Sipilä, 2008

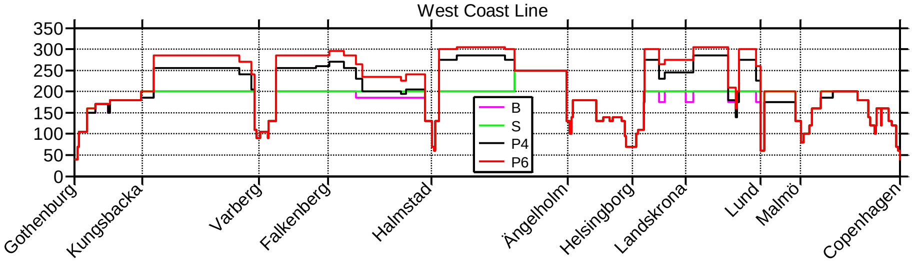


Figure 64. Possible speed profile Gothenburg–Copenhagen via Helsingborg and Malmö. The West Coast Line's converted double-track section is largely dimensioned for 250 km/h with B-trains, which would allow 280-300 km/h with a future high-speed-train (P6). Source: Sipilä, 2008

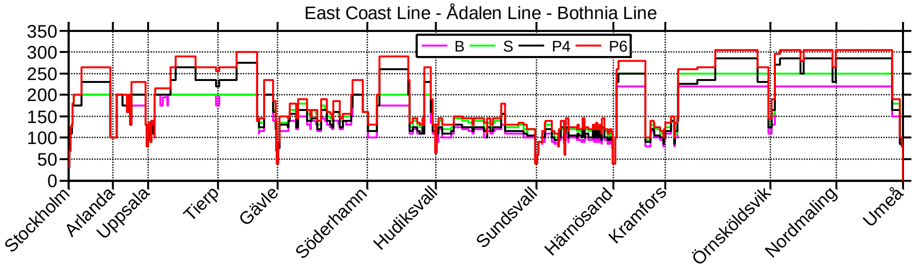


Figure 65. Possible speed profile Stockholm–Umeå. The old winding section differs markedly from the converted or new sections, where speeds of up to 300 km/h are possible with high-speed-trains (P6). Source: Sipilä, 2008

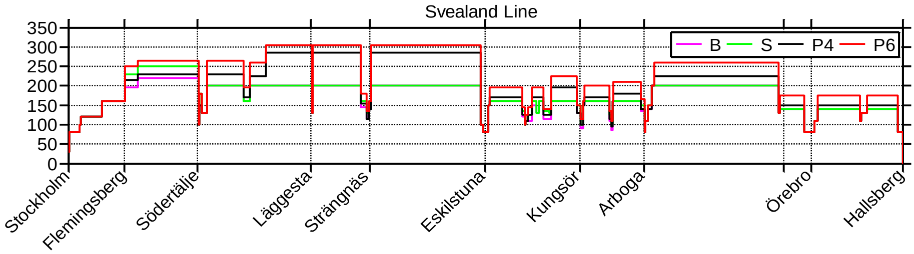


Figure 66. Possible speed profile Stockholm–Hallsberg via Eskilstuna. Here again, the new sections are noticeably different from the older sections and express trains (P6) can maintain speeds of 250-300 km/h. Source: Sipilä, 2008

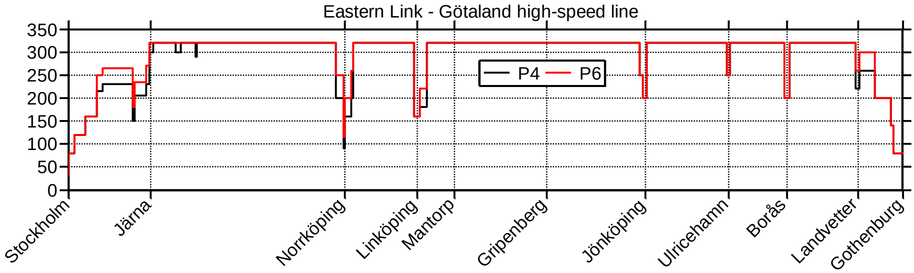


Figure 67. Possible speed profile for a planned high-speed line Stockholm–Gothenburg via Jönköping. A speed profile for 320 km/h has been assumed here also for non-tilting trains (P4), but this nonetheless means some speed restrictions mainly at stations. Source: Sipilä, 2008

The train's characteristics

Analyses of the train's characteristics as regards top speed or maximum permitted speed, the relationship between mass and output (P/m, also referred to as specific output) and starting acceleration, have been made for a number of different lines.

Table 41. Modelled train characteristics

Parameter	Level
Maximum permitted speed (km/h)	250 280 *320*
	is combined with
Output/mass P (kW/ton)	10.8 15.3 20.0 25.0 *30.0*
	is combined with
Starting acceleration a_s (m/s^2)	0.48 0.6 0.8 1.0

Excluded combinations are maximum permitted speed 320 km/h and 10.8 kW/ton since such a train would have too little tractive power to reach the top speed at all. Maximum permitted speed 250 or 280 km/h and output/mass ratio 30 kW/ton do not give any appreciable difference compared to 25 kW/ton and these combinations have also been disregarded. 320 km/h maximum permitted speed has only been analysed on newly-laid track (the proposed Götaland Line or the Eastern Link section).

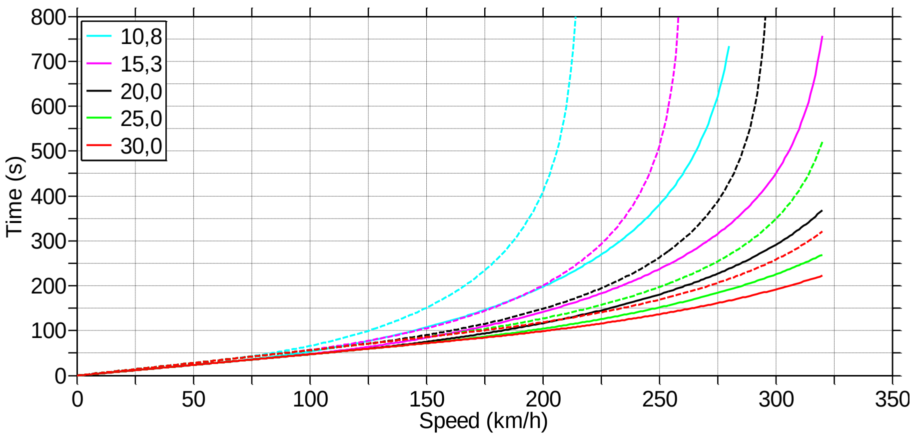


Figure 68. Acceleration time on horizontal track (solid lines) and with 10 per mil gradient (dashed lines) depending on the train's output per mass (P/m) in kW/ton. Source: Sipilä, 2008

Braking characteristics have been analysed as uniform deceleration of 0.6 m/s^2, which is so-called comfort braking even if deceleration is not linear in reality. This can be compared with the deceleration requirement, in Sweden

1.07 m/s² up to 200 km/h, to meet the relatively short advance signal distances. At higher speeds than 200 km/h, the TSI applies with somewhat lower requirements regarding deceleration depending on speed, see also Andersson (2012). Using the regenerative electric brake as the main brake, as proposed for Gröna Tåget, leads to lower deceleration than the maximum possible but gives lower energy consumption and less wear to the brakes.

A train with good braking characteristics should however be able to use more powerful deceleration than comfort braking to make up delays. Punctuality in train traffic thus gains from the train having better acceleration and deceleration than is normally scheduled and used in operation. It can also be added that in case of emergency braking the train achieve higher deceleration than the values stated here, which refer to operational braking.

After analysing a great many combinations, it is quite clear that a generally usable train should have performance that gives short running times on tracks of different character.

A selection of the results can be found in the table below. Only some of the most realistic combinations are shown here.

Read as follows: Line P4 is non-tilting, P6 tilting. Black dots indicate maximum permitted speed 250 km/h, red dots 280 km/h. The x axis is the starting acceleration (m/s^2) grouped by the vehicle's output per mass (kW/ton). The running times can be read off on the y axis.

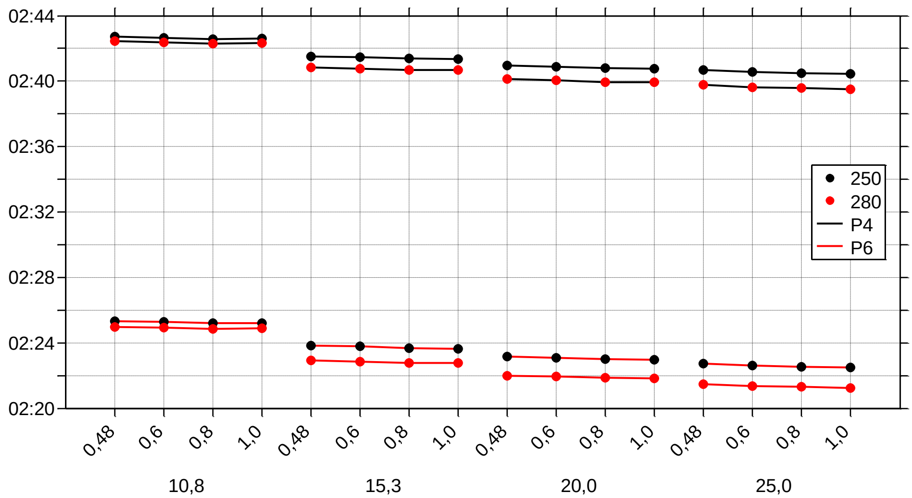


Figure 69. Running times (hr:min) on a route where tilting is of great importance (elasticity) while the vehicle's acceleration and output have extremely low elasticity – Western Main Line Stockholm–Gothenburg non-stop. Source: Sipilä, 2008

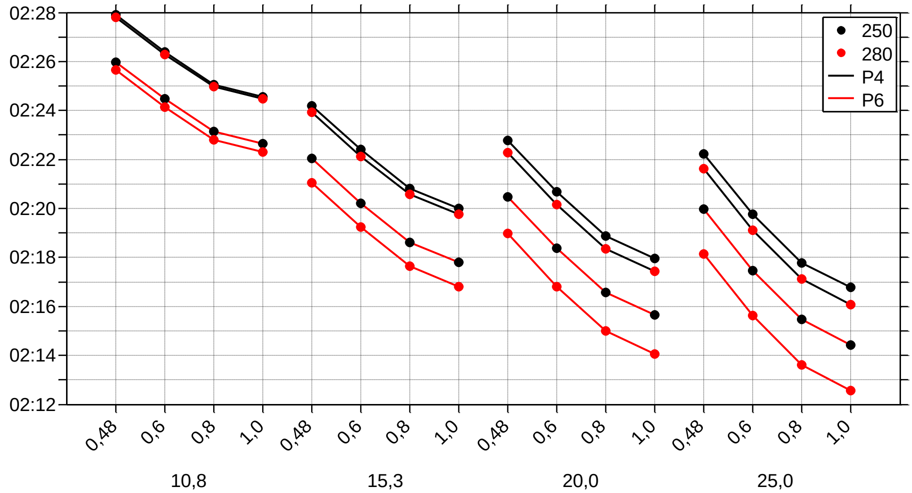


Figure 70. Running times (hr:min) on a route where tilting has little elasticity while the vehicle's acceleration and output have high elasticity – Western Main Line Stockholm–Gothenburg with 14 stops. Source: Sipilä, 2008

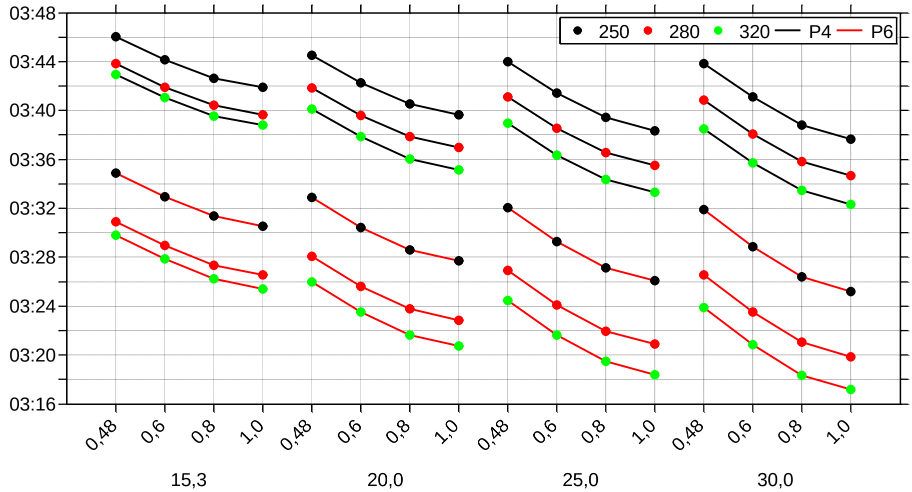


Figure 71. Running times on a route where both top speed, tilting, acceleration and output are of great importance – Southern Main Line with the Eastern Link Stockholm–Copenhagen and 13 stops. Source: Sipilä, 2008

On the basis of the analyses of the train concept with different vehicle characteristics on different lines in Sweden, a number of conclusions can be drawn.

A future train in long-distance traffic on winding lines should have tilting, a maximum permitted speed of at least 250 km/h, or more if the track is new and therefore has better geometry, a starting acceleration between 0.6 and 0.8 m/s^2 and an output in relation to its mass of between 15 and 20 kW/ton (the higher the top speed then the higher the value).

A train for traffic on alternating winding and high-speed lines should have a top speed of between 280 and 320 km/h and slightly higher output per mass of between 20 and 25 kW/ton for shorter running times. The higher the proportion of high-speed line the less the benefit of tilting and the greater the benefit from higher top speed.

There is also another important reason for increased output – to achieve more efficient and powerful regenerative electric braking that saves energy and reduces operating and maintenance costs.

Analyses of track capacity clearly show that the speed differences between the trains limit the available capacity. On high-speed lines it is therefore of importance that express trains maintain roughly the same average speed as high-speed trains, which presupposes a high top speed (Fröidh and Jansson, 2005).

Another effect is that fewer crossings occur on single-track lines and capacity utilisation is lower if the trains are as fast as possible. This indicates that the train should have relatively good performance. The train's performance should also be determined in interaction with the lines on which it will operate during its lifetime and in the choice between cheaper train or better performance the latter will mean shorter circulation times, which can reduce the number of trainsets in operation.

7.3 Capacity

Speed increases in mixed traffic

With a speed increase to 250 km/h on lines that today have mixed traffic with express trains, regional passenger trains and freight trains, if nothing is done the difference in running times between the fastest and the slowest trains will increase. This means that the number of possible train paths will decrease and that the number of overtakings where the fastest trains need to pas slower trains will increase.

On single-track lines a speed increase may be an advantage for express trains since the number of train crossings on a certain section will decrease. If there is also freight traffic, the number of overtakings of freight trains will however also increase.

The track capacity concept

Track capacity is not an unambiguous concept and it is often necessary to describe it using several measures. The most common measure is the number of train paths per hour, but in order to describe the effects of a speed increase from the point of view of Gröna Tåget, the mix of different train types and their (desired) running times also need to be taken into consideration. The most important factors affecting capacity are infrastructure, timetable and disruptions or delays.

If we limit ourselves to the number of trains on the line and for the moment disregard the fact that transport capacity is also dependent on productivity in the form of the trains' loads or sizes, it is possible to increase the available capacity (Lindfeldt, 2010) on a section of line by means of several different methods:

The infrastructure: Increase capacity through measures in the signalling system, new or extended possibilities for overtaking or crossing, or new tracks on the line.

Timetable measures: Reduce the mix of different train types, shorter running times for slower trains or extended running times for faster trains.

Vehicle measures: Replace slower trains with faster ones.

Disruptions: Increased punctuality in the system permits less reserve capacity, fewer unplanned stops and thus more trains.

Common capacity conflicts

Conflicts between desires to operate different train types on particular train paths arise for the express trains in particular on those lines where commuter traffic operates. A typical situation is where the commuter train traffic has a high frequency of service (30 minutes or more frequent) and to a regular interval timetable. The express train traffic then has to use the gaps between the commuter trains. Small margins mean that the express train can easily miss its timetable slot even with relatively small delays and thus ends up behind the commuter train. The express train's delay then grows rapidly since it can not overtake the slow commuter train according to the train priority rules in force.

Other passenger trains than commuter trains have higher average speeds through fewer stops and the conflicts with the express trains can be resolved smoothly.

Conflicts also occur between express trains and freight trains, mainly where the major freight lines coincide with the passenger traffic lines. Since the freight trains as a rule have lower priority, they have to move out of the way onto overtaking lines when they are caught up by an express train. This means longer running times for the freight trains but is otherwise a relatively simple solution provided that there are overtaking tracks at regular intervals along the lines Another solution is to offer trains paths for the slower freight train traffic during periods of less intense express train traffic, i.e. avoid the passenger traffic's peak periods.

Maintain capacity utilisation

Capacity on single-track lines

Raising the express trains' top speed from 200 to 250 km/h shortens running times by about 10%. On single-track lines with equally fast trains it is an advantage to raise the speeds since it reduces the number of train crossings along the line. Where faster trains catch up slower trains, for example freight trains, the same capacity limitation and need for places to overtake arise as on double-track lines.

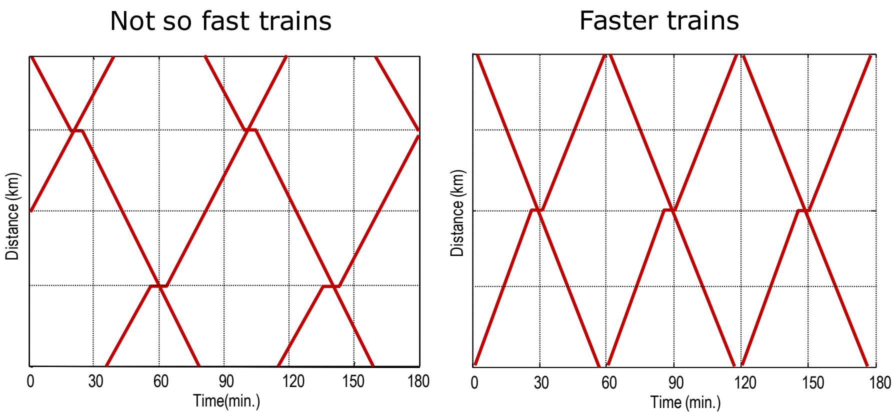


Figure 72. A line with single track and train crossings with regular frequency of service. Higher speeds mean that the timetable becomes more robust through fewer train crossings and in some cases also opportunities for higher frequency of service.

Doble-track and speed differences

There are several different ways to maintain capacity utilisation at the same level, i.e. the same number of possible train paths. As an example of effects and possible measures, capacity was analysed on the double-track Southern Main Line in the southbound direction between Katrineholm and Hässleholm during the passenger traffic's rush hour (Sipilä and Warg, planned 2012). The results are also judged to be able to be used in the northbound direction but attention must be paid to differences in the infrastructure (e.g. stations with overtaking tracks on only the one side), delay distributions and the distribution over the day (traffic peaks possibly coincide more or less with different traffic designs).

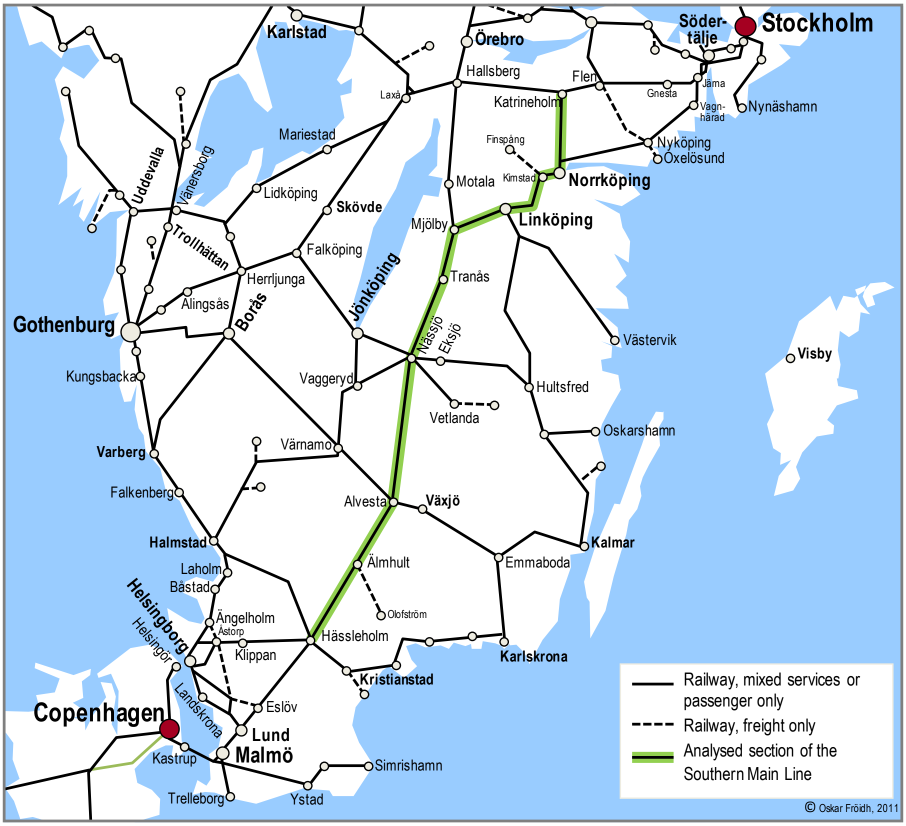


Figure 73. The double-track Southern Main Line Stockholm–Malmö with the analysed section Katrineholm–Hässleholm (400 km) indicated.

The Southern Main Line is today extremely busy and there is a demand for more train paths. Traffic is mixed, with express trains, regional trains and freight trains and different maximum speed, stopping patterns and vehicle performance. The speed differences contribute to a high capacity utilisation and reduce the number of possible train paths.

Table 42. Simulated reference alternatives

Reference alternative	***Prerequisites for express trains***	***Traffic volume***
JA2011	200 km/h (X2)	Today (2011), 4-7 trains/h (southbound)
JA2020	200 km/h (X2)	Future (2020), 15-67% more train paths[1]
GT2020	250 km/h (Gröna Tåget)	Future (2020), 15-67% more train paths[1]

[1] Most train paths between Norrköping and Linköping (8 trains/h southbound). Greatest increase up to 2020 on the sections Nässjö–Alvesta (from 3.5 to 5.5 trains/h) and Alvesta–Hässleholm (from 4 till 6 trains/h)

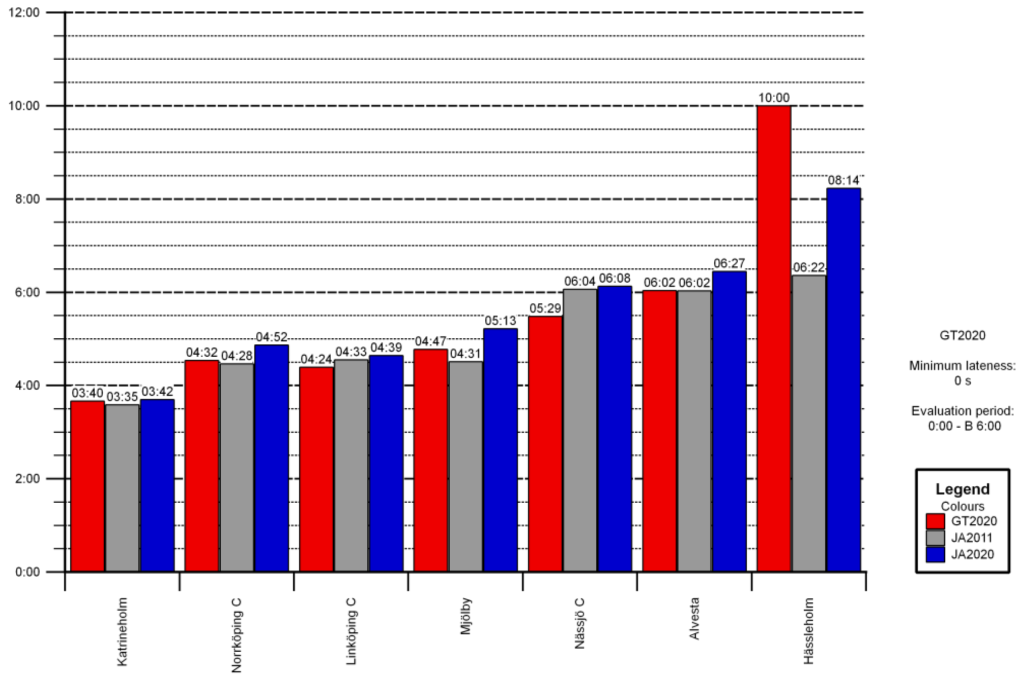


Figure 74. Average delay in minutes (arrival) for all high-speed trains in the GT2020, JA2020 and JA2011 alternatives. Source: Sipilä, H. and Warg, J. (planned 2012).

Simulation of the reference alternatives shows that the average delays for express trains increase along the line. A significant increase in the express trains' delays of almost 2 minutes occurs in the future traffic between Alvesta and Hässleholm. When the express trains are replaced with Gröna Tåget with a top speed up to 250 km/h (GT2020), the average delays on the same line increase by another 2 minutes, or 4 percentage points fewer trains on time +5 minutes. The phenomenon occurs due to the fact that delayed express trains end up behind slower regional trains that generally depart on time and the express trains have no chance to overtake. Time losses increase with faster express trains.

The analysis shows that there are already problems today with growing delays in fast-train traffic and that recoverability is negative, and that the problems will become worse as traffic increases and speed differences grow. To neutralise the effects of the express trains' increasing speeds, a number of different measures can be considered. These are presented below.

Measures to improve punctuality

Faster freight trains

An increase in freight trains' top speed is rarely motivated by the value of the freight. Mail trains are the most obvious exception. For other freight it is difficult to persuade the railway company to invest in wagons which when loaded can run faster than today's normal freight train speed of 100 km/h, while the locomotives that are normal in freight traffic can already reach 130-140 km/h.

A possible solution might be for the infrastructure manager to only offer train paths on the line for freight trains operating at 120 km/h or higher during peak passenger traffic periods. Compared to building more tracks, this is a cheap solution that distributes the limited capacity in an efficient manner but at the expense of possible timetable slots for the slower freight.

An analysis of higher freight train speeds on the Southern Main Line showed that the 100 km/h freight trains lose punctuality when the express trains are given a higher top speed. However, if freight train speed is increased to 120 km/h, this results in shorter running times since the number of overtakings and dependencies on other trains with higher priority are reduced. For other trains the effects are negligible (Sipilä and Warg, planned 2012).

The effect of higher freight train speeds is positive for capacity utilisation but the analysis has not proven that they improve the situation for fast-train traffic.

Reduced delays at stops

Measured delay data in fast-train traffic shows that express trains in Sweden often incur severe delays at stops, i.e. that the stop for passenger interchange at the stations is longer than planned. At stations with few travellers and predominantly boarding or alighting, about 50% of the trains can manage the timetable's 1-minute stop. At slightly larger stations, about 60% of the express trains manage the scheduled 2 minutes for the stop (see the figure). Another measurement from Norrköping C, which has many boarding and many alighting travellers, shows that only 30% of the express trains manage the 3-minute stop (Fröidh and Jansson, 2005).

It can be seen that the delays increase with increased load and the more passengers boarding or alighting from the train. The most important reason is that the train's entrances and design with luggage racks and aisles are not dimensioned for peak load and the dwell times normally used in the timetable (1-2 minutes).

The analysis of the Southern Main Line shows that reduced delays at stops (from "high" to "medium", see Figure 38) can compensate for the deterioration in punctuality that a speed increase for the express trains from 200 to 250 km/h leads to, i.e. 4 percentage points more trains on time (Sipilä and Warg, planned 2012). The Gröna Tåget train concept has therefore been designed with two relatively wide single doors on either side of the car located according to the quarter model (¼ and ¾ of the way along the car), and large luggage racks in the saloon close to the vestibule and the possibility for travellers to pass each other in the aisle. There is also a large entry lift for disabled travellers in wheelchairs that can be used without time being wasted. These measures allow dwell times to be shortened and the standard deviation reduced compared to today's express trains (X2) and punctuality improved.

Overtaking tracks

Overtaking, i.e. passing, slower trains may be necessary in case of large speed differences between the different types of train. It is primarily long-haul freight trains that need to be overtaken by express trains when both run for long distances on the same line.

A first measure is to build more overtaking stations to obtain shorter and more regular inter-station distances and thereby make it easier for the express trains to overtake the freight trains. This reduces waiting times for the freight trains and provides room for more trains.

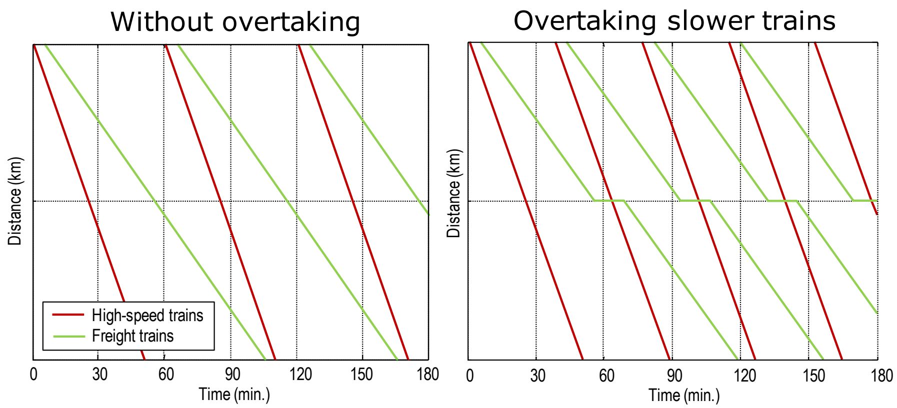


Figure 75. Examples of outline timetables with and without overtaking tracks. Overtaking allows more trains to be operated.

The most severe conflicts arise however between commuter- or regional trains and express trains when the express trains are delayed and due to priority rules or lack of overtaking tracks do not have any possibility to make up time by overtaking.

In the analysis of the Southern Main Line, the number of locations with overtaking tracks has been increased so that the distance has been shortened from 25-42 km to 11-22 km in the southbound direction. The new overtaking tracks also have platforms for regional train stops so the passenger interchanges are possible on branch lines.

In an analysis of the train traffic using simulation the new overtaking stations do not give any appreciable improvement of punctuality (Sipilä and Warg, planned 2012). As Lindfeldt (2011) has shown, the distance between overtaking stations has surprisingly little effect on the development of delays in simulations made with RailSys. Punctuality increases, but not as much as expected. This may be due to more frequent overtaking opportunities not being exploited optimally by the traffic control function or the priority criteria between the trains in case of delays preventing overtaking. There is therefore reason to analyse the issue further with improved methods.

Fewer freight trains during passenger peak hours

An effective means to reduce capacity utilisation is to reduce the number of freight trains during passenger traffic's peak periods and thus reduce the number of conflicts with freight trains. Allowing the railway companies to make freight trains longer and heavier reduces the number of freight trains. An increase in length from 630 m (normal in Sweden) to 835 m (like transit freight trains in Denmark) would for example mean 33% more freight on the train and thereby 25% fewer trains if implemented consistently. Many freight trains already have locomotives that can haul heavier trains. Longer freight trains require longer marshalling yards and longer crossing and overtaking tracks.

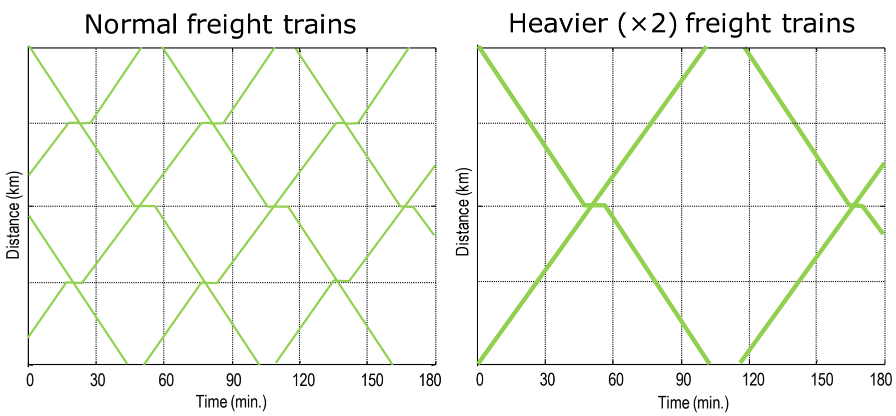


Figure 76. An example indicating capacity effects of halved number of freight trains by doubling their transport capacity.

Skip-stop at commuter stations

The past few decades have seen the establishment of several commuter stations along the main lines that lengthen the commuter trains' running times and thereby their speed differences against the express trains. The benefit to society of greater accessibility to smaller places by commuter train should then be weighed against the risk of increased delays and perhaps longer running times with capacity increments for the express trains. Where it is a question of stations with few travellers, skip-stop services can be introduced for the commuter trains, where trains pass certain stations without stopping in order to make room for more train paths on the line.

The analysis of the Southern Main Line has shown that skip-stop regional train services are an effective way of increasing the express trains' punctuality. This also reduces travelling times for most of the commuters, those who travel between the major stations, and would make room for more trains when the speed differences between the various types of train decrease. Skip-stop services for regional trains on the Norrköping–Mjölby line means that the express trains can pass without running time additions and with improved punctuality – there are fewer disruptions of the widened express train path in the timetable. Express trains could be operated in convoy to improve capacity utilisation.

Analysis of the stops on the Nässjö–Alvesta (2 new stations) and Alvesta–Hässleholm (5 new stations) routes shows that the regional trains' at these stations also has a negative impact on the express trains' punctuality, which could be eliminated with skip-stop (Sipilä and Warg, planned 2012).

Capacity additions

Some lines today have special capacity additions, i.e. additions to the express trains' running times to accommodate more slower trains, for example commuter trains.

The socio-economic calculation shows that every minute of running time including capacity additions for the express trains in a traffic design is on average valued at 300 million SEK over the calculation period of 40 years. One example is that the simulation of the Southern Main Line shows that capacity additions of 8-9 minutes on the Alvesta–Hässleholm route can maintain the express trains' punctuality (Sipilä and Warg, planned 2012). The capacity addition would thus give a socio-economic cost of 2,400-2,700 million SEK, even if it at the same time reduces the delays, which are also a substantial cost. This cost can be compared to the value of the extra commuter train path, installation costs to increase capacity or other measures to eliminate the capacity addition.

Fewer disruptions with a better timetable

Handling disruptions costs capacity. In addition to satisfied customers, punctual trains thereby also provide opportunities to operate more trains or give shorter travelling times.

One measure, if it is feasible, that leads to better punctuality is to arrange larger margins in the timetable. A greater time interval between a commuter train and an express train gives fewer knock-on delays. This can be accomplished by timetable adjustments and skip stops, but if it also means breaking the commuter traffic's fixed interval timetables with departures at the same number of minutes past the hour, it will result in a conflict with the negative value of timetable deviations for the commuters (Taktfast tågtrafik, 2010).

Planned track work, which can for example mean single-line operation on a double-track line or periodically completely closed lines, causes disruptions in train traffic. On a long route, this is something that will often cause a disruption somewhere along the line. Since track work is planned in advance, a temporary timetable can be drawn up to handle changed running times and capacity problems. Timetable planning is however a long and complicated process and sometimes operators will instead choose to operate their services with intentional delays, which reduces capacity.

Priority rules

Priorities between different types of train in both timetable planning and operation should be set on a socio-economic basis, i.e. those customers who gain most from short travelling or transportation times should have priority. In traffic operation, an alternative principle is that trains running to time shall be prioritised to minimise the train traffic's total delays, which does not however take account of the fact that the trains' passengers and freight customers have mutually differing values of travelling times and delay times. The rule means that a regional train operating on time does not wait for a delayed express train despite the fact that the express train may be even more greatly delayed when it has no chance to pass the regional train. One proposal that might contribute to better punctuality for the express trains is that they shall have priority on routes where regional train traffic is not so extensive.

On for example the Southern Main Line, it is mainly the Mjölby–Hässleholm section where express train traffic should be given priority over regional train traffic. Priority here means that in situations where an express train is approaching a regional train, the regional train shall turn onto the next sidetrack to allow it to be overtaken, regardless of punctuality.

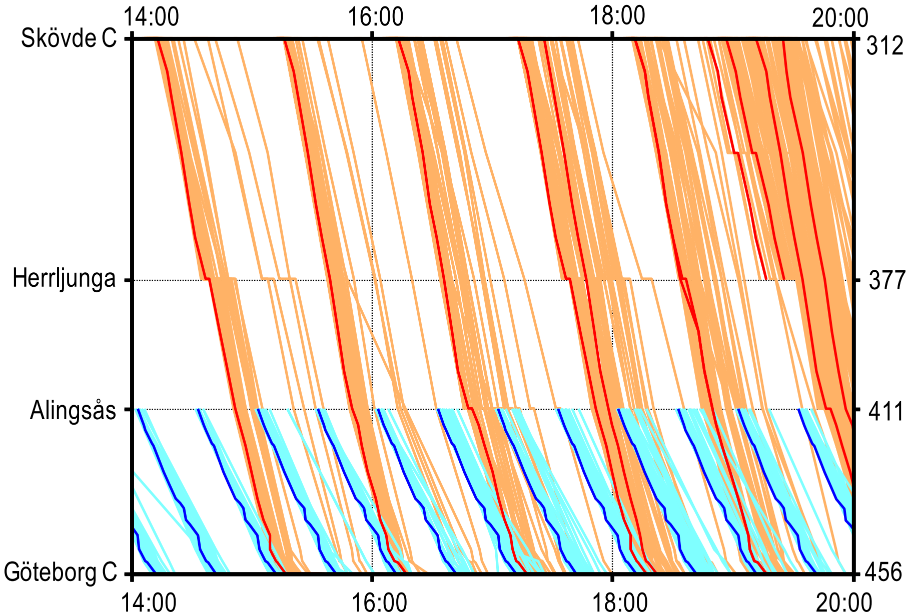


Figure 77. Planned train paths for X 2000 express trains (red lines) and slower commuter trains (blue lines), and two months of actual train running on the Western Main Line section Skövde–Gothenburg. Data: Trafikverket, prepared by Anders Lindfeldt, KTH

If the express train is immediately behind the slower train, such a manoeuvre can be assumed to delay the regional train by up to 5 minutes, which should exist as a running time addition in the regional train's timetable. For the express trains it will mean that the additional delays caused by ending up behind a regional train will be greatly reduced, and the express train may then be able to make up the time and find the planned train path channel in for example Östergötland and Skåne, where regional train traffic is more extensive.

The signalling system is important for the track's capacity. Introduction of ERTMS level 2 will mean that the time loss from overtaking is reduced since the block sections are at the same time planned to be shorter and signals are displayed in the driver's cab instantaneously. Combined with eco-driving with a driver support system will it not only lead to increased capacity, but also smoother running, see Andersson (2012).

Summary of capacity measures

The analysis has shown that it is perfectly possible to apply simple measures to compensate for the increased speed differences between slow and fast trains when the express trains' top speed is raised from 200 km/h to 250 km/h. On many lines, higher speeds are fully possible from the point of view of capacity and desirable to increase attractiveness.

Table 43. Analysed measures to improve punctuality

Measure	***Effect***
Freight trains at 120 km/h	Much improved punctuality and shorter running times in mixed traffic but small effects for express trains
New overtaking tracks	Slight improvement in punctuality for express trains, slight deterioration for overtaken trains. Provides room for more trains
Fewer (heavier) trains	Improvement in punctuality through fewer overtakings at high capacity utilisation
Lower stop delays for express trains	Improvement in punctuality for express trains Can compensate for speed increase from 200 to 250 km/h
Skip stop operation for regional trains and express trains in convoy	Much improved punctuality and capacity for express trains and freight trains, shorter travelling times for skip-stop regional trains with lower frequency of service at small stations
Capacity additions for express trains	Much improved punctuality for express trains but longer travelling times

The studied Southern Main Line is heavily loaded and the level of perturbation is already high, and the situation will be made even worse by increased train traffic in the future. Under these circumstances, special attention needs to be paid to measures to reduce the total level of perturbation, regardless of speed.

- The Gröna Tåget train concept with fewer dwell time delays than today's express trains compensates for the negative effect of the speed increase on capacity
- The total capacity situation may however require further measures to improve capacity utilisation and punctuality.

Mixed traffic with large speed differences consume more capacity and the system becomes sensitive to disruptions. It is possible to reduce the perturbations through different measures that contribute to better punctuality but the basic problem still remains. One way to achieve better punctuality in a system is to add a capacity addition to the express trains that are affected by delays and thus reduce the speed differences between slow and fast trains, but the extended travelling times however diminish the advantage of express trains. Another measure that has proven to be effective is to introduce skip-stop traffic with regional trains to increase the average speeds and thus reduce the speed differences.

A long-term solution to the conflicts between express trains and other trains is to separate the types of train. New high-speed lines like the proposed Götaland Line and the Europa Line are an effective way to increase total capacity by transferring most of the express train traffic to the new lines. Separation in itself means a great increase in the total number of possible train paths. On the main lines, therefore, the regional passenger traffic may increase, just as the freight traffic may gain 2-3 more train paths during daytime than with mixed traffic (Lindfeldt, 2009).

7.4 Track engineering prerequisites

Track substructure

Older railway bridges where the express trains' speeds are increased need to undergo control calculation. A study can show whether they need to be reinforced or replaced to cope with the increased dynamic load and resonance problems that may arise at high speeds. This applies mainly to freely supported bridges but also to stone arch bridges. They can at the same time be adapted to an increase in axle load from 22.5 tons to 25 tons, to the benefit of the freight traffic.

In some places, the geotechnical prerequisites are unfavourable. With higher speeds, various vibration phenomena can occur that will partly disturb the surroundings and put the track's stability at risk. A geotechnical survey is therefore needed to assess possible measures on those sections with lower bearing capacity where speed increases are planned (Södra stambanan, *The Southern Main Line*, 2009).

The track

Track standard

For speeds above 200 km/h the coarser UIC 60 type rails (rail weight 60 kg/m) should be laid[7]. According to the TSI, above 200 km/h a rail fastening is required that can withstand a force of 9 kN per clip (TSI HS INS, 2008). In test runs up to 300 km/h, Gröna Tåget's own Regina 9062 test train has shown that Gröna Tåget gives very low track forces and is below the TSI norm.

The track geometry is adapted to marginally higher speeds in curves by increasing the cant to a maximum of 160 mm (150 mm at present). This is a measure that can be applied during normal track maintenance and thus has a low marginal cost and will also benefit other passenger trains. Some transition curves and minor track defects may need to be adjusted for higher speeds as a one-off measure but here again the measures are relatively minor.

[7] Although it is true that Gröna Tåget's speed record of 303 km/h was set on a section with 50-kilo rails, the coarser rails are to be preferred for maintenance and comfort reasons.

Switches

The TSI allows fixed crossings in switches on tracks with speeds up to 280 km/h. At 280 km/h or higher, a swing nose is required (TSI HS INS, 2008). Swing noses exist today in many switches in Sweden but are considered to be more sensitive to operational disruption when technical faults occur and during winter than fixed crossings. This would seem to indicate a need for technical development.

The rails are normally laid inclined slightly inwards (1:20-1:40) but the TSI allows exceptions in switches and crossings if the speed is 250 km/h maximum (TSI HS INS, 2008). If the speed is to be raised above 250 km/h, either the rails at the switches need to be reprofiled or the switches replaced.

Overhead contact wire

Older overhead contact wires dimensioned for speeds up to 200 km/h or lower need to be replaced when the speed is raised, while new lines may already have an overhead contact wire dimensioned for 250 km/h. Gröna Tåget with coupled train units also presupposes that one pantograph per unit is used, i.e. 1-3 operational pantographs spaced approximately 100 m apart on every train, which puts special demands on the overhead contact wire to prevent wave motions and poor current collection.

However, pantographs with good characteristics and even upward pressure have been tested at high speeds in the Gröna Tåget programme and a research project is at present looking at what requirements need to be set for pantographs and overhead contact wires. It is therefore uncertain how much needs to be replaced as a result of the speed increase.

Level crossings

In Sweden, level crossings exist on many lines with a maximum permitted speed of up to 200 km/h; although at the higher speeds they always have barriers and obstacle detectors (for road vehicles). However, level crossings need to be eliminated as far as possible for safety reasons and are not allowed at speeds above 200 km/h.

In a survey of level crossings conducted in 2007, they were compared with a speed profile for Gröna Tåget. Divided by line, it was shown that most level crossings that need to be abolished to be able to raise train speeds above 200 km/h are located on the Western Main Line (18) and the Southern Main Line (14).

In practice, it may in some cases be a matter of building a replacement road instead of a new grade separation, which as a rule is a cheaper solution.

Signalling systems

ERTMS

A new pan-European signalling system, European Rail Traffic Management System (ERTMS), is to be introduced to enable interoperability on Europe's railways and is a binding condition for all new lines and system changes in existing signalling systems, including higher speeds than 200 km/h in Sweden (TSI HS Control command, 2006; TSI CR Control command, 2006).

Table 44. Planned introduction of ERTMS/ETCS

Country	ERTMS/ETCS	Remarks
Finland	2019-(2025)	First stage. Completion year not scheduled
Norway	2014-2030	Completion year uncertain
Sweden	2010-(2030)	First four stages. Completion year not scheduled
Denmark	2017-2021	Completed

Source: Information materials from the infrastructure managers

ERTMS consists mainly of the safety system ETCS, which replaces ATC, and the radio system GSM-R for information transfer. It also includes signal boxes and traffic control in the signalling system. In order to permit interoperability between ATC and ERTMS equipped traction vehicles, a so-called STM has been devised, which is a device that can read ATC messages from ATC equipped tracks and translate them into ERTMS language in ERTMS equipped traction vehicles.

ERTMS level 2 without optical signals in the track will be standard in most applications. Its introduction also means that the block sections can also be shortened, which is the single most important measure for increased capacity. Level 1, with signal lights, will in any case be installed in Sweden at major stations like Malmö Central, Hallsberg and Stockholm Central, since the transfer capacity in GSM-R is limited in level 2. Level 3 Regional is also being developed for more minor lines (ERTMS i Sverige, 2009).

Today's signalling system and safety system in Sweden, ATC2, has however technical possibilities to be adapted for higher speeds than 200 km/h since the systems were once specified for higher speeds of up to 300 km/h (Andersson, 2012). A dispensation would need to be granted however to adapt the ATC system for train speeds up to 250 km/h to be able to fill the gap between the introduction of ERTMS and the market's demand for shorter travelling times. Since the European Union is using directives to put pressure on member states in order to achieve interoperability in Europe by speeding up the introduction of ERTMS, it does not seem likely that such a dispensation would be granted.

Many older interlockings that is overdue for replacement and that can not be adapted to the new system will be replaced when ERTMS is introduced, which will greatly increase the project costs. Increasing speeds also requires the system to be adapted with through-signalling on longer sections.

Effects on capacity

Introduction of ERTMS level 2 as a rule means better capacity utilisation in those cases where the existing signalling system is not optimal, but the effect is among other things dependent on what mix of train types, block section lengths and certain other characteristics of the signalling system. ERTMS level 3 with moving, dynamic blocks should really be the goal in order to be able to improve capacity utilisation but level 3 at present only exists as a concept and must first be developed.

Electrical power

Power output and energy consumption change only marginally if Gröna Tåget replaces existing train types. The power output mainly increases as a result of increased travel, which requires more or longer trains. A greater degree of regenerative braking, however, may require more of the installation. Any measures taken to reinforce the electrical power supply will also benefit other train traffic, which explains why this is not included in the calculation.

Passage of platforms at high speeds

Risks for travellers

Actual risk to travellers on the platform when a train passes is not the same as the perceived risk. Even if in practice there is no difference regarding the risk to a traveller of a freight train passing the platform at 100 km/h or an express train at 240 km/h, the higher speed is perceived as a much greater danger – in spite of the fact that the trains in both cases produce roughly the same draught flow (tests in Sweden in the 1990s) and would never have a chance of stopping if someone should fall in front of the train. This would rather indicate a necessity to protect travellers from passing trains irrespective of speed if the risks are judged to be unacceptable.

A prerequisite for passing at high speed is that there is a warning system on the platform. It is also possible to install some form of physical barrier, like those erected on some stations between Hamburg and Berlin as part of upgrading for 230 km/h high-speed-trains and that keep travellers away from the edge of the platform when trains pass.

Governing norms

For access to platforms, high-speed lines of category II and III to which the lines in question belong, "Passengers' access to the platforms adjacent to the tracks where trains may run at speeds ≥ 250 km/h shall only be permitted when a train is intended to stop at the platform." (Clause 4.2.20.1 of TSI HS INS, 2008).

An investigation into changes to the norms (TSI) for class II and class III high-speed lines to permit 250 km/h instead of less than 250 km/h when passing platforms with waiting travellers might in practice be a rational measure that does not result in more than insignificantly changed risks or other consequences. The norms in the TSI would then be able to be linked to risk assessments taking train speed and other protective measures on the platform into account.

Measures to reduce risks

At those stations where the platforms are mainly located on the main line where trains speeds on track upgraded for Gröna Tåget may reach 250 km/h, the perceived risk to travellers waiting on the platform is still high. There is therefore reason to introduce some kind of barrier between passing express trains and freight trains and travellers.

Table 45. Possible measures to increase perceived safety

Measure	***Effect***	***Cost and benefit***
Speed limit of 249 km/h maximum when passing a platform	Insignificantly longer running times compared to 250 km/h. Travellers perceive a risk when trains pass	Insignificantly reduced benefit from higher speeds
Build **platform doors** on mainline platforms	Increases perceived safety on the platform at all train passages, allows 250 km/h or higher	Relatively small installation cost but higher operating costs
Build **sidetracks** (overtaking tracks) with platforms	Increases perceived safety on the platform at all train passages, allows 250 km/h or higher on main lines. Increases track capacity with possibilities for overtaking	High installation cost. Higher operating costs

Compared to building a simple platform with warnings systems on the main line, possible additional measures are relatively expensive.

An alternative is to install doors that are only opened when a train stops for passenger interchange. This also entails both an installation cost and operating costs for the devices to work in all weathers. A simpler model with a lockable exit to the platform might also be conceivable. The TSI allows train passage without speed restriction when there are no travellers on the platform.

The more expensive alternative is to build sidetracks or overtaking tracks with platforms and only admit trains that stop on the sidetracks. Passing trains use the main line at the maximum line speed, i.e. 250 km/h or more. Sidetracks cost considerably more than doors but also add track capacity by making overtaking possible. This solution is therefore appropriate for lines with mixed train traffic (express trains, regional trains and freight trains) where the track capacity is under great strain and there is a need for overtaking possibilities to be able to increase the number of trains or reduce traffic disruptions.

7.5 Socio-economic analysis

Analyses as a tool

A socio-economic analysis at an early stage is a tool to evaluate the idea of Gröna Tåget and the necessary investments in the track to be able to raise speeds and shorten travelling times. The analysis consists of a calculation that comprises both business-economic effects and effects for society and the people who use the express trains, complemented by an analysis of other benefits and costs not included in the calculation.

The socio-economic calculation is made according to the same methodology and in principle with the same values as the Swedish Transport Administration uses in investment planning, but is more general and simplified than normal investment calculations. The installation costs, which are perhaps the most important item, are calculated very generally. To refine the calculations, the system requirements regarding the line and the need for investment on each single section must be investigated in detail. The method and the values are documented in the National Rail Administration's (Banverket) handbook BVH 706 (Beräkningshandledning, *Calculation Guide*, 2009). There is a more detailed description of the socio-economic analysis (in Swedish) in Fröidh (2010).

Calculation prerequisites

Delimitation of the calculation

The principle of the socio-economic calculation is that it comprises investments in the line that are necessary to be able to raise the speed of express trains to above 200 km/h, which is at present the maximum permitted speed in Sweden. A line that is not adapted to express trains may require substantial investments, primarily in railway level crossing protection and grade separated crossings.

The investments have as far as possible been delimited to only the speed increase from 200 km/h to 250 km/h even if many measures also benefit freight traffic and other passenger traffic. On lines where speeds with Gröna Tåget will exceed 200 km/h it is assumed that today's base standard on lines adapted to express trains is fully sufficient, even if Gröna Tåget as a rule can run 5-10 km/h faster in curves than today's express train speeds thanks to increased cant and increased tilting.

New investment or reinvestment?

The calculation treats new investments, which aim to make a new activity such as operating Gröna Tåget at higher speeds possible, in a partly different way to reinvestments, which aim to replace worn-out equipment. In the case of reinvestments, as a rule new equipment with better performance than the old equipment is used and in many cases the improved performance is also a prerequisite for raising the speeds. In practice the speed-raising measures, both new investments and reinvestments, also have several, but not quantified, benefits than the calculation normally covers.

Table 46. New investments and reinvestments

	New investments	*Reinvestments*
Need	Must be made for Gröna Tåget's speed increase >200 km/h	Must be made regardless of Gröna Tåget but may need to be brought forward
Cost distribution	Burdens Gröna Tåget 100%	Partly burdens Gröna Tåget if brought forward, otherwise 100% reinvestment budget
Examples of measures	Bridges and geotechnical measures Grade separated crossings Platform safety Capacity measures	Tracks Overhead contact wires Signalling system (ERTMS)

A reinvestment that is necessary to be able to increase the speeds entails early replacement if it is made before the planned time when the equipment is estimated to be worn out. There are, however, examples where depreciation period and technical life differ. Signalling systems, including ATC, have a depreciation period of 30 years in socio-economic calculations (Beräkningshandledning, 2009). Many signal installations, however, are already older than that and do not even have a planned replacement with

ERTMS/ETCS in the ERTMS plan's time horizon up to 2030 (ERTMS i Sverige, 2009). Without a speed increase, it is here assumed that the existing signalling system will be kept and replaced with ERTMS in 2035. ERTMS completion by 2025 means early replacement by 10 years – but whether it is early or not from an economic perspective is consequently a matter for discussion. A calculation made in 2025 concerning replacement now or later may for example show that the maintenance costs or the technical limitations of the old system are so great that from an economic point of view the switch to the new system should be made immediately.

Time horizon for the alternative studied

The calculation compares a speed increase for Gröna Tåget as a study alternative (SA) as with a comparison alternative (CA). In CA, there is no increase for express trains, which is in agreement with the current plan (Nationell plan för transportsystemet 2010-2021).

The desired start of traffic for the express train traffic in SA has been assessed from a market perspective and the possibility to make the investments in the lines. In the calculation it is assumed that the first sections will have been adapted by 2017 and the remainder by 2020 and 2025, respectively.

Standard values

The standard values used in the calculation are in agreement with the values currently used in Sweden (Beräkningshandledning, *Calculation Guide*, 2009; Samhällsekonomiska principer och kalkylvärden, *Socio-economic principles and standard values*, 2008). The installation costs and train operation costs calculated using Gröna Tåget's cost model are stated in 2010 prices and are adjusted upwards by tax factor I (1.21). The calculation period is 40 years and the discount rate 4%. The remaining installation value after 40 years, the residual value, is discounted to present value.

The time values are calculated for an average distribution between business and private travellers that varies between 20% and 40% business travellers. The business travellers have a time value of 275 SEK/h and private travellers 102 SEK/h.

The marginal external costs, i.e. environmental gains from reduced emissions, are based on an assumed distribution in between newly generated travel (50%), transferred from the car (25-50%), and transferred from air (25%) where competition with air travel exists.

The benefits from grade separated crossings accrue to train and road traffic in the form of increased safety and fewer accidents, and to road traffic also in the form of shorter queuing times.

Table 47. Calculated installation costs for the lines

Line	Western M Stockholm-Gothenburg	Southern M Katrineholm-Malmö	West Coast Gothenburg-Lund	Väner Gothenburg-Öxnered	East Coast Stockholm-Umeå	Mälar Stockholm-Hovsta	Svealand Södertälje-Valskog	Total
Total Line Lenght (km)	*455*	*483*	*290*	*82*	*730*	*180*	*114*	*2334*
of which >200 km/h	*266*	*307*	*225*	*75*	*389*	*111*	*73*	*1446*
Track (km), Newer line	*102*	*0*	*478*	*164*	*559*	*290*	*101*	*1694*
Track (km), Older line	*808*	*966*	*72*	*0*	*338*	*21*	*29*	*2234*
Introduction of GT, year	*2020/2025*	*2020*	*2017*	*2017*	*2017*	*2025*	*2025*	
New investments								
Bridges, geotechnics	360	430	20	0	50	0	0	860
Grade separated crossings	580	450	0	0	80	0	0	1110
Platform safety	40	50	30	40	60	20	5	245
Capacity/punctuality	2500	2400	100	0	200	0	0	5200
Reinvestments								
Track renewal, geometry	295	310	230	0	205	100	40	1180
Catenary	0	50	140	0	20	0	0	210
Signalling (ERTMS/ETCS)	0	0	210	25	180	70	45	530
Total cost (million SEK)	**3775**	**3690**	**730**	**65**	**795**	**190**	**90**	**9335**
Residual value after 40 yrs	730	693	23	0	77	0	0	1523

For track length, a difference is made between lines built in 1988 or later (”Newer line”), and the lines built before 1988 (”Older line”). Note that the reinvestments only refer to Gröna Tåget’s share for early replacement (see text).

The calculated total installation costs for the lines studied are estimated to amount to 9,300 million SEK for a speed increase on 1,446 km of line, of which 5,200 million SEK is in respect of measures to increase capacity and improve punctuality in the medium term. On the Western Main Line and the Southern Main Line, further capacity reinforcement will be needed from 2020 on, but this is not included in the calculation.

A calculation of track length on older lines, built before 1988, and newer lines built in 1988 or later, is used as the basis for calculating the cost of bridges, geotechnical measures, track replacement, replacement of overhead contact wires and ERTMS/ETCS.

Calculation results

Basic assumption

In the socio-economic calculation, some of the lines have been combined in order to better reflect the traffic-related possibilities of a total adaptation for Gröna Tåget. These are the Gothenburg–Öxnered section of the Norway/Lake Vänern Line which is combined with the West Coast Line, and the Mälar Line which is combined with the Svealand Line for a common traffic design between Stockholm and Örebro.

Table 48. Compilation of calculations

Basic scenario Present value 2010 (SEK millions)	***Western M*** *Stockholm-Gothenburg*	***Southern M*** *Katrineholm-Malmö*	***West Coast*** *Öxnered-Gothenburg-Lund*	***East Coast*** *Stockholm-Umeå*	***Mälar+Sveal.*** *Stockholm-Örebro*
Introduction of GT, year	*2020/2025*	*2020*	*2017*	*2017*	*2025*
Investment cost	4395	4295	925	925	326
Residual value	-164	-155	-5	-17	0
Revenues	4970	6422	2839	3497	798
Production costs	-4383	-5314	-1254	-2909	385
Travelling time gains	3886	6359	2156	2594	1250
Marginal externalities	670	891	50	526	17
Grade separated crossings	95	74	0	11	0
Total benefits	**5238**	**8432**	**3792**	**3718**	**2451**
Benefits-investment cost	1006	4292	2871	2810	2125
Net Present Value (NPV)	*0.2*	*1.0*	*3.1*	*3.1*	*6.5*

The compilation shows socio-economic present values, i.e. the value of the benefits over the calculation period discounted to 2010 and including tax factors. The standardised construction time is 3 years (2010-2012) and the period in operation 40 years (2013-2052).

The Mälar Line and Svealand Line give the greatest socio-economic return, followed by the West Coast Line with the Gothenburg–Öxnered section and the East Coast Line with the Bothnia Line. All of these have long stretches of newly-built line of a standard that in principle permits 250 km/h were it not for today's signalling system. The additional cost of switching to ERTMS and other technical adaptation can be justified very well from a socio-economic perspective.

The Western Main Line and the Southern Main Line have considerably higher installation costs. There, capacity must be reinforced to improve punctuality in the form of both elimination of several level crossings and track replacement on some sections of the line.

Sensitivity analysis

In the sensitivity analysis, the installation cost and the benefits have been varied to study the sensitivity of the result to changed prerequisites and margin of error in the included values. Three different scenarios were tested in addition to the basic assumption:

1. The installation cost increases through the cost of ERTMS burdening Gröna Tåget alone.

2. Implementation ten years later and the implementation cost decreases through no reinvestments burdening Gröna Tåget.
3. Travel unchanged despite improved supply.

The results of the sensitivity analysis show that shorter travelling times by express train can bear a higher installation cost than in the basic assumption. The exception is the Western Main Line where the return was small even in the basic assumption.

If the adaptation of the express trains for higher speeds is carried out ten years later, this means that all necessary reinvestments for higher speed have been made before the speed is raised. It is consequently the reinvestment budget that prepares the ground for Gröna Tåget and this is accomplished without early replacement of track, overhead contact wires and signalling equipment. The remaining new investment can easily be borne by the reduction in travelling time and the net present value ratio increases significantly.

A scenario with unchanged travel despite the change in supply with shorter travelling times, higher frequency of service and cheaper fares seems unlikely, but it nonetheless gives an indication of how sensitive the result is. The West Coast Line, and the Mälar Line and the Svealand Line, still have positive net present value ratios, while they are negative for the others. The differences between different lines are due to the fact that the distribution between consumer surplus and producer surplus is different, where the producer surplus in the form of lower costs with shorter running times is more stable when travel stagnates.

It is also profitable to operate services with the wide-bodied Gröna Tåget even if speeds are not raised, but in that case no line adaptation is needed and it thus falls outside the socio-economic calculation.

The general value of running time

The value of the reduction in running time can be calculated generally. The business-economic value comes from increased fare revenues and lower production costs when the travelling times are shortened. The socio-economic value also includes the travellers' time gain and effects for third parties (external effects). The present value in the business-economic calculation is based on 20 years' depreciation for the vehicles and 6.5% discount rate. The present value in the socio-economic calculation is based on a calculation period of 40 years and 4% discount rate.

The result shows that 1 minute of running time saved is worth 4.7 million SEK a year for a vehicle fleet in an average traffic design, and capitalised (present value) 51 million SEK. The highest value is on the Mälar Line and the

Svealand Line, where the largest share is in respect of shorter circulation times, which give a noticeable improvement in productivity. The other lines, except for the West Coast Line, also have reduced fares, which reduces the producer surplus.

Table 49. General value of running time

SEK millions	Western M Stockholm-Gothenburg	Southern M Katrineholm-Malmö	West Coast Öxnered-Gothenburg-Lund	East Coast Stockholm-Umeå	Mälar+Sveal. Stockholm-Örebro
Operator's value of 1 minute					
Annually	4,6	5,4	1,8	4,2	6,1
Present value	51	60	20	46	67
Socio-economic value of 1 min.					
Present value	333	383	123	208	272

Weighted average of studied lines		
Annually for the operator	4,7	million SEK per scheduled minute
Operator's present value	51	million SEK per scheduled minute
Socio-economic present value	295	million SEK per scheduled minute

Average of studied lines is weighted with respect to number of departures

The corresponding socio-economic value is 295 million SEK a year per minute of running time saved. Regarding infrastructure measures, the specific value for each line should be used. The Southern Main Line has the highest value, 383 million SEK a year per minute of running time. An example calculation is that on the Southern Main Line it is worth 1,900 million SEK over the calculation period to reduce the travelling times for the express trains by 5 minutes, which is equivalent to a nominal installation cost of 1,570 million SEK.

Other benefits and costs

The socio-economic analysis also contains effects which are not included in the calculation. These may be effects that cannot be quantified or valued in monetary terms. Below follow some of the conceivable effects of raising speeds to over 200 km/h for express trains that are not included in the calculation.

- **Track maintenance.** Older lines that are given a higher speed can be assumed to then have a marginally higher maintenance cost. The early replacement of track and overhead contact wires and a new signalling system (ERTMS) that burdens Gröna Tåget on the other hand give lower line maintenance costs. Gröna Tåget's mass per seat decreases compared to the X2, which reduces track maintenance.

- **Electrical power.** Gröna Tåget's energy consumption per seat decreases compared to the X2 despite higher speeds, but increased traffic volume may marginally increase its energy consumption.
- **Infrastructure for car and air traffic.** Roads and airports are relieved through more attractive train traffic. Expansion and encroachment effects that cause delays or cancellations are not included, but on the other hand the reduced environmental loading of car and air travellers who take the train instead.
- **Shorter travelling times for other trains than express trains.** Higher speeds, mainly in curves, also give a marginal travelling time gain for other passenger trains.
- **Changes for freight traffic.** No calculations of changes as regards freight traffic are included since the approach is to balance higher speeds for express trains with maintained capacity utilisation. Longer, heavier freight trains mean lower transport costs and reduced capacity utilisation, while a greater number of overtakings may entail higher costs.
- **Natural and cultural environments.** The higher speed on existing lines has no known effect.
- **Noise and vibrations.** Gröna Tåget has better aerodynamics, which gives lower energy consumption and less noise than X2 trains despite higher speeds. Here it is assumed that Gröna Tåget can cope with the same ground vibration levels as the X2 despite higher speeds, through reinforcement of embankments in vulnerable locations.

Implementation alternatives

In the socio-economic calculations in the previous section, a speed increase for express trains from 200 km/h to 250 km/h is tested route by route. The results show that the socio-economic return is very good on those routes where there is a relatively large proportion of track that has been built or rebuilt without level crossings since the 1990s, which reduces the need for technical upgrading. There is as a rule also free track capacity to increase the express trains' speeds.

On the other main lines, where the standard is lower and capacity already strained, it does not go without saying that the benefits outweigh the costs as regards express trains' higher speeds. By means of reinvestments in new track, overhead contact wires and signalling systems that can handle 250 km/h from the outset, the object-specific costs can be brought down. Based on the socio-economic analysis, a three-stage implementation plan is proposed for speed increases for Gröna Tåget.

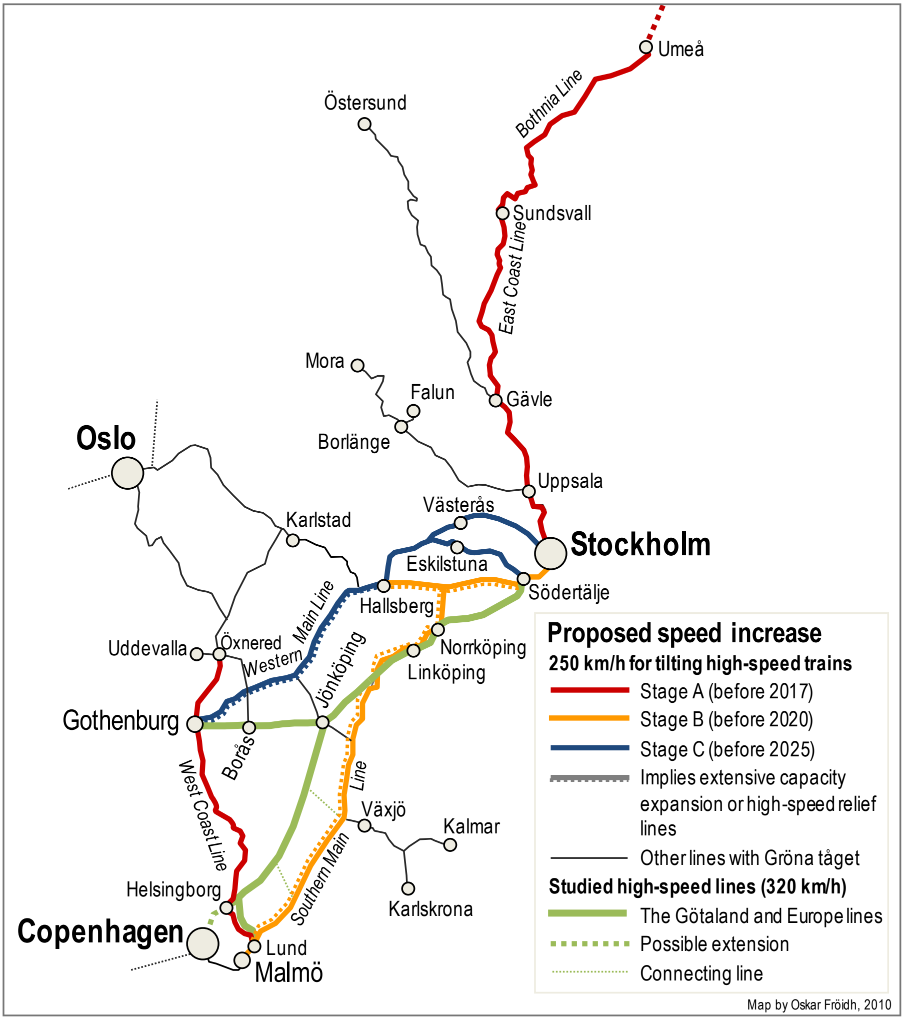


Figure 78. Proposed prioritisation of upgrading for higher express train speeds, and the Götaland and Europa high-speed lines proposed in an official report.

The first stage (A) should comprise the Gothenburg–Lund section of the West Coast Line, Gothenburg–Öxnered, and the East Coast line and the Bothnia Line Stockholm–Umeå. Considering the relatively minor measures and high socio-economic profitability, it should be carried out as early as possible and before 2017, provided that the Swedish Transport Administration (Trafikverket) revises its ERTMS plan.

The second stage (B) should comprise the Southern Main Line Linköping–Malmö in combination with capacity expansion on the Lund–Malmö section and the construction of the Eastern Link, a new high-speed link Södertälje–Linköping (not included in the analysis). The Stockholm–Hallsberg section of the Western Main Line should also be included since it is an already funded component of the ERTMS plan. Stage B should be carried out before 2020 and here the schedule for the installation of ERTMS can be maintained as it stands. The third stage (C) should comprise the Mälar Line via Västerås, the Svealand Line via Eskilstuna and the Hallsberg–Gothenburg section of the Western Main Line that as a package give a better socio-economic return.

Stage C should be carried out before 2025. The schedule holds for ERTMS installation between Hallsberg and Gothenburg. For the Mälar Line and the Svealand Line, however, installation of ERTMS must brought forward.

Since it is not known when any train operator will actually purchase express trains like Gröna Tåget, an uncertainty factor remains. The only possibility to remove this uncertainty is to co-plan vehicle acquisition with track expansion. In practice this means that the Swedish Transport Administration should reach an agreement with the railway company that acquires new express trains to also adapt the track for higher speeds.

7.6 Summary

Top speed

A suitable speed to shorten journey times by express train on conventional main lines in Sweden is 250 km/h. Tilting trains give substantial journey time gains. On track that has been built since the 1990s, even higher speeds are possible, in some cases up to 275 km/h where the track geometry permits this. The high-speed lines that are now being planned will allow trains to be operated at 320 km/h without tilting.

A suitable installed output for a train for general use is 15-20 kW/ton of train weight for a maximum speed of up to 250 km/h, and 20-25 kW/ton for 280-320 km/h. Output requirements increase with more stops and steeper slopes. Higher output is also desirable to obtain more effective electric braking, which gives greater energy recovery.

Capacity

In order to increase speeds on lines with mixed traffic, capacity needs to be reviewed. On single-track lines, shorter run times are an advantage for reducing the number of crossings between trains, while overtaking with freight trains will increase in the same way as on double-track lines. Commuter traffic often leads to a limit to the number of train paths for other trains and slightly delayed express trains become even more delayed but this problem already exists today.

One measure that has proven effective for improving capacity utilisation is to introduce skip-stop traffic with commuter or regional trains to increase the average speed of slower trains and thus reduce the speed differences. Shorter distances between crossing loops (on single-track lines) and overtaking possibilities increase capacity and have a positive effect on punctuality.

Simulation of the Southern Main Line in Sweden shows that reduced dwell time delays as can be achieved with the Gröna Tåget train concept compared to present express trains, may be sufficient to compensate for the poorer punctuality that might be a consequence of raising the speed.

Mixed traffic with large speed differences consume more capacity and the system becomes sensitive to disruptions. It is possible to reduce the perturbations through different measures but the basic problem still remains. In a longer perspective with increasing traffic, substantial capacity increases will be needed.

Lines for express trains

The measures that may be necessary for an engineering upgrade for higher speeds are higher cant (both executed and cant deficiency), and for speeds over 200 km/h elimination of level crossings, a new signalling system (ERTMS), replacement of track and switches where older types still remain, and perhaps also catenary conversion, geotechnical measures, measures on certain bridges, and measures to increase safety when passing platforms.

Socio-economically profitable

The socio-economic calculation shows that, generally speaking, it is profitable to shorten journey times by increasing the speed of express trains to 250 km/h in Sweden. The most profitable measure is to increase speeds according to planned reinvestments where the new equipment have such high performance that no further measures to increase speeds are needed. Extensive capacity measures and if many grade separated crossings need to be built are expensive measures that reduce the socio-economic return. Shorter travelling times may on the other hand justify introduction of ERTMS.

8. Conclusions

The chapter contains a discussion of the results and what consequences can be drawn from the analyses in Gröna Tåget. Some of the mainstays of Gröna Tåget are wide carbodies, shorter travelling times with tilting and a flexible design of the train concept.

8.1 Discussion

Economy with wide-bodied trains

Space utilisation is important

Good economy in train traffic is important to the travellers and the railway companies, and it becomes even more important in deregulated train traffic with competition between operators. Space utilisation is one of the three most important factors for economy alongside degree of occupancy and average speed. High space utilisation is a result of more seats in every car and in addition to double-decker train concepts wide carbodies also offer possibilities to obtain a larger furnishable area without costs increasing to a corresponding degree. In combination with tilting for shorter travelling times on conventional lines, wide-bodied trains are however a better solution than double-decker trains.

It is possible to operate wide-bodied trains in Sweden and with certain restrictions in Denmark and Norway, giving interoperability in Scandinavia. The analysis shows that the Gröna Tåget high-speed-train concept as a wide-bodied train has 15% lower costs in traffic compared to an equivalent train with the same comfort and continental carbody width. This gives a significant competitive advantage for those railway companies that have wide-bodied trains.

Standardisation

Gröna Tåget is intended for Nordic conditions and in a European perspective it is primarily cold winters with an abundance of snow and the risk of colliding with large wild animals like elks that are unique. Trains designed for continental Europe must be modified to operate reliably in the north. Gröna Tåget can however be regarded as a standard train through its being interoperable in long-distance and regional traffic in Scandinavia, a market of 10-15 billion passenger-km (2010).

Tilting for shorter travelling times

Travelling times are in the long term the most important factor for increasing the attractiveness of a mode of transport given that fares, frequency of service and other supply factors are acceptable. Tilting express trains like Gröna Tåget are a technical solution to be able to increase speeds on an old line built for other conditions than the travelling times that are commercially desirable today.

Besides Sweden, tilting trains exist in many countries, including Italy, Germany, Great Britain, Norway and Finland. The increased demand resulting from the shorter travelling times justifies the cost of the tilting system, and even more if a trainset in the circulation can be saved.

New high-speed lines are dimensioned for non-tilting trains. Express trains can however be operated at high speed with the tilting turned off on high-speed links and then continue on a conventional line with it turned on. A line network that includes both high-speed lines and conventional lines gives significant effects on travel with substantial transfers from the car to the train as a result of shorter travelling times and more direct connections, a consequence of accessibility increasing to a great many places.

Planning for higher speeds

Slow introduction of ERTMS

One of the biggest obstacles to raising speeds above 200 km/h and achieving travelling time gains for Gröna Tåget is the signalling and safety system.

A pan-European signalling system called ERTMS together with a safety system called ETCS is gradually being introduced throughout Europe. ERTMS main advantage is that it allows interoperability between countries that today have different national signalling systems. Introduction is however proceeding slowly since capacity and interoperability gains are small in comparison to the cost of the equipment both on the lines and in the vehicles. An exception is Denmark, which is planning a concentrated replacement on the entire main line network between 2017 and 2021. Travelling time gains with express trains would, however, justify a faster installation of ERTMS on many routes in Sweden, for example.

Measures for higher speeds on the lines, such as ERTMS, should be coordinated with the railway companies' acquisition of new express trains. It is therefore important that the infrastructure manager can reach agreement with the railway companies on implementation and the schedule for the best return on the investment capital.

Figure 79. Malmö C before the City tunnel was built.

Capacity on the main lines

Raising the speeds for express trains on the main lines consumes more track capacity when the speed differences between different trains increase. Lack of capacity gives a poorer supply in the form of fewer departures or departures at other times than would be desirable from a commercial point of view, such as increased sensitivity to disruptions, leading to more delays.

There are ways of reducing the impact of higher express train speeds in mixed traffic. These are primarily timetable measures such as skip-stop services with regional trains and convoy train paths. The Gröna Tåget train concept includes a design that gives less stop delays and this improves punctuality. In the short term this might be sufficient to compensate for the higher express train speeds.

In a longer perspective, however, capacity will be insufficient on lines with constrained capacity and an increasing demand. It is consequently a strategic choice if one decides on a step-wise but ultimately expensive expansion of the main lines or to build new high-speed lines specially adapted to long-distance passenger traffic, which at the same time frees up capacity for freight traffic and regional passenger traffic in the conventional network.

Gröna Tåget has a significant advantage over many other train concepts since it is eminently suitable for traffic in mixed operation between conventional lines and high-speed lines.

8.2 Conclusions about market and traffic

The market for express trains

The analysis shows that express trains like Gröna Tåget in combination with line upgrades for higher speeds up to 250 km/h may lead to increases in travel of the order of 30% compared to today's express trains, thanks to a more attractive supply. In the cases from Sweden, travelling times are shortened by 9-10% compared to the X2 (X 2000). With Gröna Tåget fares can also be reduced and frequency of service can be increased and more direct train services can be operated.

With the improved supply and yield management, future express train traffic can maintain and increase its competitiveness against the car and air services between 100 km and approximately 500 km. The limitations in track capacity without additional infrastructure investments will on the other hand mean lower frequency of service than would be commercially possible on many lines.

Economy in train traffic

Three factors stand out as particularly important for achieving good economic efficiency in train operation:

- High occupancy
- Good space utilisation
- High average speed, including dwell time.

Gröna Tåget is a proposed concept the aim of which is to improve all these points compared to existing train concepts.

Wide-bodied trains

Wide-bodied trains have room for 25% more seats than normal-width trains of the same car length since they allow 2+3 seating in economy class and 2+2 in first class. With individual armrests on all seats for good comfort, the interior width needs to be 3.3 m. This increases efficiency and reduces total costs by 15% compared to continental (normal) carbody width. Wide-bodied trains are a competitive advantage and increase train travel through a more attractive supply.

For operation in Scandinavia, Gröna Tåget can be designed as a wide train with an exterior carbody width of between 3.45 and 3.54 m. Preliminarily, on the Öresund Link to Copenhagen Central a 3.54 m wide carbody can be accommodated provided that the train is equipped with a Hold-off device (HOD) to reduce lateral body deflection. Surveys of gauges and obstacles are currently being carried out in Denmark in collaboration with Rail Net Denmark and the Danish Transport Authority.

Short, flexible trainsets

Short trainsets that can be multiple-coupled when needed contribute to increase the degree of occupancy on the trains. Fewer empty seats contribute to reduced costs per traveller and is a good way to increase productivity. This assumes that the trains are designed so that coupling and uncoupling also function in winter weather.

Considering the travel and maximum utilisation of the platform lengths, a train unit of 300 seats and a length of 108 m (4 long carbodies) stands out as most suitable for traffic in the Nordic countries.

A shorter train unit of approx. 230 seats and a unit length of 80 m is highly usable in long-distance regional traffic as a reinforcement in peak traffic and off-peak traffic on the main lines. A larger train unit of 400 seats or more can also be considered for some main lines but risks reducing the flexibility of the traffic and giving higher costs through a reduced degree of occupancy.

Punctuality

Gröna Tåget should be designed to allow punctual train traffic by dimensioning the train according to top load with full trains. Short station stops are then possible and there is less risk of delays occurring. The inappropriate design of many of today's trains gives a great spread in the dwell times, which gives poorer punctuality.

Primarily doors and entrances must be dimensioned for short boarding and alighting times with many passengers, great amounts of luggage and travellers with physical and other disabilities. Some concrete measures are to have at least two single doors on both sides of the car with split passenger flows inside the car and room to pass in the aisle, and have large luggage racks for heavy luggage and one or more entry lifts for travellers with physical disabilities.

Capacity

A measure that has proven to be effective is to introduce skip-stop traffic with commuter- and regional trains to increase the average speeds and thus reduce the speed differences. Fewer but heavier freight trains and more overtaking stations also contribute to improved capacity utilisation and punctuality.

Figure 80. Will Gröna Tåget look like this? (Fröidh/LundbergDesign)

Shorter and more predictable dwell times for boarding and alighting, as is possible with Gröna Tåget, compensate for the negative effect on punctuality of higher speeds and are important from a capacity perspective but also affect travelling times positively.

If a capacity addition were added to the express trains that are affected by delays and thus reduce the speed differences between slow and fast trains, it means that the advantage of express trains diminishes when travelling times become longer.

Implementation

The socio-economic outcome of upgrading track for higher speeds up to 250 km/h is very positive. It is a decisive feature that with Gröna Tåget it is easy to realise large gains in travelling time in long-distance passenger traffic with relatively small investments. There are therefore measures that should be given high priority. Extensive capacity measures and if many grade separated crossings need to be built are expensive measures that reduce the socio-economic return.

Implementation should however be coordinated with the railway companies' acquisitions of new trains.

8.3 What does Gröna Tåget need?

To fulfil the objectives

Gröna Tåget needs such characteristics that it fulfils the objectives of being an attractive, economically viable and environmentally friendly express train, interoperable in long-distance traffic and regional express traffic in Scandinavia. This concerns both developed technology and the implementation of various solutions that allow the objectives of the train concept to be attained.

Fast

High top speed

Gröna Tåget is dimensioned as a high-speed train according to TSI Class I (250 km/h or more) for high-speed links, even if variants with lower top speeds can be manufactured for the conventional network

- Tractive power for fast acceleration (0.6-0.8 m/s^2)
- Track-friendly bogies
- Tilting, developed technology to reduce travel sickness
- Improved and active lateral suspension (ALS) for increased comfort (and increased carbody width) on non-perfect track at high speeds.

Short, punctual stops

The train is dimensioned for short dwell times even during peak load periods and a lower standard deviation regarding dwell times.

- At least two single doors at wither side of the car (can also be located as a double-door with a pole between, one single door per 40-50 seats)
- Approx. 90 cm free door opening for single doors, as few steps as possible
- Entry lift for disabled travellers (travellers with especially heavy luggage, prams, wheelchairs)
- Aisles in saloons with possibilities to pass (at least 54 cm wide but 60-70 cm for passing)
- Several separate luggage racks for heavy luggage in the saloons (1.2-1.5 metres of rack per 10 seats), including space for prams.

Economic

Efficient space utilisation

Low fares for the travellers make the train attractive and low costs for the operators improve the economy of train traffic. It is important to use the space on board efficiently, including from the energy perspective.

- A wide carbody (2+2 seating in first class, 2+3 seating in economy class, an interior width of at least 3.30 m to permit individual armrests at all seats
- The walls should be thin, 10 cm by way of suggestion, to achieve greater interior width
- Modified lateral suspension and Hold-off device (HOD) for a 9 cm wider carbody than the Regina train
- Exterior width of 3.54 m is possible for traffic in Sweden, Norway and (preliminarily) Denmark
- Efficient seats with thin backrests and legroom under the seat in front
- Space under the cushion for hand luggage
- Flexible seats that can be sold as economy class, or first class by folding down the backrest and using it as a table.

Reliable and maintenance-friendly

The number of faults on the train must be minimised and operational and maintenance measures must be able to be carried out at intervals that suit the traffic, for example once a day during the night or during weekends. An operationally reliable train reduces costs and also means that the train is more attractive to the travellers though reduced delays.

- System redundancy, back-up systems for secure operation and a minimum of faults that stop the train
- System redundancy for equipment is critical for travellers, such as lighting, heating/cooling, ventilation, toilets and doors
- Functions in winter weather with varying temperatures between plus degrees (especially in long tunnels) with rain and sub-zero temperatures on the same journey Temperature intervals (air) from +35°C to −40°C
- De-icing with hot fluids possible
- Dimensioned for collisions with large animals such as elks and deer, with fast replacement of any damaged parts.
- Maintenance-friendly design for long maintenance intervals and fast replacement of parts

- Electric brake as normal operating brake, for reduced wear on the mechanical brake
- Moderate adhesion utilisation with at least 50% driven axles, for reliable acceleration and braking and minimum wear to wheels.

Flexible

Short train units with fast coupling and uncoupling to meet variations in demand over the day, week and season, and the possibility to reconfigure the train for different types of traffic.

- Basic design with good comfort (see below) that can be lengthened or reconfigured for different types of traffic
- 300 seats (four cars, 108 m train length) in long-distance traffic, 250 km/h or more
- 230-240 seats (three cars, 81 m train length) in long-distance regional traffic, 220-250 km/h
- Technical platform allows operation of multiple units in various combinations up to 400 m train length
- Coupling and uncoupling functions in all weathers, coupling to be protected from snow and ice
- Fast uncoupling and coupling, also includes turnaround, on-board computers and brake test. One person shall be able to couple/uncouple two units in 60 s at most. Start-up and brake test desirable in at most 60 s.
- Current collection with approx. 100 m (four-car trains) or 70 m (three-car trains) between active pantographs.

Environmentally friendly

The most important “green” characteristic is that Gröna Tåget will be attractive and invite travellers to take the train instead of the car or air. Gröna Tåget is assumed to be electrically powered using electricity generated with on average low carbon dioxide emissions (Nordic electricity mix, northern European in the long-term). There are a number of direct design measures that are also important as regards the train’s environmental performance.

- Increased regeneration when braking, high tractive output for efficient electric braking
- Driver support for eco-driving
- Improved aerodynamic design (low air resistance)
- Improved energy-efficiency, reduced losses and simplified motor cooling

- Efficient space utilisation (see Economic)
- Low external noise emissions – better at 250 km/h than today's trains at lower speeds
- Low particle emissions thanks to a large proportion of electric braking and bogies with low wheel and rail wear.

Safe

- Brake performance adapted to the Scandinavian signalling systems on existing lines
- Design of interior furnishing and luggage storage that can withstand an accident without unnecessary personal injuries and allows simple evacuation of the train
- Derailment protection that contributes to keep the train upright on the track after a possible derailment.

References

Printed sources

Ahern, A. A., Tapley, N., 2008. The use of stated preference techniques to model modal choices on interurban trips in Ireland. *Transportation Research Part A* 42, 15-27

Åkerman, J., Höjer, M., 2006. How much transport can the climate stand? Sweden on a sustainable path in 2050. *Energy policy* 34, 1944-1957

Andersen, D. H., 2005. Notat ref. 03/09466, 03.01.2005. Norwegian National Rail Administration, Oslo

Andersen, D. H., 2008a. Notat ref. 07/04705, 09.01.2008. Norwegian National Rail Administration, Oslo

Andersen, D. H., 2008b. Notat ref. 07/04705, 17.01.2008. Norwegian National Rail Administration, Oslo

Andersson, E., 2012: Green Train. Concept proposal for a Scandinavian high-speed train. Final report, part B. KTH Railway group publication 12-02, Stockholm

Andersson, E., och Lukaszewicz, P., 2006. Energy consumption and related air pollution for Scandinavian electric passenger trains. KTH, report TRITA-AVE 2006:46. Stockholm

Babikian, R, Lukachko, S., Waitz, I. A., 2002. The historical fuel efficiency characteristics of regional aircraft from technological, operational, and cost perspectives. *Journal of Air Transport Management* 8, 389-400

Banedanmark's Netredegørelse/Network statement 2012 <www.Banedanmark.dk>

Banenorm BN1-154-2 (Marts 2008). Banedanmark, Copenhagen

Bel, G., 1997. Changes in travel time across modes and its impact on the demand for inter-urban rail travel. *Transportation Research Part E* 33, 43-52

Beräkningshandledning, *Calculation guide*, 2009 BVH 706. National Rail Administration (Banverket), Borlänge

Brabie, D., 2007. On derailment-worthiness in rail vehicle design. Doctoral thesis. KTH TRITA AVE 2007:78, Stockholm

Claesson, Å., Lindh, C., 1992. Fjärrtågens punktlighet i persontrafiken. *(Long-distance trains' punctuality in passenger traffic)* KTH TRITA-TPL-92-12-86. Stockholm

Dimgård, M., Jansson, A., Kecklund, L., 2009. Dagens och morgondagens stödsystem i tågförarmiljöer (in Swedish). *(Today's and tomorrow's support systems in train driver environments)* Report MTO Safety, Stockholm

Dimgård, M., Kecklund, L., 2010. Erfarenheterna av ett tågprojekt. *(Experiences from a train project)* Report MTO Safety, Stockholm

Dobruszkes, F., 2006. An analysis of European low-cost airlines and their networks. *Journal of Transport Geography* 14, 249-264

Doganis, R., 2001. The airline business in the 21st century. Routledge, London, New York

Doganis, R., 2002. Flying off course. Routledge, London, New York

DSB Annual report 2010. Copenhagen

Effektiva tågsystem för framtida persontrafik, 1997. *(Efficient Train Systems for Future Passenger Traffic)* KTH Railway Group, published Feb. 1197, reprinted May 1999. Stockholm

Eisenbahn-Bau- und Betriebsordnung (EBO)Anlage 4 EBO(Verordnung) Gleisabstand. <www.bundesrecht24.de>, access 2011-03-24

Eisenkopf, A., 2005. Competition between low cost carriers and railways in Germany. *Proceedings of the Third Conference on Railroad Industry Structure, Competition and Investment*. Stockholm School of Economics

EN 15273-2:2010 Railway applications – Gauges – Part 2: Rolling stock gauges

ERTMS i Sverige, 2009. Folder, Banverket

Fahlén, J. and Jonsson, B., 2005. Train punctuality in a new perspective. *European Railway Review* 11, 60-63

Finnish Network Statement 2012 (10 December 2010). Helsinki

Förstberg, J., 1996. Motion-related comfort levels in trains: A study of human response to different tilt control strategies for high-speed trains. Licentiate Thesis TRITA-FKT Report 1996:41. KTH, Stockholm (also published as Särtryck 274-1997. VTI, Linköping)

Förstberg, J., 2000. Ride comfort and motion sickness in tilting trains. Doctoral thesis. KTH TRITA AVE 2000:28, Stockholm

Franke, M., 2004. Competition between network carriers and low-cost carriers – or breakthrough to a new level of efficiency? *Journal of Air Transport Management* 10, 15-21

Fröidh, O., 2003. Introduktion av regionala snabbtåg. (*Introduction of fast regional trains.) A study of the Svealand Line's impact on the travel market, travel behaviour and accessibility.)* KTH, Stockholm

Fröidh, O., 2005. Market effects of regional high-speed trains on the Svealand line. *Journal of Transport Geography* 13, 352-361

Fröidh, O., 2008. Perspectives for a future high-speed train in the Swedish domestic travel market. *Journal of Transport Geography* 16, 268-277

Fröidh, O., 2009. The 'Gröna Tåget' project – an activity approach for information and communication technologies. I *Green and ITS*, 106-115. Sweco, Stockholm

Fröidh, O., 2010. Resande och trafik med Gröna Tåget. *(Travel and traffic with Gröna Tåget.)* KTH Railway Group, Publication 1001. Stockholm

Fröidh, O., Jansson, T., 2005. Kapacitetsanalys av två principutformningar av bansystemet på Ostlänken. *(Capacity analysis of two principle designs of the track system on the Eastern Link.)* KTH, Stockholm

Fröidh, O., Kottenhoff, K., 2009. Resandet längs Blekinge kustbana före, under och efter elektrifieringen. *(Travel on the Blekinge Coastal Line before, during and after electrification.)* KTH, Stockholm

Fröidh, O., Lindfeldt, O., 2008. Svealandsbanans första 10 år – erfarenheter för framtiden av tågtrafiken och resandet *(The Svealand Line's first ten years – experiences for the future from train traffic and travel)*. KTH, Stockholm

Fröidh, O., Persson, R., 2011. Säkerhetsmarginal för trafik med breda tåg i Danmark (in Swedish). *(Safety margins for traffic with wide-bodied trains in Denmark)* PM 2011-06-21, not published

Gröna Tåget Trains for tomorrow's travellers, 2010. Folder. Trafikverket, Bombardier Transportation and KTH

Heinz, W., Kottenhoff, K., 2001. Effektiva handikappreducerande fordon – järnvägsfordon som på ett ekonomiskt sätt reducerar tågresenärers handikapp *(Efficient handicap-reducing vehicles – railway vehicles that reduce train travellers' handicaps in an economic way)*. KTH TRITA-IP AR 01-93A. Stockholm

Heinz, W., 2003. Passenger service times on trains. Licentiate Thesis TRITA-FKT Report 03:-62. Stockholm

Hofton, A., 2006. Up-date of the domestic passenger cost model to 2005 levels (Final report, February 2006). Airline Dynamics Consulting, UK

Höghastighetsbanor – ett samhällsbygge för stärkt utveckling och konkurrenskraft *(High-speed lines – a construction for society to strengthen development and competitiveness)* (2009). SOU 2009:74

Höghastighetsbanor i Sverige, 2010. Trafikprognoser och samhällsekonomiska kalkyler med Samvips-metoden *(High-speed lines in Sweden. Traffic forecasts and socio-economic calculations using the Samvips method)*. Technical report. KTH, Stockholm

Holgersson, Forsberg and Saveman, 2012. Inre säkerheten i tåg eftersatt (*Internal safety in trains neglected*). *Läkartidningen* 109 (1-2), 24-26

Järnvägsnätsbeskrivning, 2011. Network Statement 2011 (published 13/12/2009). National Rail Administration (Banverket), Borlänge

Jernbaneverket, 2008. Jernbaneverket arbeider for enhetlige stasjoner *(The Norwegian National Rail Administration is working for uniform stations)*. [www.jernbaneverket.no] 2008-08-21

Khan, S., Sundberg, F., 2002. Passenger train interiors concerning baggage, clothes and use of tables. KTH TRITA-FKT report 2002:34. Stockholm

Kottenhoff, K., 1999. Evaluation of passenger train concepts (doctoral thesis). KTH TRITA-IP FR 99-48. Stockholm

Kottenhoff, K., 2002. Utvärdering av behov av första klass i Mälardalen *(Evaluation of the need for first class in the Lake Mälaren Valley*. Commissioned report for SJ (not published). KTH, Stockholm

Kottenhoff, K., Andersson, E., 2009. Attractive and efficient train interiors. KTH Railway Group, Publication 0903. Stockholm

Kottenhoff, K., Byström, C., 2010. När resenärerna själva får välja *(When the travellers themselves can choose)*. Compilation of attitudes, perceptions and valuations. KTH, TRITA-TEC-RR 10-001, Stockholm

Lindfeldt, A., 2011. Investigating the impact of timetable properties on delay propagation on a double-track line using extensive simulation. Proceedings of Railway Engineering 2011, London

Lindfeldt, O., 2009. Kapacitet för godståg på Västra och Södra stambanan efter uppgradering till sth 250 km/h *(Capacity for freight trains on the Western and Southern main lines after upgrading for 250 km/h)*. PM, 2009-06-01. KTH, Stockholm

Lindfeldt, O., 2010. Railway operation analysis. Doctoral thesis. KTH, TRITA-TEC-PHD 10-001, Stockholm

Lukaszewicz, P., Andersson, E., 2009. Green Train energy consumption. Estimations on high-speed rail operations. KTH Railway Group, Publication 0901. Stockholm

Lundberg, O., Eriksson, D., Ranvinge, M., 2010. Design and innovation for rail vehicles. Konstfack, Stockholm

Lythgoe, W. F., Wardman, M., 2002. Demand for rail travel to and from airports. *Transportation* 29, 125-143

Mårdh, S. et al. 2010. Gröna Tåget – förarplats *(Gröna Tåget – driver's cab)*. Final report VTI, Linköping

Martin, J. C., Nombela, G., 2007. Microeconomic impacts of high-speed trains in Spain. *The annals of regional science* 41, 107-119

Mayer, R. J. P., 2005. Replacing feeder flights with high-speed trains in Europe: An economic analysis. MSc Thesis, Cranfield University, Cranfield

Mohring, H., 1972. Optimization and scale economies in urban bus transportation. *American Economic Review* 62 (4), 591–604

Nationell plan för transportsystemet 2010-2021, Förslag till, 2009. *(Proposal for a National Plan for the Transport System 2010-2021)*. National Road Administration, National Rail Administration, Swedish Maritime Administration

Nelldal, B.-L., 1998. The experience of the X2000 tilting train and its effect on the market. *Proceedings of the Institution of Mechanical Engineers Part F* 212, 103-108

Nelldal, B.-L., 2005a. Konkurrensen tåg-flyg Stockholm–Gothenburg *(Competition between rail and air Stockholm–Gothenburg)*. PM (underlag för Banverkets sektorsrapport) *(Basis for National Rail Administration's Sector Report)*, 2004)

Nelldal, B.-L., 2005b. Vidareutveckling av elasticitetsmodell *(Further development of an elasticity model)*. PM 2005-05-18, KTH

Nelldal, B.-L., Kottenhoff, K., Lind, G., Rosenlind, S. and Troche, G., 1996. Tågtrafikens möjligheter på den framtida resemarknaden *(Train traffic's possibilities in the future travel market)*. KTH, Stockholm

Nelldal, B.-L., Troche, G, 2010. Utveckling av utbud och priser på järnvägslinjer i Sverige 1990-2009 samt utvecklingen av persontrafiken i ett långsiktigt perspektiv *(Development of supply and prices on railway lines in Sweden 1990-2009).* KTH TRITA-TEC-RR 10-007, Stockholm

Network statement 2013. 10th edition, 1 December 2011. Norwegian National Rail Administration, Oslo

NSB AS annual report 2010. Oslo

Oanda, 2011. Oanda currency converter <http://www.oanda.com/currency/historical-rates/> Access 28/12/2011

Ökad spårtrafik utvecklar Sverige, 2009. *(Increased track-bound traffic develops Sweden)* Slutrapport Långsiktiga Spåret *(Final report).* IVA-M 414. Royal Swedish Academy of Engineering Sciences, Stockholm

Olsson, N., Sætermo, I.A.F. and Røstad, C.C., 2002. Konsekvensvurdering av anleggsarbeid i Vestkorridoren *(Consequence evaluation of construction work in the western corridor).* Trondheim: SINTEF Teknologiledelse

Olsson, N.O.E. and Haugland, H., 2004. Influencing factors on train punctuality – results from some Norwegian studies. *Transport Policy* 11, 387-397

Olsson, N. and Veiseth, M., 2011. *Jernbanetrafikk*. Trondheim: Tapir akademisk forlag

Pavaux, J., 1991. Rail/air complementarity in Europe. The impact of high-speed train services. Institute of Air Transport, Paris

Persson, R., 2011. Tilting trains. Enhanced benefits and strategies for less motion sickness. Doctoral thesis. KTH TRITA AVE 2011:26, Stockholm

Pettersson, P., 2011. Passenger waiting strategies on railway platforms. Effects of information and platform facilities. Master thesis. KTH, Stockholm

Rosenlind, S., Lind, G., Troche, G., 2001. LIME, model for capacity utilisation and profitability of a railway line. KTH TRITA-IP FR 01-99, Stockholm

Rüger, B., 2004. Reisegepäck im Eisenbahnverkehr. Doctoral Thesis, Vienna University of Technology

Rüger, B., 2006. Entrance situation of passenger cars—efficiency, attractiveness and operating problems. *Towards the competitive rail systems in Europe*. Conference paper at EURNEX-ZEL 2006, Zilina

Rüger, B., 2007. Optimierungspotenziale in Fernreisezugwaggons. *ETR* 4/2007, 182-185

Samferdseldepartementet, 2010. (Ministry of Transport and Communications) Mandat for videre utredning av højhastighetsjernbane i Norge *(Mandate for further study of high-speed railways in Norway).* Letter to the Norwegian National Rail Administration, reg. no. 09/856-LK. 19/02/2010

Samhällsekonomiska principer och kalkylvärden för transportsektorn: ASEK 4 (2008). *(Socio-economic principles and standard values for the transport sector)* SIKA report 2008:3

Seabright, P. (red.), 2003. The economics of passenger rail transport. A survey. IDEI Report 1, Rail Transport, Toulouse

Sipilä, H., 2008. Körtidsberäkningar för Gröna Tåget *(Running time calculations for Gröna Tåget).* KTH Railway Group Report no. 0802 Stockholm

Sipilä, H., 2010. Tidtabellsläggning med hjälp av simulering. *(Timetabling with the aid of simulation)* KTH TRITA-TEC-RR 09-007. Stockholm

Sipilä, H. and Warg, J. (planned 2012). Kapacitetsanalys av Södra stambanan (in Swedish). *(Capacity analyses of the the Southern Main Line)* KTH, Stockholm

Small, K. A., 1992. Urban transportation economics. Harwood Academic publishers, Chur

SJ AB annual report 2010. Stockholm

Södra stambanan, högre hastighet, 2009. *(Southern Main Line, higher speeds)* Concept study of Gripenberg–Lund Section. National Rail Administration (Banverket) (reg. no. F07-15662/SA20)

Taktfast tågtrafik – Effekter av styv tidtabell på järnväg, 2010. *(Regular train traffic – Effects of fixed interval timetables on the railway)* Report 2009:73. Trivector Traffic, Lund

Troche, G., 1999. Efficient night-train traffic – problems and prospects. KTH, Stockholm

TSI CR Control command, 2006. Technical Specifications for Interoperability: Conventional railways – Control-command and signalling

TSI HS Control command, 2006. Technical Specifications for Interoperability: High-speed – Control-command and signalling

TSI HS INS, 2008. Technical Specifications for Interoperability: High-speed – Infrastructure

TSI HS PRM, 2008. Technical Specifications for Interoperability: High-speed Persons with reduced mobility

Tuna, D., 2008. Fahrgastwechselzeit im Personenfernverkehr. Diploma Thesis, Vienna University of Technology

VR Group annual report 2010. Helsinki

Värden och metoder för transportsektorns samhällsekonomiska analyser *(Values and methods for the transport sector's socio-economic analyses)* – ASEK 4 (2009). SIKA rapport 2009:3

Wardman, M., 2006. Demand for rail travel and the effects of external factors. *Transportation Research Part E* 42, 129-148

Correspondence and web and personal contact

Net Rail Denmark (2011) <www.bane.dk>, access 9/12/2011

Hauenstein, Bernhard. SBB. E-mail 15/04/2011

Mägi, Johan, SJ AB. Interview on 8/3/2010

PFF, 2011. Programrådet för fordonsforskning *(Programme Board for Vehicle Research)* <www.pff.nu>, access 2011-12-23

Sollander, Stefan. The Swedish Transport Agency E-mail 4/11/2009

Trafikverket, inventering av spåravstånd. E-mail 15/04/2011

The Green Train (in Swedish "Gröna Tåget") is a high-speed train concept, that is economical, environmentally friendly and attractive to travellers. It is suited to specific Nordic conditions with a harsh winter climate, often varying demand and mixed passenger and freight operations on non-perfect track. The main proposal is a train for speeds up to 250 km/h equipped with carbody tilt for short travelling times on electrified mainlines. The concept is intended to be a flexible platform for long-distance and fast regional passenger trains, interoperable in Scandinavia.

The Gröna Tåget programme delivers a collection of ideas, proposals and technical solutions for rail operators, infrastructure managers and industry. This is part A of the final report, dealing with market, economy and service aspects, with an emphasis on the areas where research has been done within the Gröna Tåget research and development programme.

Other summary reports deal with the concept's functional requirements from a technical and economic perspective (Final report, part B), as well as a design for an attractive, efficient and innovative train from a traveller's point of view.

ISBN 978-91-7501-232-2