A New Swedish Transport System

– Presenting a Fifth Mode of Transport in Order to Alleviate the Problems in the Present Four

LUNDS UNIVERSITET
Lunds Tekniska Högskola

LTH School of Engineering at Campus Helsingborg

Technology and Society

Bachelor thesis:

Christopher Sigmond

LTH School of Engineering
Lund University
Box 882
SE-251 08 Helsingborg
Sweden

LTH Ingenjörshögskolan vid Campus Helsingborg
Lunds universitet
Box 882
251 08 Helsingborg

Printed in Sweden
Media-Tryck
Biblioteksdirektionen
Lunds universitet
Lund 2014

Abstract

Instead of investing 145 billion SEK in building a new high speed rail network, much greater value in terms of transport capacity is likely to be found in constructing a new system of tube transport with a travel speed of 600 km/h.

The suggested technology does not exist yet. However, research and development is advancing and accepting that a new technology is emerging might be the greatest hurdle to overcome in this process. Looking at the last 200 years of transport infrastructure history gives ample evidence of the major breakthroughs achieved in terms of capacity, travel time and comfort. None of these seem to indicate that we have now reached the 'end of the line'.

High speed rail, on the other hand, is hardly a new technology. It could be connected to the existing network, but therein also lies one of its disadvantages: it would be burdened by the present system.

The need to find new ways for the Swedish infrastructure is paramount. Indeed, there is something of a capacity crisis at present, which is likely to increase in the foreseeable future. Alleviating this crisis by mere tweaks and adjustments of the present systems might not be nearly enough. Also, the present trend, with increasing amounts of transportation, is nowhere near what would be needed to meet the climate goals.

Lund – Helsingborg would be an ideal place to build the first Swedish tube transport system, as the cities are far apart enough to make the difference in travel time evident, going from 30 minutes to 5.

Being a country that prides itself in being at the forefront of research and development, Sweden should take a front seat in taking this quantum leap in terms of transport technology.

Keywords: rail, technology, tube transport, vacuum tube transport, ET3, Hyperloop, transport capacity, infrastructure, Sweden, Swedish infrastructure, 600 km/h, 6 000 km/h, high speed rail, fifth transport mode.

Sammanfattning

Sverige planerar för närvarande att investera 145 miljarder SEK på att bygga en ny höghastighetsbana. Ett alternativ till detta är att satsa på att utveckla och bygga cylindertransport, även kallat vakuumrörstransport, med hastigheter på 600 km/h. Genom en sådan investering skulle Sverige sannolikt kunna få betydligt större värde för pengarna, räknat i såväl transportkapacitet som restid.

Den här föreslagna tekniken existerar inte ännu. Forskning och utveckling pågår dock för fullt. Kanske är det största hindret just nu att acceptera att en ny teknik håller på att växa fram. Genom att betrakta utvecklingen inom transportinfrastrukturen under de senaste 200 åren, är det uppenbart att det har skett många tekniska genombrott inom kapacitet, restid och komfort. Det finns inget i dag som tyder på att vi har nått vägs ände på den här punkten.

Höghastighetsjärnväg är å andra sidan knappast någon ny teknik. Den har visserligen fördelen att kunna kopplas till befintligt järnvägsnät, men detta är också en av dess nackdelar, eftersom detta innebär att många begränsningar i det nuvarande järnvägssystemet följer med till det nya.

Det råder redan i dag något av en kapacitetskris i den svenska transport-infrastrukturen och denna ser inte ut att avta under överskådlig tid. Det är därför av största vikt att hantera detta. Att då endast genomföra justeringar och optimeringar av befintligt system är detta läge inte på långa vägar tillräckligt. Dessutom är den ökande transportutvecklingen, i synnerhet avseende biltrafik, oförenligt med klimatmålen.

Lund – Helsingborg skulle kunna vara en idealisk plats för att bygga det första svenska cylindertransportsystemet. Städerna är tillräckligt långt från varandra för att restidsvinsterna ska bli uppenbara: Restiden skulle kunna minskas från 30 till 5 minuter.

Sverige är ett land som gärna tar en frontposition när det gäller innovationer. Detta är ett gyllene tillfälle att ta täten inom ny transportteknik.

Nyckelord: järnväg, teknik, järnvägsteknik, cylindertransport, vakuum, vakuumrörstransport, ET3, Hyperloop, transportkapacitet, transport, transporter, trafik, kapacitet, infrastruktur, Sverige, Sveriges infrastruktur, 600 km/h, 6 000 km/h, höghastighetsjärnväg, höghastighetsbana, femte transportslag, femte trafikslag.

Dedicated to Felicia and Tyra-Lovisa,
by the time you (can) read this
what I now consider
the future
is your
present

Preface

This is my bachelor’s thesis and thus concludes my three years of studies to become a railway engineer.

The idea for this thesis has evolved over the past two years, slowly, almost organically. As I started considering the topic at a quite early stage, I’ve had the chance to try out different ideas as I’ve gone along. This has included travelling through south India, participating in a research conference in Amsterdam as well as talking to teachers, fellow students, colleagues and people in the railway industry. And then, when all my exams were finally completed and the time came to produce the thesis, I had arrived at my focus.

Without further ado, I would like give thanks to the people who have supported me in my endeavours over the last three years.

My first thanks go to Anders Wretstrand, whom I came into contact with during the very first week of this education, during the course Transports and Society. During my second semester, Anders employed my help to develop the course, including contributing with updated course material. A year later, Anders asked me to work with the EU research project CIVITAS DYN@MO. From time to time during the last two and a half year period I have discussed my ideas for the present thesis with Anders, and it thus feels like a fitting finale that he has the role as examiner for the final result.

Thanks also Jerker Sundström, Bengt Thulin, Sven Assarsson, Tom Rye, Ragnar Hedström, Ida Thelander, Rolf Svanberg, Erik Hellqvist, Bo Viberg, Karin Wahlberg, Johannes Wolfmaier, Johan Kerttu and László Balogh, who all in significant ways have contributed to making these years memorable.

Pelle Corshammar is the supervisor of this thesis and is a person that I worked with for the last year. Pelle’s continuing support and positive attitude, has meant a lot to me.

Thanks to Theodor Sigmond and Marianne Sigmond for proofreading and commenting on the thesis.

Finally, heartfelt and warm thanks to my dear beautiful wife Magdalena, who has supported me in my times of self-doubt and shared in my successes. – Now await years of abundance!

On the train between Lund and Helsingborg, June 2014

Christopher Sigmond

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Introduction

In this thesis I will take a closer look at the capacity in the Swedish transport infrastructure. My main concern is with the problems that we face today and what I consider an effective solution to overcome some of them. This solution includes tube transport, a new mode of transporting people and light goods.

Since some of the technologies that I discuss have not been realized as of yet, there is a chapter outlining two different tube transport technologies, focusing on technical aspects, capacity and economics.

Next, a comparison of the capacity and economics of high speed rail vis-à-vis tube transport is carried out, based on the figures given by the Swedish Transport Administration and the proponents of each of the tube transport systems. In addition extensive internet searches for construction costs and estimates from primarily Europe and Asia have been assembled.

A possible new network has been sketched, with regards to the population of Sweden, and I suggest how the Swedish system for vacuum tube transport could be constructed step by step, beginning with a link between Lund and Helsingborg.

In the analysis I take a step back and discuss the results, focusing on how the overall capacity in the Swedish network could be affected by a new mode of transport in a newly built system. The analysis is concluded by a vision of the future, in terms of transport infrastructure.

Finally I draw some conclusions and present a few topics suitable for further work.

1 Background – going from four elements to five

Since even before we were humans, we have been propelling ourselves immersed in *water*; nowadays most transport by water takes place on top of it, using boats or ships.

As we emerged from the seas, we started walking the Earth; later *earth* became a medium for travel using various vessels, e.g. wagons and cars.

Travelling through the *air* was probably within the realm of human imagination (and perhaps even a reality) for a long time before Leonardo da Vinci devised his flying machines in the 16^{th} century. Then, at the end of the 18^{th} century, the hot air as well as the gas balloons saw the light of day, and thus it was possible to travel by air.

What about travelling by *fire*? Well, if we consider that the engines in the early locomotives in the beginning of the 19^{th} century were driven by steam, produced in a so called firebox, trains could be seen as travelling by fire. The steel on which trains run is also made by using considerable amounts of fire.

In addition to the four elements, the Greeks (and others) included *a fifth element*, sometimes called æther, sometimes referred to as *space*.

Space travel has been a reality for the last 50 years and space is ‘constituted of’ vacuum to a great degree and particles to a lesser degree.

Now, how could we travel by space on Earth? It has been suggested that by lowering the air pressure enough to create an artificial vacuum, or something close to it, vessels could coarse ‘through space’. This is a basic premise for one type of tube transport.

The first four modes of transport are thus travel by roads (cars, trucks, buses), by water (boats, ships), by air (airplanes, helicopters) and by rail. Could tube transport, then, be a fifth?

I for one am convinced that we are on the cusp of a new mode of transport. Regardless of whether it will in fact be some form of tube transport or some other form of new transport, a new transportation grid will have to be built. Presumably this will be a smart grid that facilitates transport between endpoints, without the need to change modes of transport along the way. In addition, this new mode of transport will not require that we as travellers are at constant vigil (as we need to be when driving a car e.g.). Also, I presuppose that the new mode of transport will be very fast and environmentally friendly, replacing most needs for travel by cars and planes – as well as trains. This is not to say that these modes will disappear altogether overnight. Rather I think it will be a gradual shift that step by step lets us travel in ways that are appropriate for our times. As for goods transport, the new system might very well be used for lighter transports, whereas the heavier goods can be transported by the extra capacity that would be freed up in the present networks.

Tube transport is a completely new way of travelling. Not only this, it requires a completely new infrastructure. And furthermore it is a technology that does not really exist yet. Even so, considering the magnitude of the problems with the presently available transport infrastructure systems, a paradigm shift of modes of transport might be the most viable way to come into phase with the transport requirements of today. Mere adjustments, fixes and tweaks of systems which are in many ways obsolete, are therefore not an option. Pollution is a major issue for road, ship and air travel. The capacity on many railway tracks is at, or coming very close to, their limit, which means that even small delays or deviations from the schedules, tend to spread in the system.

1.1 Purpose

One purpose of this thesis is to investigate the consequences of constructing a completely new transport system, rather than enhancing the existing ones.

Whether this new network is built with tube transport, or some other new technology, is not the main concern here. However, in order to elucidate that new kinds of technologies exist today, and are not some science fiction pipe dream, two tube transport technologies are described and discussed. Thus, a second purpose is to show that it is quite possible to make a quantum leap forwards in terms of modes of transport.

A third purpose is to compare high speed rail technology with a new (and as of yet unbuilt) technology, for which I have once again chosen the same two different tube transport technologies, trying to make a fair assessment of the pros and cons of either, from a Swedish perspective.

A fourth purpose is the sharing of some of my ideas on where a new transport should be built in Sweden, discussing the possibilities that this entails. Also for this mapping, the same two tube transport technologies are discussed.

1.2 Problem definition

The following problem is addressed in this thesis:

What are the effects in terms of transportation capacity and economics of constructing a new network of tube transport compared to the present estimations for a new high speed rail network in Sweden?

1.2.1 Scope

The tube transport technologies are presented as they are by their respective inventors, but no in-depth study or feasibility analysis is carried out. Rather, the technology is assumed to be sound, and the thesis concerns itself with what possibilities this opens up. However, a few comments are made on technical issues that have not been covered or are unclear in the source materials.

The technology behind magnetic levitation (Maglev) is not explained in detail.

The proposed new tube transport network is geographically limited to Sweden, with a few suggested connections to the neighbouring countries Denmark, Norway and Finland.

Tube transport is mainly suited for transportation of people and light goods. For heavier goods the present railway network is ideal. Indeed, it is assumed that one of the advantages of building the suggested new network is that the capacity for cargo transport on the existing railway tracks would increase. However, neither this nor any other aspect of goods transports is studied here.

It is assumed that better transport of people with tube transport would alleviate the problems in all present transport modes, including ships, by freeing up capacity in the railway system for more goods transportation. However, the effects on the aquatic mode of transport are not further examined in the thesis.

A modal shift from cars and also from buses and trains to bicycles would, similarly to a new tube transport network, contribute to environmental advantages. Such environmental aspects of the technologies included are not studied. The environmental aspects of the transport system in general is commented upon, albeit briefly, and merely as it relates to the climate goals set up by the Swedish government and the EU.

The suggested new system includes most of the population of Sweden, rather than merely focusing on the largest and most densely populated areas. The issue and dynamics of the centralization and decentralization of the population has, however, not been investigated further. Nor have aspects of demographics, including questions of social class, gender, age, ethnicity, religion etcetera, and the possible implications such factors may or may not have with regards to changing behaviours of transportation in the light of a new Swedish transport system.

The intrinsic problems of perpetual growth are relevant to the topic of transport, but are only peripherally hinted at in this thesis.

The financing of a new system is not included in the thesis.

2 Method

This thesis is primarily a literature study based on parts of the following works:

- The Swedish Transport Administration's report on the need for an increased capacity in the transport system.
- The Swedish Transport Administration's report on a new high speed rail network in Sweden.
- The Swedish government's national plan for the Swedish infrastructure.
- The two books on track systems and track vehicles from the Railway Group at KTH Royal Institute of Technology.
- A scientific article on vacuum tube transport in the Journal of Modern Transportation.
- A PM on Hyperloop, which is a tube transport system, written by its inventor.

I have also gathered information from a number of websites. All references have been documented in the author-year-style, and are found at the end of the thesis. Even though a large number of Swedish websites have been used, quite a few of them have English versions. Wherever possible I have used the English URLs.

In addition to the literature study, knowledge about the Swedish railway industry has been based on a number of informal conversations in connection with lectures and jobs during my present education. These conversations are too many to mention, and have not been conducted in any strictly scientific way. Thus I have merely used this information as a general point of origin for discussions about the Swedish railway industry, as the notions gathered – naturally – are heavily influenced by the personal experiences of the sources in question.

Finally, I have made my own observations of the railways over the years, especially during the last three years, during which time my knowledge of the transport infrastructure has increased manifold.

After finishing this thesis, just before going to print, I received a reply from ET3, which provided additional detailed information pertaining to the technology behind ET3. However, since this thesis does not really concern itself with the technology itself, merely describing it superficially, this new information has not rendered any changes in the text. For additional technical specifics, please see www.google.com/patents/US5950543.

2.1 Definitions

The English decimal system is used, i.e. 'one and a half' is written as 1.5. However, 'one thousand five hundred' is written as 1 500.

High speed rail is abbreviated as HSR and is used to denote tracks especially designed for high speeds, as opposed to the tilting trains running on normal tracks. When talking more generally about fast trains, the term high speed train is used. See section 3.2 on page 14 for an explanation.

The Swedish Transport Administration[1] is abbreviated as STA.

All costs are given in equivalent values for 2013, simply because a majority of the sources provided this. The currency conversions for 2013 are 1 US$ = 7.00 SEK; 1 € = 9.5 SEK; 1 CNY = 1.15 SEK. For older conversion rates as well as the price base amount[2], used to adjust prices between different years, see Table 1.

Table 1. Historical conversion rates used in this thesis.

Year	1 USD	Price base amount[3]
1975	4.40 SEK	9 700
1985	8.00 SEK	21 800
1996	*(Not used)*	32 200
2001	*(Not used)*	36 900
2003	9.40 SEK	38 600
2005	8.00 SEK	39 400
2013	7.00 SEK	44 500

An example of how the conversion has been carried out: 100 USD in 2003 is converted to the equivalent Swedish vale in 2003, which is 100 × 9.4 = 940 SEK. In order to compensate for the inflation, this value is multiplied by the quota between the price base amount in 2013 and the year in question, i.e. 2003:

$940 \times \frac{44\ 500}{38\ 600} = 1\ 084$ SEK, which is the equivalent value for 2013.

2.2 Images

All required permissions for the images included in the thesis have been kindly granted. The copyright owners are duly noted under the images.

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[1] 'Trafikverket' in Swedish.
[2] 'Prisbasbeloppet' in Swedish.
[3] SCB 1.

3 Results

> *The value of the invention (…) and the advantage the public will receive (…) may be appreciated by the (…) observations of the immense sums of money that have been expended in the formation of canals and iron rail-ways in the various parts of the kingdom, within these few years, and of the comparison of this excellent mode of conveyance with that which is now proposed.*
>
> *– George Medhurst, ca 1799.*

The railway industry has been around for 200 years or so. During the second half of the 19th century, when the technology was still quite new, and the speeds with which it conveyed people, circa 50 km/h, were astonishing to the people of that age, the railways had something of a golden age (Andersson and Berg, 2007). With the advent of the cars and buses, railways became obsolete, and much of the railways were removed (Bårström and Granbom, 2012). Then, by the end of the 20th century, the railways went through a renaissance, and once again became modern (Andersson and Berg, 2007) – or at least popular. This last shift is interesting, since the technology is basically the same. Of course, the railways are powered by electricity and not by steam; the signalling systems are at a completely different level compared to the flags and semaphores of the early days; the speeds have increased manifold (Bårström and Granbom, 2012). Nevertheless, the basic technology is still the same: steel wheels running on steel rails.

Figure 1. First version of the Swedish high speed train X2000 next to a steam locomotive (Image: Photo by Frederik Tellerup, 2004).

It is in fact not hard to see the progression from the early to the present railways. The standard gauge for railways, 1 435 mm or 4’8½”, has been used since 1825[4], and has since become norm in large parts of the world (Bårström and Granbom, 2012). There are still some steam powered locomotives that every so often parade on the same tracks that could be used by high speed trains. In other words, parts of their technologies are still compatible, even though the wagons could have been built close to 200 years apart, cf. Figure 1.

The present Swedish railway network is in many ways modern, but in many ways it is not. The technology is in several cases clearly on a different level than the technology of yore, e.g. the tilting high speed train X2000[5] (Andersson and Berg, 2007), the signalling system ERTMS, and GELD, a system for managing the electric network in the whole country (Bårström and Granbom, 2012). However, many of the tracks were built in the 19th century, and even though they have in most cases been modernised, it is still an old system that lingers on (Bårström and Granbom, 2012). This has bearings not so much on the status of the infrastructure, which can, and should, be handled with continuous maintenance (Corshammar, 2005), but on the capacity of the system. At various places the railway has been in its present location for such a long time, that the buildings constructed around the tracks are themselves old enough to claim historical precedence, which in turn means that it is difficult to modernize the geometry of the tracks or to increase the number of tracks, where this is called for.

Lund, an over 1 000 year old town in the south of Sweden, will serve as one such example. The tracks between Lund and Sweden’s third largest city Malmö, some twenty kilometres further south, opened for traffic in 1856 (Bårström and Granbom, 2012). Today they are some of the most trafficked in Sweden, with around 480 trains, of all different kinds[6], per day. An expansion to four tracks is thus well needed and long overdue. In the Swedish government’s National plan, which was published in the beginning of April 2014, the decision has finally been made to build the additional two tracks from Malmö and almost all the way to Lund central station (Regeringen 1). However, for the last 500 metres only two tracks will remain since there is not enough room for four tracks, due to the historical and cultural values of some of the buildings next to the tracks (Lunds kommun 1). See Figure 2 for an overview of some of the central parts of Lund with the culturally and

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[4] The standard gauge might go back to the Roman roads built 2 000 years ago (Bårström and Granbom, 2012).
[5] The train is actually called X2, whereas X2000 was the name by which it was marketed (Andersson and Berg, 2007) until recently, when it changed names to SJ 2000 (SJ).
[6] I have personally seen, and interacted with, commuter trains, regional trains, intercity trains, high speed trains and freight trains at this location.

historically valuable buildings marked with red. The large building called 'Armaturen 1' is from 1890 (Lunds kommun 2) whereas the smaller 'Armaturen 2' is from 1892 (Lunds kommun 3). The smaller buildings called 'Rosengården' are from the 1860s through the 1880s, but some aspects of the cityscape, e.g. the street Västergatan, have origins in Medieval times (Lunds kommun 4).

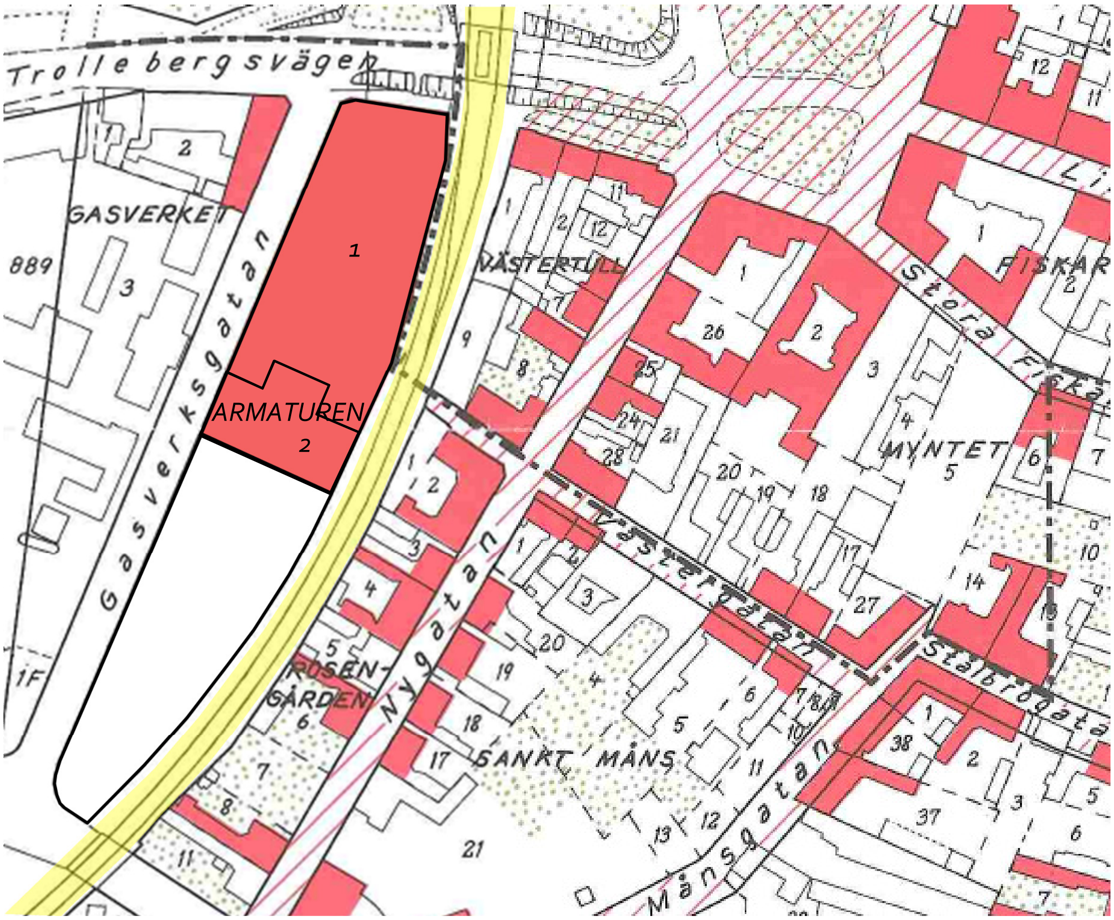

Figure 2. Some of the areas next to the railway tracks in the central parts of Lund, just south of the station. The present tracks are highlighted with yellow. All the red buildings have cultural, historical or other significant values. The hatched areas show old streets and the dotted areas show significant vegetation or gardens (Image: Map from Lund municipality; updated; yellow highlights added).

3.1 The capacity in the present transport network

According to the STA, all improvements of the transport network should be guided by the Four Step Principle. In short this principle states that measures should be taken in the following order:

1. Measures that can affect the need for transport and the choice of modes of transport.
2. Measures that make use of existing infrastructure and vehicles more efficiently.
3. Limited/small reconstructions/investments.
4. New constructions and large investments.

STA considers that the biggest and fastest improvements are to be found in step 1, i.e. through a smarter, more efficient and more sustainable use of the existing system. Even major changes in transport demand, STA states, come from measures in step 1 or step 2, whereas new investments merely can offer minor changes in the total amount of transport (Trafikverket 1).

3.1.1 Capacity problems

According to STA there are severe capacity problems in all parts of Sweden, and over 40 quite severe problems have been identified and are mentioned in a capacity report published in 2012. Most of the problems are closely linked to the goods transports (e.g. for the mining industry in the north of Sweden) and the centralisation of the population to Stockholm, Gothenburg and the Öresund region (Trafikverket 1). The problems are particularly prevalent for the railway (Trafikverket 2), and are due to many different causes.

One of these causes is that the maintenance of the railway has been wanting for a number of years, which means that there is a maintenance deficit. Thus, even with considerable maintenance and re-investments, the problems will continue for quite some time.[7] In order to really change the situation it would also be necessary to change from condition based maintenance to planned preventive maintenance (Corshammar, 2005).

Another cause of the problems is the mixed traffic on the tracks. Slow freight trains, commuter trains with many stops, fast regional trains and high speed trains all use the same tracks. This combination is detrimental to the capacity on the tracks.[8]

One solution, according to STA, could be found in further investigating the effects of a new Swedish HSR network (Trafikverket 3).

[7] Professor Evert Andersson, KTH Royal Institute Technology, lecture 2014-01-21.

[8] Johannes Wolfmaier, RailSys specialist, interview 2014-02-20. (RailSys is one of the computer programs that the STA uses for capacity simulations.)

3.1.2 Transports of the Swedish population

According to the STA the population will increase by 1 337 000 people between 2005 and 2050 (Trafikverket 1). According to SCB the population in 2005 was 9 047 752 people (SCB 2). Thus the increase in population between 2005 and 2050 is estimated to be around 15 percent. For (almost) the same period, according to STA, the different transport modes are expected to increase according to Table 2. These estimations are based on a scenario where the traffic increases in line with the present conditions and without the implementation of any further controlling measures (Trafikverket 1).

Table 2. Estimated transport volume in Sweden for 2006 and 2050 (Trafikverket 1).

Million[9] PKT[10]	2006	2050	Change	Increase	Share of the total increase
Car	89 189	149 206	67 %	60 017	78 %
Rail	14 476	26 007	80 %	11 531	15 %
Bus	10 423	11 982	15 %	1 559	2 %
Domestic flight	3 074	5 883	91 %	2 809	4 %
Pedestrians and bicycle	3 786	4 604	22 %	818	1 %
Total	**120 948**	**197 682**	**63 %**	**76 734**	**100 %**

The corresponding values from the government agency Transport Analysis[11] are found in Table 3. As Transport Analysis gives no estimations for 2050 I made a simple projection from the values given for 2006 and 2012:

$$Projected\ value_{2050} = Value_{2012} \times (1 + change\ percentage)^{6^1/_3}$$

Where 6⅓ corresponds to the number of years from 2012 to 2050 (i.e. 38) divided by 6, as there are 6 years from 2006 to 2012. E.g.:

$$Projected\ value, Cars_{2050} = 109\,600 \times 1.023^{6^1/_3} = 126\,577$$

[9] According to the report from STA it is billions, but that it clearly an error, since that would mean that each person on average walked or bicycled 400 000 km per year, which is the same as circumnavigating the Earth ten times – every year. With the values in millions instead, the values are also in line with those from Transport Analysis.

[10] Person Kilometres Travelled (PKT).

[11] 'Trafikanalys' in Swedish.

The projected change in Table 3 is the projected value for 2050 divided by the value for 2006.

Table 3. Transport volume in Sweden for 2006 and 2012 (Trafikanalys).

Million PKT	2006	2012	Change	Projection 2050	Projected change
Car	107 100	109 600	2,3 %	126 577	18 %
Rail	11 800	14 200	20 %	45 058	380 %
Bus	8 700	8 700	0,0 %	8 700	0,0 %
Domestic flight	3 300	3 400	3,0 %	4 100	24 %
Pedestrians, bicycles and mopeds	5 200	5 500	5,8 %	7 860	51 %
Total	**136 100**	**141 400**	**3,9 %**	**192 295**[12]	**41 %**

A possible explanation for the discrepancy between the values for 2006 in the two tables could be that the estimations have been carried out in different ways. Concerning the projections in Table 3, these values should be taken with caution, as they are merely based on values for two years, whereas the estimations for 2050 in Table 2 are based on much more thorough analyses (Trafikverket 1). Even so, the values in Table 3 are much more in line with the climate goals set up by the Swedish government (Naturvårdsverket) and the EU (European Commission).

Comparing the two tables, the most striking thing is that the values for 2050 in the two tables is that none of the percentages correspond, whereas the values for the total transport volume in 2050 in the two tables are very close. The differences are in the individual values (both 2006 and 2050) as well as how much the different transport modes increase, if at all. The general conclusion, however, is that the person kilometres travelled are expected to increase. This is particularly the case for medium to long trips (as indicated by the percentages for rail (which only to a lesser extent consists of light railway and underground) and flight).

3.1.3 Suggested solutions

STA, in its report, focuses on measures that

- increase the capacity of the transport system,
- contribute to better use of the transport system,
- contribute to an overall more robust transport system,

[12] The total value for the projection is the sum of the values in the column.

- help to facilitate transfers between the different modes of transport and
- contribute to a sustainable transport system.

In its report, the STA suggests a number of measures at different levels for the Swedish government to select from for implementation (Trafikverket 1).

Pertaining to a new Swedish HSR network, the report comes to the conclusion that the first two stages of said network, the Eastern Link between Järna (south of Stockholm) – Linköping and the part between Mölnlycke – Bollebygd (located between Gothenburg and Borås), should be built, regardless of whether they will eventually become parts of a future HSR network. The use of these new railways has been examined thoroughly, which has shown that the present railways between Stockholm – Linköping and Gothenburg – Borås lack in capacity as it is. These new links are thus beneficial for increasing the capacity in these places (Trafikverket 1).

In parallel to building these networks, further investigations are suggested for the remaining parts of a possible future HSR network. It is somewhat unclear whether a new HSR network would in fact be profitable from a national economic point of view or not. Different investigations have arrived at varying conclusions about this, not only in Sweden, but also in Norway and Great Britain (Trafikverket 1).

The STA, further, comments on a new connection between Sweden and Denmark, viz. between Helsingborg – Helsingør. This, the STA says, should be investigated and preferably be built, together with looking more closely at how the capacity on the Öresund bridge can be increased (Trafikverket 1).

3.1.4 Decided measures

On 18 December 2012 the Swedish parliament decided to support the infrastructure proposition which included 522 billion SEK to improve the Swedish transport infrastructure (Regeringen 2). With the new National Plan, presented on 8 April 2014, the Swedish government has specified what measures will be implemented. This plan includes some of the measures suggested by the STA. Among the large railway investments included in the National Plan are:

- Järna – Linköping, built for high speeds
- Mölnlycke – Bollebygd, built for high speeds
- Four tracks between Arlöv – Lund, Högevall

The goal of all of these investments is to increase the capacity of the Swedish railway network (Regeringen 1).

Some of the included measures have already been investigated thoroughly, and for these the building phase might begin as early as 2014 – 2016. This includes four tracks between Arlöv – Flackarp. For other measures the building phase will commence later, e.g. 2017 – 2019 for four tracks for the remaining part Flackarp – Lund, Högevall. For still other measures the National Plan entails that further investigations will be carried out. When the measures will be completed, whether those that shall be built, or those that require further investigation, is not specified (Regeringen 1).

The National Plan also includes some major road investments as well as investments in airports (Regeringen 1). These investments would presumably contribute to increased transport by car and airplanes, producing more pollution (Cogito & Factwise), which stands in stark contrast to the Swedish climate goals (Naturvårdsverket) as well as the European ditto (European Commission).

3.1.5 A society with efficient and sparse transport

The STA estimates that both the Swedish and the European climate goals demand that car traffic decreases concurrently with a doubling of travel by collective means of transport, by bicycle and by walking, all by 2030 (Trafikverket 1).

The measures in the National Plan, however, do not in any way aim at less transport. A few of them aim at more and safer bicycling. However, most aim at enabling more transport on the present roads and railroads, as well as building new ones. More transport is also the aim with the investments in shipping and airports. Even some of the railway investments aim at increasing the transports by air, since one argument for the railroads between Järna – Linköping and Mölnlycke – Bollebygd is that they will pass Skavsta and Landvetter airports respectively (Regeringen 1).

3.2 Swedish high speed trains and HSR

Sweden has had high speed trains since 1990 when X2000 was introduced. The term high speed trains is, however, somewhat ambiguous. Sometimes it refers to trains with a maximum velocity over 200 km/h (Andersson and Berg, 2007). Another definition is that there are two classes of high speed trains: Class 1 with velocities over 250 km/h and class 2 with velocities between 190 – 249 km/h.[13] Although the maximum velocity of X2000 is 200 km/h, its technology permits 210 km/h. Thus X2000 is rightly considered a high speed train regardless of definition (Andersson and Berg, 2007).

[13] Professor Evert Andersson, KTH Royal Institute Technology, lecture 2014-01-21.

There are basically two different technologies for conventional[14] high speed trains: tilting trains and non-tilting trains. The tilting trains permit high speed trains to traffic tracks that are geometrically designed for lower speeds, by tilting the car body in the curves. This is purely a means of improving the comfort for the passengers and has no implications on the safety of the train. In other words, a tilting train must still adhere to the same laws of physics as conventional trains in terms of maximum velocities in curves, in order not to derail. Non-tilting trains require special tracks, with large curve radii, enabling even higher speeds (Andersson and Berg, 2007); the latter is here referred to as HSR.

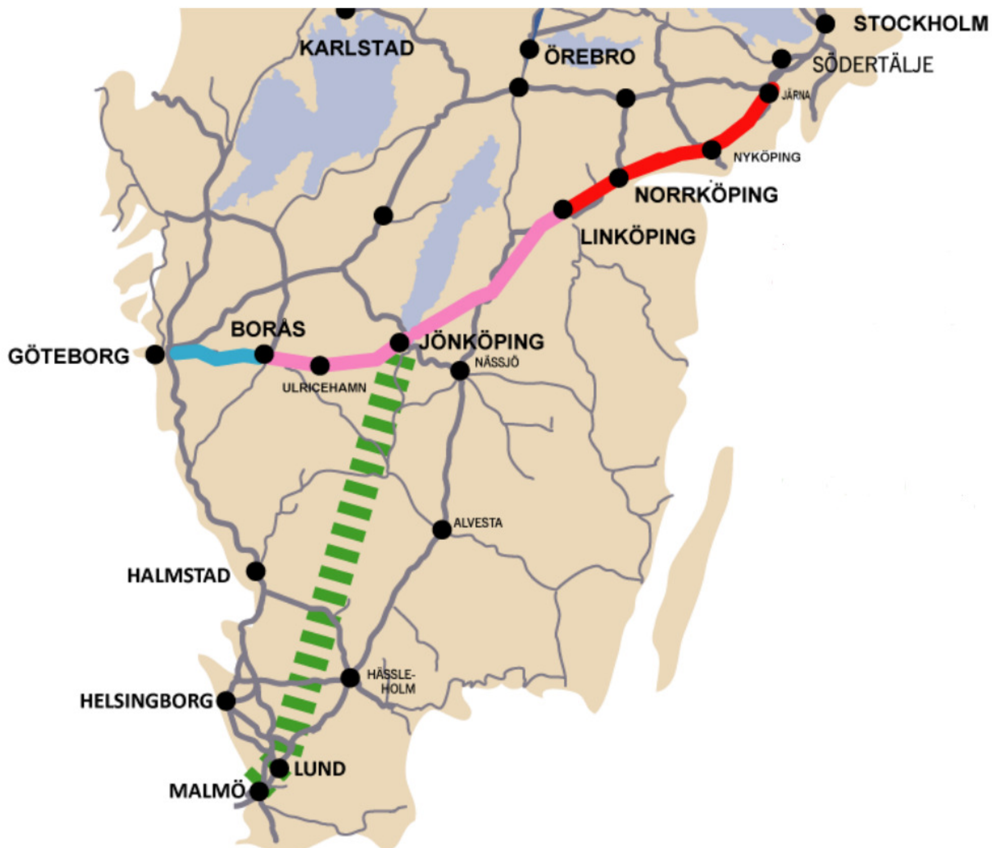

Figure 3. Proposed HSR network in Sweden. The exact location of the tracks from Jönköping southward have not been decided and may deviate from the corridor here indicated by green lines (Image: Map from the Swedish Transport Administration).

X2000 is a tilting train that permits 25 – 40 % higher speeds than conventional trains drawn by locomotives, which in practice means an average speed of

[14] Conventional high speed trains are those running on normal tracks, as opposed to e.g. magnetic levitation trains, aka Maglev.

around 150 km/h. In an international comparison this is a fast train considering that it runs on regular tracks, and is excelled only by trains running on HSR systems (Andersson and Berg, 2007).

Thus far Sweden has not had any HSR, but the first parts of a possibility for such a system are, as discussed earlier, now being planned, for building to commence in 2017 (Regeringen 1). See Figure 3 for a map showing the locations of these new tracks, viz. the red line indicating the section between Järna – Linköping and (parts of) the blue line for the section between Göteborg and Borås. In the future these tracks might be combined through the pink line, in effect connecting the metropolitan areas surrounding Sweden's two largest cities, Stockholm and Gothenburg. In the more distant future additional tracks might be constructed all the way down to Sweden's third largest metropolitan area surround Malmö. The latter have not been investigated in detail as of yet, and are thus indicated by a dashed green line.

All in all this is approximately 740 km of new railway at a cost approximated to between 110 and 170 billion SEK in price levels of 2013, with a most probable outcome somewhere around 145 bn SEK (Trafikverket 3). That is to say, somewhere around 200 MSEK per km, which is the cost that will be used in the comparisons and calculations below.

3.3 Tube transport – a fifth mode of transport

Tube transport is a technology that can be used to transporting people and goods. As its name suggests, it utilizes tubes, in which capsules are transported, somewhat like the pneumatic tubes in offices of yore, see Figure 4.

In fact, the idea to transport people and goods in tubes is far from new. At least as early as 1812 the inventor George Medhurst proposed a system that uses air pressure to propel vehicles carrying people and goods through tubes (Medhurst, 1812). The air powered engine, which Medhurst had developed a few years earlier, he called the Aeolian[15] engine (Medhurst, ca 1799).

In Medhurst's design for tube transport, the vehicle would be a carriage running on 'a pair of cast iron wheel-tracks securely laid all along the bottom for the wheels of the carriage to run upon' (Medhurst, 1812). In other words, a pneumatic tube train. Medhurst further suggests that two tubes should be constructed in parallel, for simultaneous transport in both directions (Medhurst, 1812), much like trains running on double tracks.

[15] From Aeolus, (Ancient Greek: Αἴολος) the Greek God of wind (Axelsson and Josephson, 1997).

Figure 4. Woman using pneumatic tube delivery system in Vancouver, Canada (Image: Photo by Jack Lindsay, 1946).

One of George Medhurst's main arguments for tube transport, or rather for the Aeolian engine, was that it was less costly than other forms of transport available (Medhurst, 1812).

In this thesis I will discuss two possibilities for a fifth mode of transport that, although different in some aspects, are both variants of tube transport. One is called ET3 and the other Hyperloop. And even though neither tube transport technology uses an Aeolian engine, air still plays a central role in both systems (Oster et al, 2011 and Musk, 2013).

3.3.1 Features in common for ET3 and Hyperloop

The basic designs for ET3 and Hyperloop are strikingly similar. See Figure 5 through Figure 10.

Figure 5. ET3 tubes, aligned vertically (Image: Visualization by ET3).

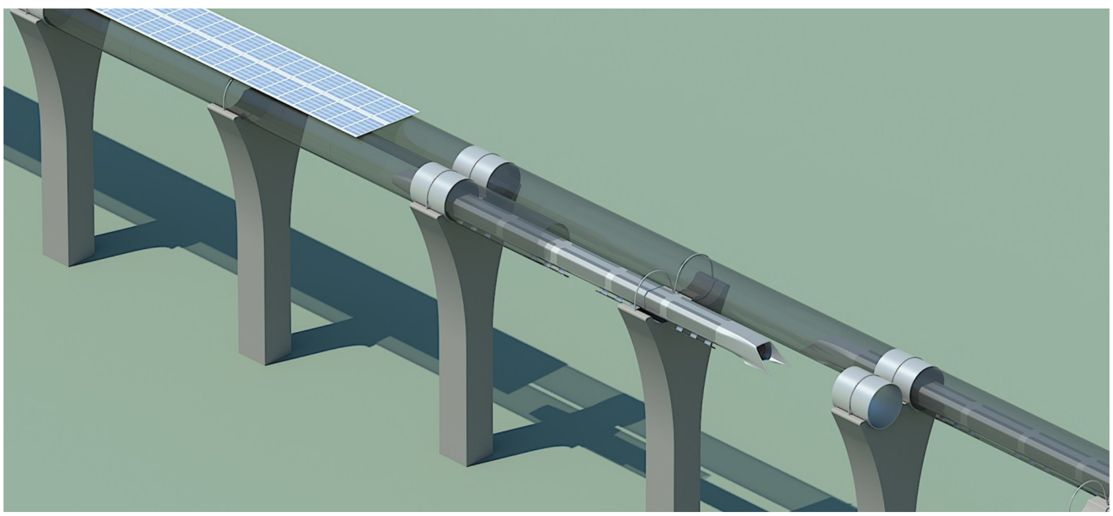

Figure 6. Hyperloop tubes aligned horizontally and covered with solar panels – Hyperloop is designed for California (Image: Visualization by Hyperloop, 2013).

Figure 7. ET3 cut through image; circular cross section (Image: Visualization by ET3).

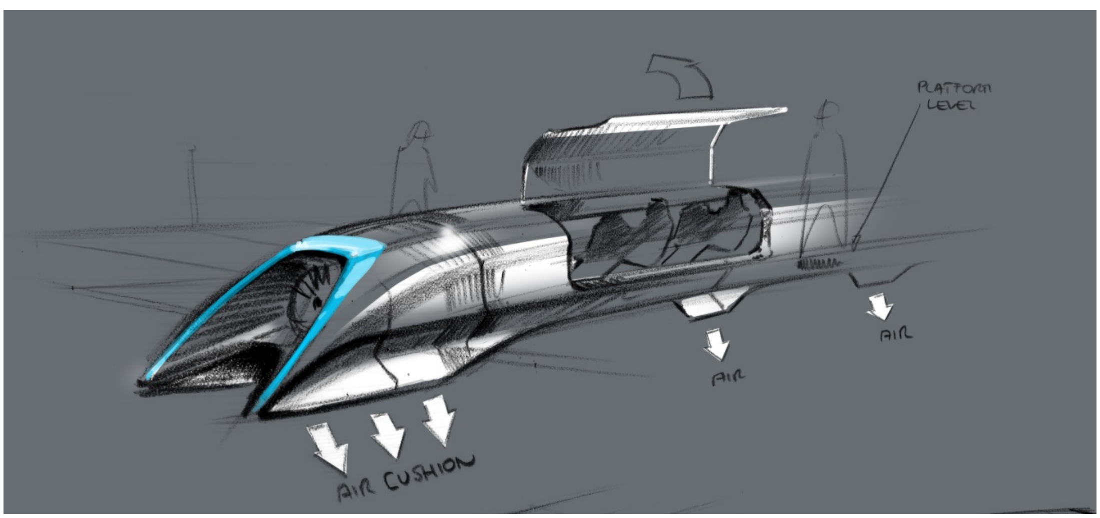

Figure 8. Hyperloop conceptual sketch; oval cross section (Image: Visualization by Patrick Grimmel, 2013).

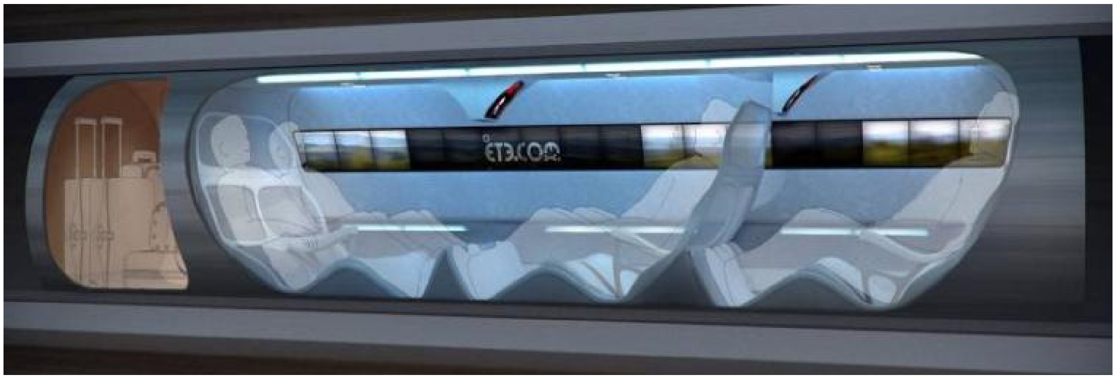

Figure 9. Six people can be comfortably seated in an ET3 capsule. The luggage is stored in a separate section (Image: Visualization by ET3).

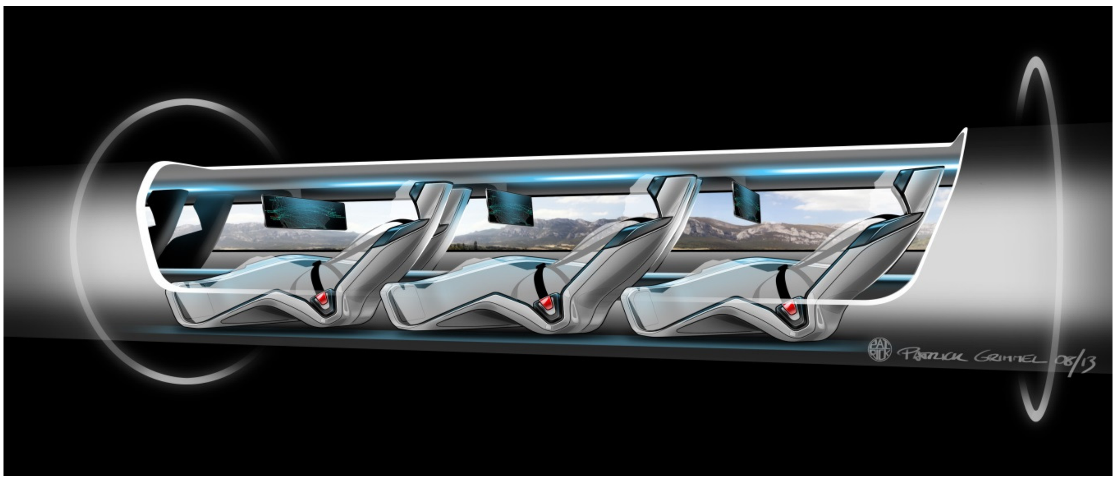

Figure 10. A part of a Hyperloop capsule that in total has 28 seats (Image: Visualization by Patrick Grimmel 2013).

3.3.1.1 The aerodynamics of tube transport

For vehicles running at speeds over 100 km/h the major resistance is normally drag, i.e. air resistance. With increasing speeds this part of the resistance increases, so that for conventional high speed trains, as well as for magnetic levitation trains, aka Maglev, most power is used to overcome the drag. For all kinds of vehicles moving at high speeds through air (regardless of technology) there are a number of other important aerodynamic phenomena. For the purposes of the present work, only one of these will be mentioned, viz. aerodynamic noise pollution. For vehicles moving at high speeds, noise pollution can have a considerable negative effect on the surroundings of the vehicle's path (Andersson and Berg, 2007). With a lowered air pressure, both these problems diminish considerably. In fact, both tube transport systems rely on a lowered air pressure to facilitate high speeds without too much aerodynamic resistance (Oster et al, 2011 and Musk, 2013).

3.3.1.2 Magnetic propulsion

The propulsion technique in both systems is based on linear synchronous motors to accelerate and decelerate (Oster et al, 2011 and Musk, 2013).

ET3 specifies that it uses regenerative breaking which wins back most of the energy used for acceleration (Oster et al, 2011). This works by converting most of the kinetic energy to electric power through electromagnetic induction which in turn slows down the vehicles. This technique is presently used when breaking electric trains, thereby regaining typically 10 – 30 percent of the energy used for acceleration (Andersson and Berg, 2007). For vacuum tube transport a much higher return can be expected (Oster et al, 2011). Presumably this technique could be used for Hyperloop as well.

3.3.1.3 Life support

Since the air pressure is low around the capsules, both types of tube transport require some form of life support (Oster et al, 2011 and Musk, 2013).

3.3.1.4 Track geometry

A maximum g-force of 1 g[16] is accepted longitudinally in both ET3 (Oster et al, 2011) Hyperloop (Musk, 2013). Laterally, however, ET3 accepts 1 g (Oster et al, 2011), whereas Hyperloop limits the acceptable comfort level to 0.5 g (Musk, 2013).

The longitudinal acceleration in regular trains is defined by the capacity of the train to accelerate and break. This value is typically around 1 m/s^2 for rail motor cars (Bårström and Granbom, 2012), i.e. about one tenth of 1 g.

The lateral acceleration is defined by the geometry of the track, and increases with smaller curvatures and higher speeds. The maximum value for trains is normally up to 0.65 m/s^2 for non-tilting trains and 0.5 m/s^2 for tilting trains (Andersson and Berg).

The difference in order of magnitude between acceptable accelerations for trains and tube transportation might have to do with the fact that a regular train enables the passengers to stand and walk around, in which case a too high acceleration could be dangerous. In both tube transport technologies all

[16] 1 g ≈ 9.81 m/s^2 as an international standard (Taylor and Thompson, 2008). However, the vertical acceleration that affects all bodies with mass due to local gravity and centrifugal acceleration varies in different parts of the world. In Sweden it is 1 g ≈ 9.82 m/s^2 (Lantmäteriet).

passengers are seated in comfortable reclining seats during the whole trip, see Figure 9 and Figure 10, which comes closer to the conditions when travelling by planes or cars.

3.3.1.5 Transporting people as well as goods

The size of the ET3 tubes has been optimized with both people and cargo in mind, of which only the former will be discussed here. When transporting people the capsule is designed for 6 passengers and some luggage, i.e. around the same size as the typical car. (Oster et al, 2011).

Hyperloop's tubes are somewhat larger in diameter, and the vehicles come in two versions – one for people and one for goods. The Hyperloop capsules for transporting people have room for 28 people (Musk, 2013).

3.3.2 ET3 – Evacuated tube transport technologies

ET3 is a consortium that is working towards establishing a standard for vacuum tube transport, with the goal of an intercontinental network of tubes.

The basic idea is that by setting a common standard for the system, it would be compatible in the whole world, thus enabling passengers to go between any two places connected to the network, without having to change vehicles (Oster et al, 2011).

In this thesis I present the vacuum tube transport technology as it is presented by ET3 on their official website[17] and in a scientific article published in the Journal of Modern Transportation. I use the term ET3 equivalently with vacuum tube transport.

One important thing that sets ET3 apart from Hyperloop is that the tubes are virtually completely emptied of air, so that a vacuum has been created (Oster et al, 2011).

3.3.2.1 Vacuum

It should be noted that vacuum is not an absolute value. Rather, the remaining air pressure can be measured as an indication of the quality of the vacuum: The less air that remains the higher quality of the vacuum. Creating the vacuum is in itself not particularly difficult nowadays. The vacuum quality proposed for ET3 is somewhere between 1.33 mPa (ET3 2) – 1 Pa (Oster et al, 2011).[18] Old cathode ray tube TVs all had vacuum inside of them of a much

[17] The official website for ET3 is et3.com.

[18] In the scientific paper by Oster et al, a vacuum level between 100 nanobars – 10 microbars (= 10 mPa – 1 Pa) is suggested, whereas the ET3 website states 10^{-5} Torr – 10^{-3} Torr (= 0.133 mPa – 1.33 mPa).

higher quality than what is required for ET3 (ET3 2). Maintaining vacuum in a tube of several hundred, or even thousands, of kilometres is nevertheless a challenge. In order to compensate for any leakages, a number of vacuum pumps are placed along the tubes. The pumps are turned off most of the time, and used only to compensate for air leakages. Pumps running continuously would thus be a signal that there is a tube rupture (ET3 2). In order for the capsules to pass from the stations into the tubes and out into the stations again, there are airlocks at all the entry and exit points (ET3 2).

3.3.2.2 The role of air in ET3

Since ET3 relies on vacuum to facilitate high speeds, a tube rupture means a rapid inflow of air. Normally this is not desired, and pumps are set up at regular intervals to compensate for any pressure drops, until repairs can be carried out. In an emergency, however, it might be necessary to stop all the vehicles at the same time. At such a time, air can be let into the entire section of the tube that needs to be stopped. This could be done quite quickly, but still slowly enough to prevent dangerously high breaking forces, and would lead to air cushions between the vehicles, in effect breaking them and concurrently preventing them from crashing into each other (Oster et al, 2011).

3.3.2.3 Magnetic levitation

In ET3, electromagnets are used for magnetic levitation, much like for Maglev trains (Oster et al, 2011). Research on Maglev has been carried out since the early seventies, primarily in Germany. There have been several attempts to build a commercial line with the German technology, but so far there is but one: Since 2002 a Maglev connects the city of Shanghai to its main international airport. Another system has been developed by the Japanese, which is called Superconducting Maglev. This technology uses superconductors at low temperatures (Andersson and Berg, 2007).

ET3 uses a new version of Superconducting Maglev called High Temperature Superconducting Maglev (HTSM). While Japanese Superconducting Maglev uses helium as a cooling agent, HTSM works at higher temperatures and can thus use liquid nitrogen. Liquid nitrogen costs only about 1/100 as much as liquid helium (Oster et al, 2011). Although helium is the second most common element in the universe, it is rare on Earth (Elding, 2014) compared to nitrogen that is the main component of the Earth’s atmosphere (Bolin, 2014).

Magnets are also used for keeping the vehicles aligned (Oster et al, 2011).

3.3.3 Hyperloop

Hyperloop was devised by visionary entrepreneur Elon Musk and his team. It is custom made for transporting people and goods between Los Angeles and San Francisco, as an alternative to the California HSR. Some details, such as the solar panels on top of the tubes, bear witness of this location of the system (Musk, 2013). However, for the most part this system is probably just as feasible for any location, and in the present thesis it is assumed that Hyperloop could be built anywhere.

3.3.3.1 The role of air in Hyperloop

In Hyperloop the air pressure is equivalent to the air pressure at 46 000 meters, which is approximately 100 Pa. This means that a tube rupture would be easier to handle in Hyperloop than in ET3. Also, the requirements for air pumps are considerably lower. However, since there is more air in the tubes, this has to be handled, in order not to slow down the capsules. This is done by mounting a pump at the front of each vehicle, which blows out the air underneath it. This air comes out through several air skis so that air cushions are created. The capsules thus coarse on these air cushions, in a fashion comparable to an air hockey table. This eliminates the need for magnetic levitation (Musk, 2013).

3.3.3.2 The propulsion of Hyperloop

The propulsion works along similar lines as for ET3. However, since the magnets are not required for levitation, the magnetic accelerators are placed at intervals, and give the vehicles a boost when needed. Approximately 1 percent of the length of the tubes would need to be equipped with accelerators. In the event of an emergency stop between the accelerators, the vehicles are equipped with wheels and electric motors for – slow – transport to the nearest convenient station (Musk, 2013).

3.3.4 Unclear or uncertain technical issues

I have identified some issues as unclear in the materials presented by ET3 and Elon Musk.

3.3.4.1 The magnitudes and characteristics of the electric and magnetic fields

Considering the amount of electricity present in and around the capsules, the magnitudes and characteristics of the electric and magnetic fields created, are a potential health hazard (Socialstyrelsen).

The characteristics of the fields are, however, not entirely clear for any of the systems (Oster et al, 2011 and Musk, 2013).

The ET3 website specifies that the magnetic fields will be between 1 – 1000 µT (ET3 3). Now, a magnetic field of 1 µT is acceptable for health reasons, but 1 mT is a quite high value, that could be a health hazard, e.g. for people with pacemakers (Socialstyrelsen).

For Hyperloop, this is not as much of a problem, since the accelerators are sparsely located. The effects of the magnetic fields might thus be less pronounced. The source material on Hyperloop has technical details on the accelerators, even an image showing the magnetic field inside the induction motor, but the strength of the field is not specified (Musk, 2013).

According to an email from Daryl Oster, the magnetic fields for creating the levitation for the ET3 capsule is considerably lower than that for a maglev train, and lower also than for Hyperloop, due to the light weight of the ET3 capsules. Also, thanks to the considerably reduced drag, there is little need for a strong electric field for maintaining speed.[19] However, this does not address magnitude of the magnetic fields during acceleration.

In addition to the strength of the magnetic field, the frequency of the alternating current has health implications (Strålsäkerhetsmyndigheten et al, 2009). The frequencies have, however, not been specified for either system (Oster et al, 2011 and Musk, 2013). In the aforementioned email Daryl Oster explains that ET3 uses permanent, and consistent, fields for levitation.

As for the electric fields, these are not mentioned in the sources.

3.3.4.2 How would the switches or interchanges work?

It is also unclear how the capsules would divert into different tubes. The ET3 website states that the system will use interchanges, much like a freeway, rather than switches, as on a regular railway (ET3 2). Exactly what this means, in terms of technical solutions is unclear. Perhaps the interchanges would be built like road tunnels allowing cars to go in different directions. The guiding system then, supposedly, directs the capsules into the corresponding interchanges. However, as the vehicles in ET3 are supposed to travel in an interval of around 10 vehicles per second, i.e. with around $1/10^{th}$ of a second between them (Oster et al, 2011), there is not much leeway, which requires a very high level of precision.

For Hyperloop there is a minimum of 30 seconds between the vehicles, which would give enough time for moving switches. If this is the idea, and if so, how it is supposed to work, is not specified (Musk, 2013).

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[19] Daryl Oster, ET3, email 2014-06-16.

3.3.4.3 Could creating vacuum be a problem for ET3?

Another issue for ET3 is the question of maintaining the vacuum. According to ET3, this not a problem (ET3 2) but according to Elon Musk, it is. However, lowering the pressure to 0.133 Pa, which is the upper end of what ET3 propose on their website (ET3 2), should not be a problem, according to Musk's own diagram on vacuum pump speeds at various pressures (Musk, 2013). A pressure of 1 Pa, as suggested in the scientific paper on ET3 (Oster et al, 2011), should pose even less of a problem.

3.3.5 The capacity of tube transport

The capacity of transportation is usually calculated as the maximum traffic flow, i.e. the amount of people or tonnes of goods, that can be transported a certain length over a certain period of time. This is basically dependent on the following two factors:

- The number of passengers per vehicle
- The number of vehicles per time unit (second, minute or hour)

The second of these two factors is, in turn, dependent on a number of other factors (Andersson & Berg, 2007).

For tube transport these other factors include but are not limited to

- The speed for the tubes in question
  - Technological limitations
  - Limitations due to curve geometry
    - Limitations on the acceptable lateral g forces
  - Permitted acceleration/retardation
    - Limitations on the acceptable longitudinal g forces
- The interval between the vehicles with concern to
  - Safety
  - Signalling
  - Speed with which the interchanges/switches can 'switch'
- The number of available vehicles
- The need for times with no traffic for maintenance
- The stability of the system, including how often there are emergency stops or other breakdowns
- Technological limitations

In order to say something about the capacity of a tube transport network, I have simplified by assuming that the system is built for the same maximum speed everywhere (600 km/h[20] and 1 220 km/h for ET3 and Hyperloop respectively as suggested by the originators of the systems), which means that the curve geometry is optimized for the top speed. I have also assumed that there are enough vehicles not to limit the amount of traffic. I have included 8 hours of maintenance every night, meaning that the system runs 16 hours per day and that there are no emergency stops or other breakdowns. This is thus a theoretical figure that might not be achieved, especially in the early years of a new system. See Table 4 for a comparison of the basic capacity of ET3 and Hyperloop.

Table 4. Comparison of the capacities of ET3 and Hyperloop.

	ET3	Hyperloop
Number of passengers/vehicle	6	28
Min time between vehicles	0.1 s	30 s
Max travellers/hour/tube	216 000	3 360
Max travellers/16 h/tube	3 456 000	53 760
Passengers/hour/station	700 / 820[21]	840
Capsules/hour/station	117 / 137[22]	30

Hyperloop's stations can service 840 passengers per hour according to the source document. With 28 passengers per vehicle this means that a maximum of 30 vehicles can depart from each station per hour, or one every two minutes. However, the same document also states that the vehicles could run as often as twice every minute, which amounts to 3 360 passengers per hour. (Musk, 2013). Perhaps this is then capacity of the tube, which could be serviced by different routes, i.e. with passengers embarking and disembarking at different stations. This has been assumed to be the case.

For ET3 the capacity of the stations is unclear. One of the source documents states that each station has the capacity of 700 persons per hour (Oster et al, 2011) whereas another states that each airlock can service 820 passengers per hour (ET3 2). 820 is based on a cycle time of 26 seconds and 6 passengers per vehicle (Oster et al, 2011), while 700 would mean a cycle time of 31 seconds for 6 passengers per vehicle:

[20] 600 km/h is not a technical speed limitation for ET3, but the speed suggested by ET3 as a nominal value for domestic and regional travel. For international and intercontinental travel speeds of 6 000 km/h or perhaps even higher might be considered, cf. 3.4.1 Technical specifics of HSR compared to tube transport and 3.5.1 Using existing corridors for localization.

[21] Please see the second paragraph below the table for an explanation of the two values.

[22] Please see the second paragraph below the table for an explanation of the two values.

$$\frac{3600 \times 6}{820} \approx 26\,s$$

$$\frac{3600 \times 6}{700} \approx 31\,s$$

I have chosen the lower value of 700 people in this thesis, to have some margin of error.

I have further assumed that the terms ‘stations’ and ‘airlocks’ are used equivalently in the source documents when it comes to the abovementioned specifications of capacity, and that the capacity is measured per airlock and that each station can service several airlocks. This is indicated in an ET3 visualization depicting a possible future station, see Figure 11. The cycle time of 26 or 31 seconds is, further, the cycle time for the airlock and not for the vehicle. Both these aspects are confirmed in an email from Daryl Oster.[23]

Figure 11. Image of what an ET3 station might look like (Image: Visualization by ET3).

[23] Daryl Oster, ET3, email 2014-06-16.

Presumably each station is served by but one pair of tubes, which would mean that there is ample time to board the vehicles, which are then sent away at regular intervals, much like at an airport.

Since the capacity of the tubes is much higher than that of the stations/airlocks, ET3's answer to more capacity is to build more stations/airlocks (ET3 2). Hyperloop, however, does not have a similar way to scale the capacity in its present design (Musk, 2013).

3.3.6 Economic aspects

The cost for constructing a tube transport system varies with the two systems. For an overview, see Table 5.

Table 5. Costs for ET3 and Hyperloop. All values are recalculated to the equivalent values for 2013.

	ET3[24]	Hyperloop[25]
Cost per vehicle	0.3 MSEK	9 MSEK
Cost per seat	0.05 MSEK	0.3 MSEK
Cost per km tube	14 MSEK	10 MSEK
Cost per station	79 MSEK[26]	875 MSEK
Passengers/station/hour	700	840
Cost for station with 12 600 passengers/h[27]	1 422 MSEK	*Not possible*

The tube cost for Hyperloop track includes all the technology required, viz. pumps, tunnelling (on the San Francisco – Los Angeles route), propulsion etc. (Musk, 2013). It is unclear whether all required technology is included in the figures for ET3 (Oster et al, 2011), but I have assumed that it is.

The capacity of an ET3 station is 700 passengers per hour (Oster et al, 2011), whereas Hyperloop can handle 840 passengers per hour (Musk, 2013). This is quite a low number of people. As a comparison the number of passengers for Stockholm Central railway station, is approximately 200 000 passengers on any given day (Andersson and Berg, 2007). Divided by 16 hours this means 12 500 passengers per hour, which corresponds to just under 18 ET3 stations. Hyperloop stations on the other hand cannot be scaled, so that is not an option (Musk, 2013). The cost of a larger station is thus only calculated for ET3 and found at the bottom of Table 5.

[24] Cost study made in 2003, Oster et al, 2011.
[25] Musk, 2013.
[26] In this context the cost for a station is assumed to be the cost for one airlock, while a station could in fact have several airlocks, cf. the reasoning in 3.3.5 above.
[27] This means a station with 18 airlocks.

3.4 HSR vs tube transport

When comparing HSR to tube transport, one of the most obvious things is the sizes of the different systems.

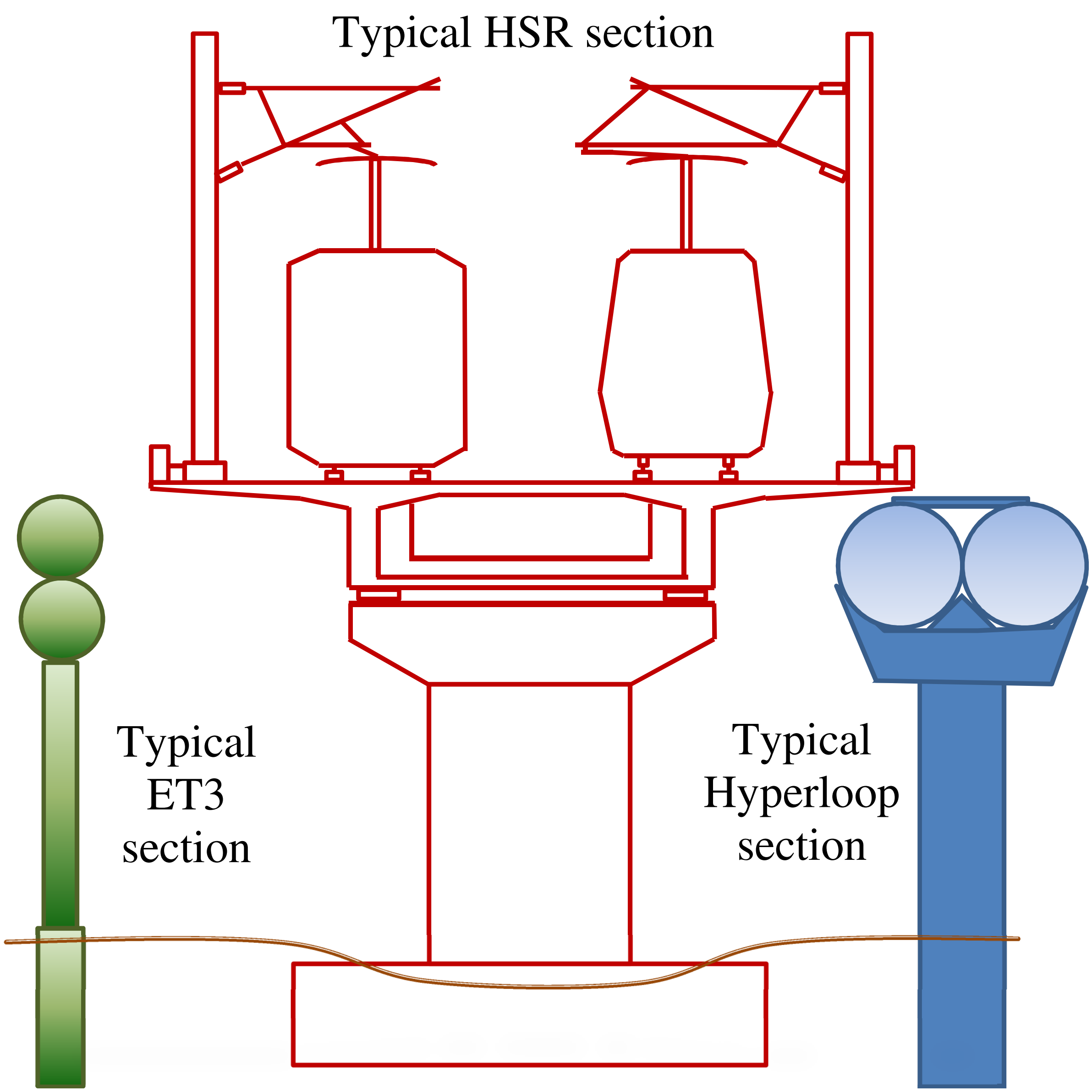

Figure 12. Comparison between typical sections for ET3, Hyperloop and HSR (Image: Redrawn and modified from original visualization by ET3; Hyperloop section added for purposes of comparison).

See Figure 12 for a comparison between a cross section of HSR built on bridges and cross sections of ET3 and Hyperloop. In building on bridges HSR does not cause a barrier in the landscape, which means that the land underneath can still be used for other purposes, e.g. farming. The tube transport systems share this advantage. However, the impact on the landscape in terms of views is considerably larger for HSR than for tubes. Also, the pylons which hold up the tracks/tubes are clearly of a different magnitude for tubes than for HSR.

3.4.1 Technical specifics of HSR compared to tube transport

Comparing the technical specifics of HSR and tube transport is not entirely straightforward, as the systems are so different. Nevertheless, for a comparison of some technical characteristics, see Table 6.

Table 6. Comparison of some technical aspects for ET3, Hyperloop and conventional HSR.

	ET3[28]	Hyperloop[29]	HSR[30]
Operating speed	600 km/h – 6 000 km/h	1 220 km/h	200 – 330 km/h
Powered by	Electricity	Electricity	Electricity
Propulsion	Linear induction accelerators	Linear induction accelerators	Asynchronous or synchronous motor
Track dimensions	Circular, 1.5m	Circular, 2.2 m	≈ 10 m × 6 m
On bridges?	Yes	Yes	Yes/No
Suspension	Maglev	Air cushions	Steel wheels
Air pressure	1.33 mPa – 1 Pa	100 Pa	101 kPa (normal)
Life support?	Yes	Yes	No

Most of the technical aspects in Table 6 are commented in other sections. The track dimensions for HSR are 10 meter width by 6 meter height, not including the pylons. For tube transport the dimensions are the diameters of each tube, so the dimensions of two tracks running in parallel would be twice that, with ET3 aligning the tubes vertically and Hyperloop horizontally. The pylons are also here not included in the dimensions. See Figure 12.

Concerning the top speed of ET3, the value 600 km/h is selected for practical purposes. The technology permits speeds of at least 6 000 km/h. However, higher speeds require larger curvatures, as well as longer acceleration and retardation times. Cf. section 3.5.1 Using existing corridors for localization.

[28] Oster et al, 2011 and ET3 2.
[29] Musk, 2013.
[30] Andersson and Berg, 2007 and Bårström and Granbom, 2012.

3.4.2 Economics of HSR compared to tube transport

The figures comparing construction costs for HSR and tube transport do not include research and development, presumably a major initial factor for the latter. Maintenance and vehicle costs are also not included in the calculations.

3.4.2.1 The costs for building HSR in different countries

For a comparison of the expected and actual costs of HSR in a number of countries, see Table 7.

The cost for constructing HSR varies by a factor of 40 according to Table 7. In other words, there is a huge variation, depending on factors such as how highly densely populated the land is and when and where the track was/will be built. The amount of tunnelling required can also be a major cost driver.

It should be noted that it is unclear whether the different values are actually comparable. E.g. all of the sources are not clear on whether costs for stations and vehicles are included in the figures. For Swedish railway construction, the station costs that are normally paid for by the STA, i.e. by the tax payers, which means that platforms, connections to platforms, weather protections and information systems are included. Other costs for constructing the stations, normally paid for by the station owners, are not (SOU 2009).

The Swedish estimated cost is right at the middle of the table together with the Chinese value for a track going through a densely populated area. The median value is thus the average of these two values.

Table 7. Comparison of the actual or estimated construction costs for HSR in various countries. All figures have been recalculated to the equivalent values for 2013.

Country	Cost per km track/MSEK
Japan, 1975[31]	21
China, estimated average for its complete 26 000 km network constructed 2005 – 2020.[32]	84
France & Spain[33]	90
China, Lanzhou – Urumqi, sparsely populated area[34]	97[35]
Belgium & Germany[36]	136
Japan, 1985[37]	161[38]
Sweden[39]	200
China, Beijing – Shenzhen, densely populated area[40]	213
Italy[41]	226
Korea[42]	316
Taiwan[43]	334
Netherlands[44]	479
UK[45]	669
California[46]	860
Median value	207

3.4.2.2 Comparing track costs between systems

In order to show the comparison more clearly between HSR and tube transport, the estimated Swedish value for HSR is shown together with the

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[31] Taniguchi, 1992.
[32] Powell, 2009.
[33] Arduin and Ni, 2005.
[34] Zehua, 2009 and The Economist, 2013.
[35] The two sources give the same value, which corresponds to 93 MSEK. However, recalculated for the value depreciation 2009 – 2013 the corresponding value is 97 MSEK.
[36] Arduin and Ni, 2005.
[37] Taniguchi, 1992.
[38] 161 is the average of the two values given in the source for two HSR tracks built in 1985.
[39] Trafikverket 3.
[40] The Economist, 2013.
[41] Arduin and Ni, 2005.
[42] Arduin and Ni, 2005.
[43] Arduin and Ni, 2005.
[44] Arduin and Ni, 2005.
[45] Arduin and Ni, 2005.
[46] Musk, 2013.

values for ET3 and Hyperloop. Since a part of the construction costs for stations is included in the figure for HSR, a part of the equivalent costs, as seen in Table 5, has been added to the figures for ET3 and Hyperloop as well. The ET3 and Hyperloop stations have a capacity of 700 and 840 passengers per hour respectively compared to 14 400 per hour for HSR (Oster et al, 2011). Thus one HSR station is the equivalent of 21 and 17 ET3 and Hyperloop stations respectively.[47]

For the Swedish HSR 7 stations are planned for the 440 km between Stockholm and Gothenburg, i.e. one station every 63 km. For the remaining 300 km between Jönköping and Malmö, only one additional station is planned. The latter part of the track is, however, as of yet not planned in detail (SOU 2009), so for the present purposes one station for every 63 km is added. I have assumed that the costs included for the HSR stations constitute one half of the total costs of the stations.

This gives the equivalent cost per km track for ET3

$$14 + \frac{\frac{1}{63} \times 21 \ \times 79}{2} \approx 27\, MSEK$$

And for Hyperloop it is

$$10 + \frac{\frac{1}{63} \times 17 \ \times 875}{2} \approx 128\, MSEK$$

With these values, the comparison between systems should be more or less 'capacity neutral'.

[47] For ET3 this is a relevant figure, since it is an integral part of this system to scale the stations as needed. Hyperloop, however, is not designed for this, but rather has the principle of a railway station, in that the capacity of the Hyperloop tubes and the capacity of the stations are corresponding to each other. For sake of comparison, Hyperloop is included in these calculations anyway.

3.4.2.3 HSR seems to be seven times as costly as tube transport

Table 8. Comparison between estimation of Swedish HSR, ET3 Hyperloop and actual costs for Swedish conventional rail.

Type of transport	Cost per km track/MSEK
ET3	27[48]
Swedish conventional double track rail, normal conditions	60[49]
Swedish conventional double track rail, densely populated area	107[50]
Hyperloop	*128*[51]
Swedish HSR	200[52]

Table 8 suggests that HSR is more than seven times as costly as ET3. Compared to Hyperloop, the cost difference is merely a factor of one and a half. However, Hyperloop was developed as an alternative to the California HSR, which costs 860 MSEK per km, see Table 7. In this comparison California HSR is almost seven times as costly as Hyperloop.

3.4.3 Capacity of HSR compared to tube transport

In order to compare the capacity of tube transport to that of HSR, it is necessary to assume something about how often it is feasible to run trains. The Shinkansen in Japan and the TGV in France have been able to run with a maximum of 10-11 trains per hour (Andersson and Berg, 2007). According to to another source it would be possible to run 20 trains per hour at 350 km/h (Nelldal et al, 2009), but this does not seem to have been tried in practice, and is therefore not included in these calculations. A Shinkansen train can transport up to 1 323 people per train, whereas a TGV Duplex train can transport 510 (Andersson and Berg, 2007). Assuming 11 trains per hour, we get 14 553 and 5 610 people respectively. See Table 9 for a comparison to the equivalent values for the two different types of tube transport.

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[48] Oster et al, 2011.
[49] Andersson and Berg, 2007.
[50] Andersson and Berg, 2007.
[51] Musk, 2013. The number is in italics to emphasize that it is a theoretical value, since it is presently possible to build scalable Hyperloop stations.
[52] Trafikverket 3.

Table 9. Comparison of the capacity of ET3 and Hyperloop to Shinkansen and TGV-Duplex.

	ET3	Hyperloop	Shinkansen	TGV
Operating speed[53]	600 km/h	1 220 km/h	285 km/h	300 km/h
# of pass./vehicle	6	28	1 323	510
Time between vehicle fronts	0.1 s	30 s	330 s	330 s
Vehicles per hour	36 000	120	11	11
Max travellers/h	216 000	3 360	14 553	5 610
Max travellers/16 h	3 456 000	53 760	232 848	89 760

TGV has 1.6 times the capacity of Hyperloop, while the corresponding figure for Shinkansen is around 4.5. The ET3, on the other hand, has almost fifteen times as high capacity as Shinkansen and almost 40 times as high capacity as TGV. This has to do with the very high number of vehicles per hour, which in turn has to do with the automated signalling system that allows the vehicles to run every tenth of a second.

It should be noted that this high capacity for ET3 is possible only with a very large number of airlocks and/or stations, in order for the vehicles to embark and disembark accordingly.

The different operating speeds show that travel time by ET3 is half that by HSR, whereas Hyperloop is more than twice as fast as ET3. In other words, travel time could be less than one fourth by Hyperloop than by HSR.[54]

3.4.4 Stockholm – Gothenburg – Malmö by HSR or tube?

The cost for the proposed 740 km Swedish HSR is circa 145 bn SEK.

Building 740 km of ET3 would cost approximately 20 bn SEK, i.e. 14 %. For Hyperloop the cost would be approximately 95 bn SEK, i.e. 66 %.

Conversely, 145 bn SEK would be enough to build 5 370 km of ET3 or 1 133 km of Hyperloop. This can be compared to the existing Swedish railroad network of around 16 500 km (Trafikverket 4). In other words, for the cost of the new Swedish HSR, the equivalent of one third of the present railroad network could be built with ET3.

[53] The operating speeds are included only for comparison and have not been included in the calculations of capacity.

[54] This does not include faster versions of ET3, which could run at 6 000 km/h or even faster.

3.5 A Swedish tube traffic network

A new Swedish transport network would be constructed in relation to the existing infrastructure. For the passengers it is vital to plan the network for intermodality, i.e. to facilitate shifts between different modes of transport.

3.5.1 Using existing corridors[55] for localization

To some extent the corridors for existing railways and road could be utilised for a new tube transport network. From a geometrical point of view this would make sense:

The lateral acceleration, a_l, of a vehicle, going at the speed, v, passing through a curve of radius, r, is[56]

$$a_l = v^2/r$$

With a lateral acceleration 1 g = 9.81 m/s^2, and a velocity of 600 km/h, which are the nominal values for regional and domestic ET3 travel (Oster et al, 2011), a curve radius of 2 832 m is acceptable. For Hyperloop the corresponding values are a lateral acceleration of 0.5 g and a nominal speed of 1 220 km/h (Musk, 2013). This gives a curve radius of just over 23 400 m.

Looking at the table with the STA's recommendations for train track curve radii, 2 832 m is between the values for a velocity of 180 and 190 km/h. The smallest curve radius for 180 km/h is 2 574 m, and for 190 km/h the corresponding value is 2 879 m. For 200 km/h the value is 3 202 m (Trafikverket 5). This means that railway tracks that have a speed limit of 200 km/h should be quite suitable for the geometry of ET3.

Indeed, there are several tracks that permit the trains to traffic at 200 km/h, but this is not the case along the whole routes. Even the heavily trafficked tracks between Stockholm – Gothenburg and Stockholm – Malmö have segments that lower the maximum speeds to as little as 140 km/h, and in some places even less (BIS).

A curve radius of 23 400 m is more than twice the radius for a track with the speed 400 km/h (Trafikverket 5), which is merely a theoretical speed, since the highest velocities for trains in Sweden is 200 km/h (Bårström and

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[55] Only the corridors surrounding roads and railway tracks are included. Other possible corridors might include power corridors, but this is not examined in this thesis.

[56] Andersson and Berg, 2007.

Granbom, 2012). This means that it is reasonable to assume that such radii are rare, if they exist at all, and that the number of usable railway corridors is smaller, probably limited to sections with straight tracks.

For roads, on the other hand, the largest required horizontal curve radius is 1 200 m (Trafikverket 6). Even though larger curve radii may exist, road corridors are generally less likely than railway corridors to provide adaptable corridors for tube transport.

From a safety point of view railway corridors might not be ideal for the location of tube transport. There is a lot of technology around railways, viz. cables for traction and electric power, signals, etc.; also, various safety distances must be adhered to. From this perspective road corridors would be better, since there is considerably less technology around roads.

The question of the more detailed localization of the tube transport network has to be investigated further with due consideration to several aspects, including, but not limited to, safety, environmental values, ground conditions, existing buildings and constructions, accessibility, topography and terrain, demographics, locations of stations, and aesthetic aspects.

3.5.2 Mapping out a new tube transport network

In mapping out a possible future tube transport network, Sweden's 40 largest localities have been considered primarily, see Figure 13. The population density in the country has also been considered, although to a lesser degree, see Figure 14. My idea is to first connect the larger cities, and then, step by step, connecting smaller ones. However, it should be emphasized that the suggested network is an overview study, and much more detailed studies would be required in order to ascertain the ideal routes. For even if the initial network would serve but the 40 largest cities, the network should ideally be located so that future stations can be built along the existing routes where they are most needed. Nevertheless, the mapped out network is large enough to start with, and it includes over 4.3 million people, which is more than 46 percent of the total population of Sweden, of 9.4 million[57] (SCB 3).

A point has also been made in including parts of the north of Sweden, rather than merely the southern, most heavily populated, areas.

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[57] The figures are from 2010, as that is when the latest census for the localities in Sweden was carried out. The next one will be carried out in 2015.

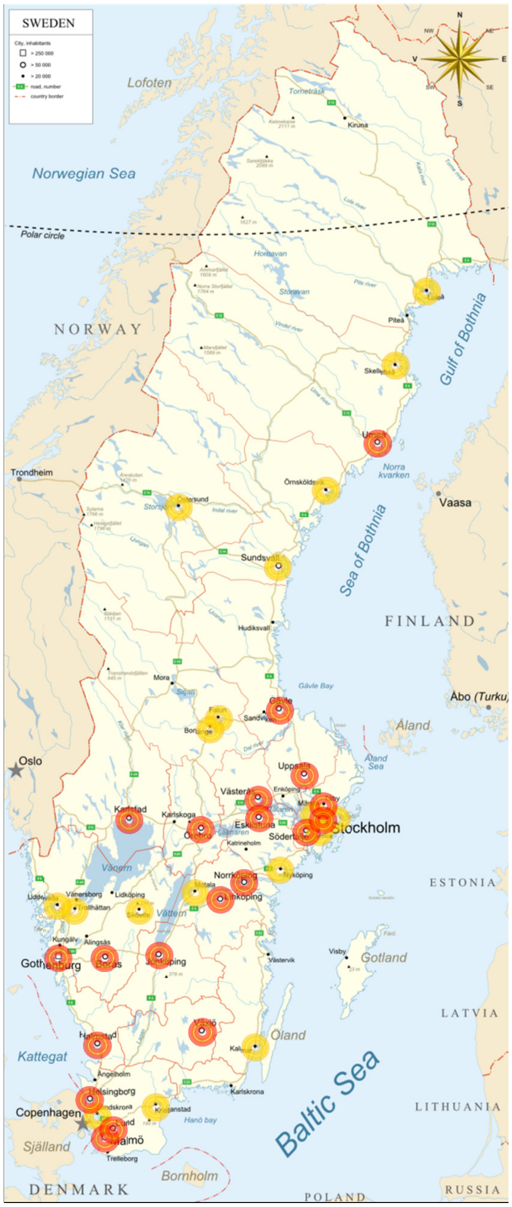

Figure 13. Map of Sweden, highlighting the 40 most populated cities. Red circles for cities 1 – 20. Yellow circles for cities 21 – 40 (Image: Map by Koyos, 2009).

Figure 14. Population density – number of inhabitants per square kilometre 2012 (Image source: Statistics Sweden, Statistical Yearbook of Sweden 2014).

Sweden's three closest neighbouring countries have also been considered. Denmark's capital Copenhagen is very close to the south of Sweden. Norway's capital Oslo is reasonably close to western Sweden, as is Trondheim, further north in Norway. The closest Finnish town is Tornio, which is only separated from the Swedish town Haparanda by the Torne river. However, this is a very small town, as is the town Kemi some 15 km to its east. Further south along the Finnish coast is the large city Vaasa, which is 100 km from the Swedish city Umeå, across the Sea of Bothnia. A bridge between these two cities could, however, perhaps be no more than 24 km.

The feasibility of building a bridge between Sweden and Finland will not be investigated in this thesis, but in constructing a road and/or railway bridge it is probably fairly uncomplicated to include tube transport. An alternative to the Swedish – Finnish bridge would be to take the coast way, which would mean a 770 km longer route, at 600 km/h adding about an hour to the journey time from Umeå to Vaasa. Another alternative would be to construct a submerged floating tunnel, as pointed out in an email by Daryl Oster.[58]

See Figure 15 for a map showing the suggested new tube transport network in relation to the 40 largest cities in Sweden, with connections to the neighbouring countries. Figure 16 shows an overview of the suggested network overlying the population density in Sweden.

A network that connects all the 40 most populated Swedish cities, including most of the densely populated areas in Sweden would be approximately 3 900 km in length and cost around 105 bn SEK for ET3. That is about 70 percent of the length of ET3 that 145 bn SEK would construct, 5 370 km. Constructing this network with Hyperloop would cost almost 500 bn SEK, in other words a considerable difference.

Including the parts in Denmark, Norway and Finland, i.e. the dashed lines in Figure 16, the network would measure around 4 250 km and cost somewhere around 115 bn SEK for ET3 and 544 bn SEK for Hyperloop, not including extra investments for a bridge between Sweden and Finland or a tunnel between Sweden and Denmark. Going the extra 770 km around the Gulf of Bothnia instead would cost an around an additional 20 bn SEK for ET3 and 99 bn SEK for Hyperloop. All three links to Norway would probably include quite a lot of tunnelling, which is also not included in this calculation.

[58] Daryl Oster, ET3, email 2014-06-16.

Figure 15. Map showing the suggested new network over the 40 most populated cities (Image: Map by Koyos, 2009, tube network in green added).

Figure 16. Population density map with the suggested new network (Image source: Statistics Sweden, Statistical Yearbook of Sweden 2014, tube network in red added).

3.5.3 The first Swedish system

The next step for the development of ET3 is the construction of a 4.8 km demo system (ET3 2). The location for this demo system could be China, with the Chinese hoping to build an ET3 prototype that ‘could be in daily use in the next 10 years', running at 500 – 600 km/h, after which they would increase the speed to 1 000 km/h (Xinran, 2010).

If this development progresses as planned, by 2018, the technology could very well have advanced far enough to be considered as a viable and justifiable option for the first part of a real system in Sweden.

The new Swedish National Plan for 2014 – 2025 was announced in April 2014. (Regeringen 1). This plan replaces the previous plan for 2010 – 2021 (Trafikverket 7). Over the last ten years, such plans have been put into effect in 2004, revised in 2007, and then new plans in 2010 and 2014 respectively (Trafikverket 8). Following this rate, it is likely that a new plan will be put into effect within the next four years. This would then perhaps also coincide with the next Swedish election in September 2018, (Valmyndigheten) as have the plans of 2010 and 2014.

The location of this first system is critical, as its success is likely to affect the way the technology is perceived for a considerable time to come. I suggest that such a first system is built between Lund – Helsingborg, between Campus Lund and Campus Helsingborg of Lund University to be more precise. The reasoning behind this choice is as follows:

1. The distance between the cities is large enough to make the acceleration to 600 km/h possible.
2. The distance between the cities is large enough to make the travel time difference compared to going by trains evident.
3. The distance is small enough to limit the construction costs within the realm of what can be justifiable as research and development.
4. A large number of people are travelling between these cities every day, primarily for work and education.
5. The system would double as an internal transport system for Lund University/The Faculty of Engineering, LTH, handling logistics of people as well as goods.
6. A new technology such as this could prove to be interesting for the Faculty of Engineering to being a part of developing.

Before transporting people, it is appropriate to test the system exhaustively with goods, so that possible errors can be discovered and adjusted while minimizing the risk for injuries or fatalities.

As a second step I suggest that the system is extended to include the Öresund Region (Öresundsregionen). This system, which could be called the "Öresund Circle", includes Helsingborg – Lund – Malmö – Copenhagen – Helsingør –

Helsingborg, see Figure 17. Stations could be built at several locations in these cities, including the railway stations (for intermodality), suburbs (for maximum availability) and along the route at smaller places such as Landskrona, Kävlinge etc. Considering the close to 4 million people living in the whole Öresund Region (Region Skåne), there is a large population base of possible travellers. This network would include a significant part of this population, all within a travelling time of less than 10 minutes.

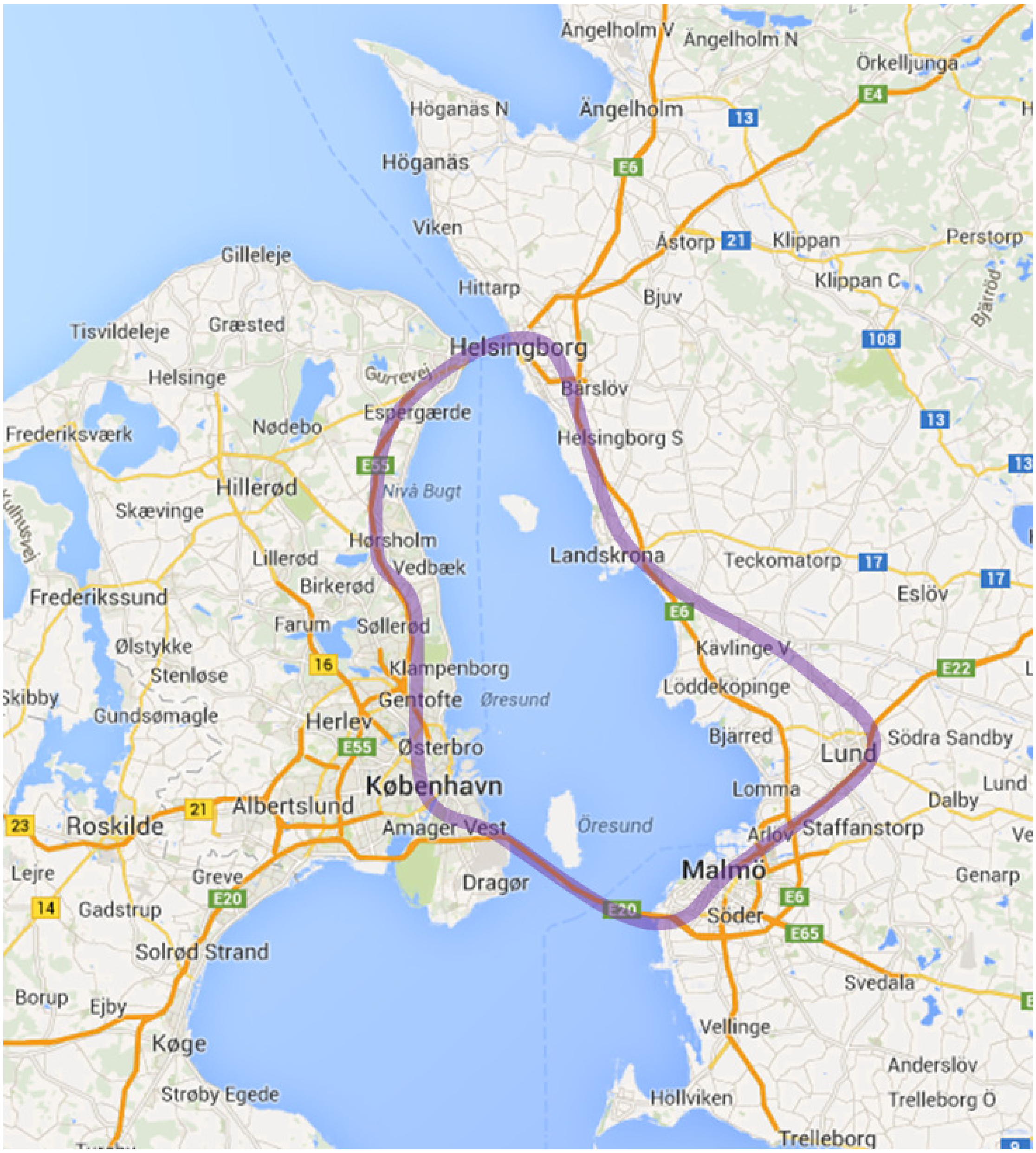

Figure 17. Overview of the Öresund region with the Öresund Circle highlighted. No exact locations are suggested in this map (Image: Map from Google Maps, highlighted path in blue added).

In order to find a more precise location, the suitable corridors would have to be identified, in cooperation with the municipalities involved as well as other parties who are directly (and indirectly) affected by the location of a new infrastructure network. However, that is beyond the scope of this thesis.

Seen at a grander scale, the Öresund Region is not only home to 4 million people, but is situated at a strategic point between Oslo, Stockholm, Hamburg and Berlin, which considered together constitute a major hub in Western Europe, see Figure 18.

Figure 18. The Öresund region seen at a grander scale (Image: Map by HH-gruppen).

One major obstacle when building railways, be it regular or high speed, is crossing water. In the proposed Öresund Circle two such obstacles exist, one between Copenhagen – Malmö and the other between Helsingborg – Helsingør. Since tube transportation is considerably lighter that rail, it is possible that it might somehow be feasible to use the present bridge between Copenhagen – Malmö for construction of the tubes. Further research would be necessary to evaluate this more precisely. For the passage Helsingborg – Helsingør, no such bridge/tunnel exists at present. However, there has already been considerable work done preparing for a tunnel between these cities (HH-gruppen). This solution has also been studied by STA (Trafikverket 1). If and when a railway and/or a road tunnel is built, the additional cost for building two tubes for tube transport is small in comparison to what the whole project would cost. And even if the discussed rail/road tunnels never see the light of day, a much smaller tunnel for two vacuum tubes would in any case be considerably less expensive.

3.5.3.1 The costs for a tube between Lund – Helsingborg

Rather than drawing the new track as a straight line between Lund and Helsingborg, it would be prepared for potential future stations. Therefore the track would be around 50 km. One station would be built at either end, which for Hyperloop means that 840 people could use the system per hour. Since ET3 is scalable, initially one airlock is suggested at either end, which enables 700 passengers per hour.

In accordance with the assumptions concerning the capacity of tube transport made in subsection 3.3.5, and with a generous embarkation and disembarkation time of 5 minutes per station and a travel time of 5 minutes for ET3 and 3 minutes for Hyperloop, as well as some margins for service, the time cycles in Table 10 are proposed.

Table 10. Cycle time for ET3 and Hyperloop capsules.

Capsule use	ET3	Hyperloop
Embarkation time, Lund	5 min	5 min
Travel time, Lund – Helsingborg	5 min	3 min
Disembarkation time, Helsingborg	5 min	5 min
Margin and service time, Helsingborg	5 min	5 min
Embarkation time, Helsingborg	5 min	5 min
Travel time, Helsingborg – Lund	5 min	3 min
Disembarkation time, Lund	5 min	5 min
Margin and service time, Lund	5 min	5 min
Total time for a return trip of a capsule	40 min	36 min
Cycle time	31 s	2 min
Number of capsules needed	78	18
Travellers per hour	700	840

With two extra capsules in either system, to have a buffer in case of a malfunction, the construction costs for a complete tube transport system between Lund and Helsingborg are shown in Table 11.

These costs do not include any research and development. They also do not include operations or maintenance.

Table 11. Construction costs for a tube transport system Lund - Helsingborg.

	ET3	Hyperloop
50 km tube	700 MSEK	500 MSEK
Station in Lund	79 MSEK	875 MSEK
Station in Helsingborg	79 MSEK	875 MSEK
Vehicle cost	24 MSEK/80 capsules	180 MSEK/20 capsules
Total	882 MSEK	2 430 MSEK

4 Analysis

'There is a general tendency of conservatism in the railway industry.'

– The above is an assessment that has been verbalised time and time again, over the last three years. This opinion has often been voiced by persons that have been working in railway industry for 20 – 30 years – and in some cases even longer. Primarily, the notion has been conveyed by individuals working in the construction phase. My understanding of this statement is that people in the railway industry tend to want to do things more or less the way they are used to and 'the way it's always been done'.

This is a two-edged sword. In some ways it is good, as it gives stability, continuity and safety, three concepts that are most fitting when discussing railways. On the other hand it makes it perhaps unnecessarily difficult to adjust to new circumstances and adopt new ways of doing things, even in situations that clearly call for this.

Now, in order to move forward, it is sometimes necessary to leave some things behind; to shift to a new system altogether that isn't burdened by the long history of the present one; to take a quantum leap forward and utilise the present knowledge in order to make the most out of the new technologies that have seen the light of day over the years. The lack of doing so can be detrimental to progress and development. And a conservative attitude can thus in some cases hinder new and better suited technologies from advancing and furthering the actual purpose of the older technologies.

4.1 Is there a capacity crisis in the Swedish transport infrastructure?

STA has come to the conclusion that there are severe capacity problems in the Swedish transport system, particularly for the railways.

In addition, the climate goals and the National Plan as presented by the Swedish government are irreconcilable. The STA makes it quite clear that the traffic must decrease and that there must be a considerable shift to collective means of travel. Even so, a large part of the National Plan focuses on improving and building new roads, without any emphasis on the collective means of transport.

The decoupling of increasing growth without increasing traffic, or indeed increasing traffic without increasing traffic related problems, seems far away. But since the suggested measures don't really aim at the former and only partly at the latter, this is hardly surprising.

Looking at matters from a transport technological point of view, and keeping in mind the STA's estimation that the traffic actually must decrease, and not increase, another pictures emerges. And given that the climate goals should be taken seriously, further investments in anything but collective means of transport, bicycling and walking should be strictly exceptional, which it presently – clearly – is not.

Let us consider the figures in the STA's forecast in Table 2. If the population increases by 15 percent, as the STA proposes, it is remarkable that all transport modes, except buses, increase by more than 15 %. Most striking is perhaps that the domestic flights are expected to almost double. In actual transport volume, the figure is only 4 %, but how come there is an increase at all? A positive thing is that the increase in transport is primarily expected to occur for medium to long trips, which happens to be the type of transport that is most easily switched to HSR or tube transport.

An increase in the transport volume for rail of 80 % looks good, but this actually constitutes a mere 15 % of the increase in transport volume, which is far too little. Indeed, 78 % of the total estimated increase in transport volume comes from cars: This increase of 60 bn PKT is more than the sum of all other transport modi in 2050, viz. just under 50 bn PKT.

Bearing in mind that the STA has analysed the situation and made an estimation of the development without any steering measures, the responsibility to change this rather dystopian view lies perhaps with the government and the individuals: It is the responsibility of the government to listen to the experts and it is the responsibility of the individuals to stay informed and act accordingly. – From a traffic technological point of view, however, things seem fairly straightforward, and I for one, cannot see any reason not to take a much more offensive position in creating the kind of transport system that would benefit us all, on both short and long terms.

4.2 Would Sweden benefit from investing in HSR?

According to STA the capacity problems in the Swedish transport infrastructure might be alleviated by building HSR. Generally speaking, HSR might be good for transporting a large number of people between two distinct points. It also has the added benefit of connecting to the HSR network in Europe. However, the suggested Swedish HSR, which would connect Stockholm – Gothenburg – Malmö and some stations in between, is a different matter:

With one HSR train every five minutes, there would be a considerable capacity for transport between the three metropolitan areas. However, since the HSR network is not completely independent, but relies on the existing tracks for the last parts coming into Stockholm, Gothenburg and Malmö, the capacity is in effect limited by the rest of the traffic. This means a significant loss of capacity for the high speed trains, but on the other hand it helps increase the capacity for the existing system.

4.3 The benefits of a new transport system

Infrastructure investments cannot influence the transport demand to any significant degree, says the STA. This conclusion is surely valid when the investments are merely adjustments of the present system. For such investments are encumbered by the present systems, as e.g. the planned HSR network would be. Now, a different situation emerges by building a completely new transport network – one that draws a new map, both literally and figuratively.

A new system could and would change the whole transport infrastructure more or less, depending on its size and capacity.

By building a new network, a modal shift to this new mode of traffic is possible. With the new mode being better optimized to suit the modern requirements, decoupling between the economic growth and the growth in transportation is possible. Or rather, the effects of the transportation, *even if it increases*, are not the same as they would be if the increase was, as estimated by the STA, in transportation by car.

4.4 Tube transport or HSR?

Comparing HSR to tube transport is a little bit like comparing a lorry to an electric sports car: they both serve a purpose, but while the former is cumbersome, noisy and best put to use carrying large loads, the latter is dexterous, swift and ideal for transporting a small group of people and/or a limited amount of light cargo.

4.4.1 Advantages of tube transport

There are several advantages of tube transport compared to HSR. Some of these include environmental and safety issues like lower noise pollution, less vibrations in the ground and the complete removal of risk of collisions with foreign objects, animals or people. Tube transport also requires much less power, since the capsules once accelerated require very little power for additional propulsion (and in the case of ET3 another very small amount for guidance). In addition most of the power used for acceleration can be fed back to the system.

The capacity of tube transport, especially the ET3 version, is staggeringly high compared to HSR. One pair of tubes can transport almost 15 times as many people as a double set of rail tracks.

Since the ET3 technology is scalable to a high degree, it is ideal for testing and once ascertained as desirable, expanding. The stations cover much less ground than the quite massive HSR stations do, which makes it easier to fit them into the existing cityscapes. Since the tubes are also reasonably small, it is considerably easier to build tube transport in densely populated areas, or cities like Lund, with a lot of culturally and historically important buildings.

The travel time is half for the 600 km/h version of ET3, or one fourth for Hyperloop, compared to that of HSR, and is comparable to flying, which would mean that most domestic flight could be phased out. The 6 000 km/h version of ET3 is in a completely different league, and well suited for transcontinental or even intercontinental trips.

The small size of the ET3 capsules paired with the flexibility of the system also means that it is much easier to get transportation that takes you all the way, removing many needs for changing between vehicles or transport modes. This adds comfort to the passengers, who can make better use of their travel time. This is also the case, although to a lesser degree, for Hyperloop.

The cost is also considerably lower for tube transport than HSR, particularly for ET3.

4.4.2 Problems with and remaining questions about tube transport

Until know, primarily the advantages of tube transport as compared to other modes of transport have been pointed out. Finally, therefore, some possible problems and remaining questions:

1. Since the technology does not exist and it is unclear if and when it will, regardless of how promising it is, there is a great amount of uncertainty pertaining to its properties and feasibility. This does not only mean that investors might be reluctant to invest money in the development of the technology, it also means that it might not even work. The only way to know for sure if it works is by building it, testing it and testing it again. Until that done, this will be an unknown factor.
2. When would the system be economically justifiable?
3. Long trips without being able to move around, stand up or go to the bathroom, being confined in a small area might not be quite the same as riding in a car. Riding in a car it is normally possible to look out through the window, open a window to breathe some fresh air, or just

drive to the side of the road whenever one wants to. In an airplane or a train one can at least stand up, walk around and go to the bathroom. Neither of these possibilities remains with tube transport. Motion sickness might in fact be a problem.

4. Despite the brilliant idea behind ET3, to create a universal system, the almost classic mistake of developing several non-compatible systems in parallel might take place once again.
5. When travelling between time zones, jet lag can be quite a problem. 'Tube lag' might be a much worse problem after travelling at 6 000 km/h.
6. The effects of accidents are difficult to predict. With failing life support and emergency stops of a long row of vehicles, it would seem that there is a risk of people getting stuck in vehicles without air for too long. Therefore there must be a way of being able to leave the vehicles, or at least to let some air in. How can this be reconciled with the fact that the tubes must be very tight and protected from ruptures? And what would happen if there is an emergency stop in a submerged floating tunnel?
7. Is there not a risk that building a universal network of tube transport would further increase the amount of travelling, when it would actually be better from an environmental point of view if people travelled less?

4.5 Is this really possible?

Is it even reasonable to expect a completely new system to be built?

Well, a new technology often seems unreal, like science fiction, until it is implemented. But once it is in place, fairly quickly it is taken for granted. Some people find it easier to look at the existing networks and systems as endpoints, destinations that we have reached, where all that remains is to make small adjustments and tweak the system. However, looking back it is evident that there have been several *major* changes in the infrastructure just in the last 200 years. Even such a modern phenomenon as mobile phones, which today are prevalent everywhere on Earth, has implications on the railway industry in modern signalling systems, as e.g. ERTMS. It is therefore wise to exercise caution before jumping to judgements such as "science fiction" or "utopia". How would a person only 50 years ago have reacted to a mobile phone? What about 200 years ago? – Probably as unbelievable as transport at 600 km/h, let alone 6 000 km/h or faster. And the latter is in fact already a reality – in space. Only, since so few of us think of space travel as a personal experience, it is hard to relate to this fact and easier to disregard that in fact, we are all coursing through space all the time, only on top of a huge globe that we call Earth.

4.6 Self analysis

Taking a step back, I will conclude the analysis by examining the thesis itself.

I realize that this is a pioneering work. When it comes to the tube transport technologies, the number of sources available on the subject is very limited. Apart from the sources I have used, and the additional source detailing the patents for ET3, as well as the personal email from Daryl Oster, I have not found any other sources on the technologies. And apart from some media coverage, there have not been any scientific articles examining this topic in detail that I am aware of. Writing a thesis with such a scarce source material has several problems, a few of which being the following:

1. Even though the descriptions that I have read are seriously done and carried out with the intention of being rigorous and objective, there is an overwhelming risk of their being biased. This is not to cast any doubt whatsoever on the sincerity of the inventors of the technologies, it is just a natural effect of someone advocating his or her own material. With independent scientists investigating the claims closer and an additional number of reports this could be remedied. With this thesis I hope to add perhaps a small contribution in this direction. And, once the technology is up and running, many of the question marks will quite naturally be swept away.
2. Not all questions are easily answered, and some guesswork has been necessary from my part. And guessing, of course, has a risk of being erroneous.

Another issue is that it is unclear how much research and development would be necessary in order to realize either of the tube transport technologies. It stands to reason that not even the inventors or the scientists working actively with the technologies know beforehand how long the development will take. Any comments on a possible time frame for when a new system might actually be built is thus at best a qualified guess.

The willingness of the Swedish, or any, government to risk embracing a new system is difficult to assess. It is true that there is a willingness to invest money in transport research, but the kind of cutting edge science that is discussed here might be too far ahead for serious consideration. That being said, with each and every step towards the realization of the technology, this willingness is likely to increase. And considering that development sometimes moves very quickly, who knows? – Even so, this is an uncertain factor.

5 Conclusions

What are the effects in terms of transportation capacity and economics of constructing a new network of tube transport compared to the present estimations for a new high speed rail network in Sweden?

My answer to the problem that is addressed in this thesis, as reiterated above, is, in short, that, provided that the technology is researched, developed and works as it is suggested to do, it would be much better for Sweden, in terms of both capacity and economics to construct a tube transport system of the ET3 type, than building HSR.

A new HSR network between the three largest cities of Sweden would alleviate some of the lack of capacity. However, in order to truly come to terms with the situation, this would not be enough. Not only would the increase in capacity take quite a long time to come into effect, it would be unevenly distributed with regards to the population of Sweden as a whole. This means that further centralisation of the population could be expected, thus furthering the need for more and more transportation. The expected costs for building a HSR network that covers but a comparatively small part of the country are also staggeringly high, the amount of which have a large degree of uncertainty as to the final outcome.

5.1 My solution to the transport capacity crisis

Concerning the lack of capacity in the transport infrastructure as a whole, the solution, in my opinion, is simple: Less transports overall, a major share of which are carried out by bicycle, walking or train. The whole society should be planned to facilitate collective travelling and bicycling. Car use and car ownership should be discouraged and financial incentives should be introduced to limit the number of trips by car. New roads should not be built, and existing ones should be questioned. In densely populated areas and localities, bicycles and pedestrians should be the norm for traffic, with cars having to adjust their speeds and behaviour accordingly. Vacations by car should also be discouraged, and the infrastructure should be adjusted with this in mind. Domestic flight should be abolished completely.

To the degree that maintained, or even increasing amounts of transportation, is deemed necessary, the research, development and construction of a tube transport infrastructure could very well be the best way forward. This would provide a major part of the population access to transport that has a number of advantages. It would be faster than domestic flight, much less expensive than HSR and more comfortable than a car. The capacity of such a network could be scaled to a much finer degree, so that once the basic network is in place, it is a fairly simple matter to add new entry points along the way, and expand those already built. Thus even smaller towns could eventually become part of the network, *without really affecting the capacity* of the network.

5.2 Further work

During the work with this thesis, several topics of interest have come up. Some, or perhaps all, of these might serve as topics for future theses:

- Thorough study of the technologies of tube transport in order to ascertain feasibility and technical characteristics.
- Examining the effects in terms of capacity on the railway network when shifting a large part of the passengers to another form of transport, e.g. tube transport. Especially the effects on the goods transports should be examined.
- Looking closer at the possibilities to effect a modal shift towards bicycles, including legal measures, taxation of cars, traffic priority to bicycles etc.
- Detailing the issue and dynamics of decentralization of the population, as related to the transportation of people and goods.
- Identification of the suitable corridors for a tube transport line between Lund – Helsingborg, in collaboration with the municipalities and other affected parties. Once this is complete, the next step is to choose the exact location for the line.
- Enquiry into the intrinsic problems of perpetual growth as it relates to transport networks and what kind of decoupling is really desirable.
- Development and discussions of models for financing a completely new transport infrastructure system, e.g. tube transport.
- Transport of light goods by tube transport.
- Points 2 – 7 in subsection 4.4.2 Problems with and remaining questions about tube transport.

6 Afterword

In order to move forward, and take a quantum leap ahead, I have no doubts that a paradigm shift concerning transport networks is required. Tube transport could very well be such a leap. The technology is young, indeed, it has not been built yet, but alas, therein lies the opportunity to seize the new at the beginning, rather than to build something that will already be 65 years old when it is completed, as HSR in Sweden would be – incidentally with 65 years old being the Swedish standard age for retirement.

Sweden has a proud history of research and development. The most prestigious science prize in the world is Swedish. Why, then, could Sweden not participate in the development of, what could very well transform the transport network of the world in a near future?

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