Roadmap for
Gröna Tåget 2 – next steps
Summary

The Gröna Tåget 2 roadmap is part of a comprehensive set of roadmaps commissioned by the Swedish “Forum for innovation in the transport sector”. It is written by a group consisting of members from academia, the system integrator Bombardier, SJ, Vectura and Trafikverket. It focuses on longer distance (regional and inter-regional) passenger train services as part of a multi-modal, or co-modal, transport chain.

The aim of the roadmap is to suggest ideas and solutions for a future Swedish high-speed concept that delivers end customer value, satisfies societal sustainability requirements and is affordable. Based on the customer's current and future needs the passenger train service must be much more attractive, reliable and efficient. At the same time the improved traffic solution must also be commercially viable for the operators and acceptable for infrastructure managers. The roadmap focuses on the train and its interaction with the infrastructure. An action plan for a gradual realisation of a Swedish Green Train high-speed concept by 2020 is suggested. This includes introduction of C-Class trains by 2015 and Demonstrator 2015-2020.

One major merit of the concept is that it can be implemented incrementally in today’s railway system without major infrastructure investment. Examples of related research and innovation challenges related to comfortable journeys are e.g. acoustic comfort and improved interior design for example enabled by wide car body concepts. Further challenges that have to be addressed are bogie designs that allow higher speeds on existing non-perfect tracks. Such bogies need to have low track attrition properties while simultaneously providing good passenger comfort. Aerodynamic design for low energy consumption, low slipstream effects for platform passages at high speed, and cross wind stability are needed. Train and station facilities should be accessible for people with reduced mobility. Reduction of travel times implies reducing stop times at stations by improved boarding facilities. Further, train performance parameters such as acceleration, braking and higher speeds on existing lines must be considered.

In the socio-economic calculations, 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, 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.

There are great possibilities to introduce solutions incrementally where benefits are obtained at each step. The majority of the solutions may be applied in existing systems also internationally, which paves the way for export business opportunities.

For the finance contribution of the program the possibilities from VINNOVA, Energimyndigheten and Trafikverket needs to be discussed. On the international arena this program may also fit well for cooperation to EU programs i.e Shift²Rail.
Time and Activity plan for a new high speed train

C-Class train  2015

- Active lateral and vertical suspension
- A light tilt system including a train positioning system
- Update of regulations and standards for the introduction of a new vehicle class.
- Winter design
- Reliability of strategic systems
- Reliable energy supply and current collection
- Materials and fire safety
- Condition based maintenance

Technologies for a reliable train 2020

- Winter design
- Reliability of strategic systems
- Reliable energy supply and current collection
- Materials and fire safety
- Condition based maintenance

Technologies for a comfortable train 2018

- Sound scapes
- Flexible interior designs
- Better vibration comfort
- Accessibility for people with reduced mobility
- Thin wall technologies for more inner space

Technologies for an energy efficient train 2018

- Aerodynamic optimization
- Energy efficient traction
- Energy efficient power supply
- Lighter trains by new carbody design (sandwich)
- More passengers per meter by thin wall technologies.

Gröna Tåget Demonstrator 2015-2020

Development of business case 2013-2017

The above suggested activities means that a new innovative high speed train concept can be commercially available to the market in 2020.
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1 Introduction

1.1 Background and motivation

The Gröna Tåget 2 roadmap is part of a comprehensive set of roadmaps commissioned by the Swedish “Forum for innovation in the transport sector”. The aim of the Forum’s roadmap exercises is to create a consensual common picture on what is needed in terms of research, demonstrations and changes in regulatory framework to achieve an efficient integrated transport system that meets societal challenges of economic and environmental sustainability whilst strengthening Swedish industrial competitiveness in general and the transport sector in particular.

The focus of the Gröna Tåget 2 roadmap is to suggest ideas and solutions for a future Swedish high-speed concept that delivers end-customer value, satisfies societal sustainability requirements and is affordable. The roadmap focuses on the train and its interaction with the infrastructure whilst recognising that a high speed concept is part of a door to door proposition in which the constituent parts must adequately and qualitatively interconnect seamlessly i.e. ticketing, passenger information systems, safe, secure, well maintained and appropriately designed station and track facilities, capacity management etc.

The roadmap suggests an action plan for a gradual realisation of a Swedish Green Train high-speed concept by 2030. One major merit of the concept is that it can be implemented incrementally in today’s railway system without major infrastructure investment. Examples of this are new interior design concepts with personalized adaptive sound zones and improved suspension, new or improved accessibility solutions for people with reduced mobility and bogie designs for better comfort and lower wheel and rail wear.

1.2 Performance of the work

A group consisting of members from academia, the system integrator Bombardier, and Trafikverket has written the Gröna Tåget 2 roadmap. The group has held regular meetings and workshops. The roadmap is based on results from the earlier Gröna Tåget programme and strategic documents such as the Railroute 2050, the ERRAC roadmaps and the Horizon 2020 draft.

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- Roger Lundén, Chalmers
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- Jan Lundberg, LTU
- Diego Galar, LTU
- Filip Kjellgren, VINNOVA
2 Common vision

The railway is an integral part of the transport system. It is often interdependent with other modes in delivering door-to-door transport services. This roadmap focuses on longer distance (regional and inter-regional) passenger train services as part of a multi-modal, or co-modal, transport chain. If longer distance passenger services are to increase their competitive advantage over other modes they must deliver increased customer satisfaction. Based on the customer’s current and future needs the passenger train service must be much more attractive, reliable, efficient and affordable. At the same time improved traffic solutions must be commercially viable for the operators and acceptable to infrastructure managers. Realising these goals is vital in achieving the better connectivity in Europe that is required to deliver sustainable economic growth and integration of the European regions.

This has implications for three areas of activity in particular:

• developing ways of ensuring that passengers are not deterred from using the rail system (physical ease of access, perceived threats to personal security, journey information and payment systems, prices and reliability of services etc.),
• promoting complementarity between different types of rail services and between these services and other modes (e.g. forging seamless links between high speed rail and urban transit systems)
• developing inter-connectivity between information systems. This issue will not be explored in this roadmap but is mentioned for the sake of comprehensiveness.

A major policy driver is the theme that “People are at the centre of EU transport policy”, which underscores the European Commission’s latest Transport White Paper [1]. The White Paper sets out a comprehensive strategy (Transport 2050) for a competitive transport. The strategy is intended to increase mobility, remove major barriers in key areas, fuel growth and employment, reduce Europe’s dependence on imported oil and secure a cut in carbon emissions from transport activities by 2050 of around 70% compared to 2008 levels.

Rail transportation is a key area in this strategy. However, if rail is to be the mode of choice for medium-distance journeys it must be appealing to end users and offer a service that dovetails with other modes in offering seamless end-to-end journeys. It must be reliable, affordable, and offer passengers the right services at the right time. This includes passengers with reduced mobility and passengers who are unfamiliar with rail travel, as well as premium-fare business travellers who use the train as an extension of their office.

The Gröna Tåget 2 roadmap bases its recommendations on the customer-value propositions described above. In developing the outline of the roadmap they have been broken down in terms of the detailed technical and design solutions that are required to fulfil the operational demands related to passenger requirements.

2.1 What should be achieved?

TX The end-customer value proposition in the Gröna Tåget 2 roadmap is to offer a comfortable and reliable journey with competitive travel times at an affordable price. The proposition must also be commercially viable for the operators and acceptable to infrastructure managers. Examples of related research and innovation challenges related to comfortable journeys include acoustic comfort and improved interior design enabled by wide car body concepts. Train and station facilities should be more accessible for people
with reduced mobility. Here we will continue the “mobility for all” principle that guided the previous Gröna Tåget programme. Reduction of travel times implies reduced stop times at stations, enabled by improved boarding facilities. Further, train performance parameters such as acceleration, braking and higher speeds on existing lines must be considered. Realising these may give rise to address the potential impact of additional weight if reliability is to be maintained or improved. In addition, from a life-cycle cost perspective, the solutions derived must be cost efficient if affordable travel is to be possible.

Increasing the environmental performance of the Gröna Tåget 2 concept requires further progress in lowering energy consumption through new traction motors, better aerodynamic design and lighter car bodies. Further external and internal noise and vibrations need to be addressed. In addition, the aim is that more than 95% of employed materials should be recyclable.

A major hurdle for any high-speed concept is the huge costs for construction of new infrastructure. Standard dedicated high-speed lines require perfect and tangent tracks. Thus, a high-speed line often requires major civil engineering works and major investments in bridges and tunnels. The Swedish X2000 concept was an approach where a more sophisticated train was developed that was able to run at higher speeds on upgraded existing lines. The Swedish Gröna Tåget high-speed concept takes this approach further by developing a train that requires less costly infrastructure investments, and that can run on tracks that will also be accessible for freight trains. Some of the technology challenges that have to be addressed here are bogie designs that allow higher speeds on existing non-perfect tracks. Such bogies need to have low track attrition properties while simultaneously providing good passenger comfort. Aerodynamic design for low energy consumption, low slipstream effects when passing platforms at high speed, and cross wind stability are further needed. In addition pressure tightness is necessary for passenger comfort at speeds above 200 km/h in tunnels and when there is a significant change in elevation.

Gröna Tåget will allow for an increased operational flexibility due to its ability to run on lines that are not dedicated for high-speed traffic. It also allows for the adaptation in response to changing demand of train length.

Finally, solutions developed in Gröna Tåget must be analysed and optimized from a maintenance point of view. Implications for the reliability and maintainability of the vehicles and the infrastructure must be considered to ensure high capacity utilisation. This is especially important in a multi-stakeholder environment where the relationship between each actor is governed by contractual obligations. Maintenance actions should also be predictable and efficient so that maintenance can be scheduled during off-peak hours, and operational failures should be minimized through an increased monitoring of the assert condition.
Fulfillment of the identified overall project goals is summarized in Table 1.

Table 1  Fulfillment of goals

| Illustration by Lundberg, Nybacka |

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2.2  Contribution to the Forum’s vision

The Transport 2030 project was undertaken during 2009-2011 with participants from industry, academia and government. The mission was to develop an overview of how the transport sector will develop until 2030. One of the results of Transport 2030 was identification of the perceived need for increased cooperation between transport stakeholders to achieve a sustainable transport system. No player can single-handedly make the changes necessary to achieve the established goals for the transport system. The necessary cooperation needs to be based on a common strategic foundation, and Transport 2030 suggested that a national forum for collaboration on policy development in the transport sector should be established. Furthermore, the transport research investigation SOU 2010:74 draws the same conclusion, and states in its final report: “Forum for continuous dialogue and collaboration between public and private partners should be established with a broad composition”.
3 Gap analysis

This chapter summarises the technology gaps that need bridging to achieve the customer values introduced above. Each technology gap is linked with a specific customer value, although most (if not all) of the developments contribute to several customer values.

3.1 Costumer Value: “Shorter travel time”

There is a strong relationship between rail’s ability to attract passenger share and train speed. Here it is important to mention that it is not the maximum train speed that is important. Assuming as low travel time door to door as possible, the average speed between the start and end point of the journey is much more important factor to take into account.

Further, vehicle speed needs to be related to the cost of implementation and the resulting energy consumption, train/track deterioration and passenger comfort. Therefore it is not obvious that dedicated high-speed lines are the best solution for Sweden – at least not from a short-term perspective. Technology gaps addressed below are capable of relatively speedy implementation without the need to build dedicated high-speed lines for 300 km/h or more. At the same it may be noted that all the technology solutions proposed should be compatible with the design for future passenger high speed trains when the high-speed network is eventually brought into service.

3.1.1 New vehicle class for shorter travel times with light carbody tilt

In Sweden three vehicle classes exist today, i.e. class A, B and S. The classes define the permitted cant deficiency when negotiating curves (which essentially limits speed in curves for the vehicle). Class A, with 100 mm of permitted cant deficiency, is mainly for freight wagons and some locomotives. Class B, for passenger vehicles with track friendly running gear, allows for 150 mm, while class S allows trains with carbody tilt to run at 245 mm cant deficiency. In addition to track friendly running gear Class S also requires carbody tilt since
the lateral acceleration would otherwise lead to comfort levels that are unacceptable for passengers.

In our opinion an additional vehicle class between B and S should be introduced. This vehicle class would allow for 185 mm cant deficiency without the requirement of full carbody tilt. Passenger ride comfort can still be ensured if a hold-off device (cf. section 3.5.3.1) that avoids bump stop contact is implemented. Further, an active vertical suspension can compensate for the carbody roll motion (light carbody tilt) that increases the lateral acceleration felt by the passengers. As a proof-of-concept, the bogies in the tested Regina 250 vehicle provide track force levels that are low enough to meet existing standards.

The technical pre-conditions exist today. Additional validation tests are needed together with a modification of existing regulations, i.e. the mentioned introduction of a new vehicle class. The main benefit for passengers would be travel times in the same range as with today’s X2000 train, but without active carbody tilt. This would make the trains cheaper, more maintenance-friendly and reduce the number of persons with motion sickness.
3.1.2 Pantograph catenary interaction

During the first phase of the Gröna Tåget programme, a concept was proposed which included shorter train-sets of about 110 m length that can be run in multiple with up to three units. Relating to today’s technology level this implies that each unit has to be equipped with a pantograph. However, multiple pantograph contact with only 110 m between pantographs at 250 km/h or above is a challenge for the dynamic interaction between pantograph and catenary: The first pantograph excites the catenary resulting in larger contact force variations for the following pantographs. The risk of poorer current collection and arcing increases significantly, cf. Figure 1.

On newly built lines high-speed catenary systems are likely to be installed. However for higher speeds on existing lines the dynamic interaction between pantograph and catenary needs to be improved. Potential solutions are stiffer catenary or better (possibly actively controlled) pantographs. The development of an optimal solution requires further investigation. Another issue is how to design insulated sections that works well also for multiple pantographs and how to handle the European TSI limit of length between pantographs.

The contribution to external noise of sound emission from pantographs at higher speeds (cf. Section 3.4.5) must be reduced as much as possible. Further, solutions must be found to the wear of carbon strips during winter caused by frost/ice must to improve reliability. This requires either an improved design of the pantograph, and/or more precise supervision or inspection/prediction to perform maintenance before failure.

Figure 1 Contact force variation as function of travelled distance at 240 km/h. a) first pantograph b) second pantograph c) third pantograph [1].

3.1.3 Aerodynamics for train speeds between 250 and 350 km/h

Requirements for reducing energy consumption as a part in improving the environmental performance are increasing. This includes reduced aerodynamic drag and more energy efficient traction. At the same time, design solutions need to address both winter and summer conditions to achieve reliability, performance and to add value for the customers.
Traditionally, aerodynamic performance has been evaluated in wind tunnels. However, this approach is rather costly and time consuming. Further, in many cases due to the large number of possible designs it is unlikely that the truly optimal design can be found without assistance of automatic tools. Today computer-aided engineering (CAE) tools are used to optimize aerodynamic performance of rail vehicles.

The aim of this project is to take multi-objective optimization, which has shown its success in the development of Gröna Tåget 1, to the next level by adding a truly multi-disciplinary approach as well as robustness to the design loop. Here also operational reliability is taken into account early in the design phase cf. Section 3.3.4.

The next step is to include a sensitivity analysis into the optimization loop in order to ensure the product performance. In order to succeed further development regarding the prediction methods is necessary. In particular the challenging Scandinavian environmental conditions need to be addressed here.

The following focus areas have been identified in this context:

### 3.1.3.1 Aerodynamic drag

Aerodynamic drag is directly linked to a vehicle’s energy consumption. For a high speed vehicle, not only the design of a front contributes to the aerodynamic drag. Features like the shape of inter-car gaps, the under-frame, and the coupling of multiple units also have an increasing impact on performance. Therefore, further development that focuses on accurate prediction and captures the time-dependent character of these phenomena is needed to improve the accuracy and achieve best performance and operational reliability.

### 3.1.3.2 Contact forces at pantographs

Research should focus on the simulation of the flow field around the pantograph, with special focus to multiple unit operation. The results will provide input to subsequent contact force computations. As the flow field is highly turbulent, further research is needed to be able to compute the flow field with sufficient accuracy.

### 3.1.3.3 Pressure tight vehicles

As mentioned above higher-speed operations increase requirements on pressure tight vehicles. This issue needs to be addressed in the project.
3.2 Customer value: “Reliable journey”

Reliable journeys are valued very highly by customers and are a pre-condition to attracting business travellers. Often a somewhat longer journey time is acceptable as long as the train arrives on time. Railway traffic is a very complex system with generally higher capacity, but lower flexibility than comparable modes of transportation. Since trains are bound to the rail system, the failure rate of both the trains and the rail system has to be extremely low. Customers also expect the trains to arrive on time, irrespective of the weather. In what follows we point out some developments we regard as crucial to achieve a cost-efficient increase in the reliability of train traffic.

3.2.1 Experience feedback testing of new technologies

New technologies may introduce unknown challenges regarding reliability and robustness of the railway system. To reveal such potential issues it is crucial to expose the new technology to realistic operational conditions, i.e. experience feedback testing.

The experiences from “Gröna Tåget 1” show that verification of the reliability of new technology is an essential key to success (See, for example, Gröna Tåget [13] p102 (and references), p142-3, 159 et seq, 187, 188). As an example of experience feedback testing active lateral suspension, permanent magnet motors and the radial steering bogies have been running in passenger traffic for over 500 000 km including two harsh winters. During this period a number of minor issues were identified and corrective actions taken.

It is suggested that tests should be carried out; first functional testing, then service without passenger and finally commercial services. These tests require close co-operation between authorities, operators and maintenance providers. Firstly safe operation with the new technology needs to be proven for the relevant authorities, secondly it needs to be proven to the operator that it will not disturb the operation, and thirdly support and understanding from the maintenance workshop is important.

To get the most out of the experience feedback tests good planning of the whole test set up is vital, e.g. preparing test procedures, methods for evaluating experience, spare parts and support with new technologies etc.
The project will seek to integrate further experience feedback tests as part of the research and development process.

### 3.2.2 Winter problems

Swedish winters are more challenging than in most other countries. As proven on several occasions, special attention needs to be given to winter-proofing any vehicle introduced to the Swedish market.

Ensuring the winter reliability of a cost-effective, high-capacity, high-speed train for Swedish winter operating conditions needs reliability needs to take into account a number of considerations including the designs required for higher speeds, managing safety at higher speeds, and coping with increased passenger capacity. These considerations can be broken down into specific technical and design challenges, such as:

- An aerodynamic front needs to have coupler hatches that close around the coupler and that function reliably in winter conditions. A high-speed train cannot operate with hatches that cannot close.
- The high propulsion power of a high-speed vehicle requires high cooling capacity in summer while the cooling also needs to work in winter conditions. Ice accumulation on the bogie could be a safety issue at high speeds and needs to be avoided due to increased weight and risk of restrictions in bogie and carbody movements.
- The functioning of large pressure-tight doors needs to be assured under winter conditions.
- Current collection in icy conditions at high speeds is complicated in general (as mentioned in section 3.1.2). In winter conditions the situation is complicated further e.g. by hoar frost on the catenary.
- Ice falling off the carbody may cause ballast spray that may damage equipment located on the underframe and can endanger the public in areas adjacent to the track.
- Wheel (and rail) damage rates typically increase dramatically during winter (a doubling of damage rates can usually be considered as benign). The more aggressive operational conditions of a high-speed train will add to this problem which has to be managed.

#### 3.2.2.1 Prediction methods

Today it is possible to predict the influence of low temperature on many systems in many areas and to verify these predictions in a climatic wind tunnel. Methods to predict the influence of snow and ice exist to some extent. There are, however, a number of areas in need of development:

- Lying snow can be drawn up and accumulate underneath a train: the effects of this require accurate modeling and study.
- Simulations of flow along a long vehicles result in very large computations due to the large number of snow particles involved. Simplified methods are needed to manage this.
- The snow/wall interaction for bouncing or sticking snow particles needs to be derived accurately since long vehicles will result in many interactions between each particle and the vehicle. This also relates to forces on the plough exerted by the
snow, which cannot be predicted accurately, leading to oversized ploughs and structures.

- Dynamic effects of compression between components, heating/cooling, impact of humid air and snow lumps dropping onto the track bed causing ballast projection and snow/ice lumps in switches needs to be coupled to the accumulation simulations.
- The influence of winter conditions on increased wheel deterioration requires an improved understanding of influencing factors. Further, predictive methods need to be improved to better account for these parameters, allowing for improved design and proper preventive maintenance actions.

3.2.3 Reliability in strategic systems in vehicle and rail system

Two main causes of traffic disruption are pantograph/catenary failures and failures related to the wheel/rail contact. Neither of these is unique to high-speed operations, but the higher speeds accentuate the issue and can cause more severe consequences. Pantograph/catenary issues have been described in section 3.1.2. As for failures in the related to the wheel/rail interface these may be manifested in the form of cracks in wheels and rails, increased wear etc. The consequences may result in costly maintenance, traffic disruptions and even accidents.

As mentioned, higher speed operations increase the loading on vehicles and track. This may have generally adverse effects (one example is the formation of so-called squats on the railhead that requires corrective grinding/milling). Further, the increased loading is especially pronounced at locations subject to higher loadings for regular traffic, such as switches & crossings, insulated joints etc. As far as vehicles are concerned, this translates to less tolerances for poorly adjusted brake systems, suspensions etc.

For a pro-active assessment of such issues in the introduction of higher-speed trains it is vital to know beforehand the difficulties that may be encountered both for the vehicle and with the track. This also relates to establishing suitable maintenance practices and alarm limits, and to evaluating related (life cycle) costs. Winter conditions, in particular, must be considered in this context as discussed in section 3.2.2. The potential of a successful strategy in terms of cost savings, reduced traffic disruptions and maintaining good-will are huge. This strategy requires an improvement in predictive capabilities regarding wheel/rail deterioration (including connected systems) and also relates strongly to the experience feedback testing discussed in section 3.2.1.

3.2.4 Fire safety design

Translating recent research and development into a safety-performance based design methodology, which enables prediction and design evaluations of fire safety concepts through computer simulations is one of the challenges of fire safety design. The objective is to interconnect:

- Methodology and results obtained in the Transfeu R&D Project whose objective was to develop a holistic approach of fire safety-performance based-design methodology able to support efficiently European surface transport standardisation.
- The results obtained in the Metro Project that further highlighted the need of taking fire load carried by passengers into consideration in the design.
• The latest research of using fibre reinforced polymer composites (FRP) for structural application in order to reduce weight of car bodies. The alternative material has good strength and stiffness qualities, environmental resistance, low weight and good forming qualities. However the load carrying capacity needs to be evaluated for different fire scenarios.

• The running capability requirements of EN 50553 with computer simulations, in order to identify areas where a rapid fire growth may impact the running capability of the train. Running capability is an important design feature as it allows the vehicle to be driven to a more suitable location for evacuation.

The interconnected aspects listed above should be integrated in evaluating concepts through computer simulations early in the design phase of new vehicles considered for a Scandinavian environment.

3.2.5 Automatic electric couplings between train sets

Instead of using multiple pantographs an alternative is to use “cable on the roof” for transferring electric power to the rear train sets in the train. The problem with this alternative is to obtain an automatic electric coupling between the train sets that satisfy both mechanical and electrical requirements needed for such a coupling.

Today there is no commercial solution on the market. Biggest challenge is to develop a coupling device between the train set which can automatically connect and disconnect without human intervention regardless of train units’ relative position on the track and weather conditions. Another major challenge is to develop control equipment for each train set, so when the cable is electrically in use it is not possible for the rear pantographs to be raised and become electrically active.

If such a technical invention could be implemented with the assurance that it would be reliable under all conditions, total reliability would increase significantly when the number of pantographs can be limited to one regardless of train length and number of units. The reliability increase applies in particular for existing conventional tracks that often have older and worn catenary systems ill-adapted to higher speeds and multiple current collections.
3.3 Customer value: “Cost efficiency”

Train travel has to be affordable. Improvements in passenger comfort and reduction of travel time must not be achieved at the additional cost of significantly higher ticket prices. Ideally ticket prices in the future should be lower than today. Note here that increased costs relate to design, manufacturing, operation and maintenance of both rolling-stock and infrastructure. Below project topics mainly related to decreasing (life cycle) costs are described.

3.3.1 Wide body trains for Scandinavia

Today most fast passenger trains have 1 + 2 seats per row in first class and 2 + 2 seats per row in second class. Enhanced cost efficiency can be achieved by adding 1 seat in each row. Such trains exist for regional services, but for long distance services the current body width does not provide enough comfort for such a configuration.

Today there are in principle two ways to increase the carbody width:

- Technical inventions implemented on the trains to reduce lateral movements
- Better use of the available space provided by the infrastructure

Both these ways have been subjects for studies within “Gröna Tåget 1”. Train modifications to further reduce the movement may be possible, but the potential is quite limited. The potential of better use of infrastructure space is likely to be much larger. Sweden is the country that currently allows the largest vehicle profile in Europe. Studies within “Gröna Tåget 1” indicated that such a vehicle might also be able to run, at least partially, in Norway and Denmark. More detailed studies including measurements of the infrastructure are necessary to finally optimize the vehicle to enable operation in all of Scandinavia. These studies may also suggest adjustments of the infrastructure where the relation between cost and benefit is favourable. Another possibility to increase passenger space without increasing the carbody width is using thinner walls, see following section.
3.3.2 Lighter carbodies with thinner walls

For new trains there is an increasing interest to reduce car-body weight. One important reason is to enable higher payload in view of the present TSI regulations [3] regarding maximum vehicle weight (17 ton/axle and 1000 ton/400 m train). A car-body weight reduction by 10% would enable approximately 14% increase of passenger payload for a wide-body or a double-decker train. In addition to greater efficiency of the transportation system, such increase of payload will reduce energy consumption and associated CO$_2$ emissions per passenger in direct proportion.

If the vehicle weight reduction is not used to increase the payload, reduced vehicle weight leads to reduced energy consumption during acceleration, which translates to reduced wear as well as lower emissions of particles. Due to the long operational life of rail-vehicles, energy and cost savings associated with lighter vehicles are substantial [4].

For these reasons there is an interest in novel material solutions for new carbodies. Such solutions can be made of various composite materials built-up in layered panel structures, such as sandwich panels made from fibre reinforced plastic (FRP) with foam or honeycomb cores. These materials also enable design of carbodies with thinner walls. Such designs are attractive for operators and passengers as the perception of space in the vehicle is improved and additional interior area is made available to be used for added comfort and for improving passenger flow when entering or exiting the vehicle.

To enable utilizing the full potential of such developments criteria as maintaining good acoustics properties must be considered and, Multi-Disciplinary Optimization (MDO) processes are necessary as discussed in section 3.3.4. At present, numerical optimization techniques are frequently used in structural design, but their application to multi-disciplinary problems is still much limited in industrial practice.

3.3.3 Condition based maintenance

The aim of condition-based maintenance (CBM) is to perform maintenance actions when and if required based on the condition of an asset. In the case of accelerating failure modes, maintenance actions could be performed earlier than initially planned to avoid costly and hazardous failure events. Maintenance actions could also be postponed in CBM in order to utilise the full potential of a system. To implement a CBM strategy, up to date knowledge of the asset condition is required. The frequency of the monitoring/inspection task is dependent on the monitoring/inspection cost, failure development time and the risk associated with possible failures. The measured condition could be used for calibration of remaining useful life (RUL) algorithms for predictive maintenance purposes or to serve as input to decision support tools for maintenance planning in CBM.

Some examples of condition monitoring systems currently installed in the Swedish network are: dragging equipment detectors, hot box detector and hot/cold wheel detectors, sliding wheel detectors, and catenary/pantograph detectors. These systems inspect the condition of the rolling stock resulting in valuable maintenance information for the operator, but they mainly serve as a protection mechanism protecting the infrastructure.

A reactive system can remove harmful wagons but in many cases when e.g. a wheel flat has been detected the damage has already been done. This event requires time-consuming inspection of the track and potential maintenance actions to restore the track. As
mentioned above, such traffic disruptions are especially cumbersome for high-speed operations.

Examples of proactive monitoring systems are; hunting vehicle detectors, wheel profile monitors etc. These systems grant the possibility to monitor and trend the deterioration of vehicle components.

- By developing new proactive wayside systems and on-board condition monitoring techniques the maintenance strategy can move from scheduled and predictive maintenance strategies to condition based maintenance. This could reduce disruptions (and costs) for corrective maintenance actions. An on-board condition monitoring system could have self-inspecting abilities measuring vital parts of the Gröna Tåget system and the ability to measure track specific failure modes. For critical assets, hard- to-reach components in tunnels or geographically dispersed assets, the failure detection time, inspection costs and the capacity consumption due to corrective maintenance is an issue. These problems could be reduced by the development of innovative on-board inspection methods.

- The knowledge of the asset condition is important when working with maintenance planning and it is especially important when dealing with functional maintenance contracts. An e-maintenance solution connecting the infrastructure manager, maintenance contractors and the operators with the right type of asset data and maintenance information would facilitate a CBM strategy in a multi stake-holder environment. By developing hybrid models combining stake-holders, data driven models, failure physics models and context driven models, a better prediction of the RUL and maintenance could be obtained.

### 3.3.4 New design solutions using multidisciplinary optimization

Today efficient computers and advanced computer-aided engineering models (CAE) enable Multi-Disciplinary Optimization (MDO) of complete or partial vehicle systems. This facilitates assessment of contradicting requirements from different areas of expertise, e.g. low weight versus good cross-wind performance.

In “Gröna Tåget 1” the cross-wind and drag resistance incompatibility was investigated using MDO and several Computational Fluid Dynamics simulations. Using this innovative method a new front shape was found that allowed reduction of the energy consumption with 25-30 % compared to the best manual solution.

Several additional parameters and design criteria may be introduced within the field of numerical optimization. Examples are weight, acoustics, interior layout, suspension parameters, vehicle gauging, traction distribution, energy consumption, structural dynamics, thermo dynamics, crash safety.

Unprejudiced use of MDO set-ups can reveal new design solutions and concepts that may increase the attractiveness of the railway system in terms of cost efficiency. This approach opens new opportunities to address large sets of design parameters and constraints together with multiple objectives, which is not possible with traditional parameter studies.
3.3.5 New train configurations

In principle all high-speed passenger trains currently have one or two configurations:

- Independent carbodies suspended by two two-axle bogies
- Two carbody ends suspended on one two-axle Jacobs bogie

The Jacobs bogie configuration reduces the number of bogies in the train, however, it also requires carbodies to be shortened, e.g. to not exceed limitations for axle load or gauge. In conclusion the potential advantages of reducing the numbers of bogies are limited. In future trains with lightweight carbodies, active suspension and electrodynamic breaking down to zero speed, the bogie might not be needed anymore. Directly suspended wheelsets or single axle bogies might be a cheaper and weight saving configuration, without causing passengers to experience unnecessary vibrations.

3.3.6 Conventional tracks vs slab tracks and viaducts

A key decision in the planning of new tracks, in particular for high speeds, is the choice of ballasted versus slab tracks. In broad terms a ballasted track can provide opportunities for continuous adjustments, but at the cost of larger track geometry deterioration, whereas a slab track decreases the track geometry deterioration rate at the cost of inflexibility and very high costs when adjustments are needed. The choice between the two solutions will also have other consequences, e.g. on noise and vibration, rail deterioration etc.

Regarding the major consequences of the choice between ballasted and slab tracks there are remarkably few technical analyses in the literature. Deterioration rates are often estimated from (more or less well founded) empirical knowledge, and the final choice may even boil down to the infrastructure manager’s chosen internal rate of return [6]. Needless to say, this is a far from ideal situation that complicates choices both between conventional and slab track, and between different slab track solutions.

A thorough investigation of phenomena influenced by the choice of track form together with the development of predictive models will largely improve the situation. With such an approach it will be possible to perform a sound Life Cycle Cost (LCC) analysis where the choice can be optimized not only for an entire line, but also for different stretches of the line.

In relation to Gröna Täget 2, this is an especially important analysis: The considered maximum speeds (250–300 km/h) coincide with the range where the choice of ballasted or slab track is far from clear and international practices differ internationally. For Swedish conditions, this choice also relates to the larger risk of ballast spray especially under winter conditions, see section 3.2.2, and the fact that the experience of slab tracks under our climatic and operational conditions is not well tested. A well-founded strategy when lines are upgraded, re-built or constructed from scratch has a major potential in construction and maintenance savings.

In this context, the choice of building elevated tracks on viaducts should also be considered. Such a solution frees up land, removes barrier effects and decreases risks of suicides etc. However it imposes additional costs and technical challenges. Sound decisions rely on thorough analysis of options.
3.3.7 Integrate technical evaluations in the planning process

All major infrastructure projects such as new/upgraded tracks, investments in new trains etc, include a long and laborious planning process. This process gradually refines general plans to specific detailed specifications. Proposed solutions are matched toward legal and technical demands and economic evaluations are carried out to select the “best” (in some sense) solution.

In this context it can be noted that technical issues will have a strong influence rather early in the project planning stage. One example is that the result of Life Cycle Cost (LCC) evaluations of the proposed solutions will depend strongly on deterioration rates and maintenance requirements; another example is that technical complications that fall under the radar in initial investigations may cause severe problems and related costs and disturbances. It can also be noted that the current trend towards more functional demands puts new requirements on both planning and contracting documentation, not the least in that demands and potentially issues have to be identified and targeted early.

In this context it is clear that early employment of technical evaluations has the potential to avoid many subsequent complications and helps in identifying optimal solutions, cf the discussion in section 3.2.1. This is, of course, far from a new idea and simulations (at different levels of complexity) are currently employed. What is proposed is to utilize recent advances in research and application to drive this approach further focusing on the introduction of Gröna Tåget 2 which provides an excellent “test-bench” involving all actors in the railway sector.

Apart from a developed evaluation framework, future application of the enhanced methodology is likely to decrease costs and complications significantly.
3.4 Customer value: “Improved environmental performance”

The life cycle environmental performance of rail vehicles is inherently high, cf. Figure 2. Further research is however needed if Scandinavian rail vehicles are to represent state-of-the-art technology regarding environmentally sustainable rail transportation in the harsh Scandinavian environment. There are clear expectations that require the transportation sector, including rail, to be able accurately to predict, optimize and communicate energy and environmental performance for future transportation solutions. Further expectations are to ensure an even safer environment for passengers and servicing personnel by introducing new, environmentally friendly materials. The following focus areas related to this topic have been identified.

Figure 2 Carbon footprint of High-speed railway traffic compared to other modes of transport [5].
3.4.1 Energy efficiency

Rail vehicle energy consumption is directly linked to the environmental impact associated with energy production. Life cycle assessment studies for vehicles operating in Scandinavia have shown that energy consumption in rail vehicle operation consistently contributes more than 50% of the total rail vehicle life cycle environmental impact. In this context, Gröna Tåget 1 included energy consumption simulations at total vehicle level [7].

With the Scandinavian mix of energy production, electrified railway traffic produce very low CO\textsubscript{2} emissions. There are however several technical improvements possible that may further reduce the energy consumption of trains.

The next step in energy efficiency optimization is to map the energy consumption of individual rail vehicle systems and components, considering their interaction with infrastructure and their operating conditions. A complete energy flow analysis, including indirect and direct energy use, covering seasonal climatic variation as well as parking, would allow for the identification of critical factors and result in the implementation of innovative solutions to optimize energy efficiency.

A parallel work stream would involve the development of specific prediction tools to be used for energy optimization of new rolling stock, taking into account both active systems such as HVAC (heating, ventilation, and air conditioning), and passive systems such as thermal insulation.

Additionally, further work should be carried out on investigating renewable energy resource utilization and implementing modern battery technology solutions for adaptive auxiliary systems optimization.

Energy optimized driving has proved to have a significant impact in vehicle energy consumption [8]. Further development of existing tools is necessary together with establishing a functional approach to driver training, cf section 3.4.2. Further a number of technical developments in power supply and traction technology of railway vehicles are foreseen in the future, cf Section 3.4.2.

3.4.2 Energy efficient power system

In recent years the interest in more efficient electric power systems for rail has increased due to an even stronger focus on green transportation. This implies new and more efficient solutions both for the on-board propulsion system and for the electric power supply system.

A driving force has behind new efficient propulsion systems has been the development of permanent magnet motors offering several advantages compared to more conventional drives, including a substantially higher efficiency.

In a similar fashion, new emerging technologies for power semi-conductors, like Silicon Carbide (SiC) devices, makes it possible to substantially improve the efficiency for all kinds of electric power converters. New semiconductors and new converter topologies make it possible to design compact converters with higher efficiency, less demanding requirements for additional filters and improved reliability.

Increased rail operations will, in addition, increase the requirements on the railway power supplies. New converter topologies and in the future new semi-conductor devices, as described above, will be important features of the converter stations. The new converter
technology also opens up for new system concepts, such as combining AC traction (alternative current) with HVDC transmission (high-voltage, direct current), with a potential to considerably reduce transmission losses. There is today an extensive need of new knowledge on how this will influence the power supply system.

3.4.3 Material technology

Research on rail vehicle material technology should focus on introducing new light weight material solutions coming from renewable resources, supporting the elimination of hazardous materials and increasing the overall vehicle recyclability rate. Modular design, material labelling and identifying potential reuse scenarios will improve resource efficiency for rail vehicles and increase recyclability rates.

Further work should also include research on conflicting technical areas such as fire protection, noise and EMC (electromagnetic compatibility) to identify suitable solutions that are harmonized with environmental performance targets. Specific focus on interiors and insulation systems is a suggested first point of investigation.

Other aspects of material technology include improved reliability and reduced environmental impact by e.g. using copper with alloys in catenary wire, carbon with metal in pantograph, improved brake pad materials etc.

3.4.4 Communication

Communicating environmental performance adds value, increases awareness and provides critical input in policy and decision-making. This supports the growth of rail transportation in Scandinavia.

Parameters to be communicated should be decided based on passenger and stakeholder feedback to ensure relevance and informative value. A sector agreement on standard communication parameters and calculation methods will ensure transparency, accuracy and comparability.

Further work should be carried out in embedding the communication of environmental performance parameters to existing passenger information systems. Dynamic, real-time systems could provide instant feedback on the actual associated environmental impact to rail vehicle operators and passengers.

Additionally, work could be carried out on investigating solutions such as eco-labelling that function as forms of indirect communication by allowing passengers to directly experience the rail vehicle features that enhance environmental performance.

3.4.5 External noise

Investigation after investigation shows that noise is the worst environmental issues in modern society. In Stockholm County every fifth person claims to be bothered by noise. The most important source of societal noise is road traffic, but railway noise is an important contributor in areas close to railway lines and yards. Simple and efficient methods to reduce railway noise emissions are to limit the speed and reduce the traffic at night. This type of noise control measure is, of course, can have a negative impact on the productivity of the railway transportation system. Hence, low noise emission from rail traffic is for many reasons desirable. Technology for reducing the noise emission such as
noise screens, quiet braking systems, pantographs etc, exists today but has to be implemented in an adequate way. Successful implementation requires a number of questions to be answered.

1. What types of sounds, emitted by passenger trains are perceived by nearby residents as annoying?
2. Are the descriptors we use to quantify the annoyance caused by rail traffic relevant?
3. What are the sources of the annoying sounds or sound levels?
4. Are there particular types of vehicles that emit the annoying sounds or sound levels?
5. Are there particular situations in which the vehicles emit annoying sounds or sound levels?

When these questions have been investigated and, at least partly, answered the noise reduction measures can be developed further.

1. Identify ways of reducing annoyance caused by the sound of passing traffic.
2. Suggest a programme to reduce the rail traffic noise emission.
3.

3.4.6 Traction noise

For reduced annoyance it is of increasing importance to effectively reduce the noise created by next generation traction equipment. This is particularly true for the electromagnetic noise of tonal character from transformers, inductors and motors. These tones can be annoying for people at platforms and in stations as well as for passengers on the train. Traction noise must also be controlled to fulfill requirements from customers as well as legislative demands.

A program to define the mechanisms of the sources and understanding the details in the noise generation by modeling and testing will be a first step. Hardware as well as software improvements should be considered.

In a second step, based on the above knowledge, noise reduction measures can be defined and evaluated.

In the third step the most promising design changes should be implemented on real systems and tested in a laboratory and if possible also on board a train.

Another type of annoying noise is loud screech created while braking. These can unfortunately be heard all over many rail stations today. This type of noise could potentially be eliminated by developing systems for replacing mechanical braking with completely quiet electric braking down to full stop at 0 km/h.

3.4.7 Ground vibrations

Ground vibration is an environmental issue that, in crude terms, has gone from being largely ignored to being regulated by law. One reason is to minimize the exposure of residents to ground vibrations: this is a key to gaining acceptance for train operations in populated areas.
To neglect ground vibrations in the planning of new and upgraded lines and in modification of operational patterns may prove very costly. The reason is that mitigations that are simple and cheap to make early on in the planning stage may prove costly and complicated in later stages of construction and operations.

Recent research\(^1\) has highlighted how design and maintenance of vehicles and track can be optimized by adopting vehicle solutions that yield low un-sprung mass, limited wheel out-of-roundness and rail roughness, stiffness irregularities, and vibration isolation (resilient rail pads, under sleeper pads etc.). Further, optimized monitoring strategies have been investigated.

What is needed in the proposed project is to integrate design against ground vibrations into the development and planning process. This includes vehicle design measures to minimize the generation of vibration, characterization of soil conditions that may require strengthening under foreseen operational conditions, predictions of vibration levels and identification of (cost-) efficient mitigation measures to reduce propagation of vibrations. To this end, the first step is to implement developed methodologies. In complicated cases this is supplemented by targeted research and development efforts.

\(^1\) For example the common European project RIVAS (http://www.rivas-project.eu/)
3.5  Customer value: “More comfortable journey”

Illustration by Lundberg Nybacka

Many people already perceive travelling by train as very comfortable. However, the next generation of fast passenger trains has to improve further. Otherwise there is a risk that higher speeds deteriorate acoustic or vibration comfort as compared to today’s levels. The perception of the ride comfort includes many aspects - vibration and acoustic comfort, temperature and air quality, interior design etc. amongst others. Also the accessibility of trains, e.g., the station area, is extremely important. Some of the other most important technical developments to further improve comfort and to attract even more passengers in the future are described below.

3.5.1  Acoustic comfort in trains

Silence is an increasingly important design parameter in developing new trains. This is true both in minimizing noise pollution of the exterior environment and for assuring a high interior acoustic comfort for the passenger. This part of the road map considers the interior acoustic comfort and proposes the development both of sound studios to establish the requirement and for personalized adaptive sound zones.

3.5.1.1  Sound studios

Traditionally, interior acoustic requirements are set in terms of A-weighted sound pressure levels. The dB(A) metric has for long been considered too blunt and one-dimensional, particularly for onboard interior noise, but due to a lack of alternatives it has prevailed as the dominant metric in contractual specifications[9]. New possibilities are opening up with the emergence of tools for sound synthesis and reproduction in combination with the train-builder’s detailed acoustic know-how of the source characters and transmission paths.

The effect of design options in a realistic environment can be both calculated and listened to in a sound design studio before the vehicle is built. The customer can select a cost-effective combination of design options to achieve a desired sound character. The goal is to take into consideration the need for both private and social areas within the train, the need
for conversations with adjacent passengers and audibility of loudspeaker announcements, in addition to suppressing single, disturbing tones as well as squeaks and rattles.

Concepts from architectural and urban acoustics can also be transferred to railway applications[10]. The term “soundscape” means the deliberate and subtle manipulation of the original sound by adding artificially created elements to enrich the experience and change the atmosphere. This concept has successfully been implemented in urban contexts like parks, shopping malls and airport terminals [11].

Setting the acoustic requirements for new rolling stock may be done in a sound design studio in future [12]. The acoustics of the studio must be possible to fully control with an extensive speaker and shaker system. It must also be perceived as a “real” compartment since the experience of the sound environment is very closely linked to all other environmental parameters. A cost benefit analysis in a listening scenario can be made directly on line in the studio.

### 3.5.1.2 Personalized adaptive sound zones

There may be incompatibilities between some of the sound quality parameters such as good speech intelligibility when combined with a substantial privacy and reduced annoyance from mobile phones. One solution is to make the local sound environment or soundscape adjustable for each seat. Another possibility is to create different sound environments in different parts of the trains to which passengers can move depending on what they would like to do: relax, eat, listen to music, sleep, talk with a colleague on the train or on the phone.

Enhanced comfort can therefore be achieved by introducing by making the local acoustic environment around each passenger adaptable. The desired set-up is the combination of the specified hardware into a software controlled system to create different modes of operation giving different functionality controlled by the passenger. Hence an adaptive acoustic environment can be created.

### 3.5.1.3 Other

The development of acoustic comfort for the interior compartment as described above should be linked to the design of future flexible interiors.

Acoustic optimization, including sound quality elements, should be an integral part of the design of railway stations and terminals (see interesting examples from RER stations in Paris e.g. Magenta).

### 3.5.2 Design and flexible interiors

The market is changing rapidly with new the options emerging, such as booking train tickets on the internet and via smartphones apps etc. This has led to new business models for the operators and the introduction of yield management. With yield management the price and availability depends on the demand for bookings at a given time. The new business models provide the ability to sell seats more efficiently and to maximize the sales. This creates a new demand for vehicles that can be adapted to maximize yields, with flexibility that allows those vehicles to be tailored to the travellers’ travel patterns and needs. The goal of this research is to create and design an attractive passenger environment that functions optimally with the operator’s new business models. This should lead to more
attractive trains, cheaper fares and greater revenue opportunities for the operators, which in the long run is good for the whole train business.

3.5.3 Active suspension

In road vehicles active suspension is increasingly important to the delivery of improved performance. Its application to rail vehicles has been relatively slow, one of the exceptions being active tilt systems, which have been in use for some decades. Active secondary suspension is applied in some high-speed Japanese trains while Bombardier is building trains with active lateral secondary suspension based on a development in Sweden within Gröna Tåget 1. In our opinion active suspension in trains can play an important role in further enhancing the performance of fast passenger trains.

3.5.3.1 Active secondary suspension

Active lateral secondary suspension can result in reduced vibration being experienced by passengers and for the carbody to be centered above the bogie in curves. This enables reduced lateral displacement by a shift of lateral bump stops, which in turn improves cross wind stability and allows a widening of carbodies. As an example, the carbody width gained permits 3+2 seating in intercity traffic in Sweden, see Figure 3. Tests within Gröna tåget confirmed the potential to improve lateral vibration comfort, see Figure 4.

Figure 3 Wider carbody in Gröna Tåget possible with Hold-off device.
3.5.3.2 Active primary suspension

Active primary suspension of passenger trains can improve passenger comfort and reduce the cost of wear and fatigue of wheels and rails. Implementation, however, is a larger step since it raises more safety related issues in the case for active secondary suspension.

In rail vehicle dynamics the classic conflict is between high critical speed on straight track and good curving behaviour. An actuator that suppresses the hunting motion and rotates the wheelset into a radial position in a curve could solve, or at least reduce this conflict, see Figure 5. The longitudinal primary suspension can be selected to be very soft, minimizes wear and rolling contact fatigue generation in curves. Further the need for a yaw damper between bogie and carbody is likely not to be needed. This would reduce the transfer of high frequency vibrations into the carbody, with reduced noise levels for the passengers as a result.
3.5.4 Accessibility for people with reduced mobility

Accessibility for disabled passengers has economic as well as societal benefits. 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 people with reduced mobility 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.

Leander (2011) summarizes the mandatory and desired features for people with reduced mobility, both in TSI and other references. Important features are listed below (Andersson, 2012):

- At least one level entrance is desirable on each side of the train.
- If a level entrance is not provided it is recommended that lifts to take wheelchairs into or out of the train are located within the train itself. Preferably, travellers in wheelchairs should be able to manage and manoeuvre the lift by themselves.

The following features are proposed for general use, i.e. for the majority of travellers, at all entrances:

- According to TSI PRM (2008) external and internal doors must have at least 0.80 m free width where passengers with reduced mobility (PRM) have to board the train.
- However, to be able to board the train conveniently and fast with two pieces of luggage a free width of about 0.90 m is preferable. The latter is proposed for all or most doors where heavy luggage has to be moved.
- A moveable step, bridging most of the gap between platform and step in the train, is desirable.

Special attention should be given to problems which might arise in the interface between platform and train. Except for the door width and the gap mentioned above, the height difference between platform and train floor is an obstacle, which has an impact not only on disabled passengers, but also for dwell times.

Gröna Tåget prescribes solutions with a high floor throughout the train, without interior steps. The approach is to lift physically disabled travellers to the train’s floor level. One idea that was looked at in the Attractive passenger environment project (Lundberg, Eriksson och Ranvinge, 2010) 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.
The entry lift needs to be developed technically to meet the demands for fast boarding and alighting, and to provide good functionality also in cold winter conditions.

Figure 6 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

3.5.5 Integrated information systems

The European Commission’s 2011 Transport White Paper foresees the need for multimodal modal shift to rail and other more sustainable means of transport including public transport. This switch is currently inhibited by the problems that many potential passengers have in accessing reliable information about service frequencies and times, prices, facilities, etc. for the whole journey. If the concept of co-modal, sustainable, seamless end-to-end journeys is to be a reality there is a need to address the provision of such information, including real-time information at times of delay and disruption (information provision when things are going wrong with a journey being a prime passenger concern). This presents research challenges both in terms of systems’ architecture and to ensure that any system is easy to access from a users’ perspective.

3.5.5.1 Inter-available ticketing

European citizens can obtain inter-availability, through ticketing across modes and receive real time traffic and journey information thanks to improved communication and information systems, allowing better services, including easy re-routing. Ticketless journeys in Europe compatible with local transport fare management systems shall be possible; Standardisation of ticketing procedures and ticket information throughout Europe are necessary.

3.5.5.2 Travel information

Public transport users often have difficulties in getting accurate information on train delays and their potential effect on connecting journeys by other modes or Railway Undertakings. The competitiveness of rail would be enhanced by systems that enable passengers to access a comprehensive picture of how their end-to-end journey is likely to be affected by
disruption to any part of the journey. This poses a critical need to deliver a more integrated service including coordination of information delivery and timetables between often competing operators for instance. A clear cooperation framework would be necessary in order to effectively deliver the necessary connectivity in order to achieve a seamless travel experience.

A minimum requirement is that passengers should be able to access reliable information about service frequencies and times, prices, facilities, etc. for the whole journey. If the concept of co-modal, sustainable, seamless end-to-end journeys is to be a reality there is a need to address the provision of such information, including real-time information at times of delay and disruption (information provision when things are going wrong with a journey being a prime passenger concern). This presents research challenges both in terms of systems’ architecture and to ensure that any system is easy to access from a users’ perspective. The realization of seamless, accurate information architecture involves all the actors in the travel chain such as train operators, operators of other modes and infrastructure managers.

3.5.5.3 Enabling information solutions on Gröna Tåget

Passengers on the Gröna Tåget will benefit from a high capacity and secure and stable Wi-Fi connections. This will enable business travellers to use the train as an extension of their office, and presumably have an even wider appeal for digitally-switched on passengers (e.g. younger age groups who want to surf as they travel). Stable Wi-Fi connection will also allow passengers to access information on connecting trains, buses or city maps thus improving their possibility to plan the future parts of the travel while seating comfortably on the train. Clearly visible displays on board the train will inform the passengers on time table connections and give accurate real time information on train punctuality and what to do in case connections are broken due to delays or degraded mode operation.

Infotainment systems in front of each seat can be used by the individual passenger who is not equipped with an own smart device for searching information about the trains on-time status, time tables for connecting trains, buses or where to find a taxi at the point of arrival.

Gröna Tåget passengers should be able to buy tickets for connecting train travels or by other modes on the train using their own devices or the infotainment system.
3.6 Customer value: “Increased capacity”

Transport demand will continue to rise for all modes, both in Sweden and internationally. If the rail sector’s share grows on the scale foreseen by the EU White paper [1], the capacity of the Swedish railway network has to increase significantly. In a long term perspective new railway infrastructure is necessary. In a shorter perspective a lot of technical developments are possible which would increase capacity on the existing infrastructure as described in this section.

3.6.1 Passenger flows (Trains and Stations)

3.6.1.1 Design for punctual stops

Station stops stand out as particularly important and critical to maintaining punctuality. Punctuality can be correlated closely with the number of passengers, occupancy on the train and departure punctuality at the point of origin.

Travel times can be shortened by designing Gröna Tåget for short dwell times while boarding and alighting many travellers at peak loading times, in turn shortening running times. The delays at stops can be reduced as regards both mean value and standard deviation and thus contribute to more punctual train traffic. A number of recommendations on how to design The Gröna Tåget final report (Fröidh, 2012, pp. 116-117) made a number of recommendations concerning doors, isles and the design for improved access or passenger flow. These need to be verified. Capacity simulations on the Southern Main Line have shown that decreased dwell times can offset the negative effect on punctuality when increasing the top speed from 200 to 250 km/h (see “Capacity at mixed traffic”). Further research should focus on specific measures to improve reliability and punctuality.
3.6.1.2 Platform and train floor heights

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 access and egress easier for travellers generally as well as those with reduced mobility and to shorten dwell times for the train. For historical reasons, however, there is no universal common standard on the railways. On most trains the floor height is between 1.10 and 1.25 m above top of rail.

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. The lowest possible floor height is 1.18–1.20 m above top of rail where bogies of 920 mm are used. The floor might possibly be a few centimetres lower at entrances and perhaps also between bogies.

European norms (TSI) permit two standard platform heights: 55 cm (intermediate) and 76 cm (high) above top of rail with a tolerance of (-3.5 cm/+0). 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 would be required, each having a step height of 20 cm and with floor height at the entry of approx. 1.15 m. A small ramp in the centre aisle would also be necessary to reach a height of 1.18-1.20 m above the train’s bogies.

3.6.1.3 Luggage on board

Luggage-handling is important as regards travelling times since the train must generally allow boarding without checking in. 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.

A number of studies show that people cite luggage as a reason for not going by train. Many train travellers also consider handling luggage to be troublesome. There are consequently reasons to further study the concept of luggage handling in stations as well in trains.

3.6.2 Capacity and mixed traffic

In order to increase speeds on lines with mixed traffic, capacity needs to be reviewed. On single-track lines, shorter running times can mean that fewer trains have to cross one another, while overtaking with freight trains will increase in the same way as on double-track lines. Commuter traffic often limits the number of train paths for other trains and slightly delayed express trains can become even more delayed. However this is not a new problem.

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 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 increasing 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.

Some of the measures, which need to be studied further are:

- Timetable planning (mixed services constraints slow/medium/fast train paths, convoy timetabling, rigid interval timetable, possibilities for separation of train types)
- Train performance (average speed for all train types; top speed, braking, acceleration, dwell times)
- Line constraints (train speed, signalling system, capacity, station layout, crossing and overtaking possibilities)
- Traffic control performance (NTL project)
- Capacity enhancements, coordinated planning of services, rolling stock and infrastructure including stations.

3.6.3 Intelligent maintenance of infrastructure and rolling stock

The vision of Gröna Tåget 2 will affect maintenance actions and planning. Higher speeds will increase the asset deterioration rate and therefore affect the inspection and maintenance intervals and renewal rate. A reduction of train free periods for maintenance due to higher capacity utilisation is also a possibility and can reduce the maintainability of the track; a shortage of side-tracks for maintenance vehicles could be a possibility and must be investigated. New technologies within Gröna Tåget 2 will also affect the system reliability and must be considered and evaluated in order facilitate a more reliable journey.

To enable efficient maintenance, some basic requirements must be fulfilled. There has to be access to updated and correct data regarding the infrastructure condition, an adequate analysis of measured data has to be made to assess and predict the health status, a suitable way of designing and implementing maintenance contracts is needed in which appropriate maintenance actions to be performed are defined. The aim of intelligent maintenance is to increase achieved capacity or to prevent capacity reduction for the Gröna Tåget 2 concept applied to the existing railway infrastructure. This should be done through increased system reliability, effective and efficient maintenance processes and maintainability studies. This implies a minimisation of the capacity consumption related to corrective and preventive maintenance actions. This will give a substantial increase in the operational capacity towards the inherent capacity of the infrastructure. The downtime due to maintenance will be reduced by appropriate maintenance decisions and optimum scheduling of tasks. In essence the output of the improved maintenance practices will facilitate:

- Early detection of functional failure and prompt organisation of right maintenance action with reduced waiting time.
- Shortened establishment time, maintenance time (Work shop, in field), withdrawal time by means of lean operation and data driven maintenance strategy.
- Optimum maintenance schedule addressing the frequency of large scale maintenance tasks. Also giving room for opportunity based maintenance as well as combining relevant maintenance actions for efficient use of train free periods.
- Effective maintenance supportability which will reduce the accumulated time when maintenance cannot be carried out due to the need to acquire maintenance resources including spares equipment, tools and man power. A decision support model for optimum scheduling will assist in establishing the required effectiveness
in maintenance logistics to assure the additional network capacity for a faster train in a mixed traffic situation.
4 SWOT analysis

The high-speed passenger concept of Gröna Tåget has some inherent system properties. What are the preconditions, i.e. possible benefits and obstacles, for implementation of the Gröna Tåget high-speed system defined by the various milestones described above? Below an attempt is made to summarize these in a so-called SWOT analysis.

4.1.1 Strengths

- Existing and functioning forms of co-operation between universities, industry, public bodies and society lead to better results with higher quality and level of innovation
- Because of the first Gröna Tåget program there is an existing platform to commence from.
- All actors have a high competence. All are active nationally with established and strong international networks.
- The railway is generally an established highly efficient and environmentally friendly system for high capacity passenger (and freight) transports
- There exists an established market with increasing demand for railway transports

4.1.2 Weaknesses

- The railway system is sensitive and failures can have a large influence on the system
- High costs are limiting investments
- Cost models that benefit infrastructure-friendly trains are not available
- Long operational lives of involved systems reduces the possibilities for modernization
- Cumbersome approval system and extensive times needed for the introduction of new solutions
4.1.3 Opportunities

- Possibilities to introduce solutions incrementally where benefits are obtained at each step
- The majority of the solutions may be applied in existing systems also internationally, which paves the way for export
- An infrastructure-friendly (track friendly and energy efficient) train will be beneficial if track access charges are diversified based on energy consumption and imposed track degradation
- Developed solution will decrease investment costs
- Developed concepts can drive the development of standards
- The developed solutions increase the possibility for, and the benefits of diversified (in time and space) traffic solutions
- Gröna Tåget has capacity and performance for 300 km/h
- Gröna Tåget allows for more cost efficient construction of tracks for 250–300 km/h
- Research and development can guide and improve regulations and approval processes
- Possibilities for tests and prototype trains in Sweden
- Competence (and development of additional competence) in development for difficult conditions (e.g. winter and mixed traffic) yields possibilities for export

4.1.4 Threats

- Conditions (market related, operational, etc) can change fast e.g. through political decisions
- Lack of capacity on the railway, and long lifetime of trains limits the possibility to introduce new trains
- A situation with mixed traffic (fast and slow trains) limits the possibilities of, and gains from higher speeds and may cause additional demands on new and existing systems (train and infrastructure), see also HCT railway
- Lack of, and/or poorly formulated standards may give a disadvantage for developed concepts
- Regulations may hinder development of new solutions
- Exclusive high speed tracks (>320 km/h following TSI norms) are introduced before 2050
5 Socio-economic evaluation

5.1 Analyses as a tool

A socio-economic analysis, including a Cost Benefit Analysis (CBA), 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. This analysis presented is a part of, but identical in results to the one presented in “Green Train final report part A” (Fröidh, 2012).

The socio-economic calculation uses the same methodology and in principle shares the same values as those used by the Swedish Transport Administration for its investment planning up to 2012, 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. Further updating to presently used factors and standard values according to the national guidelines in ASEK 5 is another measure to be undertaken.

5.2 Calculation prerequisites

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.

The calculation treats new investments, which aim to make a new activity such as operating Gröna Tåget at higher speeds possible, in a way that is partly different to the treatment of 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 calculation of both new investments and re-investments in speed-raising measures can also covers a number of un-quantified benefits.

A reinvestment that is required to increase the speeds entails early replacement if it is made before the normally planned equipment replacement time.

The desired start of traffic for the express train traffic 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.
5.3 Standard values

The standard values used in the calculation are in agreement with the values used in Sweden up to 2012. The installation costs and train operation costs calculated using Gröna Täget’s cost model are stated in 2010 prices and are adjusted upwards by tax factor 1 (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 2 Calculated installation costs for the lines

<table>
<thead>
<tr>
<th>Line</th>
<th>Western M</th>
<th>Southern M</th>
<th>West Coast</th>
<th>Väner</th>
<th>East Coast</th>
<th>Mälar</th>
<th>Svealand</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Line Length (km)</td>
<td>489</td>
<td>483</td>
<td>290</td>
<td>82</td>
<td>730</td>
<td>160</td>
<td>114</td>
<td>2354</td>
</tr>
<tr>
<td>of which &gt;200 km/h</td>
<td>266</td>
<td>307</td>
<td>225</td>
<td>75</td>
<td>389</td>
<td>111</td>
<td>73</td>
<td>1446</td>
</tr>
<tr>
<td>Track (km), Newer line</td>
<td>102</td>
<td>0</td>
<td>478</td>
<td>164</td>
<td>559</td>
<td>290</td>
<td>107</td>
<td>1694</td>
</tr>
<tr>
<td>Track (km), Older line</td>
<td>808</td>
<td>966</td>
<td>72</td>
<td>0</td>
<td>338</td>
<td>21</td>
<td>29</td>
<td>2234</td>
</tr>
<tr>
<td>New investments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridges, geotechnics</td>
<td>360</td>
<td>430</td>
<td>20</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>860</td>
</tr>
<tr>
<td>Grade separated crossings</td>
<td>580</td>
<td>450</td>
<td>0</td>
<td>0</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>1110</td>
</tr>
<tr>
<td>Platform safety</td>
<td>40</td>
<td>50</td>
<td>30</td>
<td>40</td>
<td>60</td>
<td>20</td>
<td>5</td>
<td>245</td>
</tr>
<tr>
<td>Capacity/punctuality</td>
<td>2500</td>
<td>2400</td>
<td>100</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>5200</td>
</tr>
<tr>
<td>Reinvestments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track renewal, geometry</td>
<td>295</td>
<td>310</td>
<td>230</td>
<td>0</td>
<td>205</td>
<td>100</td>
<td>40</td>
<td>1180</td>
</tr>
<tr>
<td>Catenary</td>
<td>0</td>
<td>50</td>
<td>140</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>210</td>
</tr>
<tr>
<td>Signalling (ERTMS/ETCS)</td>
<td>0</td>
<td>0</td>
<td>210</td>
<td>25</td>
<td>180</td>
<td>70</td>
<td>45</td>
<td>530</td>
</tr>
<tr>
<td>Total cost (million SEK)</td>
<td>3775</td>
<td>3690</td>
<td>730</td>
<td>65</td>
<td>795</td>
<td>190</td>
<td>90</td>
<td>9335</td>
</tr>
<tr>
<td>Residual value after 40 yrs</td>
<td>730</td>
<td>693</td>
<td>23</td>
<td>0</td>
<td>77</td>
<td>0</td>
<td>0</td>
<td>1523</td>
</tr>
</tbody>
</table>

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 Täget’s share for early replacement (see text). Source: Fröidh (2012)

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.

5.4 Calculation results

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 3 Compilation of calculations

<table>
<thead>
<tr>
<th>Basic scenario</th>
<th>Western M</th>
<th>Southern M</th>
<th>West Coast</th>
<th>East Coast</th>
<th>Mälar+Sveal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present value 2010 (SEK millions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment cost</td>
<td>4395</td>
<td>4295</td>
<td>925</td>
<td>925</td>
<td>326</td>
</tr>
<tr>
<td>Residual value</td>
<td>-164</td>
<td>-155</td>
<td>-5</td>
<td>-17</td>
<td>0</td>
</tr>
<tr>
<td>Revenues</td>
<td>4970</td>
<td>6422</td>
<td>2839</td>
<td>3497</td>
<td>798</td>
</tr>
<tr>
<td>Production costs</td>
<td>-4383</td>
<td>-5314</td>
<td>-1254</td>
<td>-2909</td>
<td>385</td>
</tr>
<tr>
<td>Travelling time gains</td>
<td>3886</td>
<td>6359</td>
<td>2156</td>
<td>2594</td>
<td>1250</td>
</tr>
<tr>
<td>Marginal externalities</td>
<td>670</td>
<td>891</td>
<td>50</td>
<td>526</td>
<td>17</td>
</tr>
<tr>
<td>Grade separated crossings</td>
<td>95</td>
<td>74</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Total benefits</td>
<td>5238</td>
<td>8432</td>
<td>3792</td>
<td>3718</td>
<td>2451</td>
</tr>
<tr>
<td>Benefits-investment cost</td>
<td>1006</td>
<td>4292</td>
<td>2671</td>
<td>2810</td>
<td>2125</td>
</tr>
<tr>
<td>Net Present Value (NPV)</td>
<td>0.2</td>
<td>1.0</td>
<td>3.1</td>
<td>3.1</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Source: Fröidh (2012)

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.
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. A number of such effects are suggested in Fröidh (2012), pp. 176-177.

5.5 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 4 General value of running time

<table>
<thead>
<tr>
<th>SEK millions</th>
<th>Western M</th>
<th>Southern M</th>
<th>West Coast</th>
<th>East Coast</th>
<th>Mälar+Sveal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator's value of 1 minute</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annually</td>
<td>4.6</td>
<td>5.4</td>
<td>1.8</td>
<td>4.2</td>
<td>6.1</td>
</tr>
<tr>
<td>Present value</td>
<td>51</td>
<td>60</td>
<td>20</td>
<td>46</td>
<td>67</td>
</tr>
<tr>
<td>Socio-economic value of 1 min.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present value</td>
<td>333</td>
<td>383</td>
<td>123</td>
<td>208</td>
<td>272</td>
</tr>
</tbody>
</table>

| 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. Source: Fröidh (2012)

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.
5.6 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, 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. This plan is seen in the map (figure).

![Map of Sweden showing proposed speed increase](image.png)

**Figure 7** Proposed prioritization of upgrading for higher express train speeds, and the Götaland and Europa high-speed lines proposed in an official report. Source: Fröidh (2012)

Since it is not known when any train operator will actually purchase express trains like Gröna Tåget, an uncertainty factor remains. The only way of removing this uncertainty is
to coordinate plans for vehicle acquisition with those for 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.

Re-calculating the CBA should be done with revised infrastructural requirements for the speed increase up to 250 km/h and updated factors according to ASEK 5.
6 Working plan and implementation

In the roadmap a lot of new technologies are described that would make fast passenger traffic on trains even more comfortable and higher environmentally performance and which would significantly increase the attractiveness. Together with measures to increase capacity – here the suggestions from the roadmap on “High Capacity Transport on Rail” are equally important – a significant increase of rail passenger traffic in the coming decades is foreseen. It is important, however, that the examined technologies are tested, validated and implemented. Therefore a new research program should be built on the positive experiences gained from the Gröna Tåget 1 project where verification in tests was a crucial part of the different work packages.

The main goal towards implementation of the new technologies described in the roadmap is to build a prototype car that will run in ordinary passenger traffic. It could for example be a car in one of the recently delivered SJ3000 train sets. As an intermediate step a test bench like the two-car Regina 9062 train set used during Gröna Tåget 1 will be needed to verify new technologies and to gain experience for the design of the prototype car.

This section should not be seen as a detailed project proposal. The following clusters for the development of the new train that are suggested give an idea of how the work could be organised.

There are great possibilities to introduce solutions incrementally where benefits are obtained at each step.

The majority of the solutions may be applied in existing systems also internationally, which paves the way for export opportunities outside Sweden.

For the finance contribution of the program the possibilities from VINNOVA, Energi myndigheten and Trafikverket needs to be discussed. On the international arena this program may also fit well for cooperation to EU programs i.e Shift2Rail.
6.1 Technologies and regulations for introduction of C-class trains

The introduction of a new train class that would allow higher speeds on existing lines for trains with a light tilt system as described in Section 3.1.1 could be achieved until 2015. Technologies that need to be further developed and verified by tests to make this possible are

- Active lateral and vertical suspension
- A light tilt system including a train positioning system
- Update of regulations and standards for the introduction of a new vehicle class.

Time Frame: 2013-2015
Main Partners: Bombardier, KTH, Trafikverket, SJ, VINNOVA

6.2 Technologies for reliable trains

Developing technologies for reliable trains is an activity that has to go on throughout the whole project. Since trains are bound to the track system reliability is crucial. Technologies that can be mentioned here are

- Winter design
- Reliability of strategic systems
- Reliable energy supply and current collection
- Materials and fire safety
- Condition based maintenance

Time Frame: 2014-2020
Main Partners: Bombardier, KTH, Trafikverket, Chalmers, LTU, Vectura, SJ, VINNOVA

6.3 Technologies for comfortable trains

Even though travelling by train is already perceived as very comfortable there are a lot of possible added values in the future. Most of those developments could enter market before 2020.

- Sound scapes
- Flexible interior designs
- Better vibration comfort
- Accessibility for people with reduced mobility
- Thin wall technologies for more inner space

Time Frame: 2014-2018
Main Partners: Bombardier, KTH, SJ, VINNOVA
6.4 Technologies for energy efficient trains

Even most of the technologies that can further reduce trains energy consumptions should be available for market introduction at 2020. Activities in this cluster are for example

- Aerodynamic optimization
- Energy efficient traction
- Energy efficient power supply
- Lighter trains by new carbody design (sandwich)
- More passengers per meter by thin wall technologies.

Time Frame: 2014-2018
Main Partners: Bombardier, KTH, Trafikverket, Vectura, SJ, VINNOVA, Energimyndigheten

6.5 Gröna Tåget 2 prototype car

For all activities in Sections 6.1 to 6.4 a test train is needed for verification. The next step is then to build a completely new prototype car based on the developments in Sections 6.1 to 6.4. To build a new car implies

- Design work
- Building of full-scale car
- Insertion in 3-5 car train for verification and experience feedback

Time Frame: 2015-2020
Main Partners: Bombardier, KTH, Trafikverket, Chalmers, LTU, Vectura, SJ, VINNOVA, Energimyndigheten

6.6 Business case for Gröna Tåget service schedule

To make Gröna Tåget 2 a success the business case is equally important. This includes both vehicle technologies but also operational and maintenance issues. These activities will be ongoing in parallel to the other technical development and to the verification tests. Activities foreseen in this cluster are

- How to operate with mixed traffic in the future
- Intelligent maintenance
- Socio-economic evaluations.

Time Frame: 2013-2017
Main Partners: KTH, Trafikverket, LTU, SJ…
6.7 Infrastructure and rolling stock development

The train itself can never be a success if the impact on the environment and the interaction with different systems within the track are studied in parallel. Some of the activities within this cluster will probably be answered relatively fast while some investigations have to go on through the whole project.

- Slab track versus conventional and viaducts
- Ground vibrations
- External noise
- Track quality versus comfort requirements, new system
- Ballast projection for higher speeds and winter conditions
- Pantograph catenary interaction
- Energy supply

Time Frame: 2014-2020
Main Partners: Bombardier, KTH, Trafikverket, Chalmers, LTU, Vectura, SJ, VINNOVA

6.8 Final implementation of Gröna Tåget train service

The final goal is to have a train according to the described concept in service. This is a business decision from an operator and train owner and cannot be part of the project. When the prototype car is in test operation according to Section 6.5 then the needed experience and verification of many innovations are there for the final implementation.

Time Frame: 2020-2025
References


[10] Billström, N. Sound design of high speed railroad cars. Proc. 16th International Congress on Sound and Vibration, Krakow, Poland, 2009


[12] Leth. S. et al, Sound design studios for setting noise requirements on new rolling stock- a future scenario, WCRR 2011, Lille


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