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Evaluation of Podcar Systems

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Preface

This publication is the translated version of *Utvärdering av spårbilsystem,* SIKA Report 2008:5. The report has its origins in a long-term project in which SIKA examined the difficulties of incorporating alternative transportation systems into the policy planning process for transport infrastructure. *A General Transport System,* SIKA Report 2006:1 was part of that project which was recently concluded with *A Planning Process for Renewal in the Transport System*, SIKA Report 2008:4.

As part of its most recent long-term infrastructure planning project, SIKA formulated a vision of a future transport system in its report *Framtidens Transporter - Vision 2040+*[*Transport of the Future—Looking Beyond 2040*], SIKA PM 2008:2.

The present study should be seen as an independent continuation of the reports mentioned above.

Björn Olsson has been responsible for the study and has written most of the report. The case study in Chapter 2 has been the responsibility of Joanna Dickinson. The traffic forecasts in Chapter 2 were made by Peter Roming from Railize, and Björn Sylvén from MaskotMedia supplied useful data on public transport in the same chapter. Göran Tegnér (WSP Analys & Strategi), Jan-Erik Nowacki (Nowab) and Ingmar Andréasson (LogistikCentrum) have been most helpful in their capacities as external advisors. A number of colleagues at SIKA have made valuable comments on earlier drafts and the report has been discussed by SIKA's Board of Scientific Advisors.

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Kjell Dahlström

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Executive Summary

Current transportation systems and infrastructures, including cars and roads, trains and railways, airplanes and airports, boats and harbours, no longer comply with the general transportation needs of society. Existing systems not only waste significant amounts of people's time, they detract from the aesthetic experience of our communities and they are responsible for the deterioration of our environment through the emission of toxic and greenhouse gases. Worldwide, accidents involving automobiles kill tens of thousands of people and maim millions more every year. The solution is clearly not to investment even more in existing infrastructures, which may only make matters worse, but to find or develop new modes of transport.

We at SIKA have recognized this problem and have taken on the task of determining and investigating existing innovative transport systems that could help address current and future transportation problems. In this report, we analyze the podcar system and we are optimistic that this visionary transportation system, in some form, holds the key to safe, efficient and economically viable transportation within and between urban areas.

A podcar system consists of fully automatic car-sized vehicles either supported on or suspended from an elevated guideway located a few metres above ground. This elevated location minimizes the risk of conflict with other traffic such as cars, buses and bicycles, and with pedestrians. A guideway dedicated solely to podcars would give greater safety and allow higher speeds. Propulsion, braking, switching, control and scheduling could all be achieved using electromagnetic power and computer technologies.

Vehicles will be able to travel non-stop from their point of origin to their destination. Passengers can decide on their destination in a number of suggested ways, such as by inserting a card reader, touching a computer screen, or, for the disabled, through speech recognition. The comfort and freedom of the podcar system resembles the comfort of our current automobiles. Podcars run automatically, thus eliminating the responsibilities associated with being a driver while at the same time virtually eliminating the risk of accidents. A journey can be private (individual), shared with family or friends, or public, if others are invited to share the podcar. The podcar is a mode of transport that lies between private and public transport, in other words a *paratransport* system.

While podcars have been seen primarily as a local transport system, SIKA believes that podcars have the potential for both local and long-distance transportation. A network of podcars can be economically viable, particularly if local systems are mutually compatible and if the long-distance connectors that link local systems to one another are incorporated into the initial planning. A network of local and long-distance systems will be able to exploit economies of scale and will allow the podcar system to be competitive, accessible and affordable.

SIKA envisions a potential development of a standardized, general podcar system (or general transport system, GTS) that, in addition to local uses, is able to:

- satisfy most of the transport needs of people and goods;
- offer local systems running at 25-50 kmph *as well as* regional and long-distance systems, running at 80-250 kmph;
- provide both public and private journeys and vehicle ownership;
- accommodate vehicles that run on guideways and on roads (so called dual-mode).

A general podcar system offers a new mode of transportation that can meet our targets for safety, efficiency, and effectiveness. Vehicles will be able to connect automatically to each other (platooning), in order to minimize congestion and maximize capacity and aerodynamics. The system will offer travel-on-demand from any station to any other station. When not in use, the vehicles will automatically find parking spaces; either at an empty station or in a special parking garage. These functional characteristics of the general podcar system go beyond local uses and will allow economies of scale, network effects, and minimal modal split. They will also allow significant market penetration and strong competitiveness.

Compared to cars and public transport, the podcar system would:

- reduce the number of deaths and injuries to nearly zero;
- reduce travel and transport times in local as well as interregional terms, thanks to its non-stop characteristic and high speed;
- reduce energy and material consumption in constructing and running the system;
- reduce to zero emissions of greenhouse gases and particles from transport; electric power is produced separately from the transport system;
- increase accessibility and mobility for everybody, including disabled people and people without driving licenses;
- enable transport “just-in-time” because of the increased assuredness of travel time and lack of the necessity of switching between modes of transport.

The economic calculations in this study of (1) a podcar system in Stockholm and (2) a podcar system in the Mälardalen region west of Stockholm, have been carried out using the established methods contained in the traffic forecasting software, “Sampers”, which is used by the government agencies for transportation, together with traditional cost-benefit analysis (CBA). Our study focuses on a short-range system in Stockholm, and on a long-range network in the

Mälardalen region. The long-range network is expected to link several local networks which can be expected to be installed in the cities of the Mälardalen region in the future.

For Stockholm, two scenarios have been analyzed and evaluated:

(1) A traditional commuter rail link on a new track connecting the north to the south of Stockholm, combined with an increased congestion charge;
(2) Scenario (1) with the addition of an outer-ring podcar system connecting the peripheral parts of the Stockholm city area.

In the case of the podcar system in the Mälardalen region, an interregional high-speed track (>200 km/h) around Lake Mälar would link the main cities, which, by the time of construction of the interregional system, could be expected to have their own local podcar systems. This interregional system can be seen as a first step in building a long-range system connecting the Nordic Triangle viz: Stockholm-Oslo-Gothenburg-Copenhagen/Malmö. This long-range, high-speed system would be able to compete with high-speed trains and airplanes. The podcar system could also serve the in-between stations in smaller towns, which the existing infrastructure of high-speed trains and airplanes is unable to do without a change of transportation mode.

The results for the Stockholm *Scenario 1* with a commuter rail link and congestion charge show a reduction of congestion in the central Stockholm area, brought about by attracting people from private car use to public transport commuting. Car traffic between the north and south of Stockholm would decrease by up to 13 percent and public transport would increase by 3 percent, compared to the reference scenario. Less congestion would mean greater accessibility for commercial transport, and thereby increased reliability and efficiency. Possibly due to the competition from other commuter train lines, Scenario 1 turns out to be uneconomical in our calculations. Depending on the costs of construction, the benefit-cost ratio lies between $-0.36 < [(B–C)/C] < -0.19$.

In the Stockholm *Scenario 2*, with the commuter rail link and congestion charge supplemented by a podcar network, the results indicate an even greater reduction in congestion, not only in the traffic between the north and south of Stockholm, but also on the entire road network. The number of journeys on public transport within Stockholm would increase a further 7 percent and interregional train travel to and from Stockholm would increase by a couple of percent due to increased capacity and accessibility. Thanks to increased accessibility, the overall market share for public transport (including podcars) would increase while the market share for cars would decrease. Our model indicates that about every third journey by public transport would be made by podcar. This would give podcars a market share of about 10 percent. Depending on the costs of construction, the benefit-cost ratio would be $-0.03 < [(B–C)/C] < 0.21$. It should be noted that the podcar system in this scenario compensates for the non-profitable commuter rail link which forms part of the scenario.

In *the high-speed podcar system for the Mälardalen region* we have calculated with an average speed of 200 kmph (124 mph) on a network connecting the cities around Lake Mälar. This podcar network would provide the commuters in the region with significant savings in travel time and would enable future expansion by linking the Nordic Triangle: Stockholm-Oslo-Gothenburg-Copenhagen. We have carried out sensitivity analyses on the cost parameters, fares and numbers of travellers. Depending on costs, the benefit-cost ratio here would be $0.35 < [(B-C)/C] < 0.59$.

To conclude, the social benefits of the podcar system are high and the chances of profitability are good. Podcar systems would increase accessibility and reduce traffic congestion, both in Stockholm and in the Mälardalen region. A general podcar system is not yet available, but much of the technology already exists.

Introduction

One of the major areas of responsibility that lies within SIKA's terms of reference is the analysis of the overall nature of the transportation and communication system in Sweden. SIKA also analyses the transport measures adopted by governments in order to assess their compatibility with the national objectives of transport policy.[1] The overriding objective of transport policy is to ensure that individuals and businesses throughout the country have access to an economically efficient and long-term sustainable transport system. This overriding objective encompasses six subsidiary objectives in the areas of accessibility, regional, development, equality of opportunity, transport quality, road safety and the environment.[2]

The problems arising in the transport sector with regard to road accidents, energy consumption, air pollution, noise and congestion, prompt the need for analyses of the various measures that could be implemented in order to meet the national transport objective. Financial instruments such as congestion charges and carbon taxes are examples of the kinds of measures that are often discussed.[3] A further example is the installation of automatic cameras along the roads in order to reduce speeding and, thereby, increase road safety.

There are also other kinds of measures that could lead to a more sustainable transportation system. Infrastructure itself has a major influence on the future development of the transportation system because of its long durability. Investments in infrastructure made today will affect travel and transport patterns for many years to come. The importance of infrastructure development and of its affect on our ability to achieve the overriding objective of transport policy is often discussed.

The current distinct division into separate transport sectors in infrastructure planning can well constitute an obstacle to the introduction of new, innovative transportation systems. As a consequence, we will fail to grasp the opportunities

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[1] SIKA's official terms of reference, http://www.sika-institute.se/upload/Om_sika/Förordning_2008.pdf

[2] The transport policy objectives have been approved by Parliament to comply with the latest transport policy act based on the Government proposals contained in SOU 2005/06:160, "Moderna transporter" [Modern Transport].

[3] *Vilken koldioxidskatt krävs för att nå framtida koldioxidmål?* [Which C02 Tax is Needed to Achieve C02 Emission Goals?]SIKA PM 2008:4.

available to help us achieve the transport policy objective.[4] Adopting a broader field of vision in social and infrastructure planning would enable potentially new solutions based on available technology to be realized.

This study includes two case studies of the potential of the podcar system in terms of its socio-economic benefits and of its contribution to achieving the transport policy objective. The first study analyzes the introduction of podcars in Stockholm as part of a solution to traffic problems in the capital. The second study evaluates the full deployment of a high-speed podcar system throughout the Mälardalen region (including Stockholm) as a way of enhancing commuting potential and, thereby, contributing to a more sustainable region.

Purpose

In a previous report, *A General Transport System*, SIKA analyzed technical solutions and the effects the introduction of a podcar system would have. This study supplements the earlier study, and, from a transport policy point of view, its purpose is to:

(1) calculate the economic costs and benefits of developing functioning podcar systems in Stockholm City and in the Mälardalen Region;
(2) examine the potential of these podcar systems to contribute to the fulfilment of the transport policy objectives defined as accessibility, regional development, equality of opportunity, transport quality, road safety and the environment.

The Stockholm case study shows how a podcar system could be developed in Stockholm as a complement to the existing public transport systems. Indirectly, the study examines the contribution a podcar system can make, even in the short term, to the effective resolution of difficult traffic problems. This will highlight the potentially significant effects on the fulfilment of the transport policy objective of the various priorities in current infrastructure plans.

The case study of the Mälardalen Region describes how a high-speed podcar network may be designed to enhance environmentally friendly commuting in the region by connecting the major municipalities around Lake Mälar. The costs and benefits of such a podcar network are also evaluated.

This study, thereby, contributes to a greater understanding of the importance of adopting an unbiased approach to the long-term planning of transport and infrastructure.

Outline

The report starts with a description of the specific features of a podcar system and what is meant by a *general* podcar system. In section 2, the case study of

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[4] *Samverkan kring regionförstoring*[*Co-operation on Regional Expansion*], SIKA Report 2007:1, and *En planeringsprocess som främjar innovation och förnyelse i transportsystemet,* [*A Planning Process for Renewal in the Transport System*] SIKA Report 2008:4.

Stockholm and its two scenarios is presented. In section 3 the perspective is widened to include the high-speed podcar network in the Stockholm-Mälardalen region. In section 4, these podcar systems are evaluated in terms of their viability, economic costs and benefits, and their ability to fulfil the transport policy objective. Section 5 presents our conclusions.

1 The Podcar System

Podcars running on guideways designated solely for that purpose, dedicated guideways, form a visionary transport system that is attracting a growing interest in many parts of the world. Several Swedish municipalities are interested in podcars and Swedish universities and consultancies have acquired a great deal of technical knowledge about the podcar system. In Uppsala, the Vectus company has built a testing ground for podcars using state-of-the-art technology.[5] At Heathrow Airport in London, a podcar system for the transport of air passengers between various terminals will soon be inaugurated.[6] There is not yet, however, any adequately tested and proven podcar technology ready for widespread use.

The idea of podcars is not new. Already in the 1950s early forms of the podcar were constructed across the United States, and in July 1969 the *Scientific American* ran a feature article giving an overview of these early experiments. During the oil crisis in the early 1970s, new developments of the concept surfaced. Since then, various forms of podcar system have been tried, with varying success. The best known system is probably that in Morgantown, West Virginia, which started in 1975 and still works well. Another example is Kabinentaxi in Hagen, Germany, built and tested in the 1970s and early 1980s. In the mid-1980s, oil became cheap and easily available, and the ideas of implementing podcar systems faded away.[7]

Figure 1.1 An example of a podcar station design. Copyright: Vectus

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[5] See www.vectusprt.se

[6] See www.atsltd.co.uk

[7] See *A General Transport System*, SIKA Report 2006:1, and Ed Anderson (1972), *Early History of PRT*, http://www.advancedtransit.org/pub/2007/EarlyHistoryOfPRT.doc

1.1 What are podcars?

By *podcar* we mean a development of what is often called Personal Rapid Transit (PRT) or Automated People Mover (APM). Various inventors and designers have provided similar but not identical definitions of podcar systems. The Advanced Transit Association (ATRA) took note of these variations and developed a definition in 1989 which is widely agreed upon today. The podcar system has all the following characteristics:[8]

- Direct origin-to-destination service with no need to transfer or stop at intermediate stations.
- Small vehicles available for the exclusive use of an individual or small group travelling together by choice.
- Service available on demand by the user rather than on fixed schedules.
- Fully automated vehicles (no human drivers) which can be available for use 24 hours a day, 7 days a week.
- Vehicles captive to a guideway that is reserved for their exclusive use.
- Small (narrow and light) guideways, usually elevated but also can be at or near ground level or underground.
- Vehicles able to use all guideways and stations on a fully connected PRT network.

Regarding technical aspects, the podcar system is technology independent. In the case of propulsion, for example, Vectus in Uppsala has chosen to use linear induction motors, while ULTra has chosen a different technique for their vehicles at Heathrow Airport in London. Vehicles may be designed in order to be able to use the road network for short distances – or interact with road vehicles – if constructed as so called *dual-mode* vehicles. An example of the use of dual-mode today is that of cars travelling on trains.

Thus the podcar is an advanced system for rapid individual or group transport, which does not involve stops at intermediate stations. The travellers choose their destination by, for instance, submitting a destination code and the system automatically selects the quickest way through the network. The system automatically maintains a safe distance between vehicles.

The podcar system seeks to combine the advantages of the car in terms of individual, flexible accessibility with the advantages of the train in terms of safety, energy consumption and environmental effects, including noise. Dedicated guideways, either elevated or at-grade, reduce potential environmental barrier effects and minimize the risk of accidents.

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[8] ATRA (2003): *Personal Automated Transportation: Status and Potential of Personal Rapid Transit*, Main report Jan 2003, Advanced Transit Association, p 10. http://www.advancedtransit.org/pub/2002/prt/main6.pdf

1.2 What is meant by a general podcar system?

The idea of developing a *general* podcar system is to extend the podcar concept to include the following characteristics:
- Passenger and freight transport (mainly high-value, lightweight goods);
- Local and regional low-speed lines, and high-speed interregional lines;
- Public and private use and ownership of podcars;
- Individual or group travel;
- Journeys with stops at intermediate stations, and non-stop journeys;
- Vehicles running on dedicated guideways and on roads (*dual mode*).

A general podcar system also means that the cars can be parked automatically if needed. Tight parking of podcars would require only a third of the volume of the ordinary car park.

To implement a general podcar system effectively, some kind of common standard specifications may be needed to allow the network to increase in size and to enable it to incorporate local systems. In this way, the concept of a seamless transport system could be realized, in which no changes of transport mode would be necessary during a journey. Furthermore, in order to reach technological consensus on important interfaces, a large-scale procurement or competition may be necessary.

1.3 Previous podcar initiatives and projects

In 2003, the ATRA made comparisons and evaluations of existing podcar technologies and their development potential and came to the conclusion that the podcar system was technically feasible and that the only thing preventing an introduction of such systems was the issue of finance.[9]

In their report, *PRT in Sweden: From Feasibility Studies to Public Awareness*[10] from 2007, Göran Tegnér et al. summarized a large number of local podcar studies from the period 1991-94 in the Swedish cities of Gävle, Jönköping and Gothenburg. The conclusions reached were that podcar systems could attract travellers and that they offered shorter journey times. In the 1990s, studies were also made in Umeå and Stockholm on the feasibility of constructing podcar systems.[11]

In recent years, the municipalities of Värmdö, Eskilstuna and Södertälje, among others, have analyzed the potential for local podcar systems.[12] So far, none of

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[9] ATRA (2003): Personal Automated Transportation: Status and Potential of Personal Rapid Transit, Main report Jan 2003, Advanced Transit Association, http://www.advancedtransit.org/pub/2002/prt/main6.pdf

[10] A summary of Swedish studies made by Göran Tegnér for a Conference in Vienna in 2007: http://advancedtransit.org/pub/2007/tegner20070422.pdf

[11] These studies were put forward at podcar conferences in Minnesota in 1996 and in Copenhagen in 1999, respectively.

[12] Eskilstuna (2008): Hållbar infrastrukturutveckling: Nytt transportsystem Spårbilar, [Sustainable Infrastructure Development: New Transport Systems, the Podcar] IST Reports-2008:1, 2008-03-29. Spårbilar för Södertälje- en transportvision, [Podcars for Södertälje- a vision of future public transport] WSP Analys & Strategi, 2008-05-30

these studies has led any of the municipalities in question to decide to go ahead with planning a podcar system. Tegnér et al. believed that the reasons for this caution were the risks involved and the issue of funding, i.e. that it was difficult and risky for a municipality or a company alone to engage in untested technology, and to invest fully in the system before there was sufficient market demand.[13]

In Sweden and the United States there is a network of municipalities called KOMPASS under the auspices of the Swedish-American *Institute for Sustainable Transportation* (IST). The network consists of representatives of the municipalities which are interested in investing in future podcar systems and its aim is to strengthen local initiatives on podcars by:

- promoting international cooperation among cities, municipalities and public transport operators;
- creating a forum for the exchange of information and experience;
- disseminating information about podcars to the public, businesses, property developers, politicians and government officials;
- working for various financial solutions;
- communicating with suppliers on common issues and planning processes;
- working through joint projects on constructing pilot tracks;
- trying to facilitate the implementation of podcar systems and to find ways of reducing costs and risks.

As mentioned above, in 2006 SIKA carried out a study called *A General Transport System*. Together with the Swedish Rail Administration (SRA) and the Swedish Governmental Agency for Innovation Systems (VINNOVA), SIKA has contributed towards funding studies of podcars. The Swedish Rail Agency is responsible for the regulatory approval of podcar systems in Sweden and their international reputation was one of the reasons why Vectus decided to locate a testing ground in Sweden.

The 5th Framework Programme of the European Union included a project called *Evaluation and Demonstration of Innovative City Transport* (EDICT), which started in 2001 and was completed in 2005. The project included 11 different universities and consultancy firms together with the 4 European cities of Eindhoven, Cardiff, Huddinge and Rome. The EDICT project was a major study that can be said to have established the podcar system in Europe. The EU Directorate-General on Energy and Transport wrote in their evaluation in 2006 that:

"PRT contributes significantly to the transport policy and all related policy objectives. This innovative transportation concept allows affordable mobility for all groups in society and represents opportunities for achieving equity. The demonstration of the PRT prototype system "ULTRA" at a test site in Cardiff, four accompanying case studies at different cities and the overall European assessment indicated high overall benefits. The specific urban Transport problems in particular of new member states, accession and candidate countries could be alleviated significantly at a lower cost than any other transport system.

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[13] A summary of Swedish studies made by Göran Tegnér for a Conference in Vienna in 2007: http://advancedtransit.org/pub/2007/tegner20070422.pdf

PRT is the personalisation of public transport, the first public transport system which can really attract car users and which can cover its operating cost and even capital cost at a wider market penetration. PRT complements existing public transport networks. PRT is characterised through attractive transport services and high safety. A first fully operational system is urgently needed to demonstrate all the capabilities and to alleviate some remaining critical issues. An active role of all key actors from city level up to the EU level is required to facilitate legislation, regulation and financial support" [14]

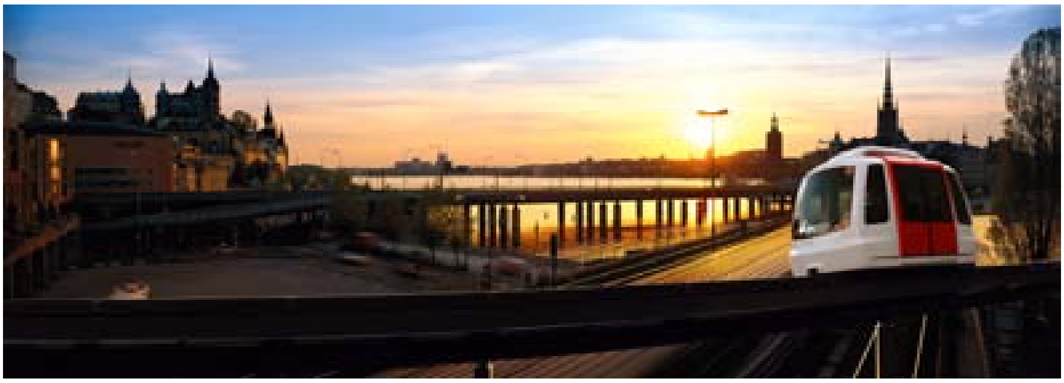

Figure 1.2 Podcar on a dedicated guideway. Copyright: Vectus

1.4 Willingness to pay and attitudes towards podcars

Apart from the risks and costs associated with the development and funding of podcars it is also important to take into account the attitudes of users to the system. Here we refer to some studies that have examined these attitudes in the past decade.

In 1996, Professor Elsa Rosenblad at Chalmers University of Technology in Gothenburg conducted a study called *Brukarens möte med ny teknik – PRT* (Users and New Technology – PRT), with the support of virtual-reality technology. The purpose was to show which problems, from a passenger perspective, could be solved by a podcar system and to describe the conditions under which the system would be accepted and utilized by the passengers. The podcar was seen by the passengers as a mix between car and bus. Half of the passengers found podcars to interfere too much with the urban environment, while half of them accepted it. Most travellers felt safe in the vehicle and the majority felt no discomfort about getting off alone at a lonely station. They argued that the same situation could occur on a bus or a tram, but wanted to be able to continue their journey if they felt uneasy or afraid. Passengers were positive to a guideway separated from other traffic, which was believed to reduce the risk of collision. Safety belts were requested and the passengers also wondered what would happen in the event of a power failure; whether the vehicle would be stuck on the track and whether there were any escape routes. Rosenblad's survey showed that the participants were in

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[14] Deliverable D2.D-2.5 Second Annual Thematic Research Summary - Other Modes, Issue 1.0 Page: 8 of 31. http://www.transport-research.info/Upload/Documents/200608/20060831_111731_26955_other-modes_D2E_issue1-0.pdf

favour of the system but that its utilization required a fully developed podcar network, provided that the urban environment was not adversely affected by the visual intrusion of the system into its surroundings.[15]

In 1998, the Stockholm County Council Traffic Office hired Transek (now WSP Analysis & Strategy), a consultancy firm, to study the market demand for and economic feasibility of a podcar network in Stockholm. The results showed large savings in travel time and a potentially high demand. They also studied the willingness of passengers to pay for this mode of transport and their attitudes towards the comfort factors of the podcar system. Half of the respondents were motorists, and half were public transport users. The willingness to pay for manned stations was high, about 50 U.S. cents per journey. This reflects the insecurity people feel in the current unmanned metro and railway stations in Stockholm. The willingness to pay for travelling 5 metres above ground was slightly negative, -7 U.S. cents per journey, i.e. respondents were willing to pay 7 cents per journey to avoid travelling 5 m above ground. This was confirmed by the fact that 20% of the respondents felt unsafe when travelling 5 m above ground; 25% of the respondents agreed that podcars were a visual intrusion into the city landscape; 13% thought that travelling together in groups would be negative; and about half of the respondents felt unsafe when riding in automated systems without drivers.[16]

During the period 2001-2005, the EDICT project used focus groups to collect detailed assessments of the advantages and disadvantages of podcars, in addition to visits to ULTra's testing ground in Cardiff. In the beginning, people were slightly suspicious, especially with regard to the effects on personal safety of using unmanned vehicles and stations. But once provided with further information about the techniques involved, attitudes became more positive. Blind people as well as people in wheelchairs found the system more user-friendly than taxis or public transport.[17] An important conclusion to be drawn is that it is vital to inform passengers and potential passengers about the technology that is incorporated into the system.

In 2006, Erik Indal and Gustaf Oscarson carried out a study of podcars in Karlstad from a user perspective. The study showed that security was one of the major factors that ought to be addressed with the introduction of the system. Women especially expressed their concerns about personal safety when using the vehicle, particularly at night because there are no personnel, around. There was a concern for the security of the system in particular with regard to the height of the podcars above ground in case of emergency and possible technical failures. However, the participants showed an interest in and willingness to use the system in the future, and the conclusions drawn were that podcars have the potential to attract more passengers than the current public transport system, and can probably even attract

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15 Elsa Rosenblad (1997), Brukarens möte med ny teknik – PRT, [Users and New Technology-PRT] Institutionen för konsumentteknik – CTH report 1997:10, Chalmers University of Technology, Gothenburg, ref i Indal & Oscarson (2007)

16 Transek AB och Logistik Centrum (1999), Spårtaxi – ett effektivt och hållbart trafiksystem. Analyser av en pilotbana i Stockholm – marknad och ekonomi.[PRT-- an efficient and sustainable traffic system. Analysis of a test track in Stockholm-- market and profitability] KFB Report No. 1999:4 http://www.kfb.se/publ/main.htm

17 http://ec.europa.eu/research/environment/newsanddoc/article_2650_en.htm

private motorists.[18]
These studies of attitudes show that people can be uncertain about the podcar system and that the system may give rise to a visual intrusion that is seen as negative. These are important aspects to be taken into account in the event of the introduction and development of a podcar system. However, the studies also show that, as in the case of most new encounters, negative attitudes may disappear on closer acquaintance with the podcars and with the acquisition of more knowledge about them.

In this report, we have taken the existence of these attitudes into account and we have, therefore, assumed that the visual intrusion could be minimized by locating as much of the guideway as possible within the existing transport infrastructure, for instance alongside roads or rail tracks.

Regarding the concern for manned stations, we make the assumption that at least a few service personnel will be present at the stations when we estimate costs. The service personnel could, for instance, help passengers with calling and boarding podcars, answer questions and similar services.

Regarding podcar safety, the Swedish Rail Agency is the regulatory body responsible for safety standards when a podcar system is developed. This means that no system would be built without the approval of the Swedish Rail Agency.

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[18] Indal & Oscarson (2007). PRT - Personal Rapid Transit: A study of PRT in Karlstad from a user's perspective http://urn.kb.se/resolve?urn=urn:nbn:se:kau:diva-758

2 Case Study in Stockholm - Two Scenarios[*]

2.1 The policy aims are not being met in the Stockholm region

SIKA's annual follow-up of the transport policy objectives shows that the objectives relating to road safety, carbon dioxide emissions, air pollution and noise are still not being met.[19] In the large urban regions, the main problem is road congestion. In Stockholm’s inner city, congestion charges have helped to reduce congestion, but in other parts of the Stockholm region congestion is on the increase.

The Swedish Road Administration (SRA) recently reported that the reduction of fuel consumption in new cars between 2006 and 2007 was the largest reduction since the start of data collection in 1978.[20] The share of biofuels also increased.[21] Despite this, carbon dioxide emissions from road transport increased almost 2% in 2007. Since 1990, emissions in the transport sector have increased by 12%. According to the SRA, the reason is a sharp increase in road traffic.

The use of biofuels, together with improved energy efficiency, has the potential to reduce carbon dioxide emissions significantly, but according to the SRA this will not in it self be sufficient if a long-term sustainable transport system is to be established. Sustainability requires effective policy instruments that reduce the volume of car traffic and which improve the prerequisites for public transport, pedestrians and cyclists.[22] SIKA agrees with this conclusion and believes that there is a potential for more “climate efficient” travel patterns in urban regions and in densely populated corridors between cities, mainly through the transfer of passengers from cars to public transport. This potential needs to be better exploited in infrastructure planning.[23]

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[*] This is a summary of the report ”Infrastrukturplanering för ökad måluppfyllelse i Stockholmsregionen” [Planning infrastructure to meet the transport policy objectives in Stockholm].

[19] Uppföljning av det transportpolitiska målet och dess delmål. [Follow-up of the transport policy objectives and their subsidiary objectives] SIKA Report 2008:1.

[20] In 2007, fuel consumption for new petrol and diesel driven cars was 7.3 liters/100km (181 g CO_2/km compared with 7.8 litres/100 km (189 g CO_2/km) in 2006. Memo on increased CO_2 emissions. Swedish Road Administration, 31st March 2008. http://www.vv.se/filer/52556/pm_okade_CO2_utslapp080327.doc

[21] During 2007 the proportion of biofuels in the road transport sector rose from 3.5% in 2006 to 4..5%

[22] Memo on increased CO_2 emissions. Swedish Road Administration, 31st March 2008. http://www.vv.se/filer/52556/pm_okade_CO2_utslapp080327.doc

[23] Infrastrukturplanering som en del av transportpolitiken. [Infrastructure planning as a part of transport policy] SIKA Report 2007:4.

Stockholm is a region with high economic and population growth. At the same time, the region faces major challenges in order to solve current transportation problems of congestion on roads and rail, of air pollution, noise, etc. Traffic congestion in Stockholm is estimated to involve annual costs of between SEK200 million and SEK 8 billion for the private and commercial transport sector, according to a number of recent calculations.[24] [25]

In December 2007, a report titled *Trafiklösning Stockholm* ("Traffic Solutions for Stockholm") was published and accepted as the basis on which the Government framed its proposal on infrastructure which was then adopted.[26] [27] The report proposed infrastructure investment worth more than SEK100 billion by 2030.[28]

The package of suggestions in *Trafiklösning Stockholm* does not, however, contribute to a better fulfilment of many of the transport policy objectives.[29] The impact assessment[30] of this report shows that, on the basis of the proposals made by *Trafiklösning Stockholm,* emissions of carbon dioxide from the traffic in Stockholm will increase by at least 77%, assuming the average fuel consumption to be consistent with that of the present fleet of vehicles.[31] [32] Even if the average consumption of fuel in cars were to fall significantly by 2030, further strong measures would be needed in order to reduce carbon dioxide emissions drastically.[33]

The impact assessment shows that the proportion of people travelling by public transport will decrease once the proposals at put in place – with the overall traffic policy being fully implemented around the year 2030, the car share will have increased from 39% to almost 50%, while the share for public transport will have

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24 Vad kostar trängseln för näringslivet? En jämförande studie av trängselns effekt på restiden och hur den kan värderas.[The cost of congestion to commerce and industry. A comparative study of travel times and their value] Trivector Report 2004:27. Stockholms City 2004..

25 Kågesson, Per: Hur förhindra en trafikinfarkt i Stockholm? [Can we prevent a traffic meltdown in Stockholm?] Nature Associates/Svenska Vägföreningen, 2001.

26 Trafiklösning för Stockholmsregionen till 2020 med utblick mot 2030. [A solution to the traffic problems in the Stockholm region for 2020 with a prognosis to 2030] Stockholmsförhandlingen [Stockholm Delegation], 19th December 2007

27 The Government's infrastructure proposals with investment guidelines for road and rail transport 2010 to 2020 is expected in September 2008.

28 Trafiklösning för Stockholmsregionen till 2020 med utblick mot 2030.[A solution to the traffic problems in the Stockholm region for 2020 with a prognosis to 2030] Brochure. Stockholmsförhandlingen [Stockholm Delegation], 19th December 2007

29 Government Proposal SOU 2005/06:160, "Modern Transport".

30 Konsekvensbedömningar av underlag till Stockholmsförhandlingens resultat. [Impact Assessment of the Basis of Stockholm Delegation's Study] WSP Analys & Strategi, November 2007.

31 The analysis in the model has been designed so that the surrounding conditions in terms of both the alternative comparisons and the alternatives in the study as based on land use dscribed in the regional plan for 2001. This means that the demand for travel is largely given in the analyses. In reality, it is more likely that the degree of expansion of the transport system will have a significant effect on the demand for travel.
Konsekvensbedömningar av underlag till Stockholmsförhandlingens resultat [Impact Assessment of the Basis of the Stockholm Delegation's Study], p. 6(38).

32 Konsekvensbedömningar av underlag till Stockholmsförhandlingens resultat, [Impact Assessment of the Basis of the Stockholm Delegation's Study] p. 8(38).

33 Konsekvensbedömningar av underlag till Stockholmsförhandlingens resultat, [Impact Assessment of the Basis of the Stockholm Delegation's Study] p. 9(38).

fallen from 42% to just over 37%.[34] The share of public transport in the volume of traffic can be measured in different ways. A different estimate shows that about 25% of journeys in the county of Stockholm are made on public transport.[35] When the package of proposals recommended in *Trafiklösning Stockholm* has been fully implemented, congestion will have increased on the roads compared to now – the proportion of bottlenecked traffic lanes at peak times in the county will have increased from the present 0.1% to 0.5%, i.e. the congestion will be about 5 times as large.[36] [37]

Trafiklösning Stockholm does not explore how the package of proposals would need to be altered to maintain or even increase the share of public transport by 2020 and 2030. Nor does it suggest how road congestion and the levels of carbon dioxide emissions from transport in Stockholm could be reduced from the current levels.

Trafiklösning Stockholm compares its package of proposals and their effects with the situation which would arise in Stockholm if nothing was done by 2030, which certainly would be much worse in terms of congestion on the roads. But there is a wide range of possible instruments and reallocations of infrastructure between these two possible outcomes which could be applied and for which economic and demographic growth are possible, while at the same time meeting the transport policy objectives. This case study of Stockholm focuses on the question of whether it is possible to reallocate investment in infrastructure among various modes of transport in such a way that the share of public transport would be increased, congestion reduced, and the transport policy objectives fulfilled.

2.2 Point of departure for the case study

The point of departure for the Stockholm case study is the importance of achieving the national transport policy objectives in the transportation system in Stockholm. The purpose is to analyze whether a reallocation of infrastructure investment towards podcar systems would in the short-to-medium term enable transport policy objectives to be achieved more efficiently than the current infrastructure plans for Stockholm.

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34 Konsekvensbedömningar av underlag till Stockholmsförhandlingens resultat,[Impact Assessment of the Basis of the Stockholm Delegation's Study p. 5(38).

35 SIKA's follow-up of objectives, SIKA Report 2007:3.

36 One means of measuring the importance of the total traffic solution for the flow of traffic and congestion is to take the proportion of lanes in the region which have reduced speed because of tailbacks. A bottleneck occurs when speed is reduced by more than a third. Even if the proportion of roads affected by major tailbacks seems little, interruptions in the flow of traffic have repercussions in large parts of the system since all traffic caught in the bottleneck is affected. Konsekvensbedömningar av underlag till Stockholmsförhandlingens resultat, [Impact Assessment of the Basis of the Stockholm Delegation's Study] p. 10(38).

37 Konsekvensbedömningar av underlag till Stockholmsförhandlingens resultat, [Impact Assessment of the Basis of the Stockholm Delegation's Study] p.10(38).

The Stockholm case study focuses on three main questions:

- Would an alternative allocation of infrastructure investment increase the fulfilment of the transport policy objectives, compared to the mix of investments discussed in *Trafiklösning Stockholm*? To answer this question we analyze the combination of an increased congestion charge (toll) with a new commuter rail link and a podcar network.

- How is it possible to construct a podcar system that acts as a complement to the existing public transport system and contributes to solving the traffic problems in Stockholm over the next 10-20 years?

- What socio-economic consequences would a podcar system have? Podcars running on elevated, dedicated guideways may help to avoid resistance to the system and lessen its physical intrusion on property and the environment. The system would also reduce the risk of accidents and the higher average speed would also contribute to shorter travel times compared to traditional public transport.

2.3 The design of the case study

The reference scenario in the case study is based on the base scenario used by the Swedish Rail Administration (SRA) and the Swedish Road Administration in their infrastructure planning for the year 2020.

In order to analyze better the effects of the new infrastructure, we assume a relatively conservative forecast of fuel prices. The fuel prices used in the traffic forecast and evaluation are thus SEK14.79 a litre for petrol and SEK14.04 a litre for diesel. The growths of population and of the economy and the increase in employment are based on the regional development plans for Stockholm.

The issue addressed in the case study is the problem of accessibility in Stockholm as discussed in several recent reports, such as the regional development plan for Stockholm and *Trafiklösning Stockholm*. The Stockholm case study analyzes two scenarios:

Scenario 1: The combination of a congestion charge with a north-south commuter rail link running west of the city centre, from Häggvik in the north to Flemingsberg in the south (see figure 2.1).

Scenario 2: A regional podcar network as a complement to the commuter rail link in Scenario 1. Thus, the congestion charge and the commuter train line are also included in this scenario (see figures 2.6 and 2.7).

Scenario 1 – North-south commuter rail link

In the first scenario, the purpose is to see whether a greater focus on public transport and policy instruments would achieve greater accessibility and better fulfilment of the transport objectives in the Stockholm region, compared to the combination of measures discussed in *Trafiklösning Stockholm* .

A key measure discussed in *Trafiklösning Stockholm* is the so-called north-south axis crossing Stockholm which is designed to increase accessibility between the northern and southern parts of the county. Today there is a proposal for a new motorway, *Förbifart Stockholm* [*By-pass Stockholm*], which is expected provide enhanced regional accessibility.[38]

For regional and local travel in city regions and in commuter corridors between urban areas, rail transport has the potential to provide safe and resource-efficient accessibility, and to reduce congestion in comparison to private cars. In Scenario 1, we analyze whether the regional accessibility objectives –between the northern and southern parts of Stockholm – can be achieved with a commuter rail link. As with *Förbifart Stockholm*, the aim with Scenario 1 is to connect some of the important regional city centres.

In *Förbifart Stockholm*, the Swedish Road Administration also presented an alternative to the highway; the so called ”Combination Alternative”, which combined a new railway track with improvements to the existing road network and congestion charges to stimulate the transfer of passengers to public transport. However, the SRA did not analyze further the socio-economic consequences and viability of this alternative.[39] Our commuter rail link in Scenario 1 is similar to the SRA’s Combination Alternative. Both are located west of the centre of Stockholm, but east of the planned motorway. However, our Scenario 1 provides more connections to the western parts of Stockholm than is suggested in the Combination Alternative.

The railway track in Scenario 1 is designed in such a way that between Häggvik and Sollentuna existing tracks are used (see figure 2.1). Shortly before Helenelund station a new double-track is drawn in tunnels in a south-west direction towards a underground station in Kista. Across Järvafältet between Ärvinge and Rissnehallen the track would go above ground. From Sundbyberg the tracks are again drawn in tunnels under Bällstaviken and Bromma Airport to another underground station at Brommaplan. From Brommaplan the tracks go south-east and cross Lake Mälar between Solviksbadet and Axelsberg, where another underground station is located. The next station is Telefonplan and the tunnel then continues under Södertäljevägen. Through Västberga, the tracks could go above ground and reconnect to the existing tracks at Älvsjö. The tunnels are expensive, but may prove necessary to minimize noise and physical intrusion along the line.

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[38] Vägutredning effektivare nord-sydliga förbindelser i Stockholmsregionen [Study of more efficent north-south road links in the Stockholm region] . SIKA registration number 026-200-07, p. 30.

[39] Nord-sydliga förbindelser i Stockholmsområdet. Sammanfattning av vägutredning. [North-south links in the Stockholm area. Summary of the roads study.]Vägverket [Swedish Road Administration] June 2005, p. 32.

- Total track length: 32.8 km of which 13.3 km is on existing tracks
- New track length: 19.5 km of which 17.5 km will be underground.
- 5 new stations: Kista, Sundbyberg, Brommaplan, Axelsberg, Telefonplan
- Capacity (2 units X60) at 5 min frequency: 20,976 passengers / hour.
- - “- at 10 min frequency: 10,488 passengers / hour.[40]

In addition to this increased capacity for public transport, Scenario 1 also includes increased levels of congestion charges for vehicles crossing Stockholm, to see whether a transfer from car to public transport is possible using this combination of measures.

An increased transfer of commuters from car to public transport can result in reduced road congestion and, thereby, increased road capacity for commercial road transport (which does not pay any charges). Therefore, a congestion charge is applied to the key motorway, Essingeleden, with the same level of charges as in the ring around Stockholm. This is similar to what was suggested in *Trafiklösning Stockholm*[41] for 2030. Since 2020 is only 12 years away, the charges have a maximum of SEK100 a day:

- high charge at peak hour times: SEK 30.
- medium charge at off-peak times: SEK 25
- low charge at off-peak times: SEK 20
- maximum charge per day: SEK 100.
- the Essingeleden motorway is also included

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[40] Maskotmedia 2008.

[41] Konsekvensbedömningar av underlag till Stockholmsförhandlingens resultat, [Impact Assessment of the Basis of the Stockholm Delegation’s Study] p. 4(38). WSP Analys & Strategi, November 2007.

Figure 2.1. Commuter rail link in Scenario 1. The picture shows underground and other rail links. Picture: Maskotmedia. Copyright: SIKA

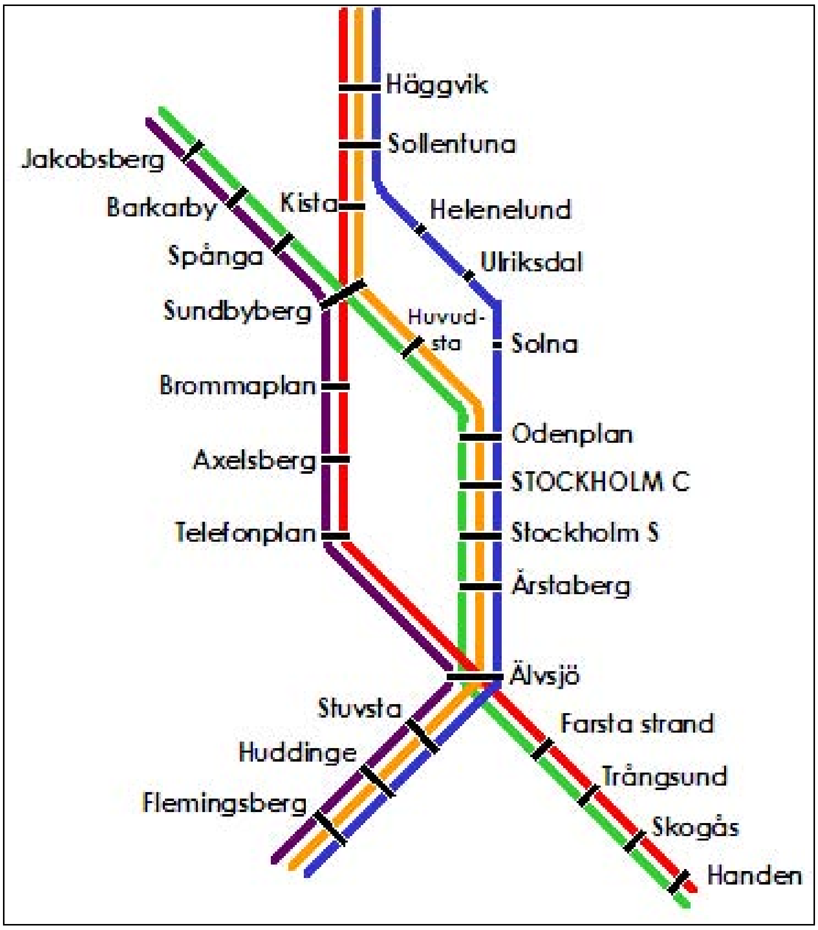

Figure 2.2. Alternative route combinations available with the proposed commuter rail link in Scenario 1. Picture: Maskotmedia. Copyright: SIKA

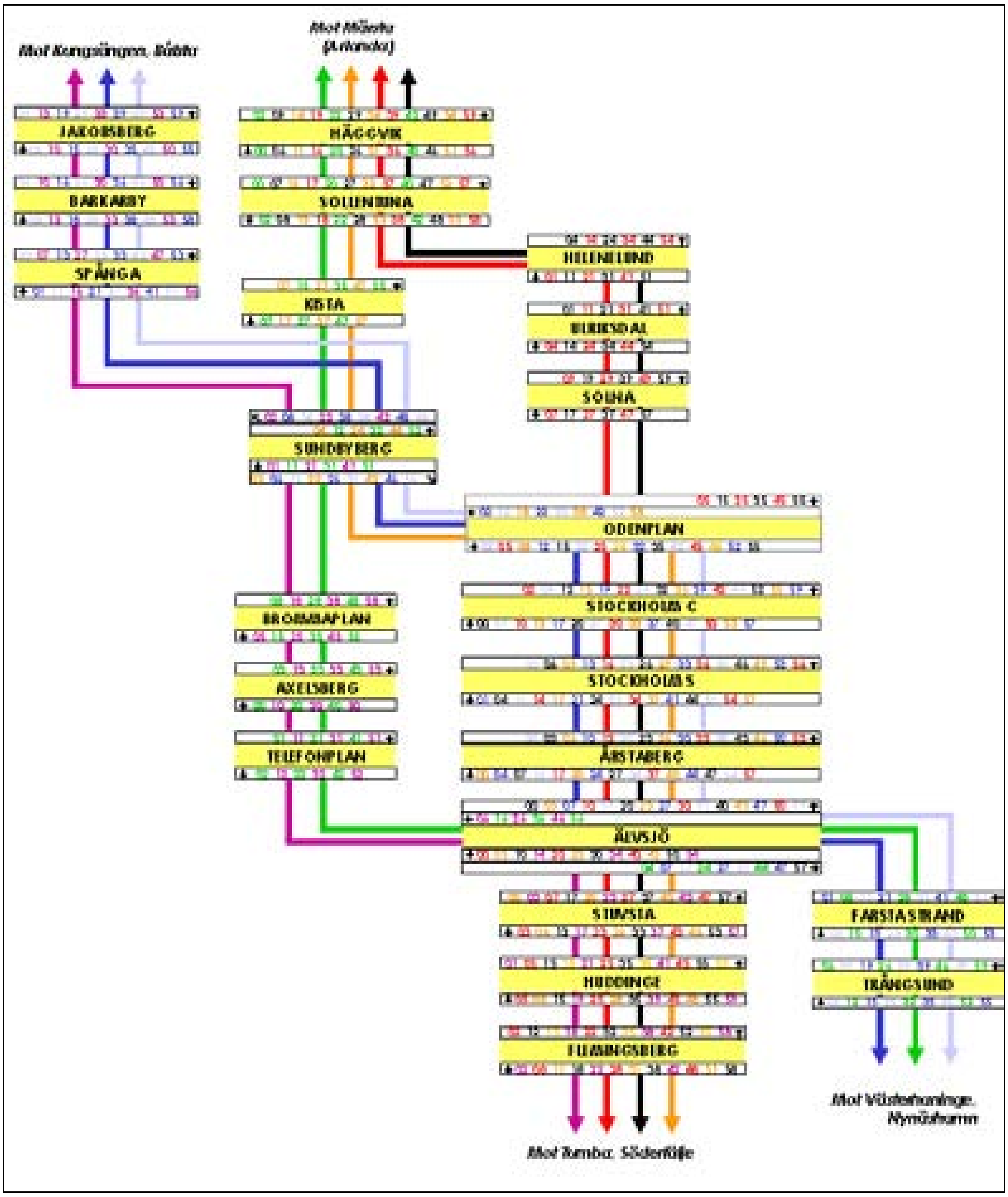

Figure 2.3. Traffic on the commuter rail link in Scenario 1. Picture: Maskotmedia. Copyright: SIKA

Scenario 2 – Podcar system in Stockholm

In Scenario 2, the purpose is to show how a podcar system can contribute to improved accessibility and better fulfilment of the transport policy objectives in the Stockholm region. This scenario is based on the commuter rail link and congestion charge described in Scenario 1. The podcar network in Scenario 2 is placed around the Stockholm region, connecting existing and future public transport nodes, commercial centres, working areas and residential areas, where the demand for accessibility is expected to be high. The capacity of this podcar system is assumed to correspond to the capacity of the commuter railway.

If each podcar is designed for up to 8 people and the podcars run with a 3-sec headway, this would mean a capacity of 9,600 passengers per hour in one direction, and double that for both directions. At peak hours, the podcar system can be adapted to provide a higher capacity by attaching podcars to each other into “podcar-trains"; 3 units attached to each other means a capacity of 28,800 passengers an hour in one direction.[42]

As in Scenario 1, this podcar system is designed and located to minimize noise and reduce its physical intrusion into sensitive natural, residential or cultural areas. Therefore, it is assumed that parts of the podcar guideway network will be placed underground. Above ground, it is expected that the guideway will be placed as much as possible along existing transport corridors such as roads or railways, to minimize intrusion and to simplify construction. If possible, the podcar guideway will also be placed at grade in order to reduce costs. Figures 2.4 and 2.5 show podcar guideways constructed along the existing road infrastructure.

Figure 2.4. Podcars exploiting the existing road infrastructure.
Copyright: LogistikCentrum

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[42] 3 podcars with 8 passengers = 24 passengers. With a 3 sec. headway this makes 24 passengers*3,600/3sec.=28,800 passengers/hour

Figure 2.5. Podcars in Stockholm.
Copyright: LogistikCentrum

The podcar system outlined in Scenario 2 is about 160 km long with 41 stations, i.e. an average of approximately 4 kilometres between stations. The stations are located at major transport nodes, commercial centres, working areas and residential areas. The podcar system in Scenario 2 is expected to act as a complement to the existing regional transport system by creating a linked network around the outer parts of Stockholm. The podcar network is located in corridors which are currently not served by public transport and it thereby connects important nodes in the region (figures 2.6 and 2.7).

Total length of the guideways: 160 km (twin track)
Total km in tunnels: about 15 km
Total km at grade, along major roads: about 115 km
Total km elevated guideways, especially in central parts of the city: about 30 km

Figure 2.6. Scenarios 1 and 2. Commuter rail link Häggvik-Brommaplan-Älvsjö (light blue) and podcar network (dark blue). Based on the general survey map ©National Land Survey in Sweden, authorisation 2008-16901. Copyright: SIKA

Figure 2.7. Stations in Scenarios 1 and 2. Based on the general survey map ©National Land Survey in Sweden, authorisation 2008-16901. Copyright: SIKA

2.4 Documentation of traffic data used in the case study

The two scenarios of improved public transport and a regional podcar system in Stockholm have been analyzed using the traffic forecasting software called Sampers, which has been developed by the Swedish transport authorities and SIKA. Sampers contains large amounts of data on population growth, economic growth, land use, and other relevant information. SIKA has followed as closely as possible the assumptions concerning the various parameters made in the report in order to facilitate a comparison. The data used in our forecasting model has been collected partly from SAMS[43] and partly from the regional urban development plan for Stockholm (RUFS 2001). This data is also used in *Trafiklösning Stockholm*.

2.5 Results of the traffic forecasts

In this section, we present some of the results from the traffic forecasts made using Sampers. A detailed presentation of the results is found in a supplementary report called "Infrastrukturplanering för ökad måluppfyllelse i Stockholm" ["Planning infrastructure to meet the transport policy objectives in Stockholm"].

Scenario 1 North-south commuter rail link

Changes in travel time
The commuter rail link in Scenario 1 shortens the public transport travel times between different areas of Stockholm. In table 2.1, the peak hour travel times in Scenario 1 are compared to those for the planned motorway *Förbifart Stockholm* (2015) and the reference scenario for 2020.

The travel times for cars outlined in Table 2.1 are from door to door, including the time spent looking for parking and time spent walking to and from the vehicle. On average, this addition to the travel time is about 10 minutes[44].

Apart from the fact that the forecast for *Förbifart Stockholm* is for 2015, the comparison is not entirely fair, since not all the underlying factors that can affect the forecasts are known. However, it can be noted that in some cases, the travel time using public transport is less than the travel time using private cars. Compared to the reference scenario, our Scenario 1 reduces the travel times in most cases, especially when travelling from north to south and vice versa.

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[43] SAMS is an acronym for Green Town Planning in Sweden and is a project run by The National Board of Housing, Building and Planning**, and the Swedish Environmental Protection Agency together with municipal and regional authorities·**

[44] WSP (2007b)

Table 2.1 Travel times, in minutes, by car and by public transport in the reference scenario, Scenario 1, and on the motorway *Förbifart Stockholm*.[45] * Indicates the shortest times.

	Förbifart Stockholm car 2015	Reference scenario car 2020	Scenario 1 car 2020	Scenario1 public transport 2020
Kista Centrum (KiC) -> SkC	29.3	32.9	31.1	26*
Skärholmen C (SkC) -> Ki C	35.2	37.2	33.7	26*
KiC->Barkarby Outlet (BaO)	17.2	13.8	13.7*	15 (Barkarby C)
BaO->KiC	19.2	15.1	15*	15 (Barkarby C)
KiC->Flemingsberg C (FlC)	38.1	40.6	38.5	27*
FlC->KiC	41.7	42.9	39.2	27*
KiC->Häggvik (Hägg)	17.7	12.5	12.5	6*
Hägg->KiC	18.2	14.1	13.8	6*
SkC->BaO	27*	43.7	41.8	30 (Barkarby C)
BaO->SkC	23.5*	39.1	37.5	30 (Barkarby C)
FlC->SkC	18.4	15.6*	15.6*	26
SkC->FlC	18.2	15.4	15.3*	26
SkC->Hägg	31.5*	40.8	37.3	32
Hägg->SkC	27.9*	38.1	36.3	32
BaO->FlC	32.3*	46.8	44.6	31 (Barkarby C)
FlC->BaO	33.5*	49.4	45.2	31 (Barkarby C)
BaO->Hägg	15.4*	18.4	18.3	23 (Barkarby C)
Hägg->BaO	15.5*	18.3	18.3	23 (Barkarby C)
FlC->Hägg	38	46.5	42.9	33*
Hägg->FlC	36.7	45.8	43.7	33*

Effects on traffic

The shorter travel times achieved by the commuter rail link cause more people to travel by bus and train, i.e. there is a transfer from cars to public transport. The total number of vehicle kilometres (vkm) during an average 24-hour day and during the rush hour, decreases by about 3 percent. The number of vkm for private cars decreases by about 4 percent, compared to the reference scenario. The number of commercial vehicle kilometres is about the same as in the reference scenario.

Effects on transportation

The total number of passenger kilometres (pkm) decreases by about 1 percent. The number of pkm for commuter trains increases by about 23 percent, while the number of pkm for cars and buses deceases by about 4 percent. The number of pkm for other train traffic decreases by 8 percent, i.e. seats become available on the trains. On the motorway crossing Stockholm from north to south (Essingeleden), car traffic decreases by about 35 percent during the rush hour, i.e. accessibility for commercial transport improves.

Effects on congestion

Congestion is measured as the number of road kilometres where the average speed is reduced compared to the speed limit. Figures 2.8 and 2.9 show the congestion in the reference scenario for 2006 and 2020, respectively. Figure 2.10 shows the congestion in Scenario 1 for 2020; "medium congestion" (in blue) increases by only 15 percent, compared to 50 percent in the reference scenario. "Serious

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[45] WSP (2007b)

congestion" (in red) increases by only 9 percent, compared to 67 percent in the reference scenario.

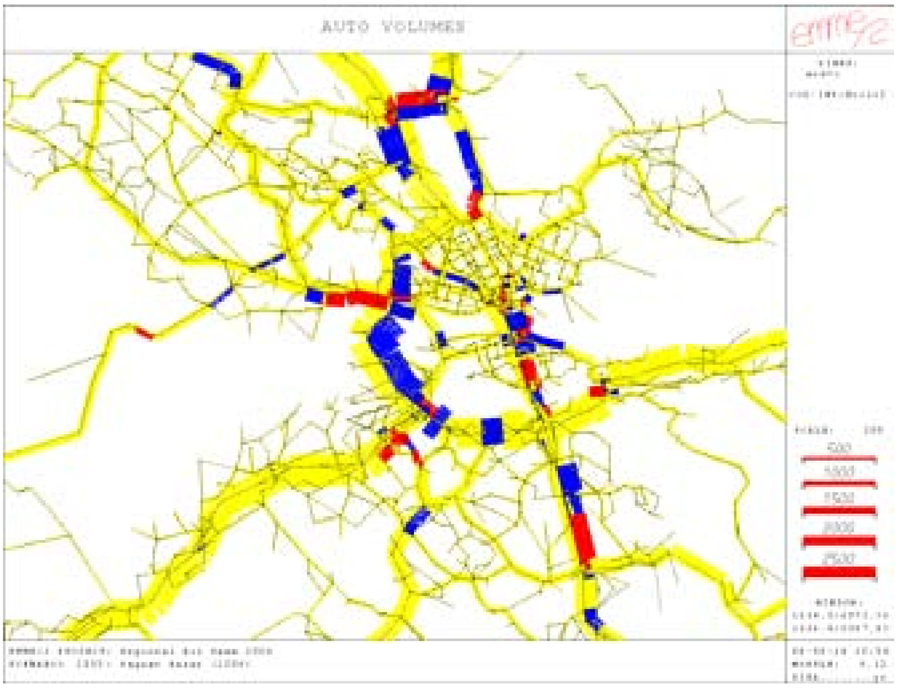

Figure 2.8 Congestion bottlenecks in the reference scenario in 2006.
Blue: speed reduced by 33 – 50 %. Red: speed reduced by >50 %. Copyright: SIKA

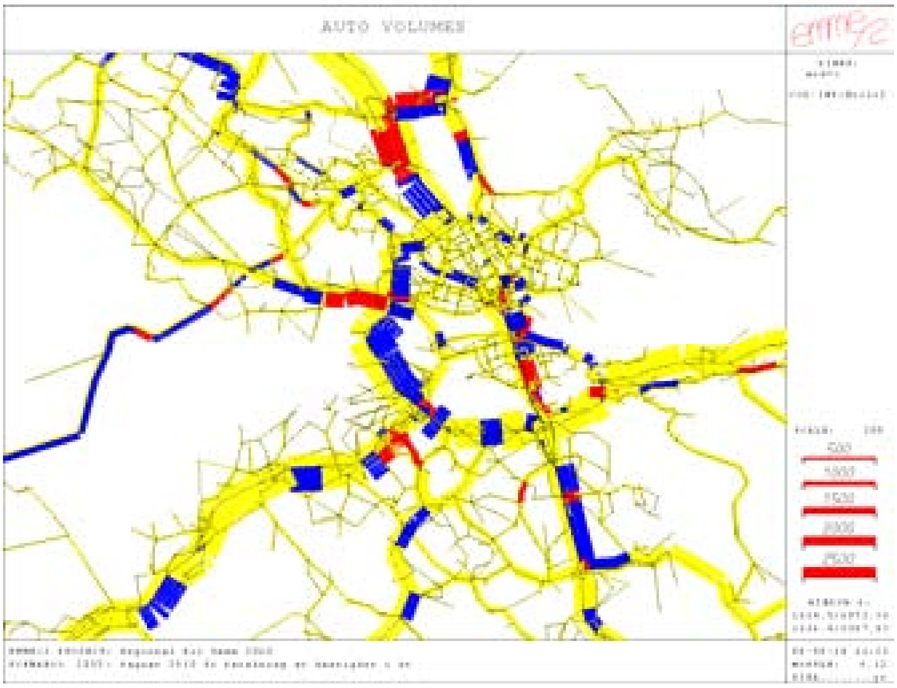

Figure 2.9 Congestion bottlenecks in the reference scenario in 2020.
Blue: speed reduced by 33 – 50 %. Red: speed reduced by >50 %. Copyright: SIKA

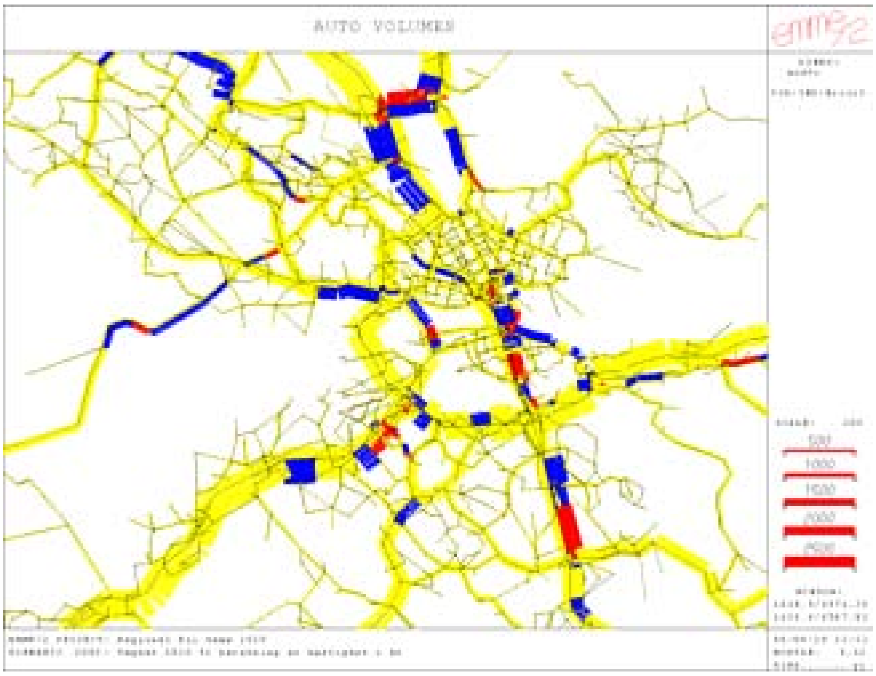

Figure 2.10 Congestion bottlenecks in Scenario 1 in 2020.
Blue: speed reduced by 33—50%. Red: speed reduced by >50 %. Copyright: SIKA

Scenario 2 - Commuter rail link and podcar system in Stockholm

Effects on traffic

With the podcar network in Scenario 2 the travel times are reduced even further, causing more people to transfer from cars to public transport and podcars. The total number of vehicle kilometres decreases by about 4 percent in an average day, i.e. 1 percent more than in Scenario 1. The number of vehicle kilometres for cars decreases by about 5 percent, i.e. 1.5 percent more than in Scenario 1. The number of commercial vehicle kilometres is about the same as in Scenario 1. During the rush hour, the number of vehicle kilometres for cars decreases by about 7 percent, i.e. 2 percent more than in Scenario 1.

Effects on transport

The total number of passenger kilometres during an average working day increases by about 2 percent, compared to the 1 percent *decrease* in Scenario 1. The number of commuter train passenger kilometres decreases by about 12 percent compared to the reference scenario, and the number of bus passenger kilometres decreases by 21 percent. The number of subway passenger kilometres decreases by 18 percent compared to *today*, which is a 32 percent decrease compared to the reference scenario. The number of other rail passenger kilometres decreases by about 11 percent. These large reductions show that there is a transfer of passengers from the traditional public transport system to the podcar system. The north-south private car traffic decreases by about 1 percent more than in Scenario 2.

Effects on congestion

Figure 2.11 shows the effects on congestion of Scenario 2. Traffic congestion is reduced further in comparison with Scenario 1. According to the forecast, the amount of “medium congestion” (in blue) increases by only 5 percent in Scenario 2, compared to 15 percent in Scenario 1. The amount of “serious congestion” (in red) increases by only 7 percent in Scenario 2, compared to 9 percent in Scenario 1.

The share of public transport journeys increases to about 32 percent, of which 32 percent are podcar journeys. This gives an overall share of about 10 percent for podcars. The share of journeys made by pedestrians or cyclists decreases slightly in Scenario 2, compared to the reference scenario. Depending on the density of the podcar network and the distance between stations, there is a slight transfer from pedestrians and cyclists to podcar passengers.

Increased travel by rail in the Mälardalen region

The forecast for rail traffic does not include journeys on X2000 high-speed trains. Also, not all regional journeys are included in this regional model, since they are dealt with in the national model. In the forecast, the effects on regional train journeys are included, as well as all journeys associated with work and commuting. The forecast shows that the increased accessibility to long-distance trains causes more people to travel by public transport, i.e. there is a transfer from cars to trains. This occurs with no external effects on regional rail traffic.

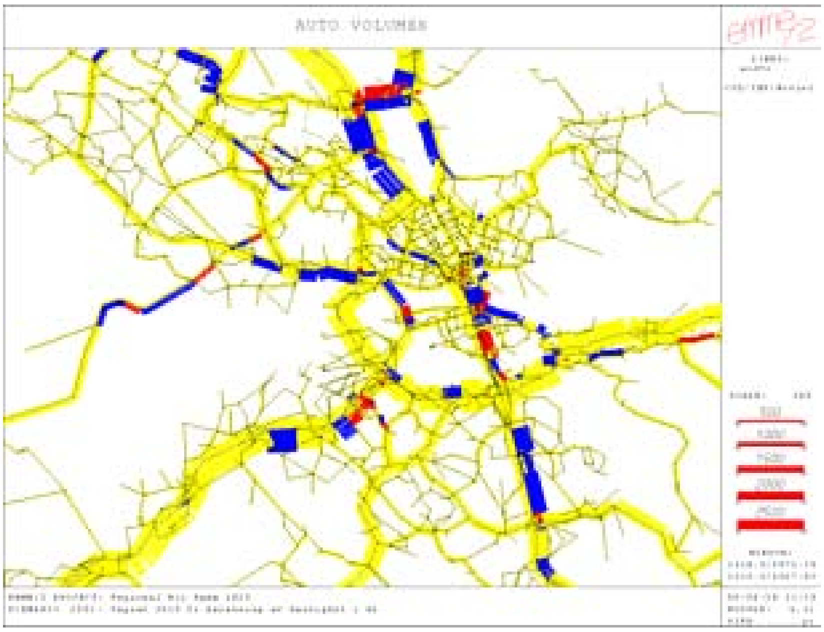

Figure 2.11. Congestion bottlenecks in Scenario 2 in 2020.
Blue: speed reduced by 33 – 50%. Red: speed reduced by >50 %. Copyright: SIKA

3 High-speed podcar system in the Mälardalen region

This case study is a cost-benefit analysis of a fully developed podcar system beyond the year 2020, and covers the entire Stockholm region. The system is designed to act as a complement to the current interregional communication systems in the Stockholm region by offering shorter travel times than the road and rail systems.

3.1 Travel in the Mälardalen region

Based on travel data from the reference scenario for 2020, used in the Sampers modelling system, we can estimate the traffic flows between the counties in the Mälardalen region. The results of the local Sampers analysis can also provide a basis for assumptions made about the transfer to podcars from other modes of transport.

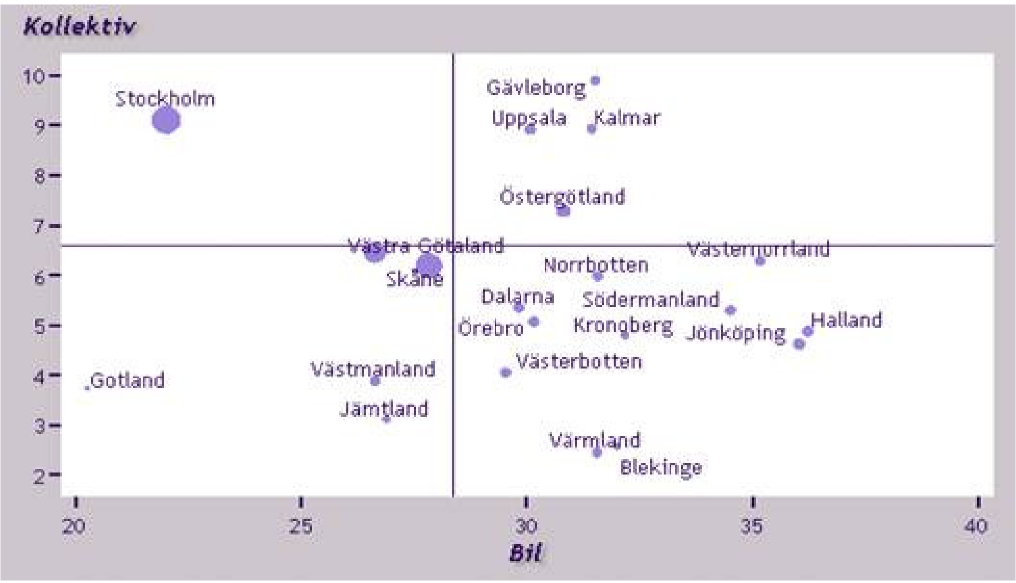

Figure 3.1. Average number of kilometres travelled per person and day by public transport and by car. Source: RES 05/06. Table 19. Copyright: SIKA

Figure 3.1 shows how the patterns of travel differ among the various counties in Sweden The four counties located around Lake Mälar - Stockholm, Uppsala, Västmanland and Södermanland - have quite different patterns of travel and are located in different quadrants in figure 3.1. Among the counties of the Mälardalen region, Stockholm has the largest number of kilometres travelled per person and day on public transport, while Södermanland has the greatest number of kilometres travelled per person and day by car.

This means, in turn, that journeys taken on a podcar system would be different for the different counties. The differences may also indicate that the current expansion of public transport may differ between the counties. According to a study carried out as part of the official SIKA survey RES05/06, approximately 220,000 journeys per day are made by car in the county of Uppsala and in the counties of Södermanland and Västmanland. In Stockholm about 1,120,000 journeys per day are made by car, i.e. about five times as many.

About 55,000 journeys per day are made by bus or train in the county of Uppsala, about 27,000 in Södermanland, and about 23,000 in Västmanland. On average, this amounts to about 35,000 journeys by bus or train in the counties around Lake Mälar. In the county of Stockholm about 400,000 journeys are made every day, i.e. about 11 times as many. More than six times as many journeys are made by car, compared to those by bus or by train.

From data provided by the Swedish Road Administration, we know that on average about 13,000 vehicles per day, mostly cars, travel on the roads between Stockholm, Uppsala, Enköping, Västerås, Eskilstuna and Södertälje. Close to Stockholm there are more vehicles. We know that there are approximately 3,000 train journeys on average per day between places in the Mälardalen region. Based on the information we have available, this means about four times as many car journeys per day are made, compared to rail journeys, between places in the Mälardalen region. The sum of all journeys in a year is about six million for the major links in the Mälardalen region. The growth of traffic is estimated at 1.7 % per year until 2020 and 1% per year beyond 2020. These growth rates mean about 10 million journeys by car and train in 2040.

3.2 The infrastructure of the Mälardalen region

The Mälardalen region has a total population of about three million. It is a polycentric region where the labour market is becoming increasingly complex and people commute between the various cities. The Baltic Sea region is expected to remain one of the strongest growth regions in the world over the next decade. Both the population of and journeys in and around the Mälardalen region are expected to increase as the Baltic Sea region is a key region in an expanding area. The OECD states, in its "Territorial Review of the Stockholm-Mälar Region", that it is one with "growing-pains". In order to be able to draw on the economies of scale of a large region, it is necessary to improve communications in the region[46].

In 2004, in its plans for the railways, the Swedish Rail Administration (SRA) gave an account of the traffic situation along the Mälar track viz, Stockholm-Västerås-Kolbäck-Arboga. The volume of traffic was high, suggesting that changes in housing and the labour markets had brought about improved efficiency of the rail links. In particular, Västerås and places between Västerås and Stockholm had growing populations and increases in commuter traffic with the Stockholm area. Business people along the link argued strongly for enhanced services to and from Stockholm, both in terms of capacity, frequency and travel time.

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[46] OECD (2006)

The travel time between Stockholm and Västerås is currently 51 minutes by train, without stops at intermediate stations. The distance between Västerås and Stockholm is 108 km. As the rail and roads run parallel the distance is the same for both. The average speed is 127 kmph for the direct train. The Swedish Rail Administration (SRA) wants to shorten the travel time to 40 minutes, meaning an average speed of 162 kmph in rush-hour. According to the Swedish Rail Administration (SRA), it may be necessary in the long term to build new railway stations in the county of Västmanland. A travel time of 40 minutes between Västerås and Stockholm, including train stops at intermediate stations, requires a much higher speed than 162 kmph.

The Swedish Rail Administration (SRA) also provides an account of the Svealandsbana, the railway line running from Södertälje through Eskilstuna to Valskog. Since the opening of the Svealandsbana, travelling has increase and the improved communications have contributed to a significantly better development of the municipalities along the link. Commuting between Eskilstuna and Stockholm has increased sharply. The large increase in the number of journeys between Eskilstuna and Stockholm has led to a shortage of capacity, including a lack of seats.

The goal is to run trains every half hour with a frequency of one train every fifteen minutes during rush hour. The distance between Eskilstuna and Stockholm is 115 km by train. The minimum travel time by rail is 53 min, meaning an average speed of 130 kmph, for direct, non-stop trains.

Today, the Enköping to Uppsala link has no train services. The fastest train journey from Västerås to Arlanda airport is via Sala and takes 1 hour and 26 minutes; the fastest bus route between Västerås and Arlanda Airport takes 1 hour and 33 minutes and the fastest route by car from Västerås to Arlanda goes through Rotebro and takes 1 hour and 22 minutes.

In their study “Den goda resan”, [1] The Swedish Road Administration gives an account of the road situation in the Mälardalen region. The E 18 is a trunk road which connects the western part of Svealand with Stockholm and is a part of the Nordic Triangle. This has been identified as a significant section of the EU Transeuropean network TEN-T. The E18 goes from Kapellskär to Stockholm and then via Västerås, Örebro, Karlstad and Oslo to Kristiansand and is of special significance for transport between Norway, Sweden-Finland and Russia. Near Västerås there are stretches where the lanes of traffic are not separated and where bottlenecks occur, which also contributes to road accidents. According to the Swedish Road Administration the number of vehicles varies from 18,000 to 30,000 vehicles a day.

The E 20, connecting Gothenburg and Stockholm, is an important road link for freight transport between Gothenburg / the West Coast and Bergslagen / the Mälardalen region / Stockholm. The part of the E 20 that runs along Lake Mälar is also included in the Trans-European Transport Network (TEN-T) that has been identified by the EU as a major transportation link.

From Södertälje to Stockholm the E 20 and the E 4 are the same road. The ports in Värtan and Frihamnen are reached through the centre of Stockholm via Uppsalavägen. According to the Swedish Road Administration, the number of vehicles varies from 35,000 to 70,000 a day. This causes major problems of mobility and road safety as well as large environmental problems for the residents in the area.

3.3 Interregional podcar track in the Mälardalen region

The long term plans of the Swedish Road Administration show that the road links in the Mälardalen region are strategically important and a large growth in traffic is predicted.

The north-south extension of the route from Västerås to Eskilstuna is a strategically important transport link. According to the national survey of journeys in Sweden, RES 05/06, there are potentially six million passengers on all or along parts of the route covering Gävle-(Sala)-Västerås-Eskilstuna-Katrineholm-Norrköping-Linköping.

Investment in infrastructure would shorten the travel time significantly. Northern Sweden would be brought about one and a half hours closer to southern Sweden which would also reduce the need for air transport. The link between Västerås and Eskilstuna is turning into one of the main links in the region and in some respects is becoming similar to the Stockholm bottleneck.

Therefore, it is important to study the impact an expansion of the podcar system would have on these routes. A more extensive podcar system for passengers can relieve road and rail networks and greatly increase the capacity of road and rail for freight. Furthermore, through a transfer of travellers to a podcar system the number of serious accidents can be reduced.

Figure 3.2. Train formation at high speed and separated vehicles at low speed. Picture: Visulogic. Copyright: SIKA

Västerås-Eskilstuna is one of the largest population clusters in Sweden and can be regarded as a centre in the western Mälardalen region. The cities of Västerås and Eskilstuna are both thinking of building local podcar networks and of linking their local networks by a bridge over Lake Mälar. Also in Södertälje there is an interest in building a local podcar network. At the Swedish University of Agricultural Sciences in Ultuna a study of the introduction of podcars in Uppsala is being made[47]. The Stockholm local traffic company has investigated the possibilities afforded by podcars and found them to be an interesting transport mode in the long term.

A possible scenario is a phased introduction of an inter-podcar network operating between the municipalities in the Mälardalen region. If these municipalities wish to build local podcar networks in the future, then a fully developed comprehensive podcar network in the Mälardalen region would make a major and beneficial contribution to the usefulness of local networks. Even if no municipal podcar networks were established in the Mälardalen region, a major interregional network would still provide substantial benefits thanks to the fast, non-stop journeys between cities in the region.

It is not likely that a fully developed Mälardalen network could be completed until well into the future. In view of the preparations and the political planning processes required, we estimate that a network can be fully operational in around 2030-40. Developments can proceed more quickly if there is a major positive response to the podcar system.

Based on the Swedish Road Administration and the Swedish Rail Administration (SRA) accounts of their plans in the Mälardalen region and on data on travel patterns and preferences, we have made a cost-benefit analysis of the economic consequences of a podcar network in the Mälardalen region. It is important to remember that this overview does not use the regular evaluation models Samper/Samkalk. Therefore, the analysis has greater uncertainty with regard to its forecasts for traffic and economic impacts than the analysis used for Stockholm.

Nevertheless, an overview of this nature can still give some insight into the potential benefits arising from the planning of a multi-phase expansion of a network in the Mälardalen region and, ultimately, an interconnection of the whole Mälardalen region to a rapid, environmentally friendly and resource efficient transport system. Figure 3.3 shows the possible structure of a fully developed high-speed network in the Mälardalen region.

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[47] Dommitzch et al (2006).

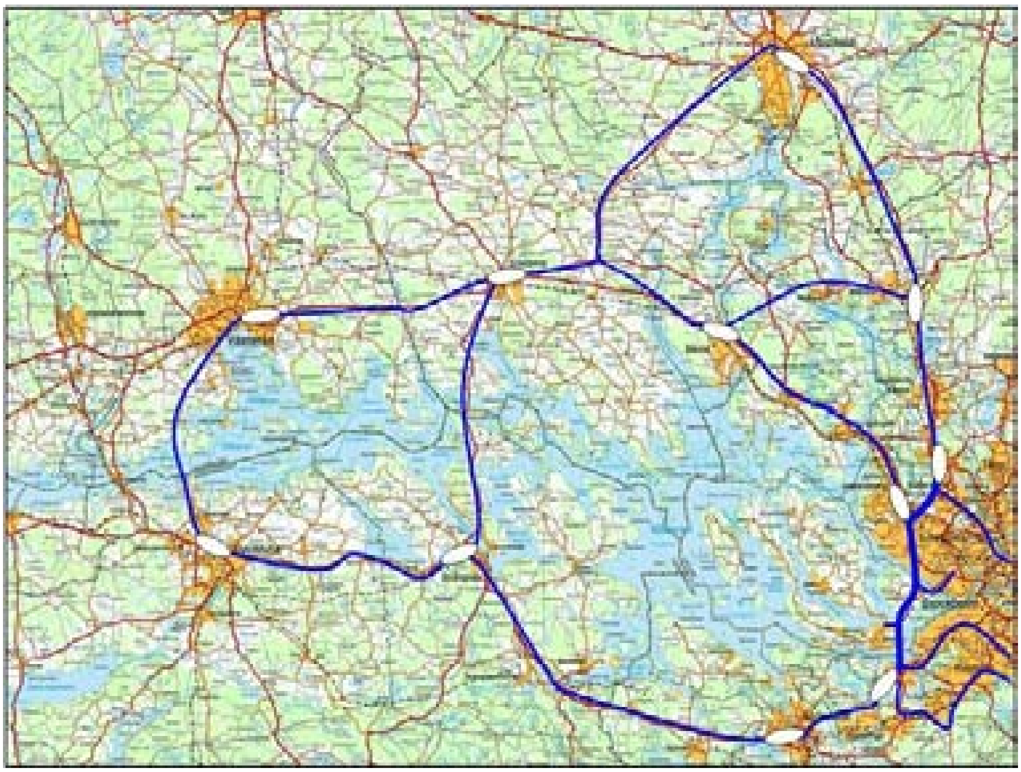

Figure 3.3. A podcar network in the Mälardalen region. Based on the general survey map ©National Land Survey in Sweden, authorisation 2008-16901. Copyright: SIKA

When the high-speed network is fully developed, local networks can be expected to expand in Stockholm, Södertälje, Uppsala, Arlanda, Västerås and Eskilstuna. The high-speed network is expected to have 11 stations each offering access to regional and local networks. The system may also have stations at other places such as Bålsta, Enköping and Strängnäs. The high-speed network is designed to make use of the existing road infrastructure, to simplify construction and reduce the effect of intrusion, since the elevated podcar track will be 4-5 metres above the ground.

Between Fittja, Barkarby and Häggvik respectively the high-speed network could run parallel to the regional network in Stockholm, either alongside or as an elevated guideway (see Figure 3.2). Table 3.1 shows the distances between the places in the Mälardalen region relevant to this outline of a podcar network.

Table 3.1. Distances for cars and podcars in the Mälardalen region. Source: Calculations based on Eniro map services. The distances for podcars are given in brackets where these differ from the distance by car for the same journey.

Distance podcar (km) Shortest distance	*STO*	*ARN*	*UPP*	*ENK*	*VÄS*	*ESK*	*STR*	*SÖD*
Stockholm (STO)		41	70	75	108	112	83	36
Arlanda (ARN)*			36	77 (65)	110 (97)	150 (127)	121 (100)	76
Uppsala (UPP)				45	79	111	83	103
Enköping (ENK)					32	65	37	88
Västerås (VÄS)						27	59	109
Eskilstuna (ESK)							33	79
Strängnäs (STR)								51
Södertälje (SÖD)								

*Podcar link Arlanda-Bålsta = approx. 35 km (see figure 3.3).

Table 3.2. Time saved using podcars (average speed 200 km/h) when compared with passenger cars. Source: Calculations based on Eniro map services

Savings in time (min) Podcar (200 km/h) - car	*STO*	*ARN*	*UPP*	*ENK*	*VÄS*	*ESK*	*STR*	*SÖD*
Stockholm (STO)		12	18	22	32	27	22	25
Arlanda (ARN)			11	25	35	40	34	17
Uppsala (UPP)				27	37	52	45	24
Enköping (ENK)					13	28	22	32
Västerås (VÄS)						28	28	39
Eskilstuna (ESK)							11	19
Strängnäs (STR)								15
Södertälje (SÖD)								

Table 3.2 shows the savings in travel time resulting from a podcar journey compared with a passenger car journey on the various links in the network in the Mälardalen region. The table shows that, for example, travelling the route Stockholm - Västerås by podcar will save 32 minutes (an average speed of 200 km/h), compared to travelling the same route by passenger car. Passengers who want to stop at intermediate stations can do so without the other travellers being affected.

The study has focused on an increase in accessibility throughout the Mälardalen and the Stockholm regions and even in peripheral links where railway services are poorly developed. The future could bring a greatly reduced need for traditional car ownership and car driving, and a substitution of electric power for fossil fuels, partly on linear electricity tracks and partly in the so-called "dual-mode” i.e. podcars which are also capable of travelling on roads. Some dual-mode vehicles have already been developed. Michelin, the tyre manufacturing company, has developed a design version of a car powered by electric hub-motors. J. E. Andersson has compared podcars with dual-mode vehicles.

3.4 Discussion of network effects

The case study shows that podcar networks have fewer negative external effects, such as noise, emissions and accidents, than traditional modes of transport.

Like other modes of transportation that are based on standardized technologies and network architecture, there are inherent positive network effects to be derived from the expansion of a podcar network. The implementation of the network, in turn, affects the accessibility of and hence the demand for travel. At the same time the expansion of the network affects the costs associated with its construction, operation and maintenance.

The benefits of the local networks, which could be constructed in Stockholm, Uppsala, Västerås, Eskilstuna and Södertälje, increase with the number of potential routes that become available when they are connected to a common interregional network in the Mälardalen region. This produces a network on a large scale, because the number of travellers who can benefit from the network increases. The positive effect of a regional network is difficult to estimate and evaluate, but it offers the potential for a major increase in travel that is not fully accounted for in analyses of a local area network.

The network effect is of course not specific to podcar systems. The network effect is a positive externality, which means that the consumption by one individual has a positive effect on the consumption of other individuals. A good example of a network effect in action is the benefit of having a telephone. As long as no one else has a phone there is no benefit in having one. But, for every person that purchases a phone the greater the benefit is for those with a phone.

Having more users of a system also means that a learning effect occurs. This may lead to the development of new technical and organizational solutions. In order for these benefits of scale to occur, it is important that the system includes certain standard elements that will facilitate construction, the availability of spare parts, learning, and so forth. The standardization of techniques creates economies of scale, which means that production costs for the extended system fall with increases in production. Production can then be simplified and thus automated and robotized. That is, the more extensive the podcar system becomes, the more it will be used, which increases the benefits. The marginal costs of production will decrease, thanks to scale. This leads to a double positive effect on the profitability of building large systems.

Because of this, the estimated costs, previously based on local and small-scale networks, are in all probability higher than the actual long-term costs, while the advantage of the system is probably underestimated. Therefore, profitability in the long-term should be greater than in the short-term.

Despite this, there may be reasons for wanting to expand the system gradually over a period of time. In addition to the budgetary and fiscal reasons for this, multi-stage expansion also gives an opportunity for people to become acquainted with the system and time for other social and infrastructure planning to adapt to the presence of the podcar system.

Thus, there is reason to take a long-term view of an investment in podcar systems even though the implementation of such systems quite quickly would give a reduction of the negative impact from cars and buses, and a decrease in the risk of accidents and energy and consumption of scarce resources. In addition, the positive externalities arise when an extensive network exits, partly for users and partly for producers and suppliers of the system. We have not taken into consideration the effects on other parts of industry that this expansion would mean. The learning effects from the production and development of the podcar system would probably have a positive impact also on other technological developments and could lead to innovative spin-offs as positive side-effects. The changes may also mean that a decline in the production of passenger cars is replaced by a growing production of podcars instead.

4 Evaluation of the Podcar Systems

This chapter gives an assessment of the three scenarios included in the study; Scenarios 1 and 2 from the Stockholm case study, and the scenario of a high-speed system in the Mälardalen region. The focus is, however, on the podcar system in Scenario 2 and the Mälardalen region. Here, we assess the socio-economic consequences – using a traditional cost-benefit analysis – and the effects of podcar systems upon the transport policy objectives of accessibility, security, environment, regional development, transport quality and equality.

4.1 Cost-benefit analysis of Scenarios 1 and 2

Benefits

Sampers, the forecast model used in this study, includes parameters which specify the revenues of the various public transport modes it covers, including ticket revenues. However, ticket revenues from the podcar system in Scenario 2 are not coded in such a way that allows for an automatic calculation of revenues. Instead, these have been calculated manually by Peter Roming, Railize, who has assisted with the traffic forecasts. Therefore, podcar revenues are presented as a separate post in table 4.1 below.

Ticket revenues from the podcars are calculated on the basis of the average public transport fare per passenger kilometre, and taking into consideration that the journey may include both the local and regional fare. The average fare per passenger kilometre is multiplied by the number of podcar passengers estimated for an average 24-hour day in 2020. The revenues are estimated at SEK4.1 million per day, which gives a net present value of SEK24.145 billion per annum.

Costs

In the model, the costs of investment and maintenance of the infrastructure must be specified in order to obtain a net present value and to assess the viability of the investment.

Investment costs

In Scenario 1, we have estimated the investment cost of the commuter rail link to be SEK17.1 billion.[48] Allowing for incidental expenses of about SEK1 billion

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[48] Based on the Swedish Rail Administration (SRA)'s pilot study 2002:08. The sum is increased by 4% per annum and with a general increase of 10% in the budgeted figure for investment. Maskotmedia 2008 Underlagsmaterial för Nordsydbanan[Documentation for the North-South Rail Link].

(5%) we arrive at a figure of approximately SEK18 billion. In Scenario 2, we have assumed that the twin-track guideway of approximately 160 km, including stations and vehicles, costs on average SEK100 million per km for the at grade or elevated stretches (115 km and 30 km, respectively) and on average SEK150 million per km for the part of the guideway which is placed underground to minimize its physical and visual intrusion (about 15 km). These construction costs per kilometre are in the upper range of cost data collected from a number of podcar studies.[49] This would make investment costs for a podcar network of SEK16.75 billion.[50] In addition, we allow for incidental expenditures of about SEK3 billion (18%), i.e. a total of SEK20 billion. Since Scenario 2 includes the commuter rail link, the total cost of this scenario is 18 + 20 = SEK38 billion. In our sensitivity analysis for Scenario 2, we include a high-cost alternative of SEK42 billion, and a low-cost alternative of SEK34 billion. The results are shown in table 4.1.

Maintenance costs for tracks

In both scenarios, we start from the annual report of the Swedish Rail Administration (SRA) on operation and maintenance costs.[51] The SRA's costs for operating, maintaining and reinvesting in track infrastructure for the years 2005-2007 were on average SEK4.89 billion. There are about 12,000 km of rail track in Sweden which gives a cost of SEK0.41 million per km.[52] This makes SEK8 million a year for our 20 km commuter rail link. A study at the Royal Institute of Technology has used the SRA data for the years 1999-2002.[53] In that study, costs of operation and maintenance were estimated to average SEK0.23 million per km at 2002 prices, but these are not fully comparable with the SRA estimates. This makes SEK4.9 million a year at 2007 prices. However, based on the data from the SRA, we assume that maintenance costs in Scenario 1 to be SEK8 million a year.

Most of the commuter rail link in Scenario 1 is located underground, while the SRA costs are based on the Swedish railway tracks which are mainly located at grade and therefore subject to weather and wind. The costs of operation and maintenance are largely due to winter conditions. Tracks underground are not exposed to weather and wind to the same extent and do not require the same costs for clearing snow, ice, falling trees, leaves, etc. However, tracks in tunnels may instead give rise to costs related to lighting, ventilation, etc.[54] Nevertheless, we believe that maintenance costs for underground tracks would be lower than for at

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[49] Hunhammar (2008), Andréasson, Tegnér, Henningsson (2008). This can be compared to the cost of a high-speed rail link between Stockholm and Malmö which the Swedish Rail Administration (SRA) estimates would cost SEK115 million per kilometre. (Banverket/Nelldal 2008b). Estimates of costs for other podcar projects is complied in a Memo from RTK in Stockholm. http://www.rtk.sll.se/publikationer/promemorior/2001/pm16_2001.pdf

[50] Estimated as 145km*SEK100million + 15km*SEK150million=SEK16,750 million

[51] BV Årsredovisning 2007, s37,[Swedish Rail Administration (SRA) Annual Report] p. 37 http://www.banverket.se/pages/1493/BV-AR-2007-TG-x.pdf

[52] Swedish Rail Administration (SRA) Statistics: http://www.banverket.se/sv/Amnen/Jarnvagen/Undersida-1-Jarnvagen/Statistik/Bandata.aspx

[53] Andersson (2007), "Empirical Essays on Railway Infrastructure costs in Sweden", Ph.D, Infrastructure, KTH, Stockholm

[54] In its analysis of the Citybanan, Transek argues that it costs more to maintain tracks in tunnels than on the surface and proposes SEK30million extra for a tunnel alternative compared to an at grade alternative. (Transek 2006:61 Samhällsekonomisk bedömning av Citybanan och Ytspåret. [Socio-economic Assessment of the Citybanan and a Surface Track])

grade tracks, which means that SEK8 million a year could be an overestimate of maintenance costs for the tracks in tunnels.[55]

In Scenario 2, the maintenance costs are assumed to be slightly lower per kilometre (SEK0.25 million per km), since the podcars have fewer moving parts and because the podcars are lighter with less axle weight than trains.[56] The resulting maintenance costs for the podcar system are then SEK40 million annually.

In the model used to derive our forecast, we apply the following cost alternatives:
Scenario 1 (commuter train):
Low: Investment = SEK16 billion, maintenance = SEK5 million/year
Medium: Investment = SEK18 billion, maintenance = SEK8 million /year
High: Investment = SEK20 billion, maintenance = SEK10 million/year

Scenario 2 (commuter train + podcar system):
Low: Investment =SEK16+18 billion, maintenance = SEK5+30 million/year
Medium: Investment =SEK18+20 billion, maintenance = SEK8+40 million/year
High: Investment =SEK20+22 billion, maintenance = SEK10+50 million/year

Podcar fleet expenses
In addition to maintenance of the tracks, there are costs for administering, operating and maintaining the podcars, including costs for control systems, cleaning, spare parts and electricity consumption. For a local system, WSP estimates these costs to be SEK1.65 million per track-km, which in our case means SEK264 million per annum. Discounted over 40 years at 4% interest rate, this gives a present value of SEK5,227 million.

In table 4, the results of the Sampers forecast are presented together with the range of costs from the sensitivity analysis (negative numbers are costs, positive numbers are revenues). Heading 6) presents podcar revenues and fleet expenses, which have not been calculated automatically by Sampers. Heading 7) presents the building / investment costs. At the bottom, the net present value (NPV) is presented together with the viability criteria. Scenario 1 has a negative NPV, while for Scenario 2, NPV is positive. Thus, the positive NPV for Scenario 2 more than compensates for the negative NPV in Scenario 1. Also, as discussed above, we have assumed relatively high costs. This indicates that the podcar system in Scenario 2 would appear to be highly profitable.

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[55] In an exchange with SIKA, SL has judged the costs of maintance for the tunnel track to be 25% lower then for a surface track.
[56] Commuter trains of the X60 model are 107 metres long, have 14 axles and with passengers weigh 2,300kg/m compared to a podcar which weighs 550kg/m including passengers.

Table 4.1. Compilation of the economic effects on national and regional traffic in Scenarios 1 and 2. Source: extract from Sampers/Samkalk.

	SC1 Commuter train		*SC2 Commuter train + podcar system*	
	High cost (SEK millions)	*Low cost (SEK millions)*	*High cost (SEK millions)*	*Low cost (SEK millions)*
1) Producer surplus	-173.33	-173.33	-7385.68	-7385.68
Ticket sales (excluding podcar incomes)	2684.87	2684.87	-18093.29	-18093.29
Vehicle costs for public transport (excl.podcars)	-2585.77	-2585.77	9641.19	9641.19
VAT on fares	-151.97	-151.97	1024.15	1024.15
Costs for track and rail infrastructure	-120.46	-120.46	42.27	42.27
2) Budget effects (incl. tax factor 2)	22596.24	22596.24	23216.55	23216.55
Fuel charge for road vehicles	-1940.40	-1940.40	-2614.79	-2614.79
Congestion charge*****	23831.74	23831.74	23553.71	23553.71
VAT on ticket sales	151.97	151.97	-1024.15	-1024.15
Costs of track and rail infrastructure	120.46	120.46	-42.27	-42.27
Vehicle costs**	432.47	432.47	3344.05	3344.05
3) Consumer surplus	-12706.19	-12706.19	2922.79	2922.79
Travel costs	159.91	159.91	93.07	93.07
Travel times******	11791.48	11791.48	27206.02	27206.02
Congestion charge*****	-24667.30	-24667.30	-24387.09	-24387.09
Costs for freight	9.72	9.72	10.79	10.79
4) External effects	3525.05	3525.05	4895.96	4895.96
Air pollution & climate gases	1066.93	1066.93	1517.43	1517.43
Traffic accidents***	2544.12	2544.12	3337.01	3337.01
Marginal wear and tear for public transport	-86.00	-86.00	41.52	41.52
5) Maintenance, running costs (M and R) & reinvestment****	-128.54	-47.65	-922.81	-518.32
M and R road traffic	33.25	33.25	47.95	47.95
M and R Rail, independent of traffic	-161.79	-80.90	-970.76	-566.27
Reinvestment railways				
Total	13113.23	13194.12	22726.81	23131.30
6) Podcar income	0	0	24145.00	24145.00
Cost of vehicles for podcars			-5,227	-5,227
Total	13113.23	13194.12	41644.81	42049,3
7) Investment Costs				
Discounted including tax factor 1 & 2	20413.50	16 330.80	42868.36	34,702.95
Total	20000.00	16 000.00	42000.00	34,000.00
Profitability criteria*				
Net present value NPV=(1+2+3+4+5+6-7)	-7300	-3137	-1224	7346
Net present value quotient NPVQ= (1+2+3+4+5+6-7)/7	-0.36	-0.19	-0.03	0.21
Present value quotient PVQ = (1+2+3+4+5+6)/7	0.64	0.81	0.97	1.21

*Profitability based on NPV>0, NPVQ >0 and PVQ > 1. **not multiplied by tax factor 2, ***including costs for internal accidents, not level crossing accidents, ****includes tax factors 1 and 2. M and R for air traffic included in vehicle costs. M and R road traffic ' includes both traffic dependent and traffic independent M and R. ***** Commercial traffic congestion charges are tax deductable and both these posts are considered to cancel each other out. Some freight is carried in private vehicles but it is not possible to determine the size of this traffic and how much is tax deductable, which is why all congestion charges that are paid are counted as non-deductable. ****** The Sampers forecast does not calculate travel time gains for trucks with or without trailers, which is why this information is not available.

4.2 Cost-benefit analysis of the podcar system in the Mälardalen region

This section gives a brief description of how the cost-benefit analysis of the high-speed podcar system in the Mälardalen region has been calculated.

Benefits

The results of the Sampers traffic forecasts for the Stockholm scenarios to 2020 indicate that we can expect about 10% of the journeys to be by podcar.[57] For 2040, we can assume that 50% of today's journeys by private car and public transport will instead be made by podcar. As described in section 3.1, we estimate the number of journeys by car and public transport in the Mälardalen region to be about 10 million in 2040. If about half of these journeys are made by podcar this will mean about 5 million podcar journeys in the Mälardalen region in 2040. If the average rate for a podcar journey in the Mälardalen region is set at SEK100 (at today's prices) the average ticket revenues will be SEK500 million.

In addition to ticket revenues, high-speed podcars generate socio-economic benefits through shorter travel times, reduced emissions, fewer accidents, and so forth. Table 4.2 shows the value of the effects which would result from increased travel by podcar. We assume that by 2040, the average car emissions of carbon dioxide (CO_2) will have been reduced to 100 g CO_2 per km.[58] Regarding emissions of nitrogen oxides (NO_x), we assume that by 2040 the average NO_x emissions will have increased from the current 0.4 to 0.5 g NO_x per km because of an increase in the proportion of diesel cars.[59]

If we assume the same travel flows as today, the social benefits are SEK6.92 billion if 100% of the current journeys by car and public transport in the Mälardalen region are moved to podcars (Table 4.2). As discussed in section 3, the traffic forecasts assume a growth in traffic of about 54% by 2040.[60] All else being equal, this means, roughly, that the benefits in shorter travel times will increase by the same amount between now and 2040. Assuming that the proportion of podcar journeys will be 50% of the number of journeys by car and public transport, then the social benefits by 2040 will be SEK4.759 billion (table 4.2). In our calculation, these social benefits are added to the podcar ticket revenues. The total annual social benefits would then be SEK4.759 billion + SEK500 million = SEK5.259 billion per annum, assuming no new journeys.

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57 The results show that 32% of public transport would be by podcar and in turn public transport accounts for 32% of the total nunber of journeys. 0.32 * 0.32 = 0.10

58 This means that the value for the reduction in CO_2 emissions at present is underestimated in table 4.3

59 This means that the value for the reduction in nitrogen oxide emissions at present is overestimated in table 4.

[60] 1.017^14 * 1.01^20=1.545

Table 4.2. Effects of a transfer to a podcar system now and in 2040 (in SEK millions).

	Now	2040			
Share of podcar journeys	100%	100%	50%	25%	10%
Benefits of shorter journey times by train[a]	1 160	1 792	896	448	179
Benefits of shorter journey times by car & bus[a]	3 612	5 580	2 790	1395	558
Reduced CO2-emissions[b]	1 043	1 043	521	261	104
Fewer fatal accidents[c]	842	842	421	210	84
Reduced NOx-emissions[d]	261	261	131	65	26
Total economic benefits (SEK millions)	6,918	9,518	4,759	2,379	951

a) Time value SEK75/hour b) Average emissions100 g/kilometre travelled c) 5,5 deaths per billion kilometres travelled d) average emissions 0,5g/fkm

Costs

We assume that in 2040 there will exist local podcar systems in some municipalities, such as Stockholm, Södertälje, Uppsala, Eskilstuna and Västerås. This means that previous experience of podcars will exist and that there is a production capacity to build podcar systems. If so, it is reasonable to assume a lower construction cost in 2040 than the SEK100 million per kilometre we estimate for 2020. Therefore, we assume that for the podcar system in the Mälardalen region the construction cost will be approximately SEK75 million per km for twin track. The total network is about 470 km long, which means a total construction cost of approximately SEK35 billion. Discounted over a period of 40 years and with 4% interest, this would correspond to an annual cost of SEK1.78 billion (table 4.3).

Table 4.3. Fixed costs for twin track high-speed (>200 km/hr) podcar network connecting the Stockholm-Mälardalen Region.

108 km	Västerås-Enköping-Stockholm C	
80 km	Eskilstuna-Strängnäs-Södertälje	
45 km	Uppsala Syd-Enköping	
60 km	Uppsala Syd-Stockholm C	
27 km	Västerås-Eskilstuna (excl. high-level bridge)	
36 km	Stockholm C - Södertälje	
44 km	Stockholm (Fittja – Barkarby – Häggvik)	
35 km	Enköping – Strängnäs	
35 km	Arlanda – Bålsta	
Total track cost 470 km at SEK75 million per km		= SEK35.2 billion
Annuity*		= SEK1.78 billion per annum
1 High-level/suspension bridge Eskilstuna-Västerås		= SEK2 billion
11 termini @ SEK200million		= SEK2.2 billion
8 vehicle depots (8*600 vehicles) @ SEK225 million		= SEK1.8 billion
10 small stations @ SEK150 million		= SEK1.5 billion
Total sundry fixed costs:		=SEK7.5 billion
Annuity*		=SEK0.38 billion per annum

*Discounting factor 19.793 (40 years, 4 percent)

Table 4.4. Variable costs for a high-speed track

Annual variable costs:

Service personnel at the stations 20 x SEK0.5 million = SEK10 million
= SEK0.01 billion
Maintenance and running costs SEK2 million/km * 470 km= SEK940 million
= SEK0.94 billion
System Costs (surveillance, checks, ticket machines etc.) = SEK0.2 billion
Total variable costs = SEK1.15 billion

Table 4.5 Socio-economic benefits for different journeys and fares

Income (SEK billions/year)	*5 million passengers/year*	*3.75 million passengers/year*	*2.5 million passengers/year*
SEK100 /journey	SEK5.26 billion	SEK3.94 billion	SEK2.63 billion
SEK150 /journey	SEK5.51 billion	SEK4.13 billion	SEK2.75 billion

Table 4.6 Total costs for 470 km of track at different costs per kilometre

Track 470 km	*SEK50 million/km*	*SEK75 million/km*	*SEK100 million/km*
Track fixed costs (annuity)	*SEK*1.19 billion	*SEK*1.78 billion	*SEK*2.37 billion
Other fixed costs (annuity)	*SEK*0.38 billion	*SEK*0.38 billion	*SEK*0.38 billion
Variable costs	*SEK*1.15 billion	*SEK*1.15 billion	*SEK*1.15 billion
Total	*SEK*2.72 billion	*SEK*3.31 billion	*SEK*3.90 billion

Assuming a twin track cost of SEK75 million per km and 5 million journeys at SEK100 per journey, the high-speed podcar network will be profitable:
NPVQ= (5.26 – 3.31)/3.31 = 0.59.

Assuming a twin track cost of SEK100 million per km and 5 million journeys at SEK110 per journey, the network will still be profitable: NPVQ= (5.26-3.90)/3.90 = 0.35

Break-even point: Assuming a twin-track cost of SEK100 million per km and fares of SEK100 per journey, there will need to be 3.75 million journeys per year for the network to be profitable:
NPVQ= (3.94-3.90)/3.90=0.01

Break-even point: Assuming a twin-track cost of SEK50 million per km and only 2.5 million journeys per year, then the fare needs to be SEK150 per journey for the network to be profitable:
NPVQ= (2.75-2.72)/2.72 =0.01

Table 4.5 shows that the social benefits are sensitive to the number of journeys, while the fare rate does not influence social benefits as much.

5 Conclusions

5.1 The Stockholm case study

Both the commuter rail link Häggvik Brommaplan-Älvsjö in Scenario 1 and the more extensive podcar system in Scenario 2 will lead to a greater use of public transport and a reduction in car traffic in Stockholm County as a whole as well as on the north-south crossing of Lake Mälar. Both scenarios include an increase in the congestion charge. The commuter link also increases the capacity for interregional trains destined for the centre of Stockholm or going north-south through the County of Stockholm. This increased capacity leads to an increase in the number of public transport journeys.

The combination of the commuter link and podcar system in Scenario 2 will have a greater impact than the proposals made in Scenario 1. However, it is difficult to estimate properly the net effect of the podcar system because this is in a combined scenario. The results indicate that besides the reduction in car journeys, there will also be a transfer of pedestrians and cyclists to podcars. This is an effect of the design of the podcar system in terms of coverage and density, combined with speed and the level of fares (which is assumed to be equivalent to other public transport services).

The higher average speed of travel in the podcar system stimulates travel and leads to major benefits in travel time compared to other forms of public transport. The benefits in travel time of the podcar system are clearly reflected in the difference in profitability between Scenario 1 and Scenario 2. The commuter link provides high social benefits but cannot cover the estimated construction costs, probably because of competition from the Citybanan rail line. Therefore, Scenario 1 has a negative net present value, i.e. does not show social viability.

Scenario 2, on the other hand, appears very profitable, with benefits in travel time that are about 3 times as high. In this scenario, we have consciously assumed high costs, and also taken into account unforeseen costs. The actual investment costs for the podcar system could, therefore, very well be lower than our estimates. Despite our estimates of high costs for the podcar system in Scenario 2, it shows a net present value of between SEK994 million and SEK9.564 billion, depending on the level of costs. Judging from the benefits in travel time, the attractiveness of podcars would almost certainly allow for higher fares, i.e. the willingness to pay for podcars is probably higher than for existing forms of public transport. A higher fare would probably mean that pedestrians and cyclists would prefer to walk and cycle, and that travel patterns would change slightly, but the podcar system would probably still be socially viable. We have not analyzed the level of fares needed to make the system commercially viable.

Due to the relatively light weight of the guideway, the podcar system appears to be efficient in terms of land-use while still enabling a high capacity. A land-use efficient system can release valuable land in urban areas and reduce the need for parking space. The podcar system allows for a more densely populated urban environment and the reduction of urban sprawl.

In combination with financial instruments to reduce congestion, a podcar system would appear to reduce car journeys and increase public transport use in Stockholm. Fewer car journeys in favour of podcars or public transport would reduce noise, reduce the risk of accidents, and reduce air pollution and greenhouse gas emissions.

Judging from our analysis, the podcar system is more attractive than current forms of public transport and may therefore result in a greater transfer of passengers to it, and thereby increase its social viability. The automatic system also reduces expenses for personnel and the need for public subsidies.

Increased accessibility in Stockholm reduces congestion for both road transport and rail transport. This benefits commercial transport, for which the congestion charge is less. Increased accessibility also stimulates regional development.

5.2 The Mälardalen region case study

The growth in the Mälardalen region will increase the pressure on Stockholm. By facilitating an increase in commuting, this pressure may be reduced and more evenly distributed across the region. The Swedish Road and Rail Administrations have major plans of investment for the region in order to facilitate commuting. Our assessment shows that a high-speed podcar system in Mälardalen can facilitate fast commuting at lower costs than many road and rail projects.

For long-distance travel, pedestrians and cyclists shift to podcars, as in a local system. Therefore, it can be assumed that the interregional high-speed podcar system will attract a relatively larger share of private car and public travellers than is the case with the local network. The interregional podcar system will connect local podcar systems, which we assume will be in existence by 2040 in municipalities where podcar studies have been made (Södertälje, Eskilstuna, Västerås, and Uppsala). On this basis, we can assume a transfer of 50% of journeys from cars and train to podcars. On this assumption, our assessment shows that an interregional podcar network could offer great social benefits for travellers, which would make the podcar system economically viable.

In addition to benefits in travel time, the safety of dedicated podcar guideways reduces the risk of accidents. The podcar system runs on electricity, which means reduced air pollution and less noise. Because of the speed and flexibility made possible by the interconnection of local and inter-regional podcar networks, the system may even compete with electric cars.

5.3 The potential of podcars

Podcars systems could contribute greatly to the fulfilment of the transport policy objectives, including reduced emissions of carbon dioxide. Our assessment shows that both local systems (as in Scenario 2) and large interregional systems may prove economically viable and profitable. The benefits of the system increase with the size of the network, as a large network increases the opportunity for travel. A large network also reduces the need to switch between different modes of transport.

To be able to compete with private car travel, podcar networks need to offer the same degree of accessibility as well as comfort, in terms of flexible door-to-door travelling. Several Swedish and international municipalities are currently discussing local podcar systems. We assume that in 2040, it can be expected that several local podcar systems have been constructed in the Mälardalen region. An interregional high-speed podcar network connecting these local systems would almost certainly be a powerful competitor to private car travel, and at the same time offer substantial social benefits, such as reduced emissions and increased safety.

The podcar system also seems to be able to offer great accessibility to the elderly, children and people without a driving license. The environmental benefits allow the system to be situated close to residential areas or commercial centres, which would allow more densely populated urban areas (reducing urban sprawl). However, a local podcar system may reduce the proportion of journeys by pedestrians and cyclists.

A large podcar network certainly means major organizational and financial challenges. However, it is important to plan ahead for a sustainable transport sector. Much of the technology is available today, but podcar systems still need to be developed further, in order to be analyzed in comparison with other transport solutions.

It is too early to argue that podcar systems may compete successfully with road and rail investment, but it is an interesting hypothesis that should be explored further.

Research is needed to find out more about the premises under which podcar systems may operate successfully as a transport alternative. Simulations may be a cost-effective way of analyzing the physical and visual impact of podcar systems, as well as design issues. Further economic analyses may show ways to improve risk-spreading and to reduce costs resulting from efficient incentive structures[61].

International innovation procurement over a number of years may create a consensus on the systems and interfaces needed to enable extensions and economies of scale. At the same time, the flexibility of the system needs to be maintained in order to allow further development.

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[61] Flyvbjerg et al (2003).

Appendix 1. Analysis of the Energy Consumption of the Podcar System

In 1994, VTI made a study[62] of the energy required to power podcars/podcar taxis compared to that required for cars and buses based on:

- The construction of guideways or roads
- The manufacture of vehicles
- Means of propulsion
- Heating of the vehicles
- Cold-start addition for cars
- Electricity transmission for podcars/podcar taxis
- Use in winter conditions.

The study applied the VETO-model used by VTI which calculates fuel consumption as a function of the vehicle, roads and ways of driving. The study made the simple assumption that electricity and fuel could be compared on a 1:1 basis, given that electricity in Sweden is generated largely throughout the year, by considering the margins for HEP and nuclear power and with the knowledge that there was over-capacity in the system. VTI have argued that even in the long term with modern electricity generating systems and the use of renewable fuels, the proportion of 1:1[63] is a reasonable assumption to make.

VTI reckoned that the materials needed for a podcar system would be approximately 200kg of steel and approximately 200 kg of concrete per metre of podcar guideway. Concrete was assumed to consume 0.8 MJ/kg (=0.22 kWh/kg) of energy and the steel sections for the guideways were assumed to require 30MJ/kg (=8.33KWh) per section. The energy requirement for the guideway would thus be approximately 6,000MJ/m (=1667 kWh/m). Land preparation and the transport of materials were expected to have low energy consumption in relation to that of manufacturing. The construction of podcar guideways requires less energy than the construction of new roads.

As the efficiency of the electric motor is high and there is little waste heat to be utilised, heating electric cars in winter is, in general, a major cost in terms of energy use. With the relatively low energy requirements to power the podcar, the need for and costs of heating became that more relevant. In the period 1st November to 31 March, the need was assumed to be 1,600W, and for the rest of the year 800W. In rush-hour traffic and on Saturdays between 9 am and 3 pm, it was assumed that 100 percent of the vehicles would be heated, for other daytime

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[62] VTI (1994)

[63] In a system in which electricity to a large degree or at the margin is generated by coal-fired power plants, 2.4 kWh of coal are needed to produce 1 kWh of electricity. An electric-powered system would, therefore, be more effecient, if it used 40% or less of the direct energy used by the coal-fired alternative system.

periods 40-60 percent and at night time 10 percent. The annual energy requirement was assumed to be 41,000kWh. Each vehicle was expected to travel 79,000km a year at a maximum speed of 36kmph, which meant that the heating per vehicle kilometre was calculated at 0.05kWh.

Given these conditions, the energy consumption, according to VTI, would be low both for the powering of the podcar and for the construction of the guideways and manufacture of the vehicles. The energy consumption for empty vehicles and for vehicles with 1.5 passengers was largely the same, because the greater weight in the vehicle with passengers was balanced by less idling at junctions and, therefore, fewer periods of acceleration and deceleration. Table A1.1 below shows the approximations in energy consumption made by VTI. The energy consumption of a podcar was estimated at 0.18 kWh per vehicle kilometre.

Table A1.1. Energy consumption in podcars, petrol-driven cars and buses in vehicle kilometres (vkm) and passenger kilometres (pkm). Source: VTI (1994)

Energy (kWh*)*	Podcar		Petrol-driven car		Bus	
	vkm	*pkm*[a]	*vkm*	*pkm*[b]	*vkm*	*pkm*[c]
Propulsion	0.11*	0.092	0.78	0.52	4.53	0.38
Cold-start addition	-	-	0.15	0.10	-	-
Heating	0.052	0.043	-	-	-	-
Total	0.16	0.13	0.93	0.62	4.53	0.38
Including efficiency of electricity transmission on the guideway	0.18	0.15**				
including the guideway***		0.18***				

a) 1.2 pass/vehicle, b) 1.5 pass/car, c) 12 pass/bus based on SLTF's statistics
* 0.13 for a linear motor (otherwise AC-motor asynchron) **0.17 for linear motor (-"-) ***energy for manufacture of guideway calculated at 0.03 kWh/pkm with a depreciation period of 25 years and 50 percent residual value for steel (in terms of energy).

SIKA asked Jan-Erik Nowacki[64] to assess the reasonableness of these estimates of heating the podcar vehicles made by VTI. Eberspächer, who manufacture car engine preheaters, recommend the use of a car heater of 0.4kW at an outside temperature of +7 ^{0}C and one of approximately 1KW at -2 ^{0}C. Podcars have, however, slightly larger interiors and the doors are opened and closed more often when used in public transport, whereby Nowacki judged the estimate made by VTI to be reasonable.

The VTI study does not take into account energy consumption for air-conditioning in the summer. In a study from 2008 of the heating and air-conditioning of electric cars, the question of whether the air-conditioning system could be modified to be used as a heat pump during the cold period of the year was explored. If heating is through a heat pump the heat factor will be

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[64] Jan-Erik Nowacki, KTH and Nowab

approximately 3 at an outside temperature of -2 ^{0}C and above 5 at +7 ^{0}C. This means that the expected use of energy even including some cooling in the summer could be reduced by half, i.e. 2000kWh a year.[65]

The estimate of energy consumption of 0.18kWh per vehicle kilometre arrived at by VTI is supported by the calculations we asked Jan-Erik Nowacki to make. To confirm this estimate and at the same time bring an element of realism into the analysis the energy consumption of the Vectus and ULTra podcar systems has been roughly estimated for comparison. Listed below is some of the information used by Nowacki for his calculations and some of the assumptions made:

> The air resistance is the same for both vehicles and has been set to 125 N at a speed of 45 km/h (the vehicles are not designed for high speed $Cv \approx 0.66$);
> Drag is put at 0.6 percent of the weight for Teflon-coated steel wheels and 1 percent for wheels with pneumatic rubber tyres;
> Heating, air conditioning, lighting and steering equipment is assumed to use approximately 1.7kW;
> An average efficiency of 80 percent has been adopted for a rotary electric motor with variable-speed control;
> An average efficiency of 70 percent has been adopted for a linear induction motor—the increased effect on the guideway by the motor is negligible;
> To charge and discharge the batteries from the grid is assumed to have a cyclical efficiency of 65 percent;
> To charge the batteries in the vehicle using a trailing wheel on the guideway is assumed to have a cyclical efficiency of 50 percent;
> Defrosting a guideway on which wheels are used for propulsion and braking can require a great deal of energy, but this has been ignored;
> If the primary energy required to generate electricity is included (in accordance with EU directives), then the values in figure A1:1 and A1:3 (podcars) need to be multiplied by roughly 2.5,
> Stations and service workshops have not been included. They are assumed to use less energy per passenger kilometre than the equivalent facilities for the system they replace.

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[65] Ricardo Arboix Barreto (2008)

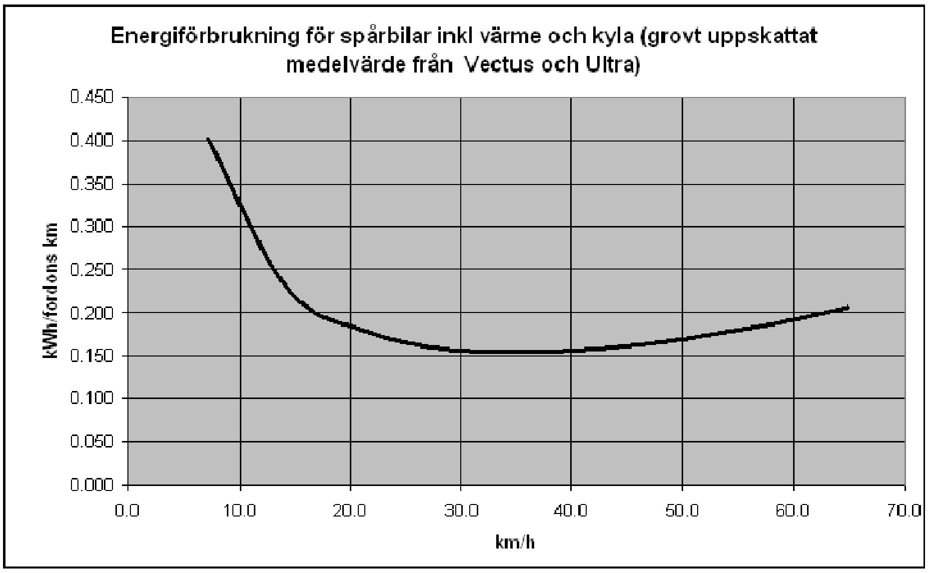

Figure A1.1. Approximate average energy consumption per kilometre including heating and air-conditioning for Vectus and ULTra

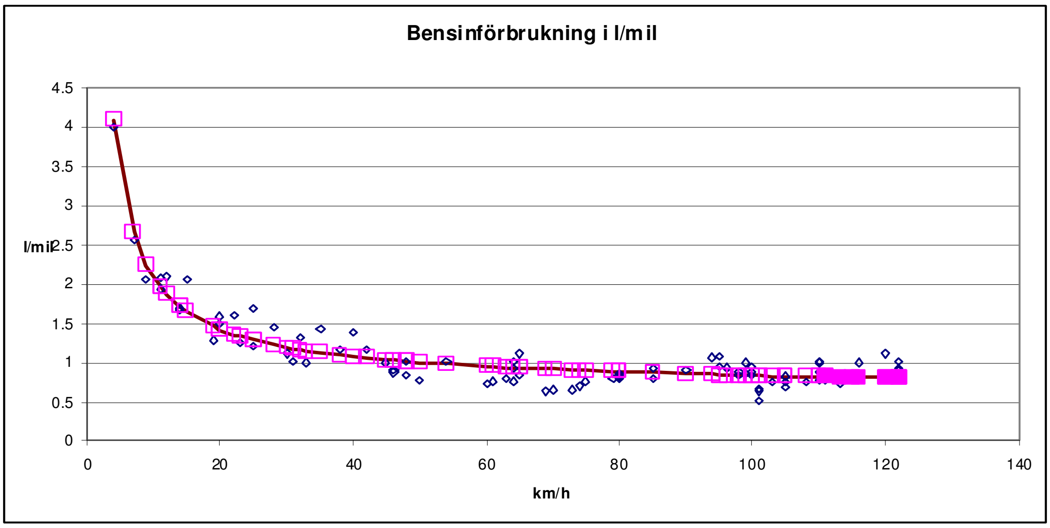

Figure A1.2 Fuel consumption at different speeds for a Saab 9-5, in litres/10 kilometres

The solid curve in figure B1.2. is corrected for a fixed consumption per hour, drag that is independent of speed and air resistance that increases linearly with speed (quadratic per kilometre). The coefficient of correlation is high (0.95).

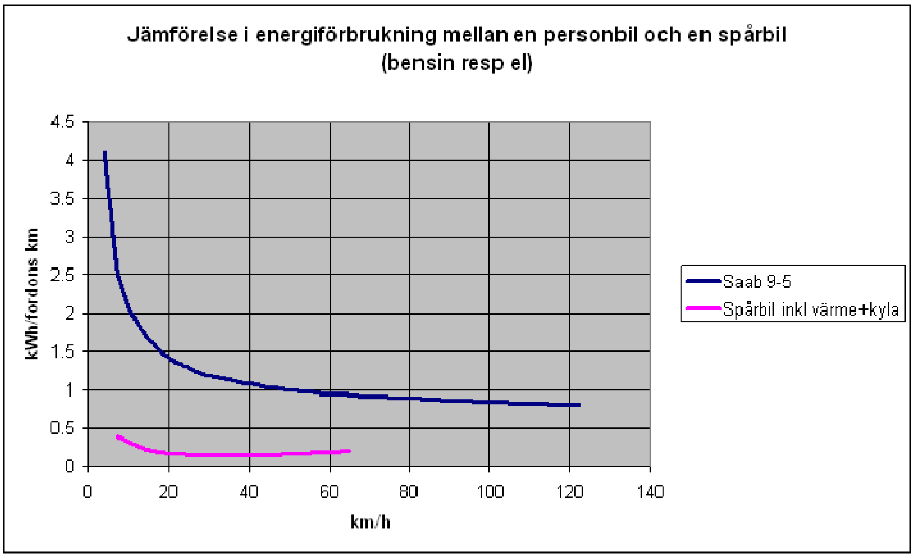

Figure A1.3. Comparison of energy consumption of a private car and a podcar at different speeds (petrol and electricity respectively)

If the energy content of petrol is calculated as 8.7kWh/litre then the corrected curve for the car can be compared with the average for the podcars used by Ultra and Vectus. A comparison of the average energy consumption of podcars and private cars shows that the podcar uses 5 times less energy than the car (fig. A1.3). Even if the electricity were to be generated in an oil-fired condensation power station with an efficiency of 40 percent, the podcar would still use only half the energy of today's motor cars.

Similar calculations

J.E. Andersson (1988) has calculated the probable energy consumption of podcars at 0.09kWh per passenger kilometre (compared to 0.15kWh per passenger kilometre in our case). The comparison is, however, complicated by the lack of information about Andersson's assumptions for materials, type of energy and intensity of traffic.[66] Alvehag *et al.* (1992) have calculated the energy consumption for the FlyWay system, and reached the figure of 0.2kWh per kilometre for a four-seater vehicle, which with a utilised capacity of two gives a figure of 0.1kWh.[67] The figures provided by Alvehag *et al.* apply only to propulsion. Morgantown People Mover provide figures of energy consumption of 0.4 kWh per travelled kilometre at fully utilised capacity (8 seated and 12 standing passengers), i.e. 0.02kWh per passenger kilometre. These figures are almost certainly only for propulsion.

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[66] Andersson, J E (1988)

[67] TFK (1992)

Comparison with electric cars

Today there is a natural interest in electric cars and hybrid vehicles. Climate policies and technical developments will also stimulate an increased interest in energy-efficient cars. The comparison of podcars and petrol-driven cars leads, therefore, on to a discussion of the comparative energy consumption of podcars and electric cars.

Electric cars vary considerably in their performance. A normal electric car often has a 13kW electric motor, but some electric cars have motors of up to 180kW to enable powerful acceleration, such as the models produced by Tesla Motors and Venturi.[68] For speeds of around 40km/h a 5kW motor is more than adequate, which means 0.125 kWh per vehicle kilometre.[69]

Electric cars use approximately 0.1 to 0.2 kWh/ kilometre, i.e. podcars and electric cars have roughly the same level of energy consumption. The electricity needs of a re-chargeable, hybrid vehicle are also calculated at 1,500 kWh a year (the Prius+, for example, uses 0.16kWh per kilometre). A million cars would therefore require an energy consumption of approximately 1.5TWh.[70]

Elforsk, state that the electricity power grid can cope with the addition of a few million plug-in electric-hybrid cars without any noticeable effect. The reason they give is that the grid is designed for cold winter days when a great deal of energy is consumed.[71] If this is the case, then the grid ought to be able to cope with the numbers of electrically-propelled podcars we count on here. If podcars are introduced, then the number of electric cars needed would be fewer.

If 100 billion vehicle kilometres by car were to be substituted by podcars, then electricity consumption would increase by 15-20 TWh (just over 10%). Wind power could generate half of this requirement, and the replacement of direct electric heating by heat pumps is an example of how the other half could be met. In all, fuel consumption could be reduced by 75-100TWh.

Podcars or electric cars act as a complement the irregular supply of electric power from renewable sources as the batteries have a large storage capacity. According to Elforsk, roughly 300 5MW wind-power turbines placed out to sea could supply the electricity needed for the millions of electric-hybrid cars that would be needed to reduce oil dependency by 40% in private cars. New, renewable sources of energy such as vertical wind power turbines, wave power and solar cells are being developed.

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[68] www.teslamotors.com and www.venturi.fr

[69] Ingemar Andréasson, private correspondence.

[70] Kristina Birath, private correspondence.

[71] Elforsk memo, www.elforsk.se

Techniques of propulsion

A distinction needs to be made between driving and supporting a vehicle. Seeing magnetic hovering for vehicles as an alternative to wheels is perhaps far-fetched, but other alternatives such as air cushions are not considered, for the moment. The two alternatives for propelling a vehicle have their advantages and disadvantages.

Today's synchronised permanent magnet motors can produce a high degree of efficiency in revolving wheels. They can have variable speed control through standardised frequency convertors which can also be directly integrated into the wheel (hub motors). Linear motors have, in general, a somewhat lower degree of efficiency. This is because it is more difficult to maintain a small gap between the moving and stationary parts of a motor in a linear movement compared to one that is rotating.

Table A1.3 Various techniques used in podcars

Support	*Propulsion*	*Example*
Wheels	Wheels	Ultra
Wheels	Linear motor	Vectus
Magnet	Linear motor	Transrapid

Table A1.4 Differences between wheel hub drive and magnet drive

Wheel	*Magnet*
+ Simple and cheap	- More expensive
+ Simple motor	- Requires the more expensive linear motor
- Tyre treads and wheel bearings	+ No contact surface and no service
- Noise from contact surfaces	+ Can be designed and constructed to be silent
- Problem with slippery tracks	+ Braking and acceleration assured

In some linear motor designs, propulsion and support are combined, whereas in others the magnetic support construction is dependent on a permanent magnet being repelled by a track of non-magnetic metal at high speeds. Unfortunately, a relatively high speed must be attained for the construction to work and to give a lower level of friction than wheels, for example.

Dual-mode vehicles already have a technique for using hub motors which weigh approximately 8 kilos and have an electric motor of 54kW, e.g. Michelin Conception Development.[72] An interesting comparative study of hub motors has been carried out by scientists in Germany.[73] In the USA, J. E. Andersson has made a comparison of podcars and dual-mode vehicles.[74]

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[72] Dagens Nyheter [daily newspaper] 30th Nov. 2007

[73] Gerling *et al.*

[74] http://www.advancedtransit.org/pub/2008/anderson_dm.pdf

Appendix 2. Basis for Calculations

Previous studies of costs

In this section we give an account of the findings of other studies and surveys when estimating the various costs involved in a podcar system. These estimates constitute a basis for our assumptions in this survey.

Foreign surveys/studies
In 2003, the ATRA produced an overview of comparisons and evaluations of existing podcar technologies and their development potential in which 14 systems were evaluated on the basis of technology and costs.[75] At the time of the study, 4 of these 14 had constructed prototypes: Cybertran, Frog (CyberCab), Taxi 2000 and ULTra. Among these four, the cost of building beams and guideways varied from USD2.6million/mile (Taxi 2000) to USD5 million/mile (Cybertran), i.e. from SEK9.8 million/kilometre to SEK19 million/kilometre. Each beam that supports the guideway covers approximately 4 sqfeet (=0.5m^2) for each 60-90 feet (=20-30m). Additional costs that might arise, such as as a result of the need to expropriate land from private landowners, have not been included.

The cost of stations varies from USD100K to USD500K per station, i.e. from SEK0.7 million to SEK3.5 million per station. The cost of vehicles is estimated to be from USD2.1 million/mile (Taxi 2000 takes 4 passengers) to USD8 million per mile (Cybertran takes 6-20 passengers). Smaller and lighter vehicles mean lower costs. But then the guideway is expected to have no more than 50 vehicles per mile, i.e. approximately 27 vehicles per kilometre.

Other costs can include modifications to buildings, parking places and adjustments to building facades for reasons of aesthetic quality. ATRA deems overhead costs of 10 percent for planning, environmental impact assessment and project management to be reasonable. If the guideways are placed along the existing road system, which is a public utility, then there will be no extra costs for land expropriation. ATRA reaches a figure for total costs of between USD6.27 and USD15.4 millions per mile, i.e. between SEK24 and 58 million for these four systems. To provide a twin-track guideway would cost twice as much (at 2003 prices).

ATS Ltd., who build ULTra, have surveyed the costs of building the pilot system in Cardiff. Their figures for the costs of materials and the cost of construction lie between GBP19 million and GBP40 million (= approx. SEK220—440 million)

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[75] ATRA (2003), Personal Automated Transportation: Status and Potential of Personal Rapid Transit, Technology Evaluation, Jan 2003, ATRA, http://www.advancedtransit.org/pub/2002/prt/tech6.pdf

for 20 km of guideway, 22 stations and 2 depots. The total costs, including overheads etc, are calculated to be between GBP33 million and GBP58 million (=approx. SEK363—638 million). This means a total cost per kilometre of SEK18—32 million with roughly one station per kilometre (NB at 2005 prices).[76] A twin-track guideway would cost approximately SEK29—54 million per kilometre.

A study by Buchanan (2006) analysed a podcar network of approximately 55km in Daventry, England. The network was planned to have 48 stations and 500 vehicles. In this case, the elevated guideway was calculated to cost SEK24.2 million per kilometre and a twin-track guideway SEK36.7 million per kilometre, i.e. an extra cost of approximately 50%. An at grade guideway would cost only SEK6.8 million per kilometre with SEK8.8 million for a twin-track guideway, i.e. an additional cost for the latter of approximately 30%. The cost of building stations is estimated at SEK1.8 million for a station at grade and SEK3.4 million for a station on an elevated guideway. The stations are on average 1 kilometre apart.[77]

Swedish surveys/studies

Tegnér *et al.* (2008) provide a survey of 18 different calculations of the costs of a podcar system which had been made between 1998 and 2008. They found an average value of SEK61 million (standard deviation SEK24million). A cost interval plus/minus a standard deviation would then give SEK36-85 million in investment costs per kilometre for a single-track guideway.

LogistikCentrum have calculated on behalf of Skanska, who are the construction company for Vectus, with regard to Kvarnholmen in Nacka. They estimate that a guideway of 9 kilometres would cost SEK70 million per kilometre and 16 stations are estimated to cost SEK3 million each. The vehicle fleet will consist of 120 podcars costing SEK0.5 million each. The control system is calculated at SEK10 million. In total, this means an investment cost of SEK83 million per kilometre of twin-track guideway.

In a Swedish pilot study for a local podcar network in Eskilstuna, an analysis has been made of five studies of costs and the conclusion was reached that investment costs could vary from SEK50 million to SEK85 million per kilometre (at 2007 prices). The extra cost of a twin-track guideway would probably not be 100% but rather 30-50%. A relatively high estimate for the cost of a twin-track guideway would be approximately SEK100million per kilometre, including stations.[78]

In addition to costs of materials, which are affected by the prices of raw materials, there are also costs for development, construction, installation, quality control, procurement, bids and project management. Furthermore, there will be a need for

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[76] ATS Ltd (2005), Infrastructure cost comparisons for PRT and APM, Kerr, James, Arup & Partners; Craig, ATS Ltd, ASCE APM05 Special session on PRT

[77] Buchanan (2006), Daventry Development Transport Study, nov 2006, Daventry District Council.

[78] Hunhammar (2008), S: Nytt transportsystem Spårbilar, Förstudie Eskilstuna Kommun, 2008-03-29, IST rapport 2008:1, Stockholm [Development of Sustainable Infrastructures: Podcars, the new transport system. A pilot study by Eskilstuna Municipality, 29th March 2008, IST Report 2008:1, Stockholm]

education and training, documentation and other matters. Even though there may be economies of scale to be made in the manufacturing process, there are many costs that are specific to the project and which are difficult to predict. It is, therefore, essential to be prepared for possible unforeseen increases in costs.

On the grounds of simplicity, we assume that the cost of a twin-track guideway would be approximately SEK100 million per kilometre including stations, approximately the same as the Eskilstuna case. Furthermore, we carry out a sensitivity study where we investigate the effects of higher construction costs.

Economies of scale and mass production

The cost per kilometre calculated above is based on estimates from relatively small podcar networks. It can be assumed the longer the guideway, the more the costs will fall due to economies of scale. This can be compared to the construction of other types of infrastructure such as roads and railways. Economies of scale can also occur in the manufacture of podcars and in this case the curves are probably much steeper, i.e. the production costs per podcar will fall rapidly with increased production. Potential economies of scale are illustrated in the following figure:

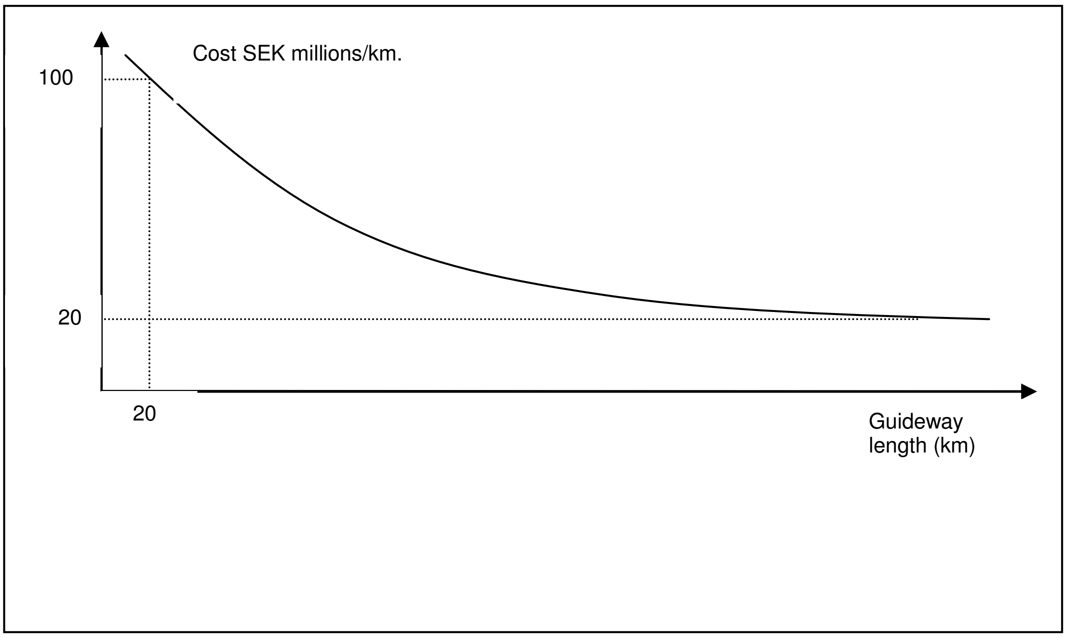

Figure A2.1 Economies of scale and mass production

The total size of the network affects construction costs, but it also influences the catchment area and demand for services. The profitability of a podcar system is affected both positively and negatively by a large network and it is difficult to determine the accumulated effect of a large network on profitability.

Profitability of production is also influenced by the frequency with which items are ordered. A large manufacturer needs many large orders in order to maintain levels of production and product development. This is an important issue, but is beyond the scope of this report.

Maintenance and running costs

Running costs are difficult to estimate before we have gained experience of an operational system. ATS/ULTra calculate their running costs on the basis of the length of the guideway, proportion of elevated guideway and the number of passenger per year. The running costs per guideway kilometre vary from SEK2.74 per kilometre at 300 journeys per day to SEK3.4 per kilometre at 1,700 journeys per day.[79]

Edward Andersson at PRT International (previously with Taxi 2000) has calculated the running costs in a systematic cost-estimate for three systems of different sizes with guideways of: 16 km, 40 km, and 80 km (approximately 0.7 km between stations). The costs per guideway kilometre he arrived at were SEK1.35 per kilometre; SEK1.77 per kilometre and SEK1.92 per kilometre, respectively(at 2000 prices).[80]

LogistikCentrum have carried out a cost-estimate for a podcar system at Kvarnholmen in Nacka (9km). This estimate includes personnel (manager, service personnel, operatives, and cleaners), spare parts, electricity (SEK0.5-0.6 per kWh) and control systems. They calculate the cost to be SEK1.65 per kilometre. The Kvarnholm estimate included the costs of management, operation, servicing, cleaning, spare parts and system support. The number of cleaners and mechanics was estimated in relation to the number of podcars.[81]

Recently WSP and LogistikCentrum have carried out a podcar survey for the municipality of Södertälje.[82] There the first phase of the guideway will be 11 kilometres long and the running costs are calculated at SEK18 million a year, i.e. SEK1.64 million per guideway kilometre.

Buchanan (2006) states that running costs are SEK5.43 per vehicle journey. A depot with space for 500 podcars would cost roughly SEK68 million and the cost of the system, such as control systems, vehicle protection systems, surveillance and ticket machines would cost SEK163 million in all.

Socio-economic principles and calculated value

To ensure compatibility between this socio-economic analysis of podcar systems and similar analyses of other transport systems, SIKA has followed the socio-economic principles and calculated values recommended by ASEK for the

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[79] www.atsltd.com

[80] Finansiering av spårtaxi – jämförelse med buss och järnväg, [Financing podcar taxis—a comparison with buses and trains] WSP Analys & Strategi

[81] WSP: Finansiering av spårtaxi…[Financing podcar taxis—] (p. 58).

[82] Spårbilar för Södertälje – en transportvision, [Podcars for Södertälje--a vision of future transport] WSP Analys & Strategi, 30th May 2008

transport sector, and which SIKA's forum for governmental agencies in the transport sector has adopted.[83]

A costing period is defined as the number of years a measure will give socio-economic value calculated on the basis of the starting year (start year for traffic). When the economic life is assumed to be 40 years or less the costing period is normally equated with the economic life of the object. We count on a 40 year costing period for the podcar guideways.

Socio-economic discount interest is at 4 percent and the commercial cost of capital is 6.5% according to ASEK (p.74).[84]

The calculated value of travel time depends on the type of journey: travelling to work, business journeys, and private journeys. Stockholm-Västerås, Stockholm-Eskilstuna and Uppsala-Eskilstuna are journeys that are over 100 kilometres long and the saved travel time on these routes is calculated at SEK102 per hour for private journeys. ASEK recommends that travel time for private journeys is calculated at SEK51 per hour for regional journeys (<100 kilometres) and SEK102 per hour for long-distance journeys (>100 kilometres) (ASEK p 92). The travel time value for business journeys is calculated at SEK275 per hour irrespective of whether they are regional or long-distance journeys (p.99).

ASEK 4 recommends that tax factor 1 is set at 1.21 and that all cost items in a socio-economic calculation must contain (be multiplied by) tax factor 1. This recommendation means that if it is applied caution and restraint will be incorporated into the use of public funds (page 76). ASEK proposes that tax factor 2 be 1.0 in normal cases, which means that none of the marginal costs of financing taxation are charged against the costs of investment, running costs and costs of maintenance (p.82).

With regard to air pollution caused by $C0_2$ and NO_x, it is clear from ASEK (p.134) that on average private cars emit 176 g of $C0_2$ per vehicle kilometre and 0.44 g of NO_x per vehicle kilometre. For light-weight goods vehicles, the figures are 236g $C0_2$ per vehicle kilometre and 0.864g NO_x per vehicle kilometre; for heavy goods vehicles the figures are 917.2g $C0_2$ per vehicle kilometre and 9.303g NO_x per vehicle kilometre; and for buses 699g $C0_2$ per vehicle kilometre and 7g NO_x per vehicle kilometre. For electrified railway lines it is assumed that these are not linked to any emissions (ASEK p. 134), which is why we assume that the energy consumption of a podcar system is not linked to emissions.

ASEK recommends that $C0_2$ is calculated at SEK1.5 per kilogram (p.146) and that NO_x is calculated for regional effects at SEK75 per kilogram (p.129). When calculating the costs involved for densely populated areas the regional effects are

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[83] Samhällsekonomiska principer och kalkylvärden för transportsektorn [Socio-economic principles and calculated value for the transport sector]
(ASEK 4), SIKA memo 2008:3, http://www.sika-institute.se/Templates/FileInfo.aspx?filepath=/Doclib/2008/PM/pm_2008_3.pdf

[84] Samhällsekonomiska principer och kalkylvärden för transportsektorn [Socio-economic principles and calculated value for the transport sector]
(ASEK 4), SIKA memo 2008:3, http://www.sika-institute.se/Templates/FileInfo.aspx?filepath=/Doclib/2008/PM/pm_2008_3.pdf

to be added to the local effects. For the sake of simplicity, we assume that the traffic in the Mälardalen region only gives rise to regional effects.

SIKA's statistics show that a fatal accident involving private cars occurs once in every 4.5 billion vehicle kilometres travelled by private cars. We have used this figure in our estimates of the reduced costs of accidents.

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