

# Evaluation of the feasibility of a new North-South Metro line in Stockholm from an infrastructure and capacity perspective

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## **Abstract**

From a sustainability point of view, the development of Stockholm County both in terms of population and activities will induce a high demand for public transport needs in the coming decades. Several districts currently badly linked to the Stockholm rapid transit network will see a large increase of inhabitants and workplaces, like Hagastaden or Årstafältet. Therefore a new North-South high capacity and fast connection is needed between these areas and the rail network. This thesis will estimate the corridors and the infrastructure of this new line.

Since another objective of the new North-South Metro line is to create an alternative to the existing radial network with all the lines merging to Stockholm Central station, this thesis will also evaluate how this new line will improve the robustness of the global public transport network in Stockholm region. That is, how the passenger loads on the other lines will be influenced by the new link as the aim is to decrease the load on the existing overcrowded stretches (e.g. around T-Centralen) and reduce travel times. Comparisons will be made between the different alternatives, with and without the new line, to evaluate the efficiency of the new line in terms of passenger load, travel time savings and economically.

## **Sammanfattning**

Från ett hållbarhet perspektiv ska Stockholms läns utveckling medföra ett högt behov av kollektivtrafik i de närmaste decennierna. Några distrikt som har för närvarande dåliga anslutningar till den spårtrafiken ska se en stor ökning av antalet innevånare och arbetsplatser, liksom Hagastaden eller Årstafältet. Därför krävs en ny snabb förbindelse med hög kapacitet mellan dessa distrikt och det befintliga spårnätet. Detta examensarbete ska beräkna korridorer och infrastruktur för denna linje.

En annan inriktning för den nya tunnelbanelinjen är att skapa ett alternativ till det befintliga radiella nätet där alla linjer slår ihop vid Stockholms centralstation. Detta projekt ska räkna ut hur den nya linjen ska förbättra Stockholms läns kollektivtrafiks robusthet. Det vill säga hur passagerare flöden på andra linjer ska ändras eftersom syftet är att minska flödena på de mest trafikerade sträckorna (omkring T-Centralen till exempel) och att minska restider. Jämförelser ska genomföras mellan de olika alternativ, med och utan den nya linjen för att bedöma nya linjens effektivitet från passagerare belastning-, restidsvinster- och ekonomiperspektiv.

## Definitions

*Congestion rate: percentage of seats used by the passengers onboard a public transport vehicle.*

*Cycle time: time needed for a public transport vehicle (train, bus) to run an entire route in both directions.*

*Headway: time between two consecutive departures at a station on a public transport line.*

*Interstation: stretch of a railway line between two consecutive stations.*

*Layover time: time needed at the end station for a train/bus to turn back.*

*Occupancy rate: see Congestion rate.*

*OD (origin-destination): pair of stations in the network that determines a trip between these two stations.*

*Running time: time needed for a public transport vehicle (train, bus) to run from the first station to the last one on a given route.*

*SL (AB Storstockholms Lokaltrafik): the public transport authority in Stockholm region.*

*SLL (Stockholms läns landsting): Stockholm County Council, Stockholm Region Council.*

*Spare ratio: percentage of extra vehicles needed for a given public transport line to prevent availability failures due to maintenance, accidents...*

*Trafikverket: the Swedish transport administration.*

*Transfer penalty: extra time added in travel time calculations that represent the passenger's reluctance to transfer from one line to another.*

*VOT (value of time): in this work, value of the saved travel time.*



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## 1. Introduction

### 1.1. Background

Stockholm region is one of the agglomerations that have the fastest development in the world. This situation implies more inhabitants, more activities and new districts but on the other hand, the rail network did not develop as fast. The last major Metro extension was done in 1985 on the Blue line with the opening of five new stations between Västra skogen and Rinkeby via Sundbybergs centrum. By now, the last Metro extension was only for one stop from Bagarmossen to Skarpnäck in 1994 on the south-eastern branch of the Green line.

All the Metro lines as well as the long distance trains (*Regionaltåg* and *Fjärrtåg*) and the commuter trains meet at the central station which leads to an overcrowding of the trains near this main hub and many transfers at this station. The Tvärbanan light rail line is already connecting Solna to Sickla via the suburbs (Sundbyberg, Alvik, Årsta) but it is quite far from the city centre where most of the activities are located. For the commuter trains, a new tunnel called Citybanan ("the City Line") is being built under the city centre of Stockholm between Tomtebodan and Stockholm Södra station with two new stations: Stockholm City (that replaces Stockholm Central station for the commuter services) and Stockholm Odenplan (that replaces Karlberg station). It will allow an increase of capacity for both regional and long distance railway traffic through Stockholm Central station. But the key node in the whole network will still remain Stockholm Central / T-Centralen station.

Concerning tangential travels, the service was done only by bus or by car. The Essingeleden motorway bypass opened in 1966 for car and truck traffic between Västberga in Southwest of the city and Pampas interchange in Solna via the Essinge islands. But the motorway became soon overcrowded because of the high demand. In order to limit the congestion on the Essingeleden, the new light rail line Tvärbanan opened in 2000 to connect Alvik to Gullmarsplan via Liljeholmen. This was the first attempt to build a public transport line that connects the suburbs together without passing through the city centre. In 2002 the line reached Sickla udde, and in 2013 a new extension has been opened from Alvik to Solna centrum. In mid-2014, the final stop, Solna station, will be open to allow transfers between the Tvärbanan and the commuter train branch towards Märsta, Arlanda airport and Uppsala.

As the Tvärbanan is a light rail line operated with tramway-like vehicles (275 passengers per A35-stock vehicle), the passenger capacity of the line is quite low (6600 passengers per hour in one direction with a 5-minute headway and double A35 units). As a comparison, the new C30 rolling stock for Stockholm's Metro can board 635 passengers per vehicle and offers a capacity of 15240 passengers per hour in one direction with a 5-minute headway and double C30 units.

The blue bus line number 4 is also the most crowded bus line in the SL network with approximately 60000 passengers per working day. It connects Radiohuset in Östermalm to Gullmarsplan via Tekniska högskolan (near Stockholm Östra station), Odenplan, Fridhemsplan, Hornstull, Stockholm Södra station and Skanstull. With the Tvärbanan light rail line, it is one of the only ways of crossing Lake Mälaren with public transport west of the T-Centralen / Slussen corridor. This is one of the reasons for the important passenger load of bus line number 4.

## 1.2. Goals and limitations

### Aim and goals

This thesis is a pre study about the feasibility of building a new North-South Metro line in Stockholm region based on the future development areas and to cope with an increasing public transport demand.

A new high capacity public transport line is needed to connect all the radial lines in the central part of Stockholm so that the number of transfers in the central station decreases. This new link will as a result create a more robust network, densely meshed so the travel alternatives increase. The new connection across Riddarfjärden (part of Lake Mälaren) will allow a decrease in the occupancy rate on board bus line number 4 on Västerbron and Metro red line due to the high number of travels between the northern and the southern banks of Lake Mälaren.

The new public transport line will link the different districts in high development or in high densification so it will increase the economic balance of the infrastructure and the attractiveness of these districts. They will be important nodes in the network in terms of population and workplaces.

This project will focus on the general infrastructure of the line and carry some analysis about capacity and passenger accessibility (passenger loads and travel times). The idea is to extend the Odenplan – Arenastaden planned line to the North and to the South to create a meshed high capacity public transport network in Stockholm region's core.

### Limitations

The construction of a new Metro line in a dense built environment and a very specific geography (water flows, stiff rocks...) like Stockholm is complex. The development of the city depends on political decisions and may vary along the time. Some ongoing transport projects in Stockholm region are not yet budgeted or politically voted so it is difficult to predict the situation of the public transport network at the time of the opening of the new North-South Metro line studied in this report. Changes in the transport network compared to base network used in this report will have an influence on the travel flows in the city so the capacity of the line will have to be readapted.

Moreover, the work done in this project will be a first sight for the evaluation of the feasibility of the new Metro line using a simple transport model with *Matlab* software. More developed and more precise studies will have to be carried out, especially about price evaluation and travel flows in order to get an extensive overview of the line and its effects on the congestion of the other lines. For example, one can say that prices are not fixed in time and may increase depending on the economic situation, but it is not taken into account in this thesis.

The calculations for the travel times will include all the rail stations (commuter train, Metro and light rail) together with the stops of some main bus lines (4, 176, 471...) that have a connection with the rail network as these lines are important links between the different municipalities. Thus this study will only focus on public transport users. As it is impossible to model and

analyse the travel patterns for each passenger in a large area and a large period of time, this report will focus on the morning rush hours from 7:30 to 8:30 during a usual winter weekday. During this period, most of Stockholm region's inhabitants go to work or to the school/university.

Finally, this report is about a public project that would be managed by Stockholm Region. That means that it could be subject to change due to some political decisions.

### 1.3. Approach

This project has two main parts: the infrastructure part (i.e. where the line should go) and the capacity analysis part (i.e. how the travel times and passenger flows will be impacted). Therefore, the study will be carried out in three steps.

First, since it will be needed for the analysis and calculations, data and information will be collected:

- Distribution of population and workplaces in Stockholm region,
- Districts in development and places of interest in the future,
- Existing and planned rail network in Stockholm region (lines, frequencies...).

Then, the study will focus on the different alternatives for the new Metro line, using the CAD (computer-aided design) software *MicroStation V8*:

- Rough definition of the different corridors,
- More precise definition of the stations and their location,
- Analysis of the stations' impact on their environment,
- Evaluation of the costs for each alternative corridor.

Finally, the capacity and the accessibility of the new line will be evaluated (using *Matlab* software):

- Definition of the characteristics of the vehicles and line performances (passenger capacity, maximum speed, travel times between stations),
- Estimation of relation between land use and passenger load with regression calculations,
- Creation and calibration of a network model with data and situation from 2012,
- Creation of the adjacency matrix for the initial situation in 2030 and then for each alternative,
- Analysis of the new passenger flows, travel times and vehicle occupancy.

An additional step will be to compare the cost evaluation for the construction of the suggested line with the travel time saving as well as the operating costs with the benefits from ticket sales and regional subsidies. This will allow the choice between the different alternatives not only with the capacity results as the political decisions will be made mostly with the costs.

## 2. Public transport situation in Stockholm region

### 2.1. Existing rail network

#### Rail network structure

The public transport system in Stockholm County is supervised by *Storstockholms Lokaltrafik (SL, Greater Stockholm Public Transport, part of the Stockholm County Council SLL – Stockholms läns landsting)* and operated by different private companies such as MTR, Arriva and Keolis. The global network is quite diversified in terms of transport means. It consists of a commuter train network called *Pendeltåg*, a Metro network called *Tunnelbana* (shorten *T-bana* or just *T*), five light rail lines called *Lokalbana* (*Roslagsbanan, Saltsjöbanan, Lidingöbanan, Tvärbanan* and *Nockebybanan*) and one tram line called *Spårväg City*. A commuter boat line (*Sjövägen*) as well as several bus lines complete the rail network for local services.

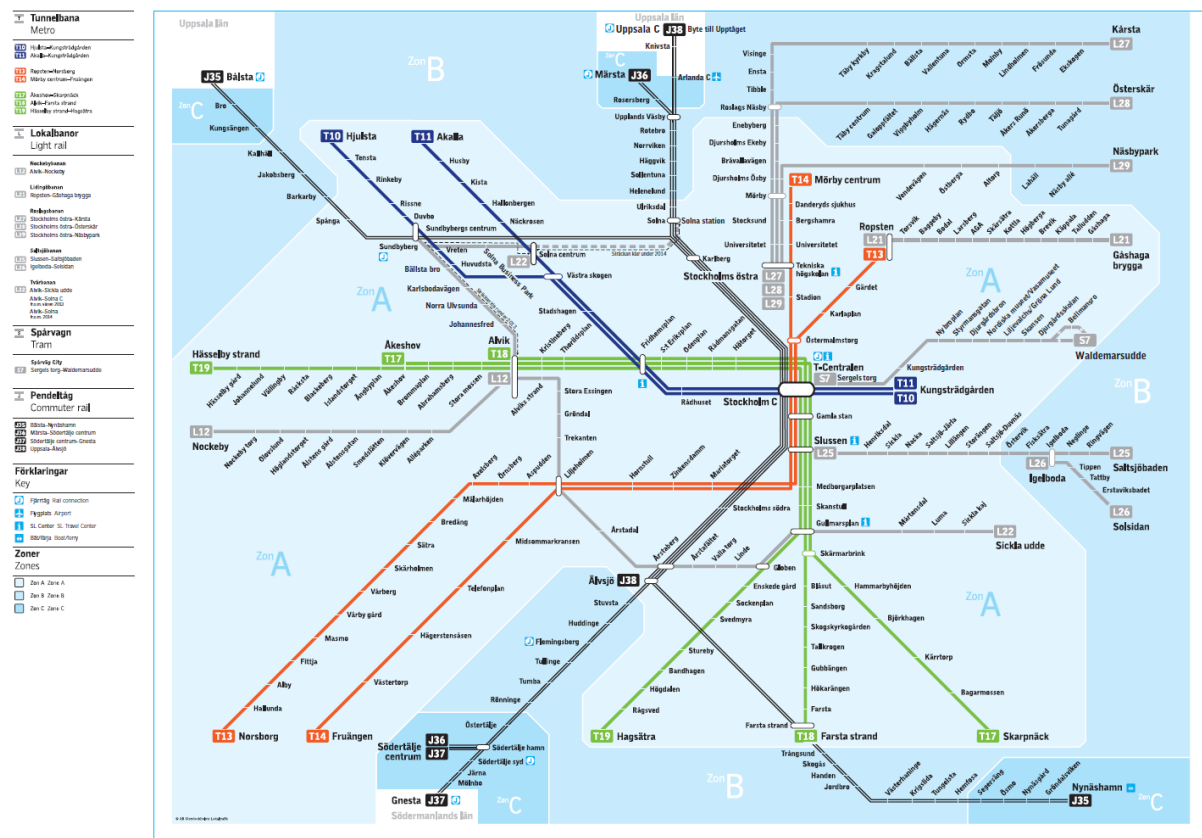


Figure 1: Map of the SL's railway network in 2014. Source: SL.

The commuter train links Stockholm Central station to the suburbs (Sollentuna, Järfälla, Huddinge) and remote cities (Sigtuna, Södertälje, Nynäshamn) in the North and the South of the county. Since December 2012, it consists of four lines:

- Line J35 from Bålsta (in Uppsala County) to Nynäshamn via Kungsängen, Stockholm Central and Västerhaninge,
- Line J36 from Märsta to Södertälje centrum via Stockholm Central,
- Line J37 from Södertälje centrum to Gnesta (in Södermanland County),

- Line J38 from Uppsala to Älvsjö via Arlanda airport and Stockholm Central.

The Metro network connects each district of Stockholm and the closest suburban towns (Sundbyberg, Solna). Nowadays it consists of seven lines forming three “main” lines called blue, red and green lines:

- Blue line from Kungsträdgården to Hjulsta (line T10) and Akalla (line T11),
- Red line with lines T13 (Norsborg – Ropsten) and T14 (Fruängen – Mörby centrum),
- Green line from Hässelby strand to Skarpnäck (line T17), Farsta strand (line T18) and Hagsätra (line T19).

The Roslagbanan network connects Stockholm Östra station to the north-eastern suburbs like Täby, Österåker and Vallentuna. It consists of three lines:

- Line L27 from Stockholm Östra to Kårsta via Roslags Näsby and Vallentuna,
- Line L28 from Stockholm Östra to Österskär via Roslags Näsby and Åkersberga,
- Line L29 from Stockholm Östra to Näsbypark via Djurholms Ösby.

The Saltsjöbanan network connects Stockholm to the municipality of Nacka in the South-east. It consists of two lines:

- Line L25 from Slussen to Saltsjöbaden via Nacka and Igelboda,
- Line L26 from Igelboda to Solsidan (shuttle line, in connection with line L25 at Igelboda).

The Lidingöbanan connects Stockholm to the municipality of Lidingö in the North-east. It consists of one line (L21) running from Ropsten to Gåshaga brygga at the eastern part of Lidingö Island.

The Tvärbanan (Swedish for “crossways line”) connects the western and the southern suburbs directly without passing through the centre of Stockholm. The light rail line L22 runs from Solna centrum to Sickla udde via Sundbyberg, Alvik, Liljeholmen and Gullmarsplan. During 2014, the line will be extended from Solna centrum to Solna station.

The Nockebybanan (line L12) runs in Stockholm (Bromma district) and connects Nockeby to Alvik.

The Spårväg City tram line connects T-Centralen station to Djurgården Island. It consists of one line (S7) running from Sergels torg to Waldemarsudde on Djurgården.

### **Boat and bus lines**

In addition to the rail network, there is a commuter boat line and several buses to reach all the remote sectors to the rail network and the main activity zones in Stockholm region.

The commuter boat line Sjövägen connects different municipalities to the centre of Stockholm. It consists of one line (80) running from Nybroplan to Frihamnen in Stockholm, via Nacka and Lidingö municipalities.

In the SL network, there are approximately 500 bus lines divided in two different types: the blue buses (*Blåbussar* or *Stombussar*) and the classic red buses.

The blue bus network is mainly a complement to the rail network as it connects the different commuter trains and Metro lines together with the municipalities not served with the rail network (Ekerö, Norrtälje, Tyresö, Vaxholm, Värmdö...). There are 18 blue bus lines: 4 high frequency trunk lines in Stockholm inner city (bus lines 1 to 4) and 14 high frequency express lines in the suburbs.

The red bus network is the classic bus network covering the entire Stockholm County. Some lines running in dense areas (line 160 between Årstaberget and Gullmarsplan for instance) have a high frequency while some other lines run less than 5 services a day.

### Summary of the existing rail network

The table below recaps the main characteristics of each rail network, as of 2014.

Type	Name	Line	Stretch	Length (km)	Stations
Commuter train	Pendeltåg	J35	Bålsta - Nynäshamn	109	28
		J36	Märsta - Södertälje centrum	75	24
		J37	Södertälje centrum - Gnesta	31	6
		J38	Uppsala C - Älvsjö	74	16
		<b>Total</b>		<b>241</b>	<b>53</b>
Metro	Tunnelbana	T10 (blue)	Kungsträdgården - Hjulsta	15	14
		T11 (blue)	Kungsträdgården - Akalla	16	12
		T13 (red)	Norsborg - Ropsten	27	25
		T14 (red)	Fruängen - Mörby centrum	19	19
		T17 (green)	Åkeshov - Skarpnäck	20	24
		T18 (green)	Alvik - Farsta strand	18	23
		T19 (green)	Hässelby strand - Hagsätra	29	35
		<b>Total</b>		<b>108</b>	<b>100</b>
Light rail	Roslagsbanan	L27	Stockholm Östra - Kårsta	42	18
		L28	Stockholm Östra - Österskär	29	18
		L29	Stockholm Östra - Näsbypark	11	11
		<b>Total</b>		<b>65</b>	<b>38</b>
	Saltsjöbanan	L25	Slussen - Saltsjöbaden	16	14
		L26	Igelboda - Solsidan	3	5
		<b>Total</b>		<b>19</b>	<b>18</b>
	Lidingöbanan	L21	Ropsten - Gåshaga brygga	9	14
	Tvärbanan	L22	Sickla udde - Solna station	17	25
	Nockebybanan	L12	Alvik - Nockeby	6	10
Tramway	Spårväg City	S7	Sergels torg - Waldemarsudde	3	11
		<b>Total rail</b>		<b>468</b>	<b>269</b>

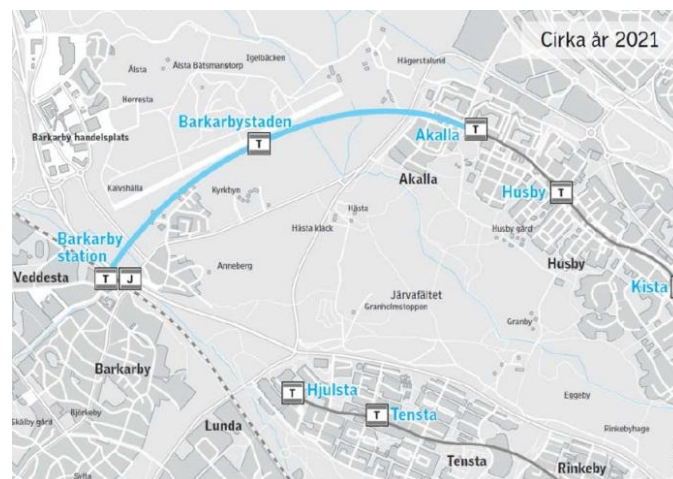
Table 1: Characteristics of SL's railway network. Source: SL.

## 2.2. Plans from Stockholm County Council

On November 11<sup>th</sup> 2013, Stockholm County Council (SLL) has come to an agreement with the Swedish State and four municipalities (Järfälla, Nacka, Solna and Stockholm) to build new extensions of the Metro system by the year 2025 [1]. The predicted cost of this Metro development is approximately SEK 19,5 billion (ca. € 2,2 billion). Three extensions of the blue line as well as the creation of a totally new Metro line are planned.

### Extension to the Northwest

A 2,4-kilometre extension of the blue line from Akalla to Barkarby station in Järfälla municipality will connect Kista business district with the Lake Mälaren railway line (*Mälardbanan*). The new Barkarby – Stockholm Väst station will offer connections with the regional trains from and towards Västerås and the commuter trains running between Stockholm and Kungsängen/Bålsta. There will be one intermediate station, Barkarbystaden, a planned district with approximately 10000 inhabitants and 10000 workplaces at the end of construction.

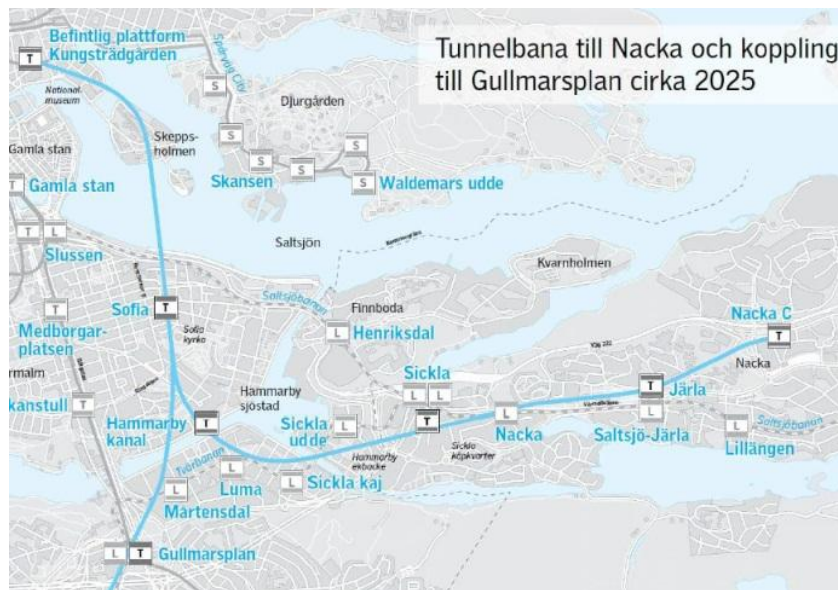


**Figure 2: Proposal for the extension to Barkarby station.** Source: *Stockholmsförhandling*.

### Extensions to the Southwest

A 7,6-kilometre extension of the blue line from Kungsträdgården to Nacka centrum will connect the south-eastern suburbs (Sickla, Nacka) directly to the centre of Stockholm without changing in Slussen. In the current situation, all the traffic from Nacka and Värmdö is done by the Saltsjöbanan and several buses ending in Slussen where the passengers have to change to the Metro. This extension is also intended for the covering the fast development of Nacka in the coming decades (the municipality has 92873 inhabitants as of 2012).

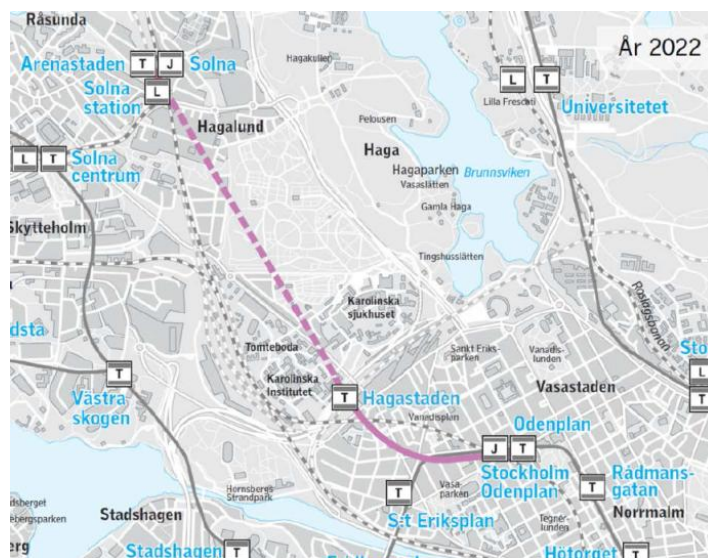
Another extension will be built from Kungsträdgården to Gullmarsplan where the blue line will take over the Hagsätra branch from the green line. This will allow higher frequencies on all the Metro branches in the southern suburbs (Hagsätra, Farsta and Skarpnäck) since the green line would only have two branches (Farsta and Skarpnäck) instead of three.



**Figure 3: Proposal for the extensions to Nacka and Gullmarsplan.** Source: Stockholmsförhandling.

### A new line to Solna

The creation of the new Metro line from Odenplan to Arenastaden (near Solna station and the Friends Arena) with an intermediate station will serve Hagastaden, a new developing high density district (13000 inhabitants and 36000 workplaces are planned) near the new Karolinska Institute.



**Figure 4: Proposal for the new Metro line Odenplan – Arenastaden.** Source: Stockholmsförhandling.

In Stockholmsförhandling report [2], the new line from Odenplan to Arenastaden is shown as north-western branch of the green line. Direct trains from the southern branches of the green line will go directly to Arenastaden during off-peak hours. The line will be autonomous during the rush hours to not interfere with the regularity of the green line and to not constrain the capacity on the Hässelby branch. To prevent the passenger traffic increase in the coming decades, it is interesting to see how the station of the new Metro line can be set so the green line and the new line are totally independent.



### 2.3. Other public transport development proposals

#### Original proposal from SLL for Hagastaden

A proposal for new North-South Metro line between Odenplan and Arninge (in Täby municipality) had been presented on June 5<sup>th</sup> 2013 by SLL [3].



**Figure 6: Proposal from SLL for a line from Odenplan to Arninge.** Source: SLL Trafikförvaltningen.

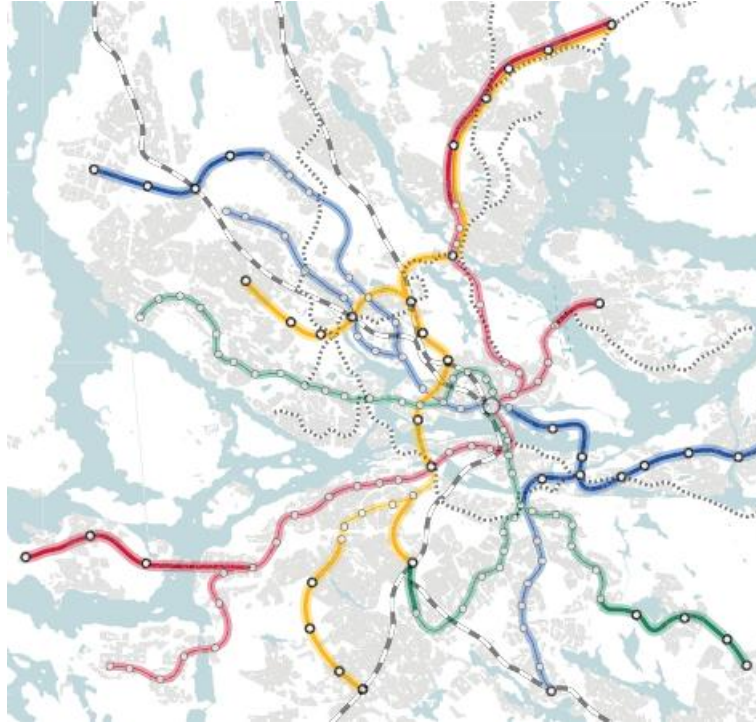
The main idea of this study is to improve the access to Stockholm city centre from the new Hagastaden district and the municipalities northwest of Stockholm (Danderyd and Täby). The study gives two different solutions for the connection in Odenplan: either the new line is a branch of the green line and uses the existing Odenplan station on the green line or the new line is totally independent and a new station is built in Odenplan.

The first solution is cheaper since no extra station is needed in Odenplan but it decreases the capacity both towards Arninge and Hässelby. The second solution does not decrease the capacity between Hässelby and Odenplan on the green line and allows an extension of the new line southwards.

A question can be asked about the utility of building a new high frequency Metro line in the same stretch as the Roslagsbanan train (between Roslags Näsby and Arninge) while the Roslagsbanan is being upgraded with double track sections and new trains. However, the high capacity link between Danderyds sjukhus and Solna station, which is missing in 2014, is a good idea that will be used for the new North-South Metro line.

## The “Stockholm 2070” proposal

On June 26<sup>th</sup> 2013, the consultant company Sweco, the current Stockholm Metro operator MTR and the construction company Skanska co-signed a study about how Stockholm will look like in 2070 from a land-use and public transport point of view [4].



**Figure 7: Proposal from the “Stockholm 2070” study.** Source: Sweco/MTR/Skanska.

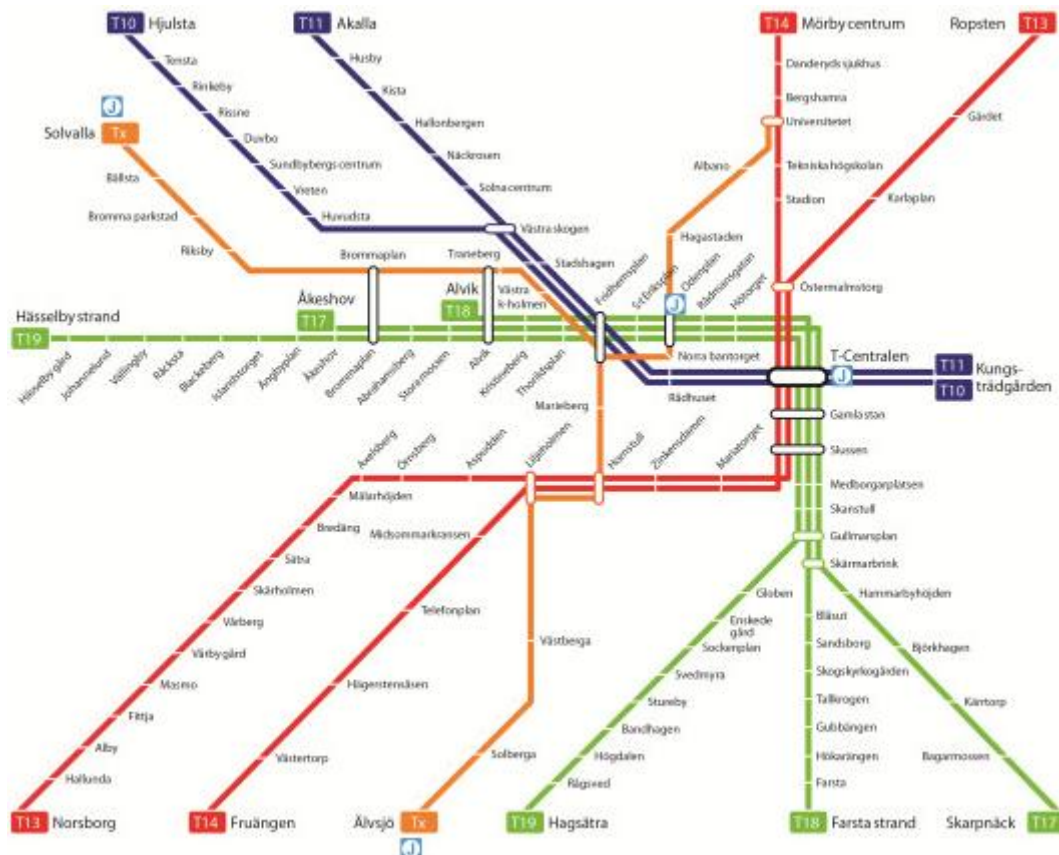
The idea of this study is to prevent Stockholm from traffic congestion in the 60 years to come by forecasting how the public transport network and the land-use should develop for each decade from now.

The main innovation is the “yellow line” that gives a new connection between the northern and the southern suburbs that confirms the importance of building a new North-South high capacity link in Stockholm region.

Building the entire proposed network is a long term process so one has to give a priority among the different extensions. The extensions that are presented in Figure 7 differ a little bit from the SLL proposal (see chapter 2.2) but are more likely to be built in the coming two decades.

## The “orange linjen” proposal

On March 26<sup>th</sup> 2013, the Swedish political party *Miljöpartiet de Gröna* presented the Orange Line project (“orange linjen” in Swedish), a new Metro line for Stockholm region [5].



**Figure 8: Proposal from the Miljöpartiet political party.** Source: Miljöpartiet de Gröna.

According to Miljöpartiet, this new Metro line is intended to offer 300000 extra seats per day (compared to current situation) and decrease travel times by 10 minutes in average between the northern and the southern parts of Stockholm. The total project from Älvsjö to Universitetet and Solvalla would cost approximately 30 billion SEK for 20 kilometres of double track.

The Orange Line fits to SLL agreement for the Odenplan – Arenastaden section. The construction would be divided into three steps:

- First step: Hagastaden – Liljeholmen to solve the main problems (Hagastaden and flows across Lake Mälaren).
- Second step: Universitetet – Hagastaden and Liljeholmen – Älvsjö to have a comprehensive North-South link.
- Third step: Marieberg – Solvalla to go along with the rehabilitation of Bromma airport area.

## The “lila linjen” proposal

In February 2013, the Swedish political party *Socialdemokraterna* presented the Lila Line project (“lila linjen” in Swedish), a new Metro line for Stockholm region [6].



**Figure 9: Proposal from the Socialdemokraterna political party.** Source: Socialdemokraterna.

The aim of this Metro line is to avoid transfers in T-Centralen / Stockholm Central station. The Socialdemokraterna project is similar to the project developed in this report since it links Danderyds sjukhus in the North to Hagsätra in the South. However, the Lila Line has fewer stops and does not fit to SLL agreement for the Odenplan – Arenastaden section.

Compared to the Stockholm 2070 project, this is a medium term project with lower construction cost. The Lila Line would be 17 kilometres long and cost 17 billion SEK according to the Socialdemokraterna.

### **3. Definition of the alternative corridors**

The new North-South Metro line is intended to create new travel possibilities to the western parts of Stockholm, the planned districts of Solna municipality (Arenastaden, Hagastaden) and Stockholm. Therefore an identification of the main places of interest north of Arenastaden and south of Odenplan is needed as the new line consists of two extensions of the planned Odenplan – Arenastaden line. This analysis will be done using the population statistics for years 2012 and 2030 in Stockholm region [7, 8] and the current plans for urban development in Stockholm Municipality [9].

#### **3.1. Identification of the places of interest**

##### **Places of interest in northern suburbs (Danderyd and Solna)**

The north-eastern municipalities are connected to Stockholm only by express buses and by the Roslagsbanan light rail line, ending in Stockholm Östra station. The end station is located besides Tekniska högskolan station on the red line of the Metro and leads therefore to an overcrowding of the section between Tekniska högskolan and Östermalmstorg where many workplaces are located and where the red line splits in two branches (Ropsten and Mörby centrum).

In 2012, according to SL [10], there were 6400 passengers getting off the Roslagsbanan at Stockholm Östra station during the morning peak hours between 6:00 and 9:00 (out of 13200 passengers alighting at Stockholm Östra during one typical winter weekday). At the same time, 3900 passengers go aboard the Metro and 2300 passengers take the bus in Tekniska högskolan.

For the new North-South Metro line, a station near Danderyds sjukhus Metro station and Mörby station on Roslagsbanan could split the passengers' flows before the Stockholm Östra end station: passengers going to the West of Stockholm will use the new line towards Kungsholmen and passengers going to the centre-East (Östermalm, Slussen) will continue to change in Stockholm Östra station.

Moreover, the Danderyd's hospital (Danderyds sjukhus) has approximately 3500 employees and there is a large bus station for all the buses coming from the municipalities in the Northeast (Täby, Vallentuna, Österskär). 6900 passengers get off the buses at this stop between 6:00 and 9:00 in a normal weekday morning, 5500 passengers take the Metro there during the same period.

Bergshamra is an isolated district of Solna municipality because of the geography. It has a radial connection to the centre of Stockholm thanks to the Metro's red line. However, for any connection to the West, people have to use blue bus lines 176 and 177 towards Solna centrum, Sundbyberg and Ekerö. Even though they are frequent (one bus every 10 minutes), the buses are often stopped in the congested E18 motorway as well as in Solna and Sundbyberg during the morning and evening peak hours. That is why a faster and more reliable link is needed from Bergshamra westwards.

Järva krog is located at the junction between motorways E4 (Stockholm – Arlanda airport – Uppsala) and E18 (Västerås – Kista – Norrtälje). Several bus lines use these motorways to reach the cities in the North of the region and to connect the closer suburbs to Kista business and science district. Moreover, a new area called Nya Ulriksdal will be built near Järva krog with 1500 dwellings. An idea could be to have a transfer in Järva krog between the new North-South Metro line and express buses towards Kista or use the Metro station to limit the buses that usually continue to Stockholm city centre and are dependent on the car traffic during the peak hours.

The new urban area Arenastaden takes its name from the Friends and Tele 2 arenas located near Solna commuter train station. These arenas are the first part of the development of the area that should gather in the long run approximately 3000 dwellings and 15000 workplaces. In 2014, Solna station will also be an important node in the rail network for the northern suburbs since the Tvärbanan orbital light rail will be extended from Solna centrum to Solna station, allowing direct travels between the two northwards branches of the commuter rail (connections at Sundbyberg and Solna stations).

Finally, in the Haga district (Solna municipality), the Karolinska University Hospital (*Karolinska universitetssjukhuset*) and the Karolinska Institute are merging to create the New Karolinska (*Nya Karolinska*) medical and health centre. The new hospital will be integrated in a new residential and business area called Hagastaden that is being built simultaneously to create a major urban area at the administrative limit between Solna and Stockholm. Hagastaden will have at the end 13000 inhabitants and 36000 workplaces.

Place of interest	Connecting transit lines	Population (2012)	Workplaces (2012)	Development projects
Mörby station	Roslagsbanan	1460 inhabitants	N/A	-
Danderyds sjukhus	Metro red line Buses	1049 inhab. in DS + 5711 in Stocksund	ca 3500 in Danderyd's hospital	-
Bergshamra	Metro red line	8185 inhabitants	N/A	-
Järva krog	Buses	12596 inhab. in Järva	N/A	Nya Ulriksdal: 1500 dwellings
Arenastaden - Solna station	Commuter train Tvärbanan (2014) Buses	8690 inhabitants in Hagalund + 17299 in Råsunda	N/A	Arenastaden: 3000 dwellings and 15000 workplaces
Karolinska univ-sjh - Karolinska institutet	Buses	1232 inhabitants in Haga	ca 9000 in KUS and ca 4200 in KI	Hagastaden: 5000 dwell. and 36000 workplaces

**Table 2: Places of interest in the northern suburbs.** Sources: SLL-TMR, Solna stad.

In the following figures (figures 10 to 12), the red squares (■) represent the developing areas (with the corresponding number of planned dwellings and workplaces) and the purple circles (○) represent the main transfer nodes in the public transport network. The proposed Metro line is drawn with orange lines (—). The different letters in boxes represent the connecting transport lines: **T** for Metro lines, **J** for commuter train lines and **L** for light rail lines.

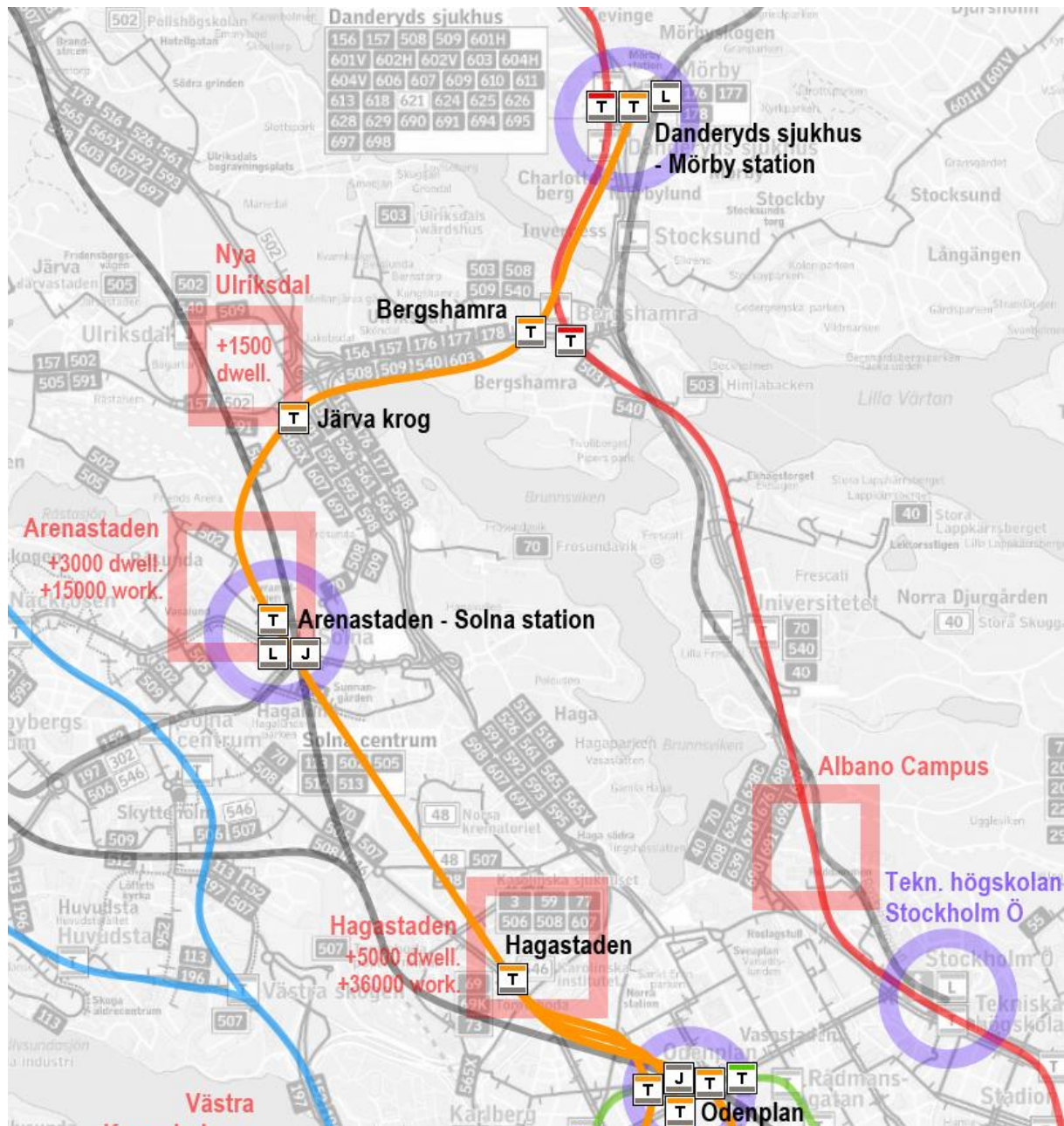


Figure 10: Own proposal for the northern suburbs. Background and logos: SL.

### Places of interest in the city centre of Stockholm (“innerstaden”)

The city centre of Stockholm gathers the highest rate of workplaces in the whole Stockholm County. Most of the biggest companies are located in the so called “City” area, i.e. between the Stockholm Central station and Östermalm. As an example, Klara and Jakob districts had 86738 workplaces in 2012, which represents 14% of the workplaces in the whole Stockholm municipality.

Since Kungsholmen Island, located west of “City” area, had 56432 inhabitants and 58668 workplaces in 2012, the island is an attractive zone in Stockholm but it suffers from a lack of connections to the North and the South of the region. Even though the island has two Metro lines reaching the Northwest (Bromma, Vällingby, Sundbyberg and Kista) and the Southeast (T-

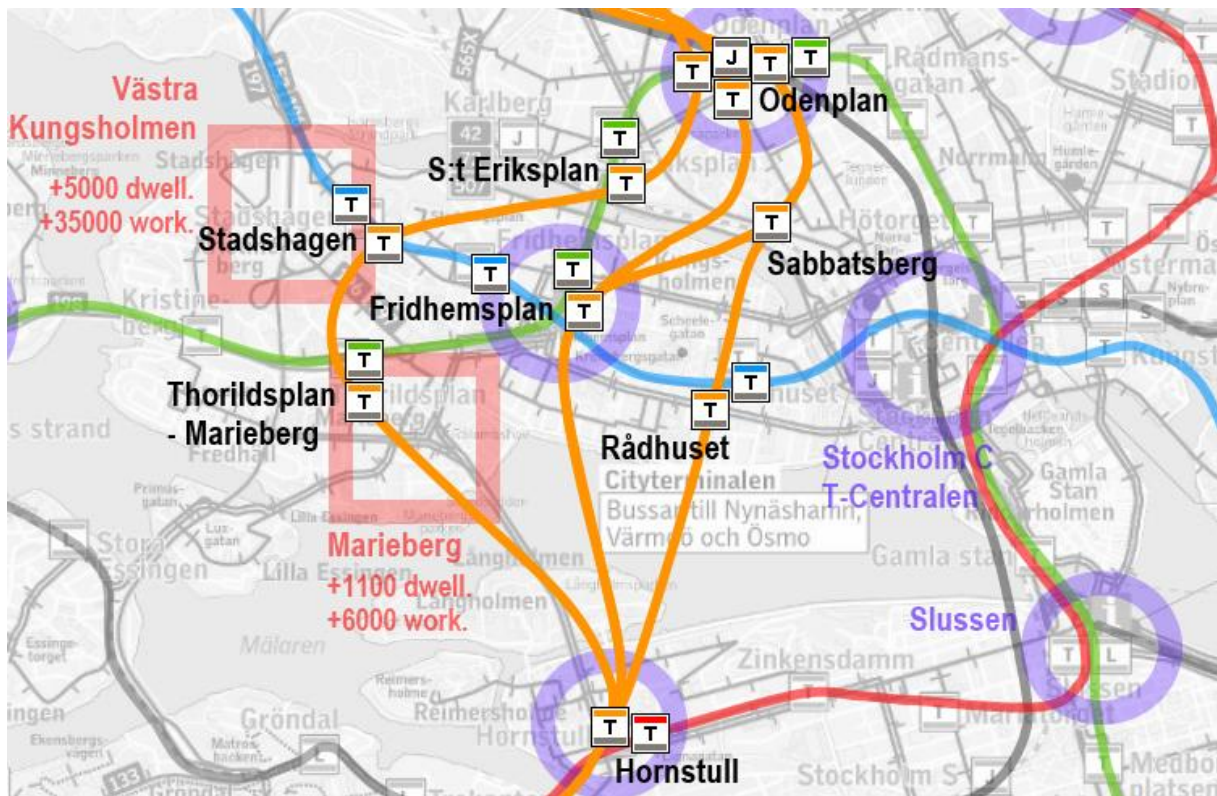
Centralen and Nacka in the future), connections to the Northeast (cities in the Roslagen area) and to the Southwest (Liljeholmen and West of Södermalm) depend only on the bus line number 4 with its low regularity between Stockholm Östra station and Hornstull because of the mixed traffic with cars. There is a need for a more reliable connection to these sectors from Kungsholmen Island.

In Norrmalm, Odenplan will be a large transfer node in SL network in 2017 when the Citybanan tunnel will be open for commuter trains with the Stockholm Odenplan station. The aim of the new Metro line is to offer fast connections for passengers coming from the Bålsta (commuter train) or Hässelby (Metro green line) and going to the Hagastaden complex.

Södermalm Island (excluding Gamla stan and Södra Hammarbyhamnen) is a district with 104710 inhabitants and 67601 workplaces as of 2012. Some important places are Slussen, Södersjukhuset (South hospital), Hornstull and Skanstull shopping centres. From Hornstull, Slussen is accessible with the red line of the Metro, the hospital and Skanstull can be reached with the blue bus line number 4. So Hornstull is a good access point to the rest of Södermalm Island.

Place of interest	Connecting transit lines	Population (2012)	Workplaces (2012)	Development projects
Odenplan	Commuter train (2017) Metro green line Buses	14733 inhab. in Gustav Vasa (GV) + 13251 in Östra Matteus	11417 in Gustav Vasa (GV) + 6590 in Östra Matteus	-
S:t Eriksplan	Metro green line Buses	GV + 15217 inhab. in Västra Matteus	GV + 10930 in Västra Matteus	-
Sabbatsberg	Buses	GV + 4108 inhab. in Södra Adolf Fredrik	GV + 12858 in Södra Adolf Fredrik	-
Fridhemsplan	Metro green line Metro blue line Buses	14746 inhabitants in Östra S:t Görän	10536 in Östra S:t Görän	-
Rådhuset	Metro blue line Buses	19585 inhabitants in Kungsholm	20636 in Kungsholm	-
Stadshagen	Metro blue line Buses	7180 inhabitants in Stadshagen	18707 in Stadshagen	Västra Kungsholmen: 5000 dwell. and 35000 workpl.
Thorildsplan	Metro green line Buses	3159 inhabitants in Marieberg	6171 in Marieberg	Marieberg: 1100 dwellings and 30000m <sup>2</sup> workplaces
Hornstull (on Södermalm)	Metro red line Buses	13647 inhabitants in Norra Högalid	4455 in Norra Högalid	Nya Hornstull: shopping centre

**Table 3: Places of interest in Stockholm city centre.** Sources: Statistik om Stockholm, Stockholms stad.



**Figure 11: Own proposal for Stockholm city centre.** Background and logos: SL.

### Places of interest in southern suburbs (“söderort”)

The southern districts of Stockholm (i.e. those south of Södermalm Island) have a large proportion of dwellings. The main activities are located in Liljeholmen district (together with Årstadal district) where there are already some workplaces (by Årstaviken) and where 7000 additional workplaces as well as 4000 extra dwellings will be built. Liljeholmen is already an important node in the public transport network with the red line of the Metro, the Tvärbanan orbital light train and several bus lines connecting all the south-western suburbs down to Södertälje municipality.

Västberga gathers the Årsta container terminal and an important logistics centre with DHL and others carriers but since it is only a large industrial area, it is not relevant to create a station at this location, the existing bus services are sufficient. Moreover, the dwellings in Västberga (5276 inhabitants in 2012) are also close to Telefonplan station (ca 1 km). Solberga is a residential area (8432 inhabitants) but with only 500 dwellings planned in the coming years, it has also frequent connections to Telefonplan and Älvsjö stations thanks to bus number 142.

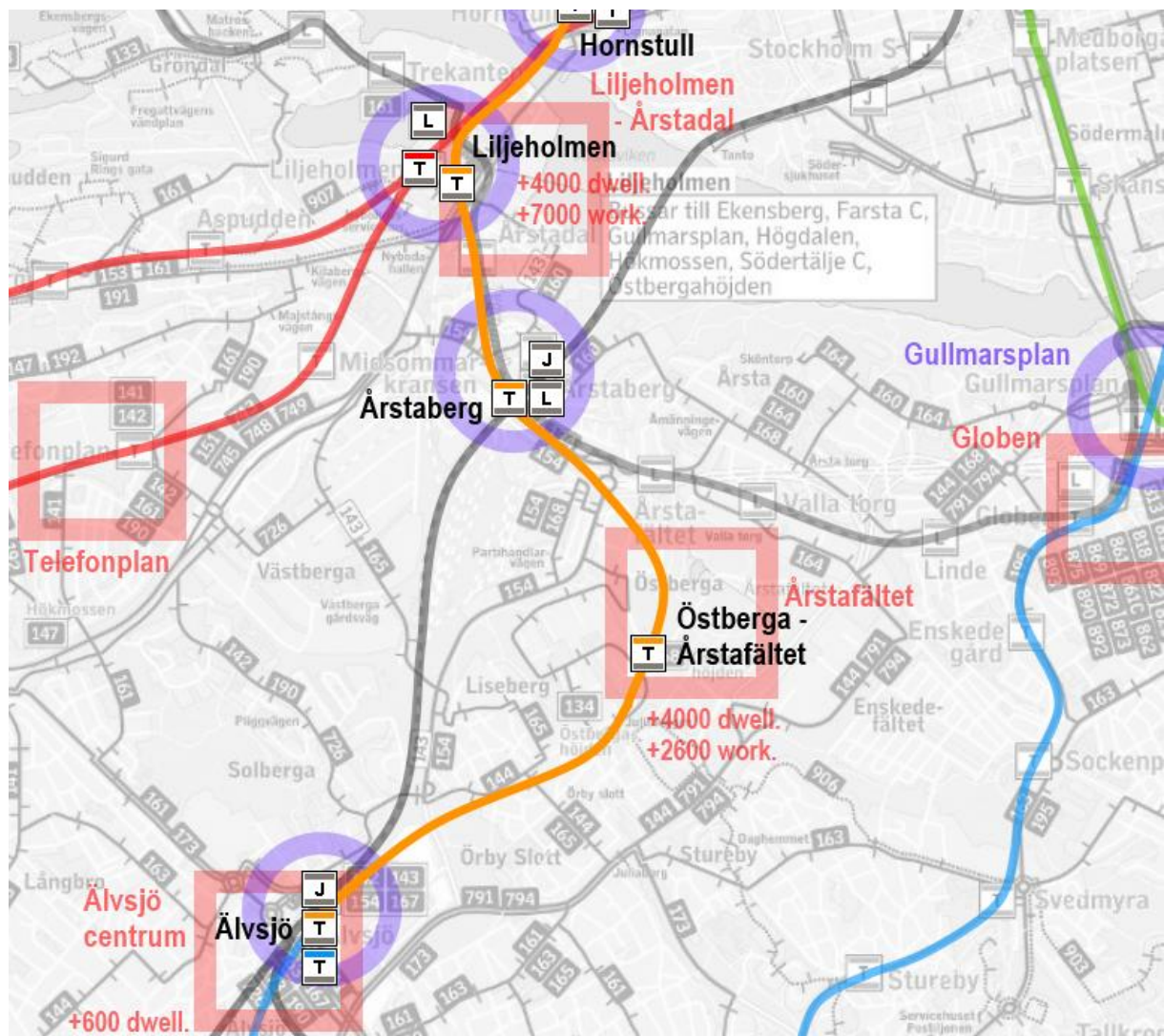
Årstafältet is a field that will be used to develop and strengthen the Östberga urban area. Additional 4000 dwellings and 2600 workplaces are planned in the Årstafältet/Österberga area. Östberga had 5624 inhabitants in 2012 but the area is only connected to Liljeholmen and Gullmarsplan stations by bus (20-minute journeys from Östberga to these stations). A connection to Älvsjö can be interesting to connect the area to the South.

The Stockholm international fairs and congress centre (*Stockholmsmässan*) is located just besides Älvsjö station. Opposite the tracks, 600 extra dwellings are being built in Älvsjö centrum

simultaneously with the renovation of the commuter train and bus station. In the future, an extension of the Hagsätra metro line could be done up to Älvsjö to allow faster travels from Högdalen, Rågsved and Hagsätra districts to the commuter train.

Place of interest	Connecting transit lines	Population (2012)	Workplaces (2012)	Development projects
Liljeholmen	Metro red line Tvärbanan Buses	10809 inhabitants in Liljeholmen	14821 in Liljeholmen	Liljeholmen-Årstadal: + 4000 dwellings and + 7000 workplaces
Årstaberg	Commuter train Tvärbanan Buses	17656 inhabitants in Årsta (access with frequent bus 160)	3426 in Årsta	-
Östberga-Årstafältet	Buses	5624 inhabitants in Östberga	2356 in Östberga	Årstafältet: 4000 dwellings and 2600 workplaces
Älvsjö	Commuter train Buses	1049 inhab. in Älvsjö + 8432 in Solberga	2284 in Älvsjö + 2809 in Solberga	Älvsjö centrum: 600 new dwellings

**Table 4: Places of interest in the southern suburbs.** Sources: Statistik om Stockholm, Stockholms stad.



**Figure 12: Own proposal for the southern suburbs.** Background and logos: SL.

### **First sketch of the line with the four alternatives**

To sum up, the main places of interest in a North-South corridor are:

- Danderyds sjukhus / Mörby station for the transfer with buses and Roslagsbanan,
- Odenplan, Fridhemsplan, Liljeholmen and Älvsjö for their importance as large transfer nodes in the public transport network in Stockholm region,
- Arenastaden, Hagastaden, Marieberg and Årstafältet for the development and the densification of these areas in both terms of population and workplaces.

After the identification of the important zones, the stations can be chosen and the stretches can be drawn (see figure 13 below). The colour of the stations indicates the transfer possibilities.

For the infrastructure study, the line will be separated into three different sections since the northern and the southern sections are common to all the alternatives:

- Danderyds sjukhus to Hagastaden,
- Hagastaden to Hornstull with four different corridors,
- Hornstull to Älvsjö.

The four alternatives between Hagastaden and Hornstull are:

- A1: Hagastaden – Odenplan – S:t Eriksplan – Stadshagen – Thorildsplan-Marieberg – Hornstull
- A2: Hagastaden – Odenplan – Fridhemsplan – Hornstull
- A3: Hagastaden – Odenplan – Sabbatsberg – Fridhemsplan – Hornstull
- A4: Hagastaden – Odenplan – Sabbatsberg – Rådhuset – Hornstull

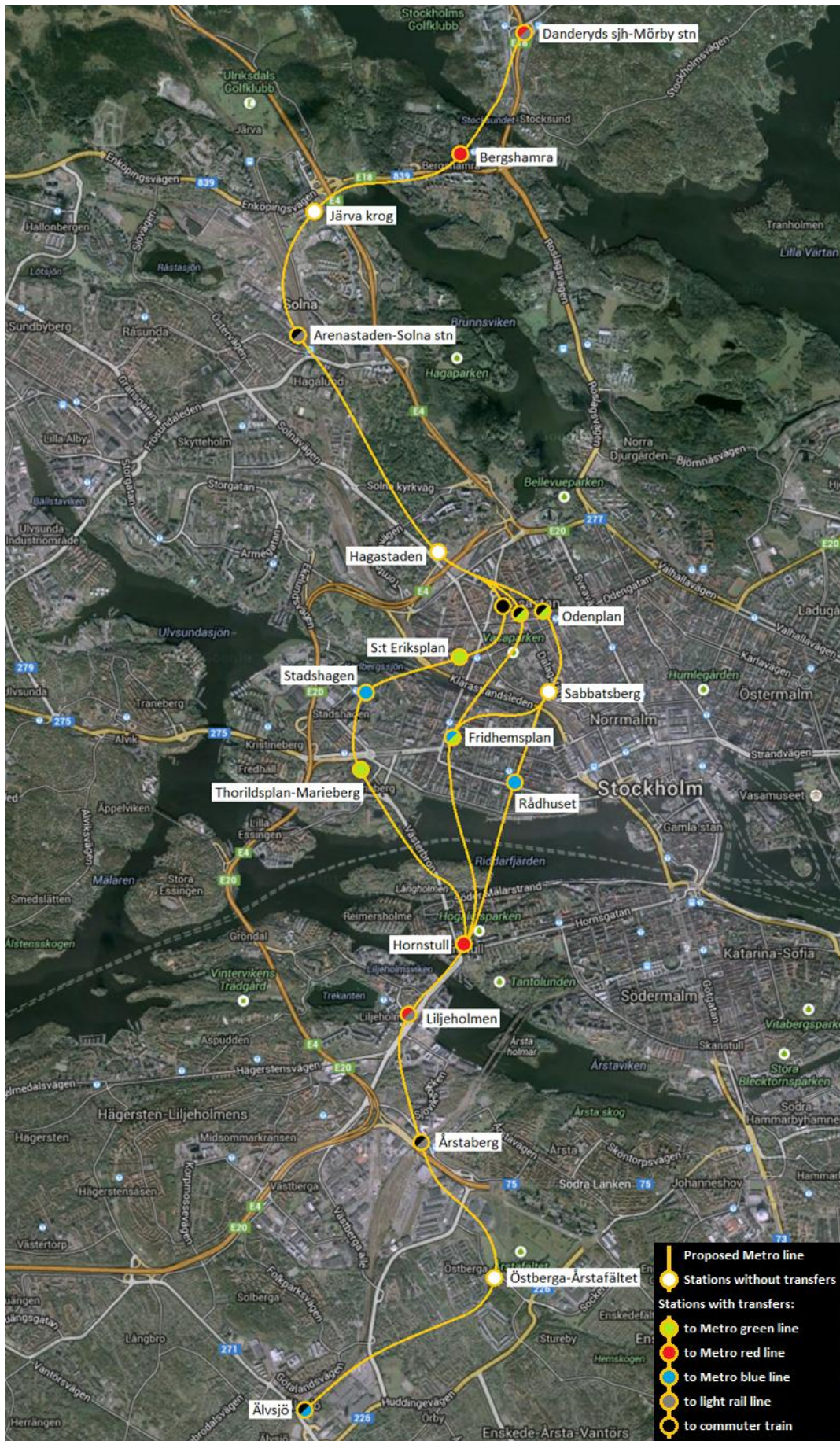


Figure 13: Sketch of the line with the four alternatives. Background: Google Maps.

## 3.2. Characteristics of the suggested Metro line

### Structural works

Since the new Metro line will be mainly **underground** due to the high density of buildings at the ground level, one has to pay attention to the depth of the other Metro and commuter train lines, depth of building foundations, water flows, geography and composition of the ground (soil, rock).

For the **train depot**, there are two alternatives depending on if an existing depot is used or if a totally new depot is needed for the new line.

If there is no planned depot on the new line, the first step in the construction is to have a connection to the existing Metro network. Since having a connection tunnel in the inner city is complicated, a connection with the red line could be made near Danderyds sjukhus or Liljeholmen. The advantage of a connection in Liljeholmen is the proximity to the existing train depot beyond Liljeholmen station. Moreover, as a train depot is being built in Norsborg for the red line's vehicles, Liljeholmen depot could be used for the garage and maintenance of the new line's rolling stock. The new line could be opened first between Danderyds sjukhus and Odenplan or between Arenastaden and Årstaberget depending on the most cost efficient solution.

### Tracks and rolling stock

The track gauge on the new Metro line will be the **standard gauge** (1435 mm) in order to run the service with the same vehicles (C30 rolling stock) as on the three other Metro lines. The **homogeneous rolling stock** reduces the maintenance costs and facilitates the vehicle exchanges in case of shortage in the number of ready-for-service vehicles. The number of vehicles needed for exploiting the rush hours' service on the new Metro line will be determined later in this report.

For drawing the line, one also has to respect some restrictions concerning the **track geometry**. The maximum gradient is 40‰ outside stations and 10‰ at stations. For speed limit 90 km/h, in the horizontal plane, the minimal curve radius is about 500 metres. For 90 km/h, in the vertical plane, the optimal convex and concave radii are 3000 metres.

### Stations

In SL network, all the existing Metro stations but one (Johannelund) have one or several **island platforms**, i.e. the tracks are around one central platform. This configuration allows direct transfers from one branch to another on the same line (e.g. Östermalmstorg), platform-to-platform transfers from one line to another (e.g. Gamla stan) or it allows to choose the first train that comes from one branch when going to the trunk (e.g. Västra skogen). The island platforms are also more efficient than the side platforms since only one staircase, one set of escalators and one lift are needed to reach both Metro directions from the ticket sales hall. The passengers don't have to choose their direction before being on the platform. If they are waiting on the

wrong platform side, they just have to cross the platform to take the train in the other direction (no need to go up and down).

Whenever it is possible, the stations of the new line will have an island platform with a minimal length of 140 metres (equivalent to two C30 units) and a minimal width of 6 metres. As most of the existing stations have two entrances or more to spread the accessibility to the Metro system by reducing the **egress time**, the new line will also use this method to enlarge the **catchment area** of the Metro stations [11].

### 3.3. Northern section (Danderyds sjukhus – Hagastaden)

The final stop of the new line will be located between **Danderyds sjukhus** station and **Mörby station** so passengers can easily transfer to the red line and the buses at the West entrance and to the Roslagsbanan at the East entrance. Like Danderyds sjukhus station on the red line, the station can be built using the cut-and-cover method since the environment only consists of one large bus station and “Danderyds sjukhus” motorway interchange. If it implies too much disturbances for the car traffic on the E18 motorway, a blasted station can however be built.

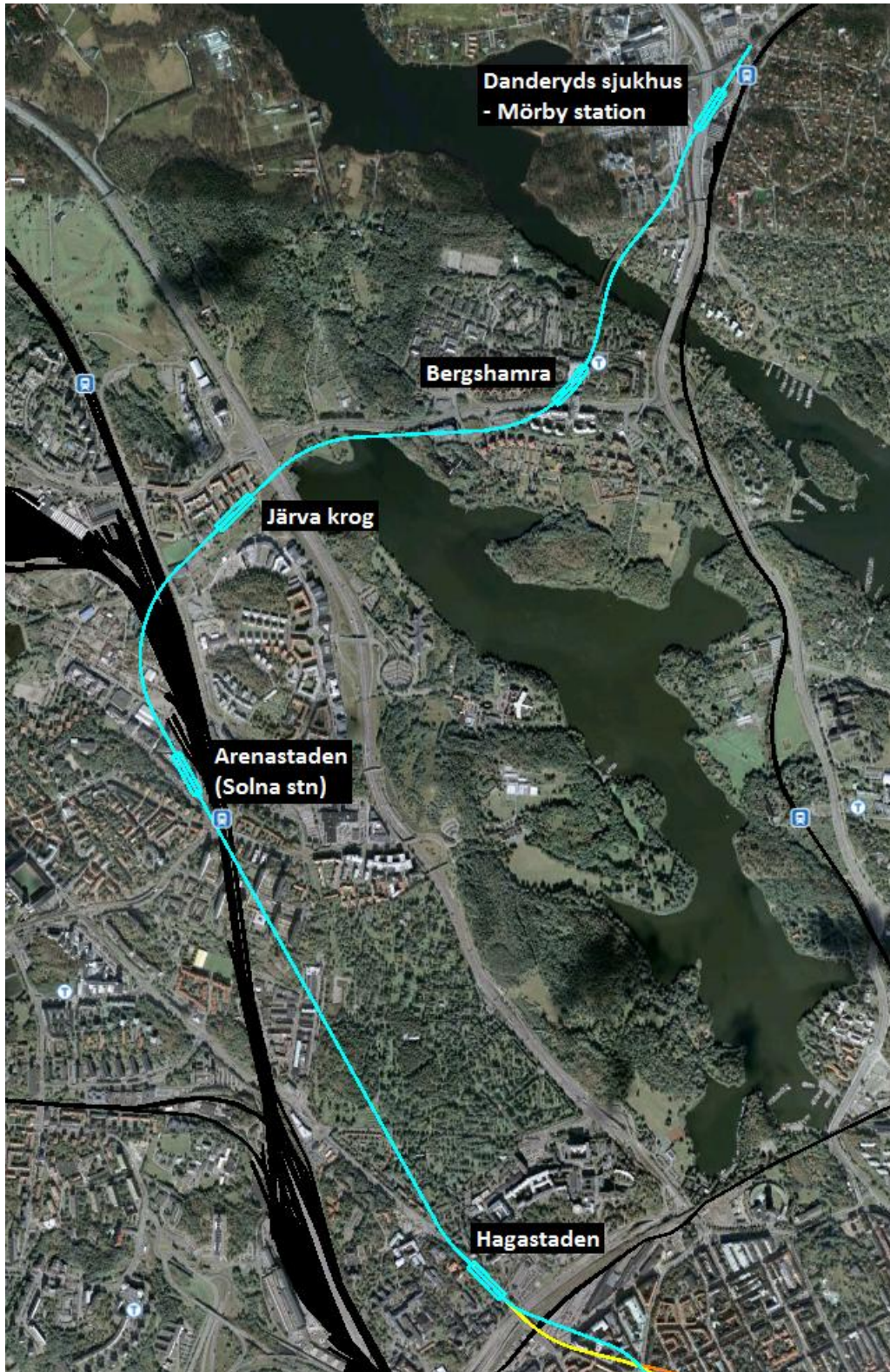
From Danderyds sjukhus to Bergshamra, the new line will follow the Metro’s red line that is underground except a bridge over Stocksundet water flow. From Bergshamra to Hagastaden, the line will be in tunnel because of the constructions.

**Bergshamra** station will be underground and connected to the red line station with some corridors forming an eastern entrance together with the existing entrance on Bergshamra torg. Two West entrances could be created on Barks väg towards the south-western part of the district.

**Järva krog** station can be located south of the “Järva krog” E4-E18 motorway interchange with two southern entrances: one on Gustav III Boulevard to serve Frösunda area and one on Galoppvägen to facilitate the access to the Nya Ulriksdal area. If a bus station is desired for the buses coming from the North, an entrance from this bus station can be created near Nämndemansgatan.

**Arenastaden** station will be underground since all the area is being made denser. The North entrance could be near Mall of Scandinavia shopping centre to offer a fast access to Friends Arena. On the other side, the South entrance will have a direct connection with Solna commuter train station and the last stop of the Tvärbanan on Frösundaleden.

According to Hagastaden development maps, **Hagastaden** station will be located below the existing Karolinska Hospital’s parking lot along Solnavägen. It will be an underground station because of the dense area with the new Karolinska complex. In this report, the entrances could be on both sides of Solnavägen since the station is located under this street and closer to the core of the area.



**Figure 14: Line between Danderyds sjukhus and Hagastaden.** Background: Google Earth.

### 3.4. Central section (Hagastaden – Hornstull)

#### Western corridor A1 (via Stadshagen and Marieberg)

The aim of alternative A1 is to connect the western parts of Kungsholmen. Västra Kungsholmen (near Stadshagen station) and Marieberg (near Thorildsplan station) will see a large increase of population and workplaces in the coming years according to the urban planning division in Stockholm City.

**Odenplan** station would be located west of the new commuter train station and under Hälsingegatan because the line has to go westwards to reach Stadshagen. As a result, the connection to the green line would be only possible via the commuter train platforms, which mean more than 300 metres for transferring. A northern entrance could be located on Vanadisplan and a southern entrance at the crossing Hälsingegatan/Karlbergsvägen.

Therefore a transfer station would be created in **S:t Eriksplan** for the transfers between the new line and the green line. The station would be located under S:t Eriksplan with an East entrance at the crossing Torsgatan/Odengatan and a West entrance on S:t Eriksgatan using the existing access to the green line. The transfer distance would be less than 100 metres.

**Stadshagen** station would be located under Kellgrensgatan in the middle of Stadshagen district. The northern entrance would be merged with the existing one for the blue line on Sankt Göransgatan. A southern entrance could be located on Lindhagensgatan where several offices are being built.

**Thorildsplan-Marieberg** station would be located in front of Lärarhögskolan under Rålambshovsparken, just south of the existing Thorildsplan station for the green line. There would be a North entrance to allow this transfer and a South entrance towards Rålambsvägen to connect to the developing Marieberg district.

#### Central corridor A2 (via Fridhemsplan)

The aim of alternative A2 is to connect Fridhemsplan, the existing transfer node in Kungsholmen with bus lines 1, 3 and 4 as well as Metro green and blue lines, to the other main nodes in the city centre (Odenplan and Liljeholmen). There is no development project but there were already more than 21000 inhabitants and 17000 workplaces in the station's catchment area in 2012.

**Odenplan** station would be located under Dalagatan and south of the Metro green line station. The connection to the commuter train station and the green line platform would be done through a northern entrance on Karlbergsvägen. A southern entrance on Odengatan would allow a direct access to Vasaparken and to the North of Sabbatsberg district since there would not be any intermediate station between Odenplan and Fridhemsplan stations in this alternative.

If possible and in order to reduce the depth of the station, **Fridhemsplan** station would be built along the existing green line station and above the blue line's tunnel. The entrances would be common with the green line's ones (Fleminggatan and Drottningholmsvägen) and transfers to the blue line would also be possible. This station is common for alternatives A2 and A3.

### **Central corridor A3 (via Sabbatsberg and Fridhemsplan)**

As for alternative A2, the aim of alternative A3 is to connect Fridhemsplan to the other main nodes in the city centre but adding a stop in Sabbatsberg since it is the only district in the city core without any Metro station.

**Odenplan** station would be different from the one for alternative A2: it would be located north of the new commuter train station and north of the green line station under Upplandsgatan. The connection to the commuter train station and the green line platform would be done through a southern entrance on Karlbergsvägen. A northern entrance would be located on Frejgatan. This station is common for alternatives A3 and A4.

**Sabbatsberg** station would be located under Tegnérgatan just at the end of Barnhusbron to give an easy access to the rail network for people living (4317 inhabitants in 2012) and working (6569 workplaces in 2012) in this area.

**Fridhemsplan** station is common for alternatives A3 and A2.

### **Eastern corridor A4 (via Sabbatsberg and Rådhuset)**

The aim of alternative A4 is to open the eastern part of Kungsholmen towards the North and the South since the district has access to the blue line in an East-West direction only. The aim is also to improve the access to Sabbatsberg.

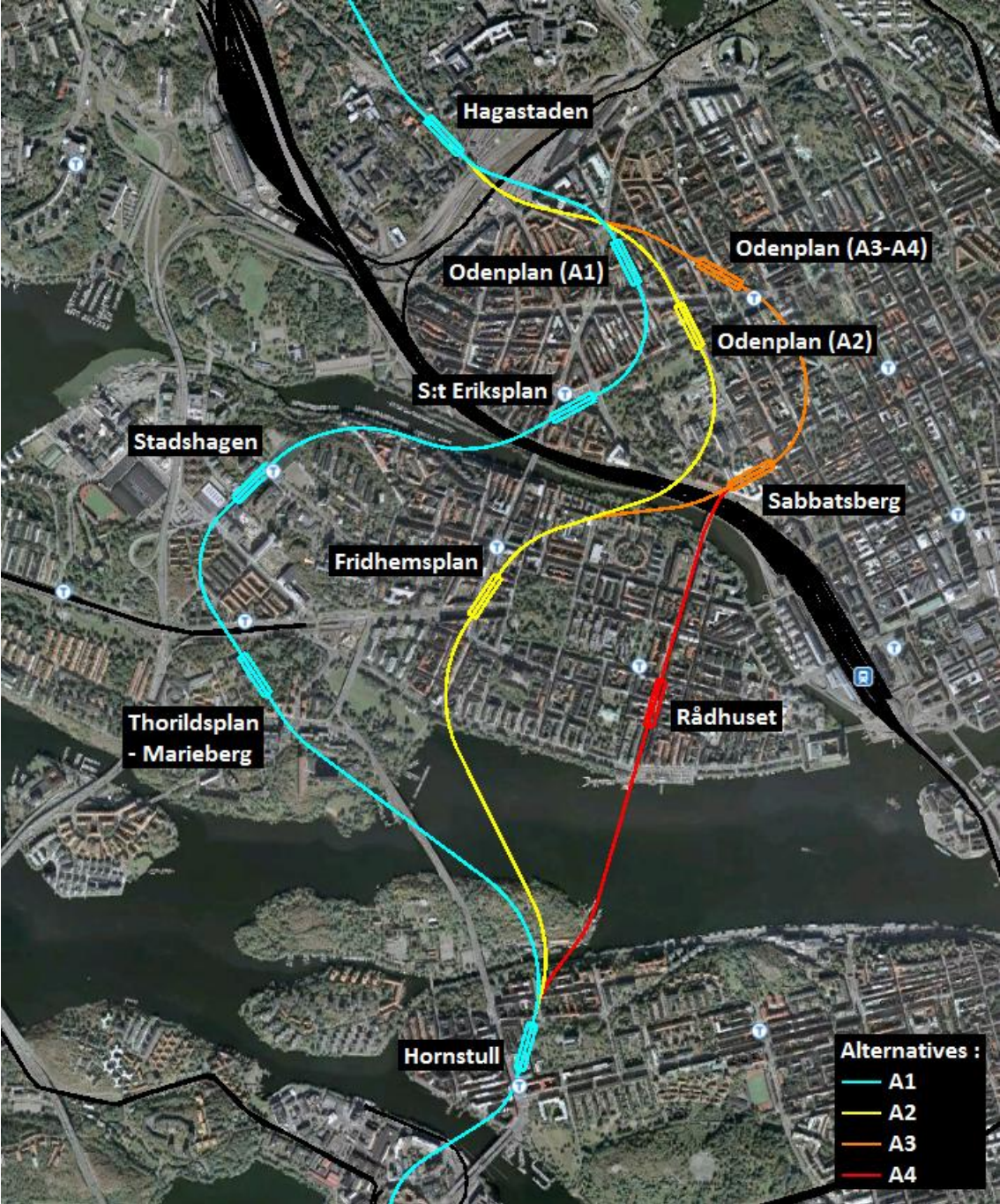
**Odenplan** and **Sabbatsberg** stations are common for alternatives A3 and A4.

If possible, the line would run cross Barnhusbron bridge (over the Klara sjö river and the railway tracks) with the same method used for the green line between S:t Eriksplan and Fridhemsplan stations: the bridge is double-stacked with the street on the upper level and the Metro tracks on the lower level. In that case, Sabbatsberg station would be built using a cut-and-cover method since the tracks would go directly on the bridge at the western end of the station. A walkway could be added to the bridge to have a direct connection from the station to the North-East of Kungsholmen.

**Rådhuset** station would be located under Scheelegatan, south of the existing blue line station. A northern entrance would be merged with the blue line's one located near the courthouse ("rådhuset" in Swedish). A southern entrance would give a direct access to Kungsholmstorg and the Lake Mälaren northern bank.

**Summary of the four alternatives in the city centre**

The figure below shows the different alternatives in the city centre between Hagastaden and Hornstull stations. They are quite different but as explained before, they answer to different needs. In chapter 4, the costs and impacts of each alternative will be discussed. The following colour code will be used for the alternatives: A1 in blue, A2 in yellow, A3 in orange and A4 in red.



**Figure 15: Line alternatives between Hagastaden and Hornstull.** Background: Google Earth.

### 3.5. Southern section (Hornstull – Älvsjö)

Because of the densely built area around Hornstull Place, **Hornstull** station will be underground with a connection to the red line of the Metro. Depending on the depth of the red line's platforms, the new line's platforms could be sensitively deep under street level. The South entrance will be merged with the red line's one and the access to Nya Hornstull shopping centre. A North entrance could be located at the crossing Pålsundsgatan/Högalidsgatan so the station would be under Högalid Park.

For **Liljeholmen** station, the new line will be besides the underground bus terminal but opposite the red line since the red line's southbound platform. The West entrance would be connected to the bus station and as a consequence to the red line. The Tvärbanan light rail stop could also be reached from this entrance. An eastern entrance could be placed on Årstaängsvägen to reach the different dwellings and workplaces in the developing Årstadal district.

In order to improve the connection between the West and the East of Årstaberg commuter train station, **Årstaberg** station on the new Metro line will be located below the railway tracks and along the Tvärbanan tracks. A West entrance can be located towards Sjöviksbacken to reach the southern part of Årstadal and the East entrance would strengthen the bus terminal and the connection to the Tvärbanan line.

The aim of **Östberga-Årstafältet** station is to serve Östberga and Årstafältet. A North entrance can be located near Valladammen Lake since it will be the central point of the new Årstafältet district. The South entrance could have an access from the crossing Östbergavägen/Östbergabackarna (near bus stop Östbergahöjden) for people living in Östberga. Since the station would be located right under Årsta golf, the question will be if one can create the station with the cut-and-cover method or totally underground to protect the golf.

For the end station **Älvsjö**, there are several possibilities. The station can be built with the cut-and-cover method under the existing Älvsjö bus terminal to the west of the commuter train station. In that case, the length is long enough for installing one or two reversing tracks after the Metro station. This solution increases the possible capacity since the trains don't stay by the platform for reversing. Another solution could be to build the station under the railway tracks together with the station for the extended Metro line from Hagsätra so the transfers between with the commuter trains are optimised (no long transfer corridor). This solution is more difficult to carry out since it would need traffic closures for the commuter, long distance and freight trains passing Älvsjö station. A last solution is to build the two Metro stations on the eastern side of Älvsjö station. The line from Österberga would go between the existing tracks and the congress centre and the line from Hagsätra would end before the congress centre (Stockholmsmässan). In this report, the last solution with the station between the existing tracks and the congress centre will be used for all calculations. The station for the Metro line from Hagsätra would be located in the continuation of the new line from Östberga-Årstafältet.

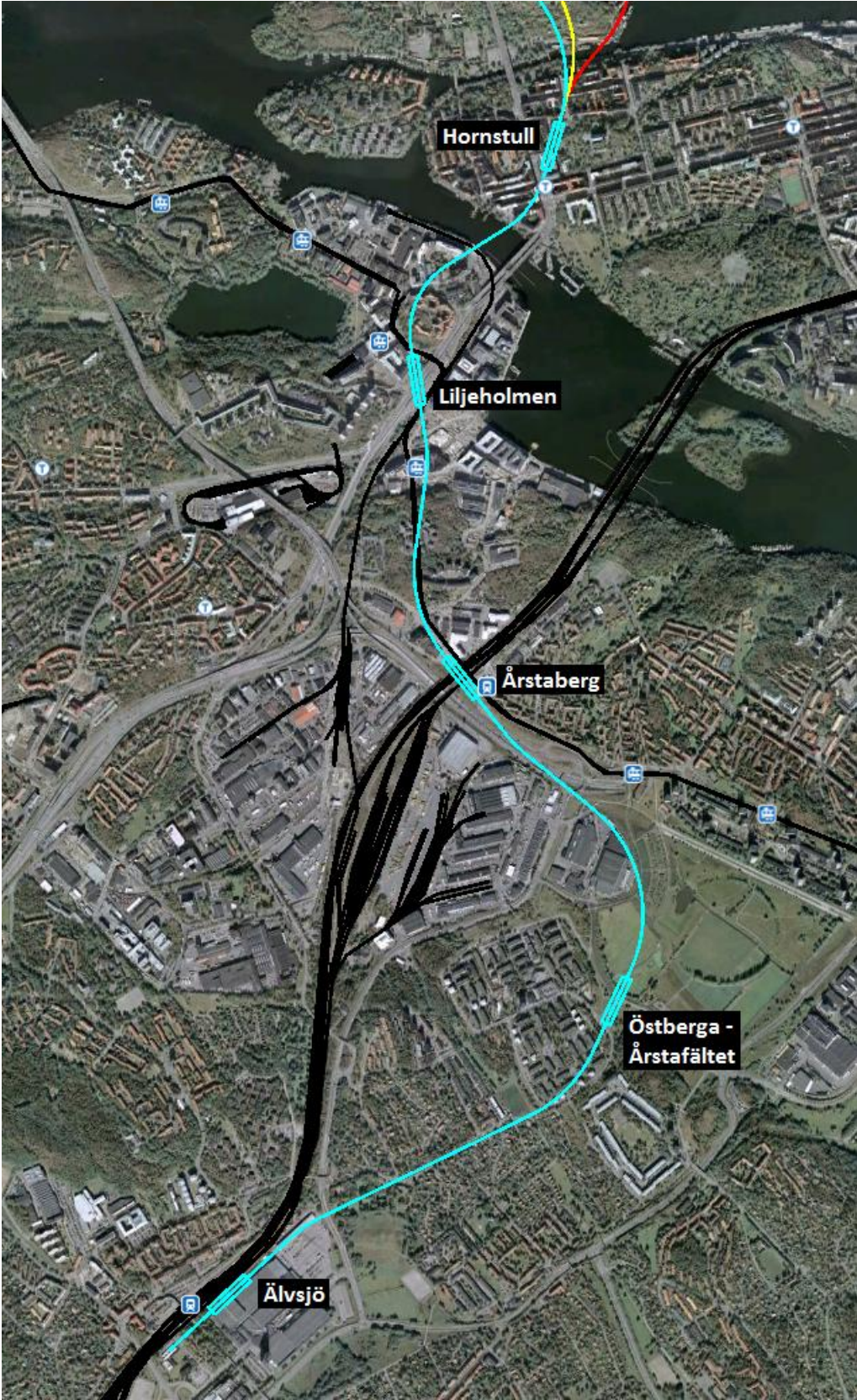


Figure 16: Line between Hornstull and Älvsjö. Background: Google Earth.

## 4. Analysis of effects of the infrastructure

### 4.1. Methodology for calculations

The track geometry has an impact on the maximum permitted speed for the rail vehicles. In this report, the following maximum speeds will be assumed for the different horizontal curve radii of the tracks:

Curve radius	Maximum speed
500 m	90 km/h
400 m	80 km/h
300 m	70 km/h

**Table 5: Maximum speed vs horizontal curve radius.** Source: SL.

In a straight line, the maximum speed is the maximum speed allowed by both signalling and vehicle's performance (i.e. 90 km/h for a Bombardier *MOVIA*® C30 train set). As a result, the curve radii have to be as big as possible to allow higher speeds as one can understand from Table 5 above.

Since the interstation distances ( $d_{inter}$ ) are quite short for the new Metro line (less than 5 kilometres), one will consider the maximum speed constant along the interstation and equivalent to the most restrictive maximum speed if there are some sharp curves between the consecutive stations.

The acceleration/retardation time and distance are the time and distance needed for a vehicle to run from 0 km/h to a given maximum speed. One will assume that the acceleration and retardation are constant and equivalent to respectively 1 m/s<sup>2</sup> and -1 m/s<sup>2</sup> for the C30 train sets so the times and distances will be equal for acceleration and breaking. Then, the equations of motion are used depending on the maximum speed.

$$v_{max} = at_{acc} + v_0$$

$$d_{acc} = a \frac{t_{acc}^2}{2} + v_0 t_{acc} + d_0$$

Where:

- $a$  is the value of the acceleration or retardation (in m/s<sup>2</sup>),
- $t_{acc}$  is the acceleration time (in seconds),
- $v_{max}$  is the maximum speed (in m/s),
- $v_0$  is the initial speed (in m/s),
- $d_{acc}$  is the acceleration distance (in metres),
- $d_0$  is the initial distance (in metres).

For acceleration, since the train is initially stopped in the station,  $v_0 = 0$  and  $d_0 = 0$ . The system of equations is then solvable: one has 2 equations with 2 unknowns ( $t_{acc}$  and  $d_{acc}$ ).

$$t_{acc} = \frac{v_{max}}{a}$$

In Table 6, the acceleration/retardation time and distance are given for the three speed limits seen in Table 5:

Speed (km/h)	70	80	90
Acceleration time (s)	19,44	22,22	25
Acceleration distance (m)	189	246,9	312,5

**Table 6: Acceleration/retardation time and distance according to the speed.**

To estimate the total travel time between two consecutive stations (interstation time), the full speed travel time  $t_{full}$  is needed. This full speed time is the time the train will take to run the full speed distance  $d_{full}$  at the maximum allowed speed  $v_{max}$ . The full speed distance is deduced from the acceleration and interstation distances:

$$d_{full} = d_{inter} - 2 * d_{acc}$$

$$t_{full} = \frac{d_{full}}{v_{max}}$$

Then, the total travel time needed to run from one station to the next one (interstation time  $t_{inter}$ ) is:

$$t_{inter} = t_{full} + 2 * t_{acc}$$

For instance, for a 2000-metre interstation with a maximum speed of 90 km/h and an acceleration of 1 m/s<sup>2</sup>, one will have the following results:

Acceleration distance (m)	312,5
Acceleration time (s)	25
Full speed distance (m)	1375
Full speed time (s)	55
Interstation travel time (s)	105
<b>Interstation time</b>	<b>1 min 45</b>

**Table 7: Example of travel time for a 2000-metre interstation with  $v_{max} = 90$  km/h.**

The idea behind these calculations is to use an adequate speed according to the interstation distance. With a short interstation distance (less than one kilometre), the difference in travel time between a maximum speed of 70 and 90 km/h is negligible. When the interstation distance reaches two kilometres, the difference in travel time is more significant. That is why one can use sharp curves in the city centre where the stations are close to each other and large curve radii in the suburbs. The Figure 17 below describes this phenomenon.

The maximum speed can be reached only if the interstation distance is longer than 378 metres for 70 km/h, 494 metres for 80 km/h and 625 metres for 90 km/h. But generally, as shown in Figure 17, the travel time is equivalent regardless speed for interstation distances shorter than 700 metres.

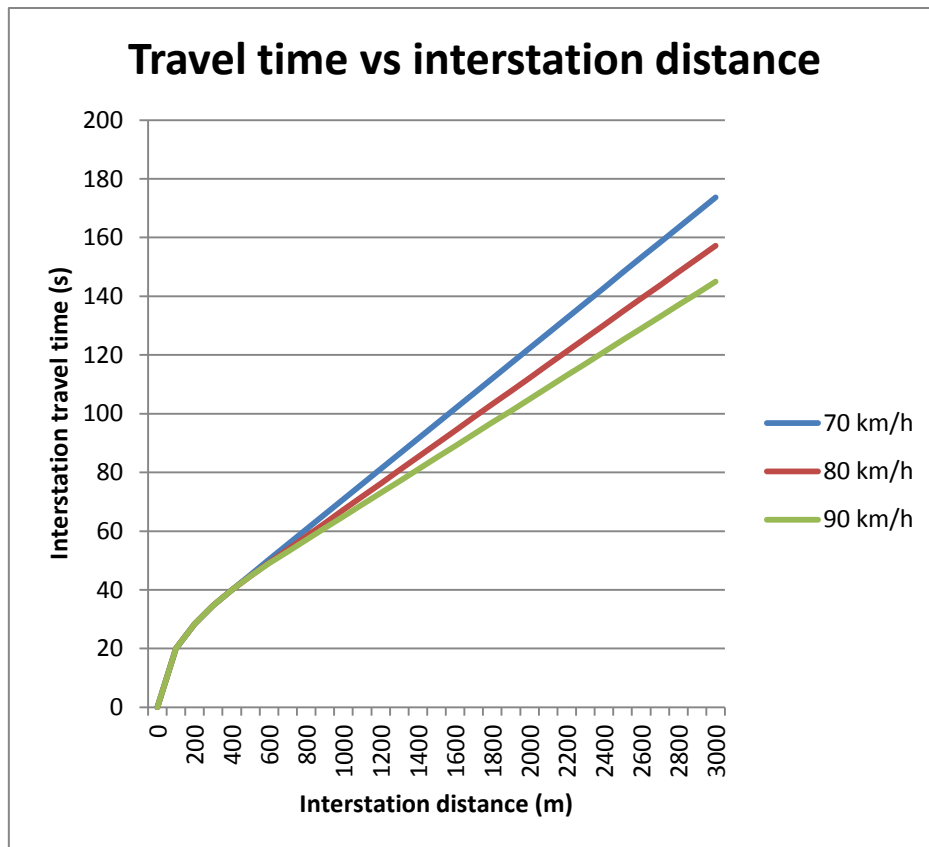


Figure 17: Travel times vs interstation distance for different maximum speeds ( $a = 1 \text{ m/s}^2$ ).

The distances between the stations are calculated between the centre of each station and following the track with the help of MicroStation software. Then, the interstation travel times can be calculated thanks to the previous formulas. All the data for the distances and travel times are gathered in Table 8 below.

Stretch		Distance	Max speed	Interstation time
Danderyds sjh	Bergshamra	1257 m	90 km/h	1 min 15
Bergshamra	Järva krog	1507 m	90 km/h	1 min 25
Järva krog	Arenastaden	1242 m	90 km/h	1 min 15
Arenastaden	Hagastaden	2363 m	90 km/h	2 min 00
Hagastaden	Odenplan A1	884 m	70 km/h	1 min 05
Odenplan A1	S:t Eriksplan	702 m	70 km/h	0 min 55
S:t Eriksplan	Stadshagen	1339 m	90 km/h	1 min 19
Stadshagen	Thorildsplan	865 m	70 km/h	1 min 04
Thorildsplan	Hornstull	1910 m	90 km/h	1 min 41
Hornstull	Liljeholmen	1094 m	70 km/h	1 min 16
Liljeholmen	Årstaberg	1153 m	90 km/h	1 min 11
Årstaberg	Östberga	1473 m	90 km/h	1 min 24
Östberga	Älvsjö	1849 m	90 km/h	1 min 39
Hagastaden	Odenplan A2	1244 m	90 km/h	1 min 15
Odenplan A2	Fridhemsplan	1545 m	80 km/h	1 min 32
Fridhemsplan	Hornstull	1855 m	90 km/h	1 min 39
Hagastaden	Odenplan A3-A4	1210 m	90 km/h	1 min 13
Odenplan A3-A4	Sabbatsberg	998 m	70 km/h	1 min 11
Sabbatsberg	Fridhemsplan	1170 m	80 km/h	1 min 15
Sabbatsberg	Rådhuset	975 m	90 km/h	1 min 04
Rådhuset	Hornstull	1420 m	90 km/h	1 min 22

**Table 8: Description of each interstation with distance, maximum speed and travel time.**

The sum of the different interstation distances leads to the following total distances for the different alternatives:

	Alt. A1	Alt. A2	Alt. A3	Alt. A4
Total length	17,639 km	16,582 km	17,170 km	16,540 km

**Table 9: Total length between Danderyds sjukhus and Älvsjö for each alternative.**

Assuming that we have 20 trains (140 metres) per hour and per direction (3-minute headway), a layover time of 5 minutes and a spare ratio of 20%, we have the following need in vehicles:

	Alt. A1	Alt. A2	Alt. A3	Alt. A4
Number of stations	14	12	13	13
Running time (min)	29,61394	26,23632	27,97774	27,50668
Running time (min)	29,5	26,5	28	27,5
Cycle time (min)	69	63	66	65
Needed vehicles	23	21	22	21,6667
<b>Needed vehicles</b>	<b>23</b>	<b>21</b>	<b>22</b>	<b>22</b>
Spare vehicles	4,6	4,2	4,4	4,4
<b>Spare vehicles</b>	<b>5</b>	<b>5</b>	<b>5</b>	<b>5</b>
<b>Total needed vehicles</b>	<b>28</b>	<b>26</b>	<b>27</b>	<b>27</b>

**Table 10: Vehicles needed between Danderyds sjukhus and Älvsjö for each alternative.**

## 4.2. Evaluation of investment and operating costs

As the economic balance of a public transport project is important, after designing the new Metro line with the different stretches and locations of stations, a first evaluation of the infrastructure costs can be done. The main items to consider are the stations (open-air or below ground), the location of the tracks (on a bridge, on the ground or in a tunnel) and the need of a train depot.

Infrastructure items	Cost (M SEK)
1 cut-and-cover station	500
1 underground station	600
1 km bridge or over ground	400
1 km cut-and-cover	500
1 km blast tunnel	600
1 km sink tunnel	700
1 train depot (17 trains)	1600

**Table 11: Infrastructure cost per item.** Source: SLL for depot (Norsborg).

The cut-and-cover method for stations and tunnels is used when the line is just below the ground level and in a zone without any construction (road, field or park). It is cheaper than digging a tunnel or a station deep in the ground. A sink tunnel is used when a line has to cross deep water flows, the example taken for this study is the sink tunnel installed in 2013 between Söder Mälarstrand and Riddarholmen for the Citybanan commuter train tunnel opening in 2017 under Stockholm inner city.

The infrastructure costs will include the costs for buying train sets that will be necessary for the service on the new line (calculations done in chapter 4.1). It will also include the construction of a train depot if necessary. There is already Nyboda depot near Liljeholmen that could be used if a connecting track is built between the new Metro line and the red line.

Each of the three alternatives will be studied as well as three different stretches in case the politics think it is too expensive to build the whole line in only one step (**Danderyds sjukhus – Älvsjö**).

Since the main idea from Stockholm County (SLL) was to connect Arenastaden (Solna station) to Odenplan via the new Hagastaden district, the two alternatives will include that stretch:

- Intermediate section **Danderyds sjukhus – Odenplan** if we want to focus on the improvements for people living or working in Hagastaden and for those coming from the Northeast region with the Roslagsbanan train in Mörby station.
- Intermediate section **Arenastaden – Årstaberget** if we want to focus on the improvement of the Mälaren Lake crossing and the passenger charge reduction on the bus line number 4. This solution also links three commuter train stations and all the Metro lines to reinforce the robustness of the network.

### Entire new line between Danderyds sjukhus and Älvsjö

One can see that the alternative A1, that is longest, is also the most expensive (22 billion SEK) compared to the other ones. The alternative A2, which is the shortest by going directly from Odenplan to Hornstull via Fridhemsplan is the one that minimize the number of trains needed as well as the number of stations; it costs 20,3 billion SEK.

Danderyds sjh - Älvsjö	Alt. A1	Alt. A2	Alt. A3	Alt. A4
C30 train sets (140 m)	28	26	27	27
<b>Total train sets</b>	<b>2975</b>	<b>2762,5</b>	<b>2868,75</b>	<b>2868,75</b>
Cut-and-cover station	2	2	2	3
Underground station	12	10	11	10
<b>Total stations</b>	<b>8200</b>	<b>7000</b>	<b>7600</b>	<b>7500</b>
Overground section	0,239073	0,239073	0,239073	0,439073
Cut-and-cover section	0,431515	0,431515	0,431515	0,431515
Blast tunnel section	15,05469	14,35858	14,76642	13,93658
Sink tunnel section	0	0	0	0
<b>Total track sections</b>	<b>9344,201</b>	<b>8926,536</b>	<b>9171,236</b>	<b>8753,337</b>
Train depot	1	1	1	1
<b>Total depots</b>	<b>1600</b>	<b>1600</b>	<b>1600</b>	<b>1600</b>
<b>TOTAL COSTS (M SEK)</b>	<b>22119,2</b>	<b>20289,04</b>	<b>21239,99</b>	<b>20722,09</b>

Table 12: Example of infrastructure costs for the entire line Danderyds sjukhus – Älvsjö.

### Intermediate section between Danderyds sjukhus and Odenplan

One can see that the alternative A1, that is shortest, is also the cheapest (10,56 billion SEK) compared to the other ones but the difference is not that remarkable (200 M SEK). This is due to the fact that all the alternatives have the same stretch except for the location of Odenplan station. However, the alternative A1 would give bad connections to the green line since Odenplan station would be located far from the green line's station.

Danderyds sjh - Odenplan	Alt. A1	Alt. A2	Alt. A3	Alt. A4
C30 train sets (140 m)	15	15	15	15
<b>Total train sets</b>	<b>1593,75</b>	<b>1593,75</b>	<b>1593,75</b>	<b>1593,75</b>
Cut-and-cover station	1	1	1	1
Underground station	5	5	5	5
<b>Total stations</b>	<b>3500</b>	<b>3500</b>	<b>3500</b>	<b>3500</b>
Overground section	0,239073	0,239073	0,239073	0,239073
Cut-and-cover section	0,215896	0,215896	0,215896	0,215896
Blast tunnel section	6,110833	6,471304	6,437317	6,437317
Sink tunnel section	0	0	0	0
<b>Total track sections</b>	<b>3870,077</b>	<b>4086,36</b>	<b>4065,967</b>	<b>4065,967</b>
Train depot	1	1	1	1
<b>Total depots</b>	<b>1600</b>	<b>1600</b>	<b>1600</b>	<b>1600</b>
<b>TOTAL COSTS (M SEK)</b>	<b>10563,83</b>	<b>10780,11</b>	<b>10759,72</b>	<b>10759,72</b>

Table 13: Example of infrastructure costs for the Danderyds sjukhus – Odenplan section.

### Intermediate section line between Arenastaden and Årstabergr

The differences are the same as for the entire line: the alternative A1 is the most expensive (13 billion SEK) whereas the alternative A2 costs 11 billion SEK.

Arenastaden - Årstabergr	Alt. A1	Alt. A2	Alt. A3	Alt. A4
C30 train sets (140 m)	20	17	18	18
<b>Total train sets</b>	<b>2125</b>	<b>1806,25</b>	<b>1912,5</b>	<b>1912,5</b>
Cut-and-cover station	0	0	0	1
Underground station	9	7	8	7
<b>Total stations</b>	<b>5400</b>	<b>4200</b>	<b>4800</b>	<b>4700</b>
Overground section	0	0	0	0,2
Cut-and-cover section	0	0	0	0
Blast tunnel section	8,869566	8,173457	8,581291	7,751459
Sink tunnel section	0	0	0	0
<b>Total track sections</b>	<b>5321,74</b>	<b>4904,074</b>	<b>5148,775</b>	<b>4730,875</b>
Train depot	0	0	0	0
<b>Total depots</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>TOTAL COSTS (M SEK)</b>	<b>12846,74</b>	<b>10910,32</b>	<b>11861,27</b>	<b>11343,38</b>

Table 14: Example of infrastructure costs for the Arenastaden – Årstabergr section.

### Comparison of investment costs

The intermediate sections cost half the price of the construction of the whole line. However, one has to be careful that when an infrastructure is built in several phases, it is finally more expensive than if it had been built in only one phase. In this thesis, the gains in travel times or in passenger load will be calculated for all the alternatives (solution Danderyds sjukhus – Älvsjö) to evaluate with more variables which one is the most efficient, both economically and practically.

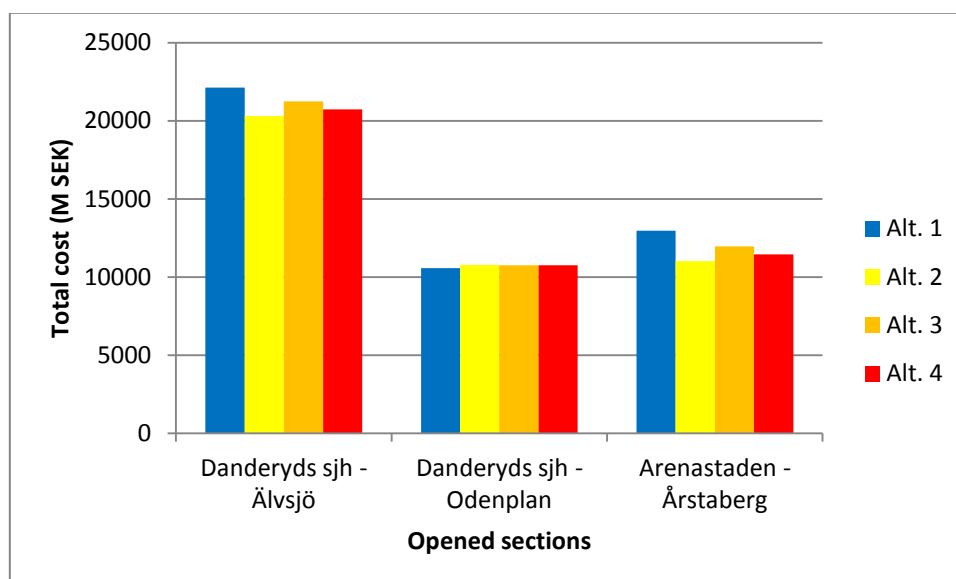


Figure 18: Infrastructure costs for each alternative and each section of the new line.

## Operating costs

After calculating the investment costs, the operating costs have to be calculated to estimate the real total cost of the new Metro line after opening. Table 15 gives the operating costs for the different SL systems in 2012 according to SL annual report [12].

SL system	Operating costs in 2012 (M SEK)
Metro (Tunnelbana)	3400
Commuter train (Pendeltåg)	1864
Light rail (Lokalbana)	899
(Bus)	(5675)

**Table 15: Operating costs in 2012 for the different public transport systems in Stockholm County.**

Since the commuter train and the light rail networks will not evaluate as much as the metro network, one can assume that the operating costs will remain stable and follow the increase in operating costs, around  $\tau = 3\%$  per year over the period 2008-2012. The bus operating costs are not taken into account due to the network model that includes only few bus lines.

The extensions of the Metro blue line in 2020 and the proposed North-South Metro line represent approximately 29 km extra double track (12 km and 17 km respectively) in the Metro network that was 108 km long since 1994. That is why, the operating costs in 2012 are equivalent to  $OC_{Metro,km,2012} = 31,5$  M SEK/km/year and this cost per kilometre will be used for calculations.

Each year  $i$ , the re-evaluation of the operating costs will be:

$$OC_{Metro,km,i} = \left(1 + \frac{\tau}{100}\right) * OC_{Metro,km,i-1}$$

$$OC_{commuter,full,i} = \left(1 + \frac{\tau}{100}\right) * OC_{commuter,full,i-1}$$

$$OC_{light,full,i} = \left(1 + \frac{\tau}{100}\right) * OC_{light,full,i-1}$$

That leads to the following general formula for year  $i$ :

$$OC_{total,full,i} = OC_{Metro,km,i} * l_{Metro,i} + OC_{commuter,full,i} + OC_{light,full,i}$$

Where:

- $OC_{total,full,i}$  is the annual operating cost for the entire rail network in year  $i$ ,
- $OC_{Metro,km,i}$  is the annual operating cost per kilometre for the Metro network in year  $i$ ,
- $l_{Metro,i}$  is the length of the Metro network in year  $i$ ,
- $OC_{commuter,full,i}$  is the annual operating cost for the commuter train network in year  $i$ ,
- $OC_{light,full,i}$  is the annual operating cost for the light rail network in year  $i$ .

Table 16 gives the entire rail network's operating costs for each alternative. Buses are not taken into account.

	Alt. A1	Alt. A2	Alt. A3	Alt. A4
Year i	Operating costs $OC_{total,full,i}$ per year (billion SEK)			
<b>2012</b>	6,163			
<b>2030</b>	12,08	12,02	12,06	12,02
<b>2079</b>	51,42	51,18	51,31	51,17
	Sum of operating costs $OC_{total,full,i}$ over 50 years (billion SEK)			
	1363	1356	1360	1356

**Table 16: Operating costs (without bus) for the different alternatives.**

The different alternatives have sensibly the same network operating cost (1360 billion SEK) due to the small variance in track length between them.

In chapter 5.2, the benefits from the ticket sales and the regional subsidies will be compared to the operating costs to evaluate the profitability of the project.



## 5. Analysis of the capacity and the accessibility

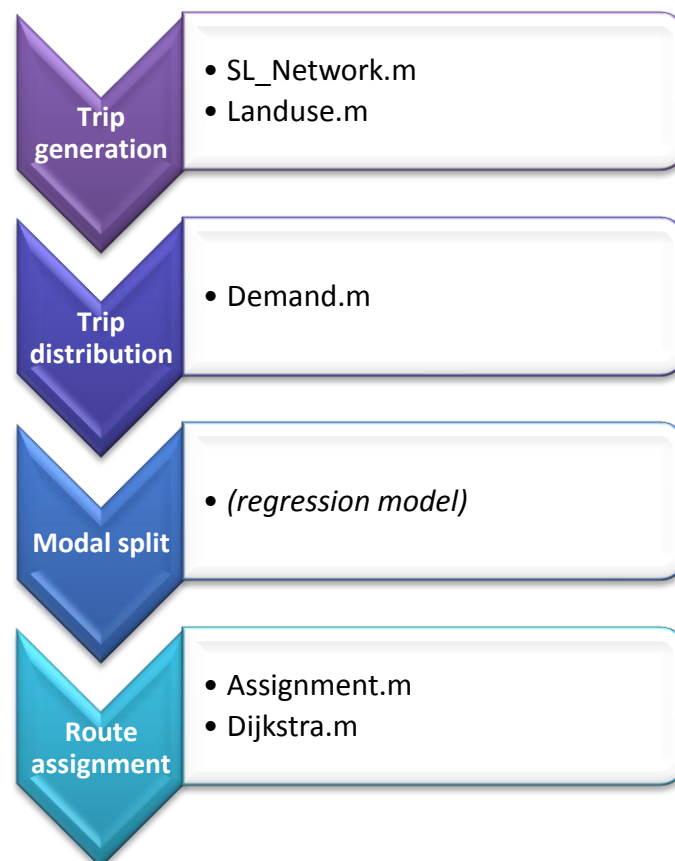
### 5.1. Methodology for transport model and calculations

#### Written programmes and 4-step model

To determine the passenger load on each stretch and the travel time for each origin-destination (OD), a MATLAB algorithm is being written. It consists of 5 sub-programmes:

- SL\_Network.m,
- Landuse.m,
- Demand.m,
- Assignment.m,
- Dijkstra.m.

The different sub-programmes follow the **four-step model** [13] used for transport planning (see Figure 19).



**Figure 19: The four-step model used to estimate passenger flows in the SL network.**

## Trip generation

The trip generation step defines the numbers of trips starting and ending in the network that is studied (number of origins  $O_i$  and destinations  $D_j$ ). In this project, since the study period will be the **morning peak hour** from 7:30 to 8:30 during a normal weekday, one will focus on the home-based trips starting from the dwellings and ending in the work zones or education places.

A regression model will be first calibrated using the land-use data (population, workplaces) from 2012 [7, 8] together with the boarding and alighting data from 2012 [10]. Then, the trip generation can be estimated for year 2030 by applying the regression model to the land-use forecasts from the demographic statistics. A zonal regression will be used since the obtained data about population and workplaces (Stockholm County SLL, Stockholm Municipality) are aggregated, i.e. only given per zone.

The transport network is modelled as an **adjacency matrix**  $A$  where each row  $i$  and each column  $j$  is a node (station or stop) or a *centroid* in the network. In this matrix,  $A_{ij} = 1$  if there is an *oriented link* (a public transport line) or an *oriented connector* between the nodes/centroids and  $A_{ij} = 0$  otherwise. Figure 20 below explains how the transport network is represented, the trips are initiated and finish at the centroids. For stations without transfers, the centroid and the node merge together for simplification. For stations with transfers, the centroid connects each station of the transfer point and all the stations are linked together as well with so called connectors (transfer corridors in reality).

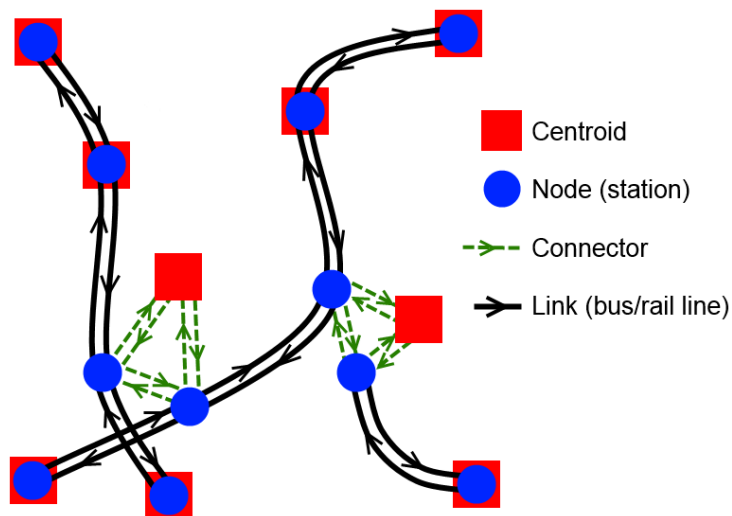


Figure 20: Network representation used for the simulation.

## Trip distribution

The trip distribution step defines the number of trips going between each pair of zones  $i$  and  $j$ . The pairs are determined using a **gravity model**, a probabilistic model based on the “weight” of the origin  $i$  and the destination  $j$ . That is, the number of inhabitants at origin  $i$  and the number of workplaces at destination  $j$ . The resulting trip pairs are gathered in an origin-destination matrix (also called “O-D matrix”).

The following formulas are used to determine the number of trips between each pair of station in the network.

$$V_j^i = \beta_{inv} * t_{j,inv}^i + \beta_{wait} * t_{j,wait}^i$$

Where:

- $V_j^i$  is the utility of the transport from origin  $i$  to destination  $j$ ,
- $\beta_{inv}$  is the in-vehicle and transfer times variables,  $\beta_{inv} = -0,02$ ,
- $\beta_{wait}$  is the waiting time variable,  $\beta_{wait} = -0,00001$ ,
- $t_{j,inv}^i$  is the in-vehicle and transfer times from origin  $i$  to destination  $j$ ,
- $t_{j,wait}^i$  is the waiting time (assumed to 1 minute on the whole network for simplification).

The variables  $\beta_{inv}$  and  $\beta_{wait}$  have been set in order to calibrate the *Matlab* model for SL network in year 2012 to the real traffic values available from SL measurements and estimations.

The destination specific part of the utility function ( $V_j$ ) is expressed as follows:

$$V_j = \ln \text{alighting}$$

Where:

- *alighting* is the total number of alighting passengers.

$V_j^i$  is the maximum utility since there is no mode choice. The number of trips between each pair of station is a gravity model so the probability of choosing destination  $j$  from origin  $i$  depends on the weight of the origin  $i$  (number of boarding passengers from dwellings) and destination  $j$  (number of alighting passengers towards workplaces) as well as the travel time to go from  $i$  to  $j$ . The probability  $P^i(j)$  of choosing destination  $j$  from origin  $i$  is expressed as follows:

$$P^i(j) = \frac{e^{V_j + V_j^i}}{\sum_{j'} e^{V_{j'} + V_j^i}}$$

Where:

- $V_j$  is the destination specific part of the utility function,
- $V_j^i$  is the utility of the transport from origin  $i$  to destination  $j$ .

Finally, the number of trips  $T_{ij}$  from origin  $i$  to destination  $j$  is defined as follows:

$$T_{ij} = \text{boarding}(i) * P^i(j)$$

Where:

- $boarding(i)$  is the number of boarding passengers in origin  $i$ ,
- $P(j)$  is the probability of choosing destination  $j$  from origin  $i$ .

Since the O-D matrix must be the same for all the alternatives, it will be calculated from the A0 alternative (i.e. the network in 2030 without the new line) and then be used for the other alternatives (A1 to A4) so that the demand is constant.

### Modal split and regression model

In this study, the mode shares are not taken into account. The simulation is done only with the public transport users. The determination of the modal split is done using a **regression model**. On one hand, a regression is done between the number of boarding passengers at a station and the number of people living in the zone around the station. On the other hand, a regression is done between the number of alighting passengers at a station and the number of workplaces and education places in the zone around the station.

Since one cannot know the shape of the regression function, the regression will be done individually for each line. The social environment is different for each line so the modal split will vary from one line to another.

To estimate the proportion of inhabitants living in the surroundings of a station who will take the public transport to go to work, a regression function will be created. The same method is used to find the proportion of workers using the public transport system to go to work. With the data from SL concerning boarding and alighting passengers, we obtain for example the following graphs (see Figure 21 and Figure 22). Since the data from SL takes into account people transferring between two transport lines, the transfer stations will not be included in the regression model because the boarding and alighting data is biased for these particular stations.

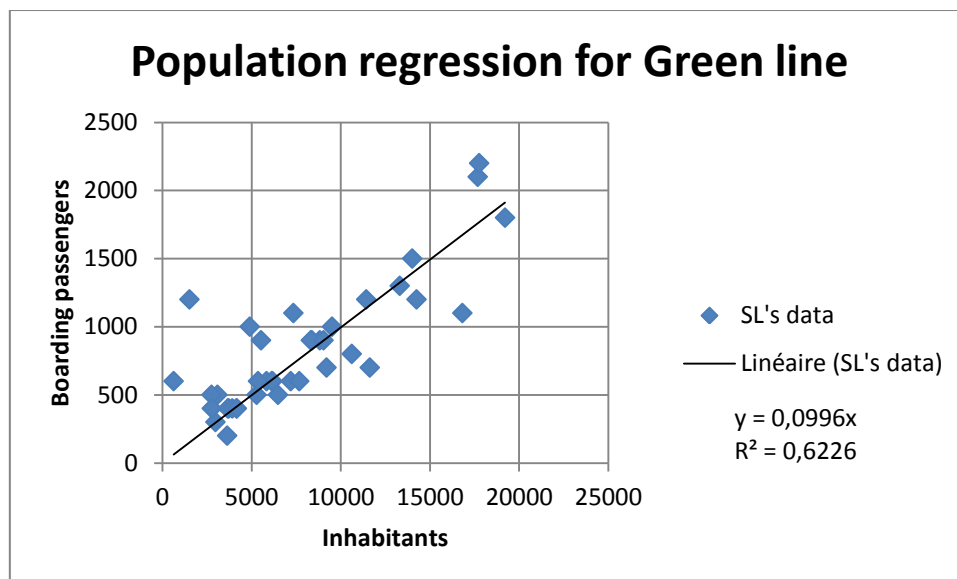


Figure 21: Example of linear regression for population around the Green line in 2012.

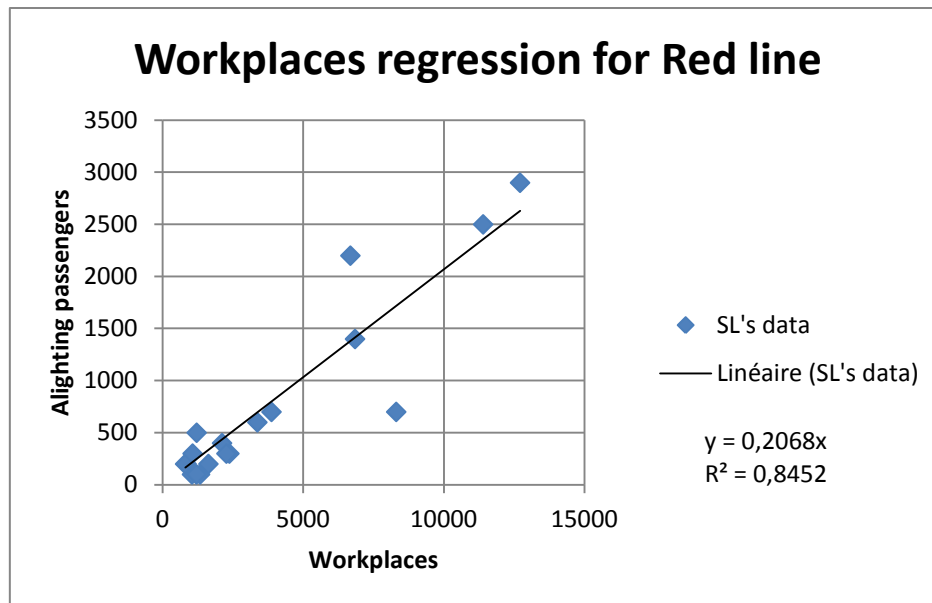


Figure 22: Example of linear regression for workplaces around the Red line in 2012.

The figures show a correlation between the number of inhabitants and the number of boarding passengers and on the other hand between the number of workplaces and the number of alighting passengers. One can assume that approximately 10% of the total population living around a station of the Green line will use the Metro for work or education purpose during the morning peak hour. Concerning the workplaces, one can assume that approximately 20% of the people working or studying around a station of the Red line come there with the Metro.

Since the socio-economic situation differs from one line to another, there will be different regression models for each public transport line. But globally, from these regressions, one can assume that the number of passengers using a public transport stop during the morning peak hour is linearly related to the population living, working or studying in the surrounding area of the stop.

### Route assignment

The route assignment step defines which route the passengers will use to go from the origin  $i$  to the destination  $j$  in the transport network. In this project, the Dijkstra algorithm will be used to calculate the shortest path (in travel time) between each pair of places in the network. Then, one will assume that all the passengers will always use the same path between two places if the characteristics of the network are not fluctuating.

The programme Model.m gathers all the previous steps and run them in the right order to calculate and display the desired results (passenger flows and travel times).

## 5.2. Evaluation of the new passenger flows

In Figure 23, the number of passengers crossing the Lake Mälaren in year 2030 during the morning peak hour (7:30 – 8:30) is compared between alternatives A0 to A4 (with section Danderyds sjukhus – Älvsjö open for the new line) for each line crossing the lake:

- Metro red line: Gamla stan ↔ Slussen,
- Metro green line: Gamla stan ↔ Slussen,
- Commuter train (Pendeltåg) : Stockholm City ↔ Stockholms södra,
- Bus line number 4: Fridhemsplan ↔ Hornstull,
- Metro new line: Thorildsplan/Fridhemsplan/Rådhuset ↔ Hornstull,
- Tvärbanan line: Stora Essingen ↔ Gröndal,

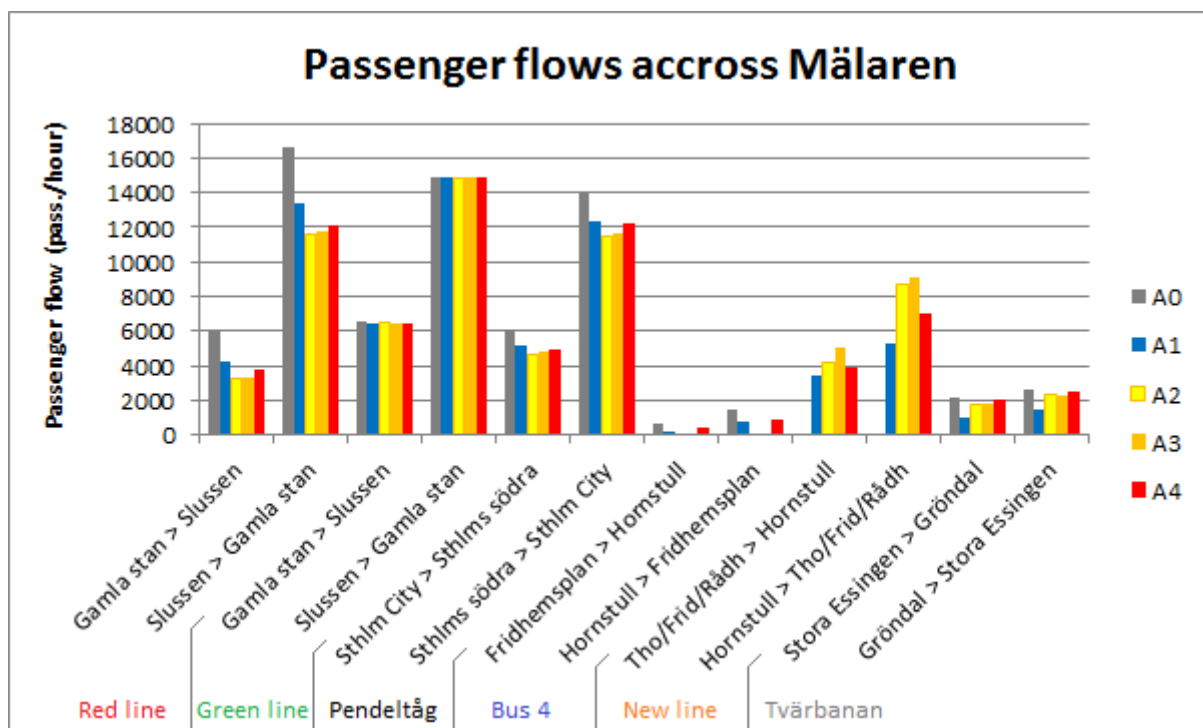
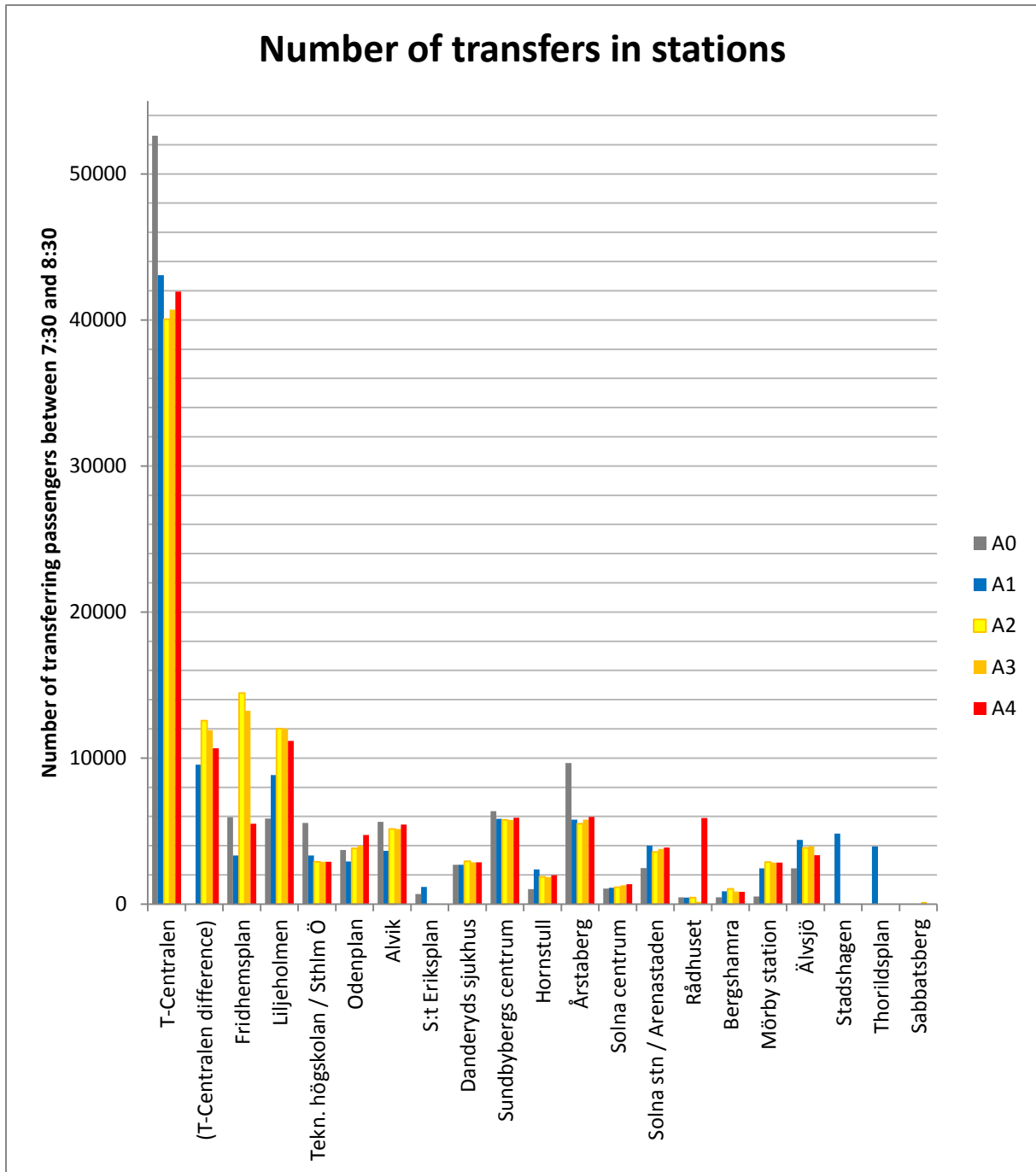


Figure 23: Passenger flows on the stretches across Lake Mälaren in 2030 for each alternative.

A shift of passengers from the Red line and from the commuter train (Pendeltåg) towards the new Metro line is visible for alternatives A1 to A4 compared to alternative A0. This is due to the fact that the new line connects the southern branches of the Red line to Kungsholmen (Fridhemsplan station) faster than the detour via T-Centralen. It is the same reason for the commuter train line: passengers coming from the southern suburbs and wishing to reach Kungsholmen will change in Årstaberget to the new Metro line. Passengers coming from Södermalm Island will take rather the new line in Hornstull station to continue their journey northwards, avoiding transfers in T-Centralen.

Since one of the objectives of this proposed new Metro line is to decrease the number of transfers done in Stockholm City / T-Centralen node, Figure 24 shows the number of passengers transferring at given transfer stations in year 2030 during the morning peak hour (7:30 – 8:30) compared between alternatives A0 to A4.



**Figure 24: Number of transfers done between two lines in given stations in 2030.**

During a typical morning peak hour in 2030, without the new Metro line, more than 52000 passengers would transfer between the commuter train (Stockholm City station) and/or the three existing Metro lines (in T-Centralen station). If the new Metro line is open, it implies a decrease between 9500 (alt. A1) and 12500 (alt. A2) transferring passengers per hour at this node that is the major transfer node in Stockholm rail network. This decrease would lead to a more acceptable congestion in the transfer corridors of T-Centralen station, especially at the ticket gates.

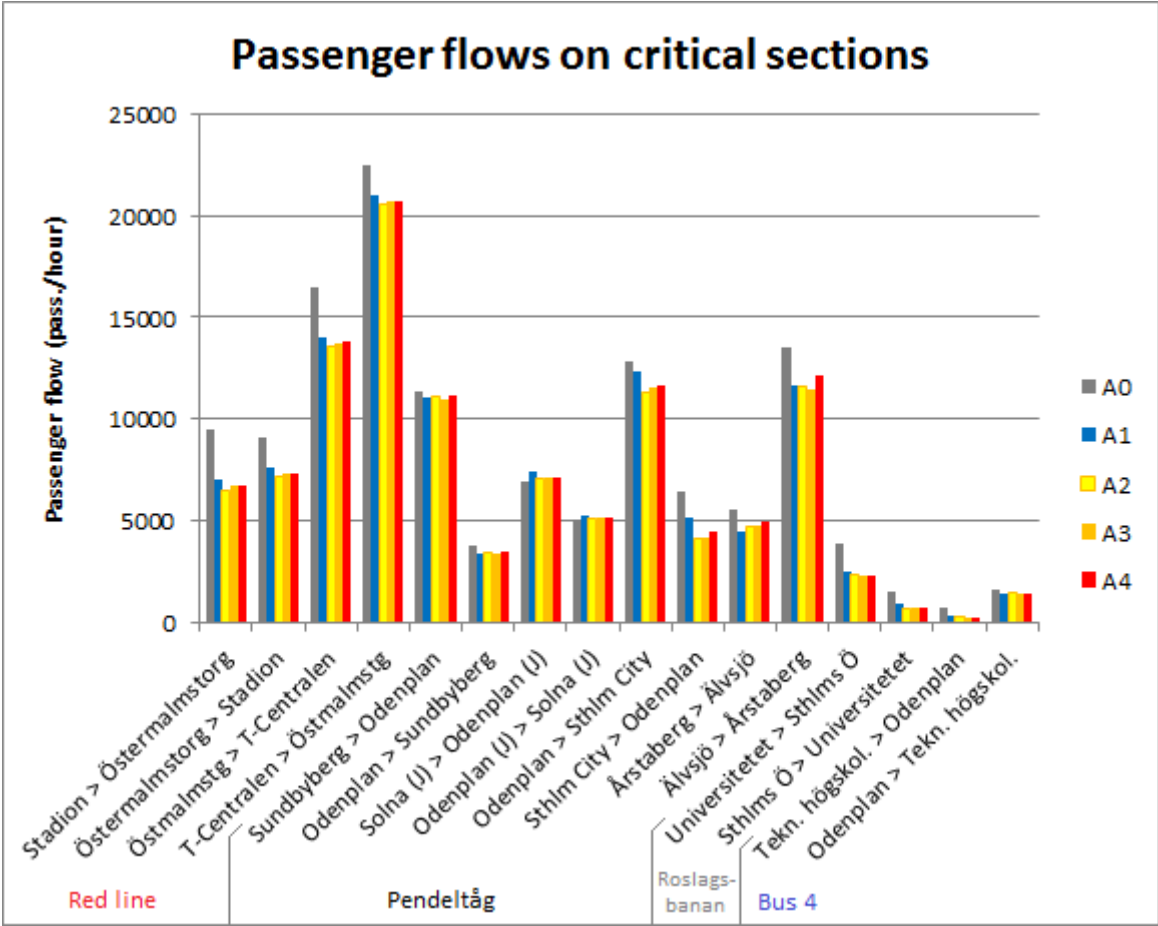


Figure 25: Passenger flows on the most crowded stretches in 2030 for each alternative.

In Figure 25 as in Figure 23, the highest changes in passenger load are observed on the Metro red line and on the Roslagsbanan light rail line. On the stretches from Tekniska högskolan to Östermalmstorg stations and from Mörby to Stockholms östra stations, the passenger load decreases by 30 to 40% thanks to the connection in Danderyds sjukhus between the Metro red line, the new Metro line and the Roslagsbanan line (in Mörby station) that allows passengers coming from the north-eastern municipalities (Danderyd, Täby, Vallentuna and Österåker) to split between the red line and the new line of the Metro system to continue their journey towards Stockholm’s inner city.

To evaluate more in details the impacts of the decrease in passenger load, the loads have to be compared to the offered vehicle capacity (see chapter 5.4). According to SL’s report about transport planning in Stockholm region [14], the passenger load leads to different perceived congestion (from passengers point of view) as explained below:

- Good perception if 100% of seats are taken and less than 20% of standing capacity is used.
- Fairly good perception if 100% of seats are taken and 20% to 40% of standing capacity is used.
- Bad perception if 100% of seats are taken and more than 40% of standing capacity is used.

In the following charts (Figure 26 and Figure 27), a comparison is made between passenger flows in alternatives A0 and A2 for the southbound and northbound directions of Metro red line.

In both directions, the average headway is 5 minutes (2 trains per 10 minutes) between Mörby centrum and Östermalmstorg and 2 minutes (5 trains per 10 minutes) on the stretch Östermalmstorg - Liljeholmen. That allows an average headway of 3,3 minutes (3 trains per 10 minutes) between Ropsten and Östermalmstorg to cope with the development of Gärdet/Värtahamnen area.

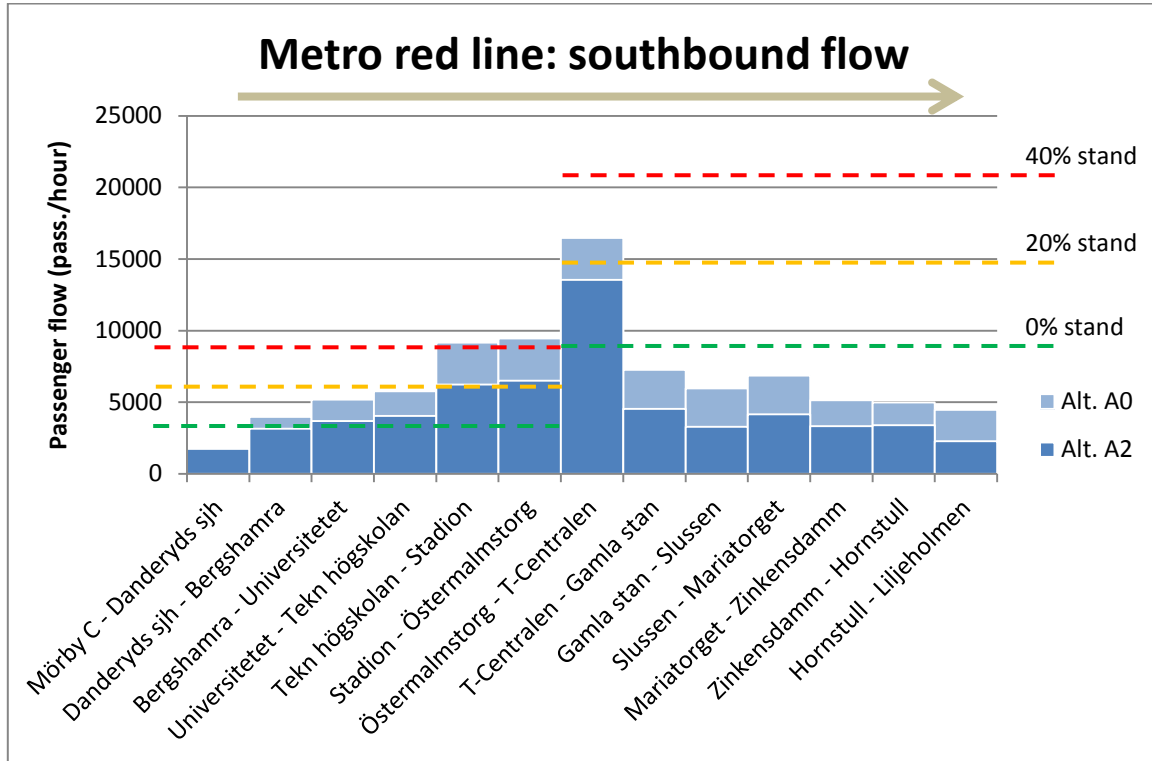


Figure 26: Southbound passenger flow on the Metro red line in 2030.

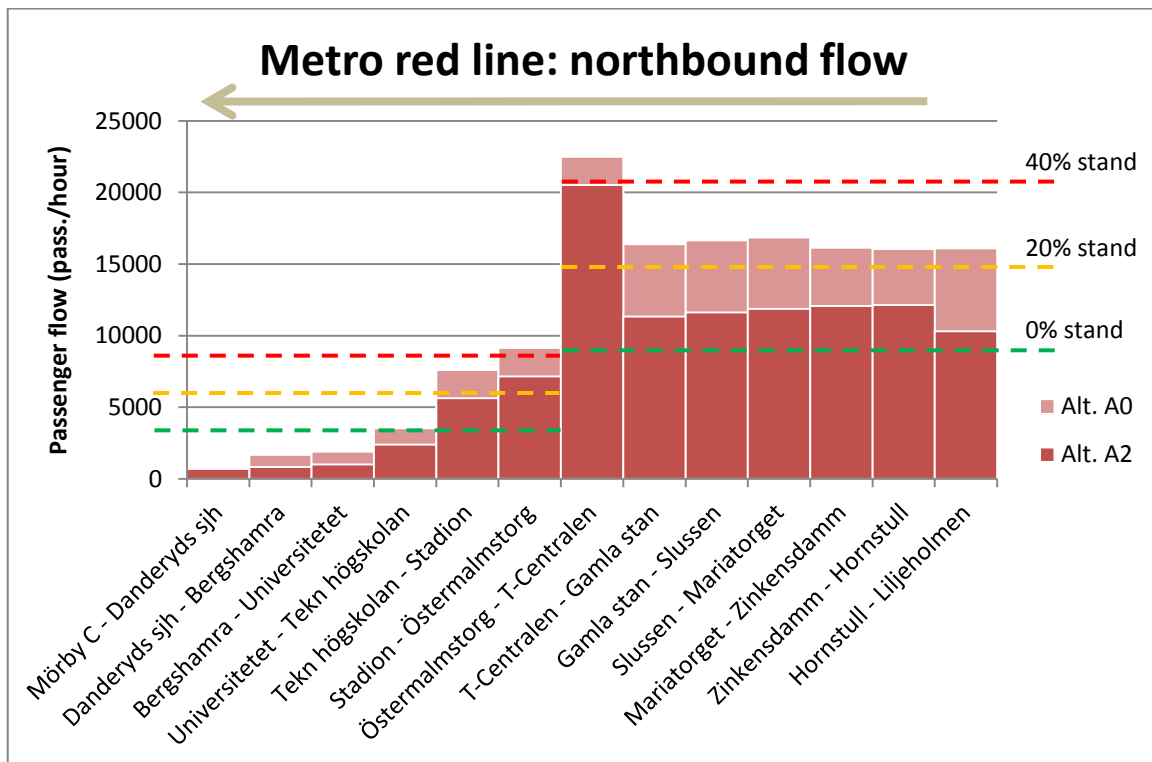


Figure 27: Northbound passenger flow on the Metro red line in 2030.

In 2017, thanks to the implementation of a new signalling system and to answer the passenger demand, the peak hour frequencies on the Metro red line will be increased to 18 trains per hour on the Mörby centrum and Norsborg branches and consequently 30 trains per hour on the central trunk. Ropsten and Fruängen branches will keep their current frequency (12 trains per hour). However, with the proposed Metro line from Danderyds sjukhus to Älvsjö, the passenger load in the morning peak hour is estimated to be higher on the Ropsten branch than on the Mörby branch.

In 2030, with 12 trains per hour, the Ropsten branch is not impacted by the new line: it has more than 40% standing passengers between Karlaplan and Östermalmstorg in all the alternatives (A0 to A4). In Figure 26 and Figure 27, the entire Mörby branch has less than 40% standing passengers in 2030 with alternative A2 (almost equivalent to A1, A3 and A4) and only 12 trains per hour. As a result, the new Metro line allows a shift of the frequencies between the two branches to have an acceptable occupancy (less than 40% standing passenger) on both branches and thus lead to a general improvement in terms of comfort on the Metro red line.

The commuter trains (Pendeltåg) will also gain some advantages from the new Metro line. The passenger load between Älvsjö and Stockholm Odenplan stations will decrease in both directions (see appendices) as the new Metro line acts as a parallel route for passengers going to Kungsholmen district.

### 5.3. Evaluation of the new travel times

The transport model described in chapter 5.1 gives a travel time matrix that is then used for the route choice calculation. As this route choice is based on the shortest path in terms of travel time, some examples of travel time savings (compared to alternative A0) are given in Table 17 for relevant origins-destinations in order to prove the utility of the proposed Metro line.

Origin-destination (O-D)	Alt. A1	Alt. A2	Alt. A3	Alt. A4
Danderyds sjukhus – Arenastaden	- 6	- 6	- 6	- 6
Danderyds sjukhus – Odenplan	- 6	- 6	- 6	- 6
Danderyds sjukhus – Fridhemsplan	- 3	- 8	- 7	- 4
Danderyds sjukhus – Hornstull	- 2	- 6	- 4	- 4
Danderyds sjukhus – Liljeholmen	- 3	- 7	- 5	- 5
Odenplan – Hornstull	- 4	- 8	- 7	- 7
Odenplan – Liljeholmen	- 2	- 6	- 5	- 5
Fridhemsplan – Hornstull	0	- 2	- 2	0
Fridhemsplan – Liljeholmen	- 2	- 9	- 9	- 4
Hornstull – Årstaberget	- 4	- 4	- 4	- 4
Hornstull – Älvsjö	- 9	- 9	- 9	- 9
Roslagsbanan – Kista	- 8	- 8	- 8	- 8
Roslagsbanan – Vällingby	- 3	- 4	- 4	- 4
Roslagsbanan – Barkarby	- 7	- 7	- 7	- 7
Roslagsbanan – Solna centrum	- 8	- 9	- 9	- 9
Kista – Skärholmen/Telefonplan	- 6	- 7	- 7	- 6

**Table 17: Example of travel time savings (in minutes) for given O-D or zones in 2030.**

One can see that alternative A2 gathers the largest travel time savings compared to other alternatives. That is why it has the largest saved hours during the morning peak hours (see Figure 28). Almost all travel times between the important nodes in the northern and western parts of Stockholm are reduced. This applies to transfer stations such as Liljeholmen or Fridhemsplan and to multi-purpose areas such as Kista or Solna.

In the different alternatives, the main travel time savings corresponds to the trips between the north-eastern part of the region (Roslagsbanan line, Norrtälje and Vaxholm municipalities) and the north-western suburbs (Vällingby, Barkarby, Solna, Kista). The connection between the Northwest (Kista, Sundbyberg) and the Southwest (Skärholmen, Telefonplan) are made faster thanks to the new link across Lake Mälaren acting as a shortcut avoiding the transfer between Metro red and blue lines in T-Centralen for the passengers.

The new stations along the proposed line also have large time savings (see Table 18) since they have an improved and fastest access to the rest of the public transport network. In the four studied alternatives, their access do not rely exclusively on buses, therefore passengers to and from these stations can travel quicker.

Origin-destination (O-D)	Alt. A1	Alt. A2	Alt. A3	Alt. A4
Järva krog – Danderyds sjukhus	0	0	0	0
Järva krog – Fridhemsplan	- 6	- 12	- 10	- 7
Järva krog – Hornstull	- 12	- 16	- 15	- 15
Järva krog – Liljeholmen	- 10	- 14	- 13	- 13
Järva krog – Årstabergr	- 5	- 8	- 7	- 7
Järva krog – Älvsjö	- 5	- 8	- 6	- 6
Hagastaden – Danderyds sjukhus	- 15	- 15	- 15	- 15
Hagastaden – Fridhemsplan	- 3	- 9	- 7	- 4
Hagastaden – Hornstull	- 10	- 14	- 13	- 13
Hagastaden – Liljeholmen	- 11	- 15	- 14	- 14
Hagastaden – Årstabergr	- 5	- 9	- 8	- 8
Hagastaden – Älvsjö	- 5	- 9	- 7	- 7
Östberga-Årstafältet – Danderyds sjukhus	- 9	- 13	- 11	- 11
Östberga-Årstafältet – Fridhemsplan	- 8	- 15	- 15	- 10
Östberga-Årstafältet – Hornstull	- 13	- 13	- 13	- 13
Östberga-Årstafältet – Liljeholmen	- 6	- 6	- 6	- 6
Östberga-Årstafältet – Årstabergr	- 2	- 2	- 2	- 2
Östberga-Årstafältet – Älvsjö	- 13	- 13	- 13	- 13

**Table 18: Example of travel time savings (in minutes) from the new stations in 2030.**

Another way to represent the travel time saving is to look at the savings in passenger-hours between the alternative A0 (without the new line) and alternatives A1 to A4 (with the new line). The passenger-hours represent how much time is spent by the passengers in the transport network.

The number of passenger-hours  $PH_k$  is calculated for each origin-destination pair  $k$  as follows:

$$PH_k = N_k * t_k$$

Where:

- $N_k$  is the number of passengers on the origin-destination pair  $k$ ,
- $t_k$  is the total travel time from origin to destination on OD pair  $k$  (in hours),

The total number of passenger-hours in the network is the sum of all passenger-hours on all the OD pairs in the public transport network.

To illustrate the differences in saved hours between the alternatives in year 2030 (see Figure 28), the number of hours spent by passengers travelling within the SL network during the morning peak hour (07:30 – 08:30) is compared between the alternative A0 and alternatives A1 to A4: that gives the number of hours saved by passengers having a shorter travel time during the morning peak hour thanks to the proposed Metro line.

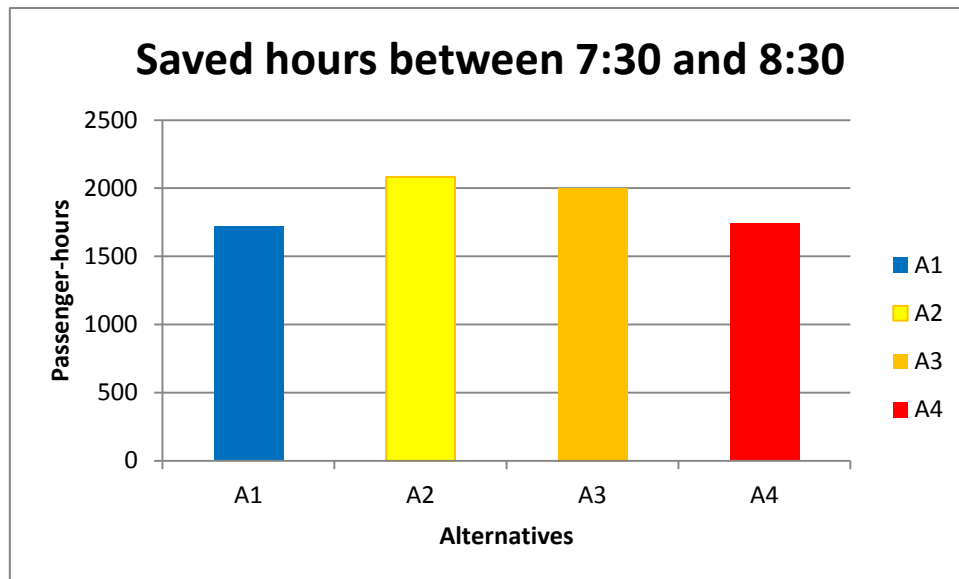


Figure 28: Saved hours in the whole SL rail network for each alternative in 2030.

### Value of time (VOT) calculations for investments

As of April 2014, according to the Swedish Transport Administration [15], the **values of time** (VOT, expressed in 2010 prices) used for the socio-economic calculations of travel time savings due to investments of new infrastructure construction are:

- $VOT_{\text{train}} = 69$  SEK per saved hour (in travel time) per passenger for commuter trips using short distance train services (commuter train, Metro, light rail train).
- $VOT_{\text{train}} = 173$  SEK per saved hour (in transfer time) per passenger for commuter trips using short distance train services (commuter train, Metro, light rail train).

Since both travel and transfer times are merged in the model's calculations, the value of time used for calculations will be  $VOT_{\text{train}} = 121$  SEK that is the average between both values. This value is valid for the first year of operation of the new infrastructure, i.e. year 2030. Then a yearly discount  $\delta = 3,5\%$  has to be applied to these values until the end of the infrastructure's economic lifetime, that is 50 years for a new railway infrastructure, i.e. until 2079.

The value of  $VOT_{\text{train}}$  for year  $i$  can be expressed as follows:

$$VOT_i = \left(1 - \frac{\delta}{100}\right) * VOT_{i-1}$$

As the population will increase by approximately 2% per year, the increase in number of passengers  $N_i$  using SL network will be assumed to be around 2% per year as well. That leads to a yearly increase in saved hours by  $\gamma = 2\%$  too.

The number of travel time saved hours  $H_i$  (during one hour) for year  $i$  can be expressed as follows:

$$H_i = \left(1 + \frac{\gamma}{100}\right) * H_{i-1}$$

To calculate the annual benefits from the travel time savings, it is assumed that the situation with the given saved hours happens 6 hours per day, 250 days a year. So the following formula can be used:

$$VOTB_i = 6 * 250 * H_i * VOT_i$$

Where:

- $VOTB_i$  is the value of time benefits for year  $i$  (in SEK),
- $H_i$  is the number of saved hours between 07:30 and 08:30 for year  $i$  (in hours),
- $VOT_i$  is the value of estimated  $VOT_{train}$  for year  $i$  (in SEK).

The value of time benefits are then summed for the whole economic lifetime of the line (50 years) and compared to the investment costs for the new Metro line. The balance gives an estimation of the relative profitability of the project from an implicit benefits (VOT) point of view (see Table 19).

		Alt. A1	Alt. A2	Alt. A3	Alt. A4
Year $i$	$N_i$ (pass./hour)	Saved hours $H_i$ between 07:30 and 08:30			
2030	174225	1722	2083	2001	1743
2079	459747	4544	5495	5280	4599
Year $i$	$VOT_i$ (SEK)	VOT benefits ( $VOTB_i$ ) per year (million SEK)			
2030	121	313	378	363	316
2079	21,1	144	174	167	146
		Sum of VOT benefits over 50 years (billion SEK)			
		10,9	13,2	12,6	11,0
		New line's construction costs (billion SEK)			
		22,1	20,3*	21,2	20,7
		Economic balance (billion SEK)			
		-11,2	-7,1	-8,6	-9,3

**Table 19: VOT balance estimation over the new line's economic lifetime (2030-2079).**

One can point out that the benefits from the values of travel time savings are lower than the construction costs of the proposed Metro line for all the alternatives, which makes the project economically not profitable. This is due to the fact that not all the travellers are taken into account as well as the modal shift from car to Metro that would decrease congestion and travel time on roads and add more passengers saving time using the public transport system.

The alternative A2 is however the most interesting since it has the lowest investment costs and the highest benefits from the value of travel time savings calculations. More detailed calculations will be needed in further works to get better results. A solution is also to decrease the investment costs by, for example, buying half of the Metro vehicles needed for the line as the demand will not be high enough to use long trains (140 metres) in the first years of operation. By doing so, the new investment cost would be **19 billion SEK** instead of 20,3 billion SEK for alternative A2.

### Tickets and subsidies calculations for operation

The new Metro line will also increase the operating costs for the Metro operator company. These so called “running costs” have to be covered by the tickets revenues and the subsidies from Stockholm region.

In 2012, the average SL's revenues were  $NTT_{2012} = 28,06$  SEK per trip divided into two sources:  $TR_{2012} = 14,14$  SEK per trip from ticket sales and  $OS_{2012} = 13,92$  SEK per trip from Stockholm County's subsidies [12].

As the average ticket prices and subsidies from Stockholm County increased by approximately 2% per year over the period 2008-2012, the increase in ticket revenues per trip  $TR_i$  and operating subsidies per trip  $OS_i$  will be assumed to be around 2% per year as well. That leads to a yearly increase of the net turnover per trip  $NTT_i$  by  $\alpha = 2\%$  too.

The annual net turnover per trip  $NTT_i$  for year  $i$  can be expressed as follows:

$$NTT_i = TR_i + OS_i = \left(1 + \frac{\alpha}{100}\right) * (TR_{i-1} + OS_{i-1}) = \left(1 + \frac{\alpha}{100}\right) * NTT_{i-1}$$

As seen before, the increase in number of passengers using SL network will be assumed to be around  $\gamma = 2\%$  per year as well. The number of trips done in the rail network  $N_i$  during one morning rush hour (07:30 – 08:30) for year  $i$  can be expressed as follows:

$$N_i = \left(1 + \frac{\gamma}{100}\right) * N_{i-1}$$

To calculate the annual benefits from the tickets and subsidies, it is assumed that the situation with the given trips happens 6 hours per day, 250 days a year. So the following formula can be used:

$$NTTB_i = 6 * 250 * N_i * NTT_i$$

Where:

- $NTTB_i$  is the net turnover benefits for year  $i$  (in SEK),
- $N_i$  is the number of passengers using SL network between 07:30 and 08:30 for year  $i$ ,
- $NTT_i$  is the value of estimated net turnover per trip for year  $i$  (in SEK).

The net turnover benefits are then summed for the whole economic lifetime of the line (50 years) and compared to the operating costs for the new Metro line. The balance gives an estimation of the relative profitability of the project from an operational point of view, using “running costs” (see Table 20).

			Alt. A1	Alt. A2	Alt. A3	Alt. A4
Year i	N <sub>i</sub> (pass./hour)	NTT <sub>i</sub> (SEK)	NTT benefits (NTTB <sub>i</sub> ) per year (billion SEK)			
2030	174225	40,08	10,5			
2079	459747	105,75	72,9			
			Sum of NTT benefits over 50 years (billion SEK)			
			<b>1620</b>			
			Total operating costs over 50 years (billion SEK)			
			<b>1360</b>			
			<b>Economic balance (billion SEK)</b>			
			<b>+260</b>			

**Table 20: Operating balance estimation over the new line's economic lifetime (2030-2079).**

One can point out that the benefits from the net turnover are higher than the operating costs of Stockholm County's rail network, which makes the project economically profitable. The alternatives are on an equal step since the differences in operation costs for the new Metro line are negligible compared to the operating costs of the total network. But the operation costs for alternative A1 would be thus higher since the trains have to run a higher distance compared to the other alternatives. Alternative A2 would have the lowest operating costs.

Note: The operating costs do not include the bus operation costs since the study do not take into account the entire bus network. The economic balance should therefore be read with caution.

#### 5.4. Evaluation of the occupancy rate

In this thesis, the occupancy rate is defined as the percentage of seated passengers in the trains, trams and buses in the studied network. It is calculated for each stretch  $k$  as follows:

$$OR_k = \frac{PF_k}{OC_k}$$

Where:

- $OR_k$  is the occupancy rate on stretch  $k$ ,
- $PF_k$  is the passenger flow on stretch  $k$  (in passengers/hour),
- $OC_k$  is the maximum offered seating capacity on stretch  $k$  (in passengers/hour).

The passenger flows were determined in chapter 5.2. The maximum offered capacity is determined from the vehicle capacity and the frequencies on each stretch of a public transport line.

	<b>Pendeltåg</b>	
<b>Train characteristics</b>	<b>1 x X60</b>	<b>2 x X60</b>
Length (m)	106,5	213
Width (m)	3,26	3,26
Max speed (km/h)	160	160
Number of seats	374	748
Standing passengers	526	1052
Total vehicle capacity	900	1800
<b>Frequencies / headways</b>	<b>1 x X60</b>	<b>2 x X60</b>
2 trains per hour / 30 min.	1800 seats/h	3600 seats/h
3 trains per hour / 20 min.	2700	5400
4 trains per hour / 15 min.	3600	7200
5 trains per hour / 12 min.	4500	9000
6 trains per hour / 10 min.	5400	10800
8 trains per hour / 7,5 min.	7200	14400
10 trains per hour / 6 min.	9000	18000
12 trains per hour / 5 min.	10800	21600
15 trains per hour / 4 min.	13500	27000
18 trains per hour / 3,3 min.	16200	32400
20 trains per hour / 3 min.	18000	36000
24 trains per hour / 2,5 min.	21600	43200
30 trains per hour / 2 min.	27000	54000

**Table 21: Example of offered seating capacity for the X60 commuter trains.**

In the algorithm, a matrix is created gathering the occupancy rates for all stretches. Then, one can calculate the average occupancy rate on the whole public transport network by using the following formula:

$$\widehat{OR} = \frac{\sum_{k=0}^n OR_k * PF_k}{\sum_{k=0}^n PF_k}$$

In Figure 29, the average congestion rates are compared between alternatives A0 to A4.

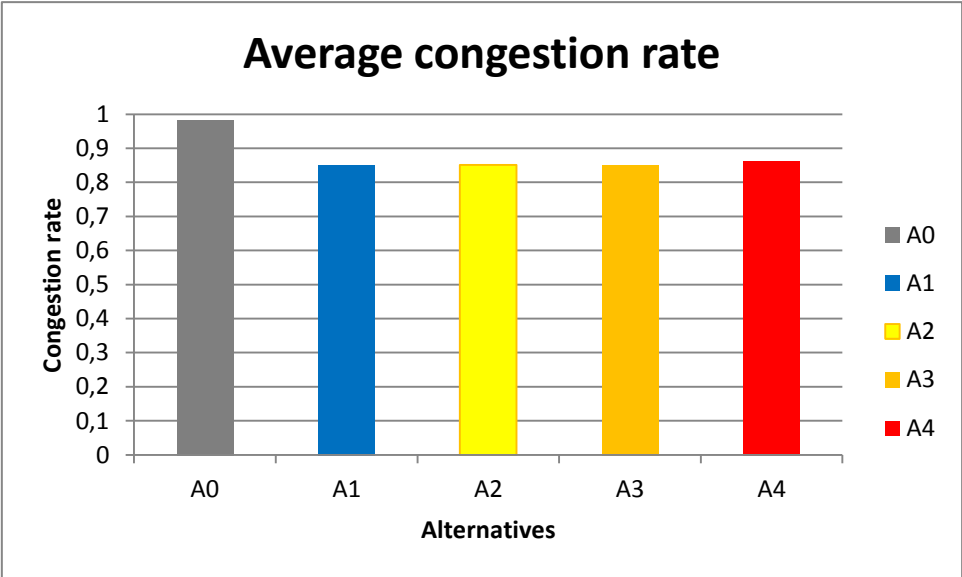


Figure 29: Average congestion rate in the whole network for each alternative.

The suggested Metro line has a positive impact on the average occupancy rate (from 0,98 to ca. 0,85) in the whole studied network compared to the alternative A0. It does not reduce the occupancy everywhere with the same factor since some stretches located far from the new Metro line are not impacted by the opening of the line (Lidingöbanan line for instance). On the other hand, the Metro red line has the highest drop in congestion rate since the new Metro line acts as a parallel connection between Danderyds sjukhus and Liljeholmen stations.

## 6. Conclusion

### 6.1. Summary

This thesis was a pre study about the feasibility of building a new North-South Metro line in Stockholm region based on the future development areas and to cope with an increasing public transport demand.

The proposed new Metro line runs from Danderyds sjukhus station to Älvsjö station via Bergshamra, Järva krog, Arenastaden, Hagastaden, Odenplan, Hornstull, Liljeholmen, Årstaberget och Östberga-Årstafältet in order to serve the main transfer points in the city and the developing districts mainly located along a North-South axis.

Four alternative stretches are located between Odenplan and Hornstull stations: via Stadshagen and Thorildsplan (A1), via Fridhemsplan (A2), via Sabbatsberg and Fridhemsplan (A3) and via Sabbatsberg and Rådhuset (A4). All these alternatives have a positive impact on the network compared to the initial situation as it creates new possibilities and it prevents from the network's saturation. However, it appears that alternative A2 has the highest benefits in terms of travel time savings and decrease in passenger load.

The passengers coming from Danderyd municipality and the Northeast with the Roslagsbanan train will decrease their travel time towards Solna municipality and the western parts of Stockholm City (Kista, Vällingby and at some extent Kungsholmen). The bus line number 4 will also decrease its occupancy rate between Odenplan and Hornstull as the new Metro line will take the "long distance" passengers (those travelling between the main nodes), granting a more local utility to bus line 4 (stops between the main nodes).

With alternative A2, the number of passengers transferring in T-Centralen / Stockholm Central station decreases also sharply compared to alternative A0: from 52000 to 40000 passengers per hour. This will reduce the congestion at the gates and in the corridors of this station that is the most crowded in the network. Most of the transfers are shifted to Fridhemsplan and Liljeholmen stations. With the proposed line, the two stations will gain respectively 8000 and 6000 extra transferring passengers per hour during the morning peak hour. As a consequence, an increase in the corridor capacity has to be carried in order to cope with the new passengers.

Concerning the costs-benefits analysis (CBA), the benefits from ticket sales and subsidies are high but they will depend on the evolution of both passengers' finances and the County's finances in the future. Since the number of passenger is assumed to increase constantly, this leads also to high margins.

The benefits from the value of travel time savings (VOT) are indirect since the profits from VOT are not going to the transport companies or administrations; they correspond to benefits created by passengers working mainly outside the transport sector. However, they are relatively high, especially for alternatives A2 and A3 (respectively: 13,2 and 12,6 billion SEK). These benefits mean that the project has positive impacts on the society in Stockholm region.

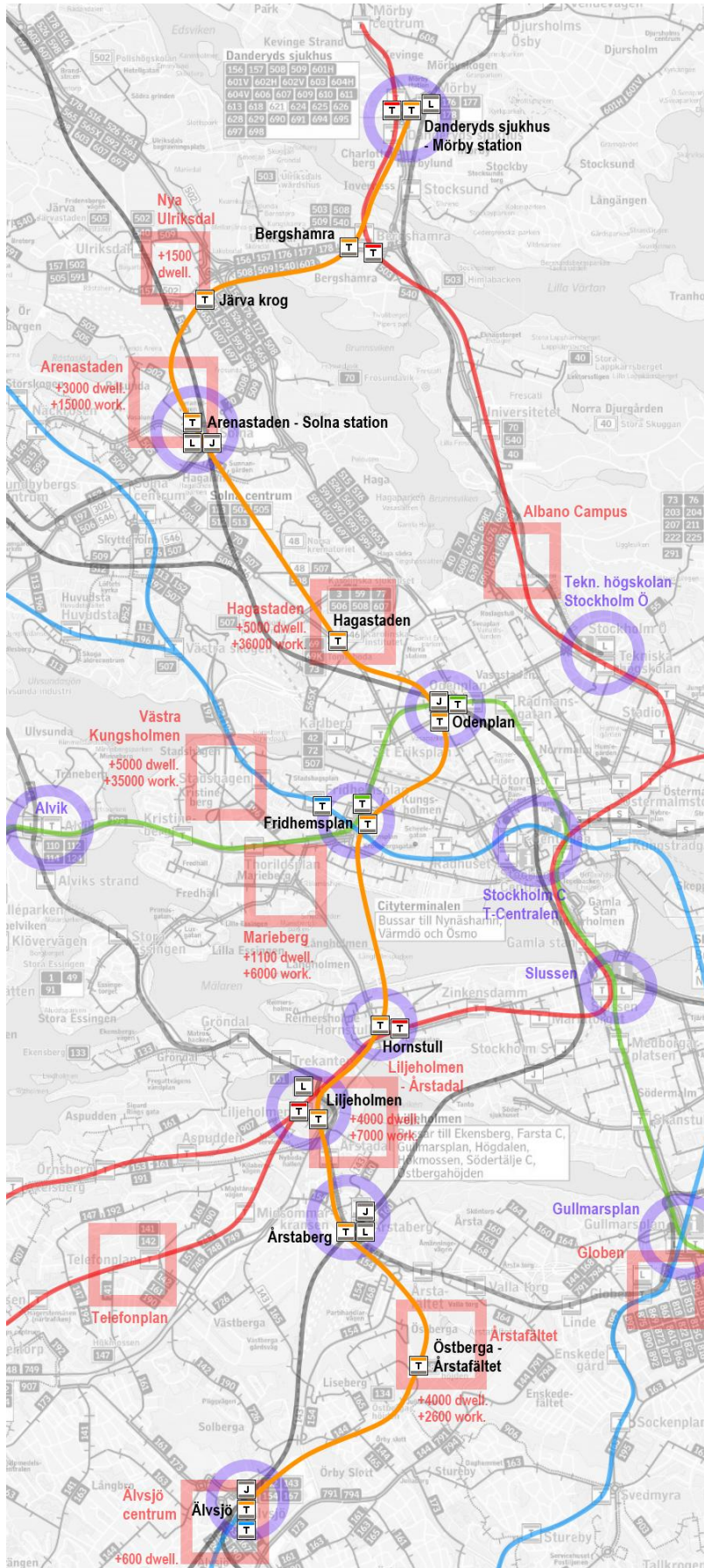


Figure 30: Final aspect of the suggested Metro line with alternative A2, horizon 2030. Background and logos: SL.

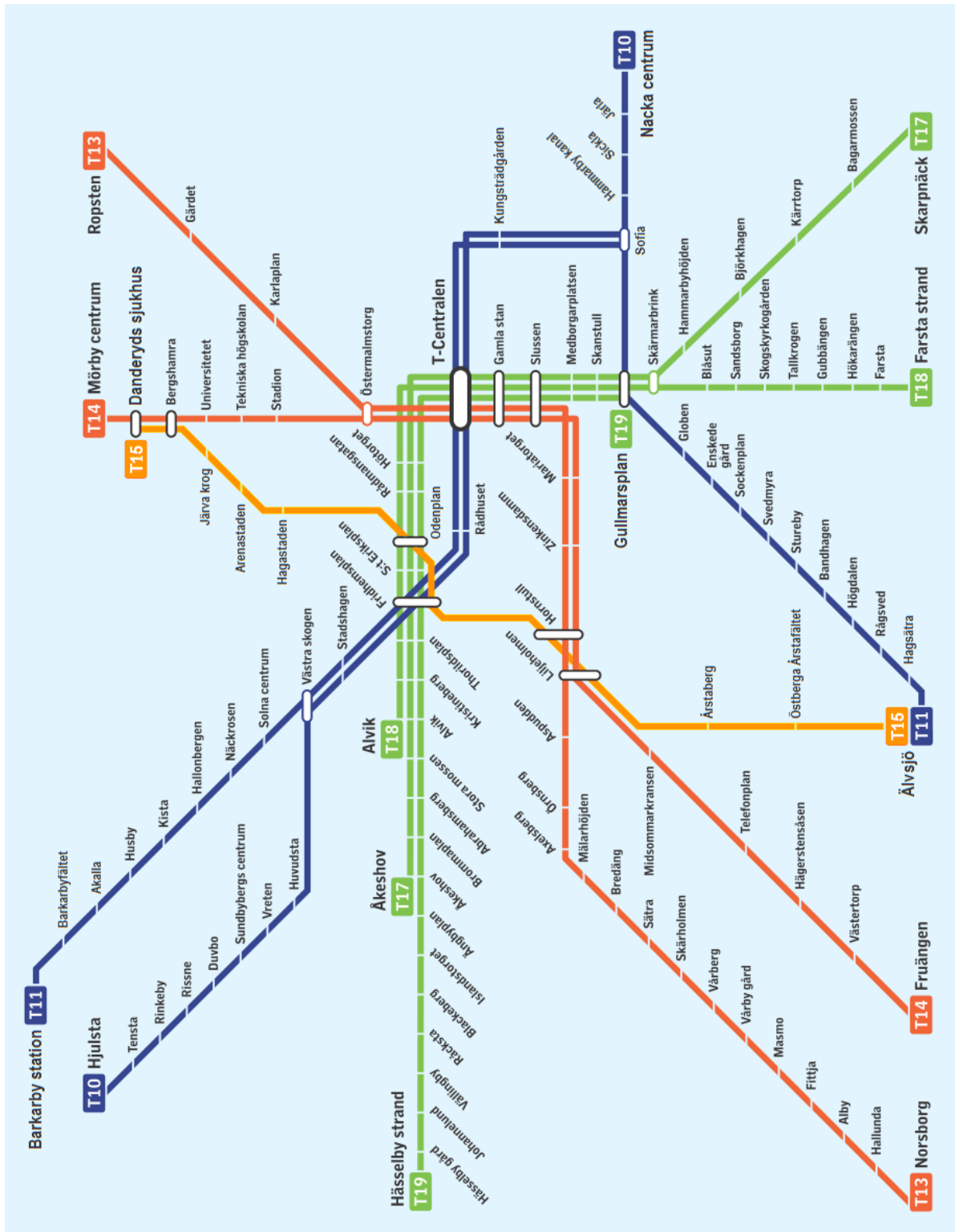


Figure 31: Example of how Stockholm’s Metro system could look like in 2030. Background and logos: SL.

## 6.2. Recommendations

The results from this thesis show a clear need in opening a new North-South high capacity link in the public transport network. The comparison between the four studied alternatives points out that **alternative A2**, going from Danderyds sjukhus to Älvsjö station directly via Odenplan, Fridhemsplan and Hornstull, is the most cost-efficient compared to the benefits for passengers on the entire network. It reduces the average congestion rate and the average passengers' travel time. It is also the cheapest alternative in terms of estimated construction and operation costs.

The opening of the new Metro line allows also more trains (18 trains per hour) on the Ropsten branch than on the Mörby centrum branch (12 trains per hour) on the Metro red line in order to cope with the expansion of Gärdet/Värtahamnen and Norra Djurgårdsstaden districts. This situation leads to a more acceptable crowding in the trains (less than 40% standing passengers) on both branches compared to the situation in 2017 with 12 trains from Ropsten and 18 trains from Mörby centrum in the morning peak hour.

The model created and used in this thesis is a simple model that can be used in really first steps of a traffic analysis process in order to develop new transport infrastructures. By comparing with existing models (mainly using *VISUM*), the results are quite similar thanks to the calibration step done in the beginning of the research.

The effects of the opening of the suggested Metro line on its environment could be analysed in order to evaluate if there is an increase of public transport users due to a modal shift from car to the new line [16].

## 6.3. Further analyses

SL (Greater Stockholm Public Transport) uses clearly defined models and routines to analyse passenger demand and passenger flows: *Sampers/Sims* model for passenger demand (based on demographic data) and *EMME* (or *VISUM*) software for route assignment. The model created in this thesis does not use SL's routines and does not include all the bus lines in SL network. Therefore further studies with SL's models will be needed to have detailed and more accurate results about the effects of the proposed line in the existing network.

Moreover, all travel time calculations used in this thesis do not include time multipliers and transfer penalties since calculations are based on "real times" and not "perceived times". A new analysis should be done with these factors and penalties, as well as better waiting time estimations.

The passenger path choices were only based on the shortest way using Dijkstra algorithm. The next analyses should include factors such as congestion sensibility and congestion minimisation. They should also include a real mode choice process based on car ownership and household incomes as well as the road network and the extensive public transport network (all bus and boat lines).

The new Metro line infrastructure will need further calculations to clearly evaluate the feasibility of building tunnels, bridges, stations and depots both technically and financially. As a result, the socio-economic study will be more accurate and could be presented to the decision makers at SL and at the Stockholm County Council (SLL). Benefits from ticket sales and regional subsidies could finance the construction of the new Metro line.

All the further analyses about this project will depend on the decision makers' choice and other political decisions [17] to continue or not the studies for the North-South line suggested in this report.



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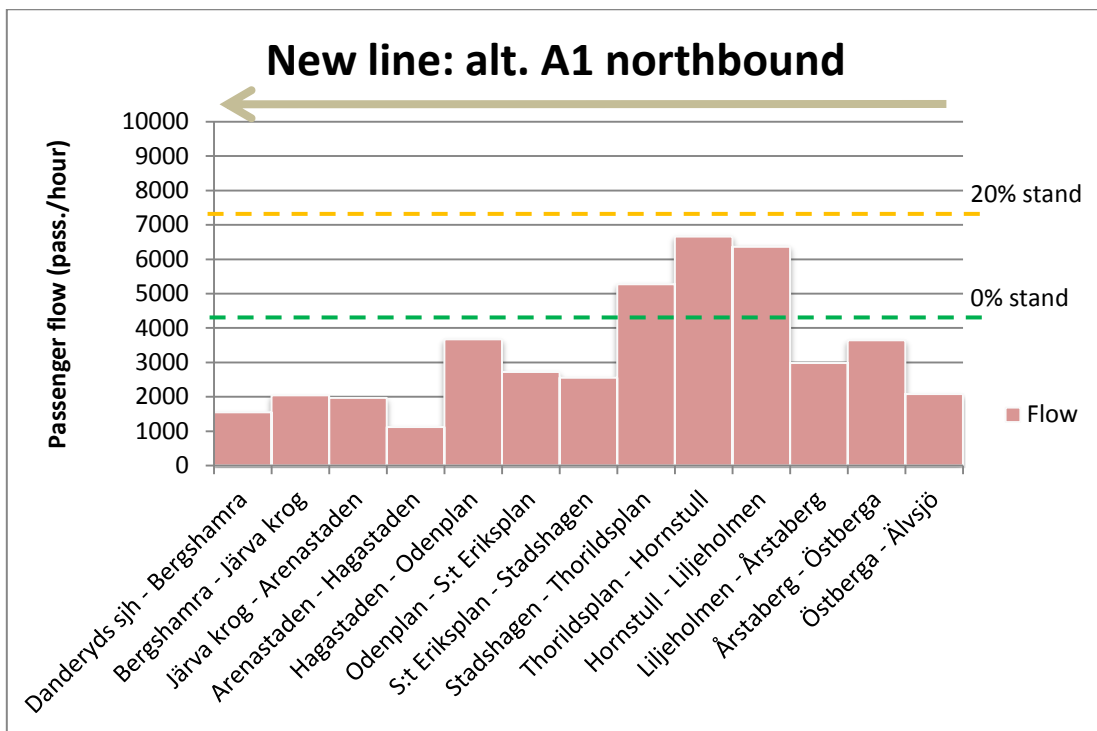
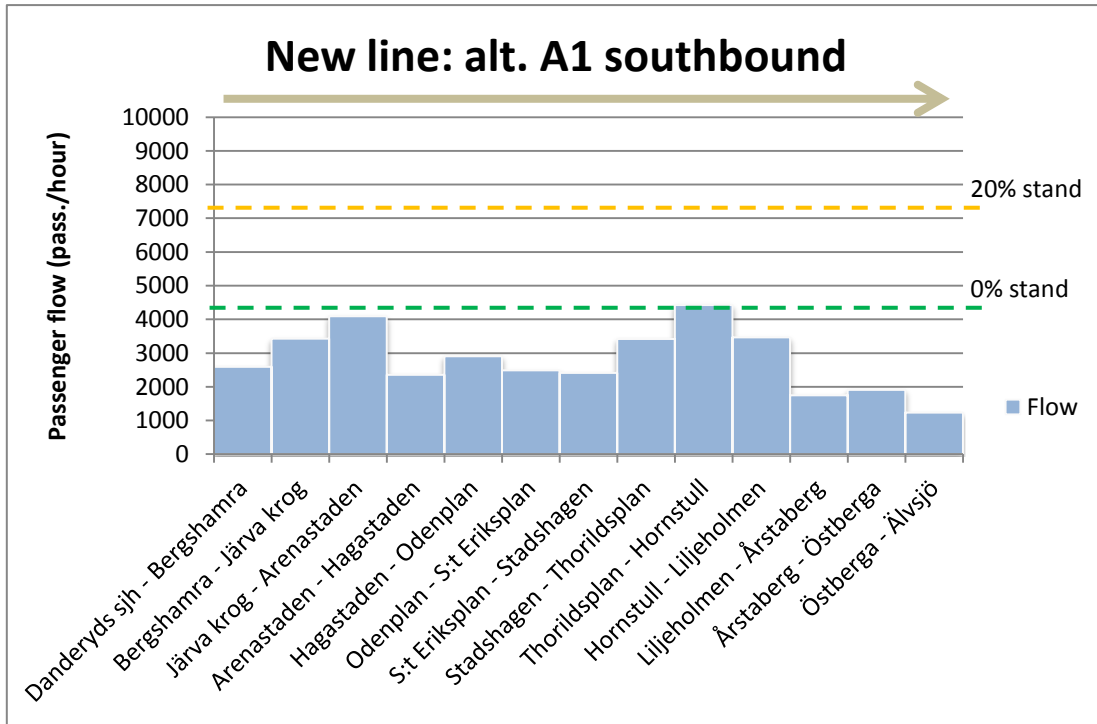
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## Appendices

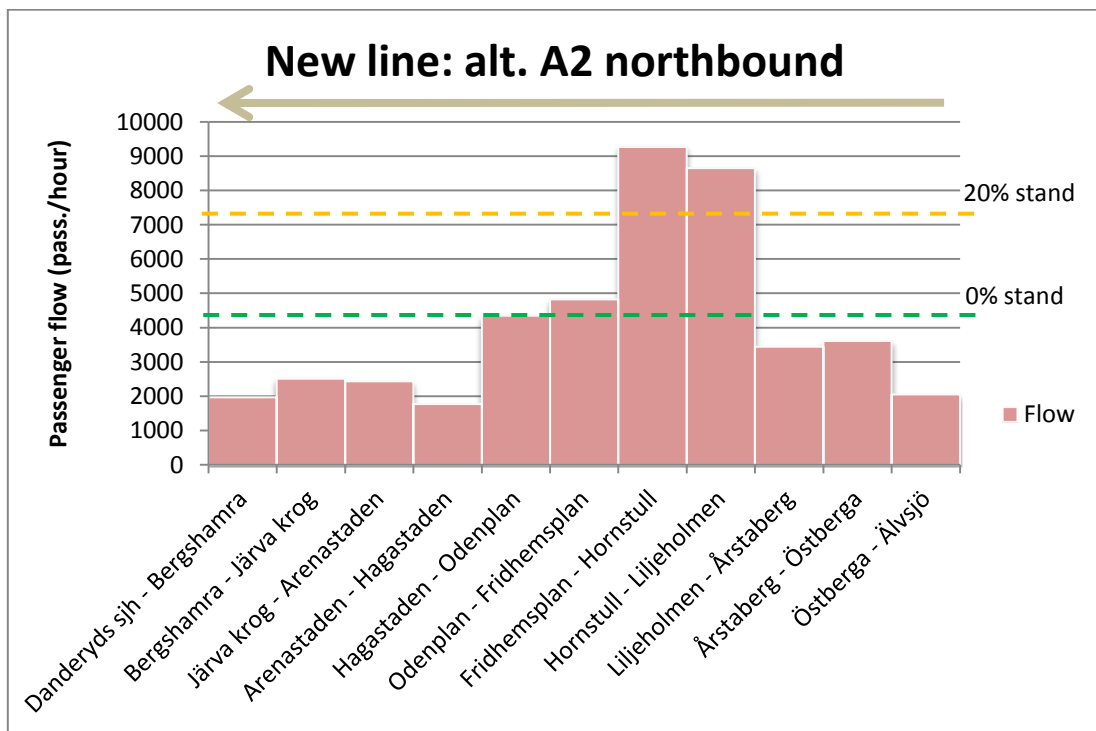
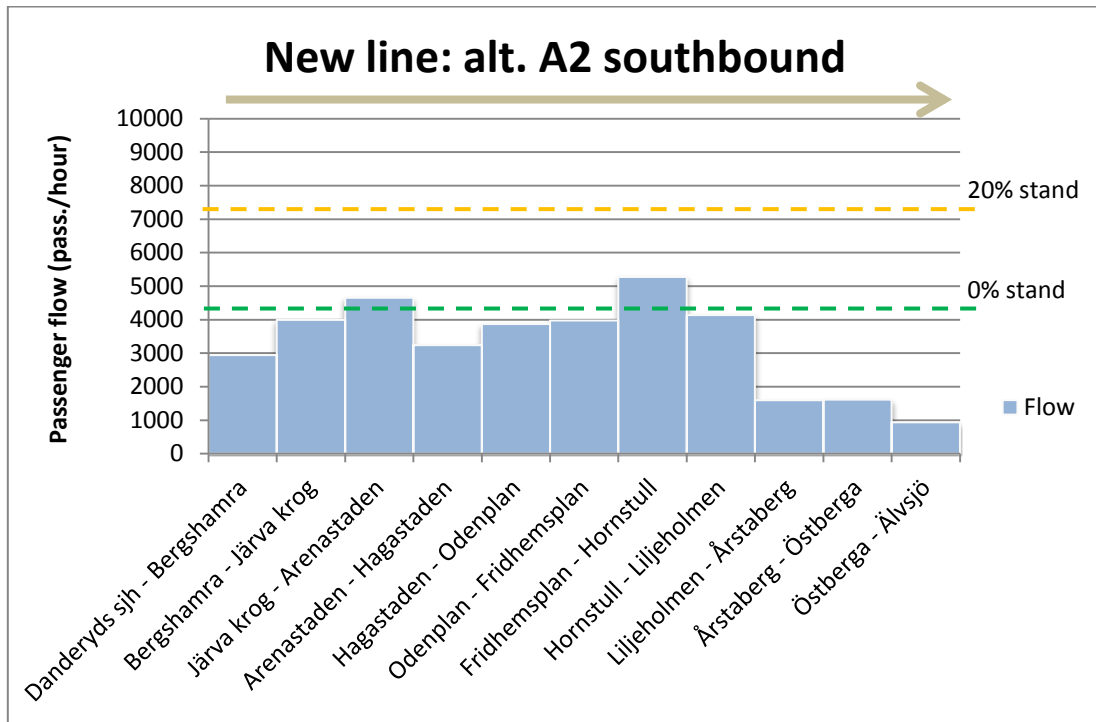
### Passenger flows for the new Metro line with alternative A1 in 2030

Simulation made with a 4-minute headway in the morning peak hour between 07:30 and 08:30.



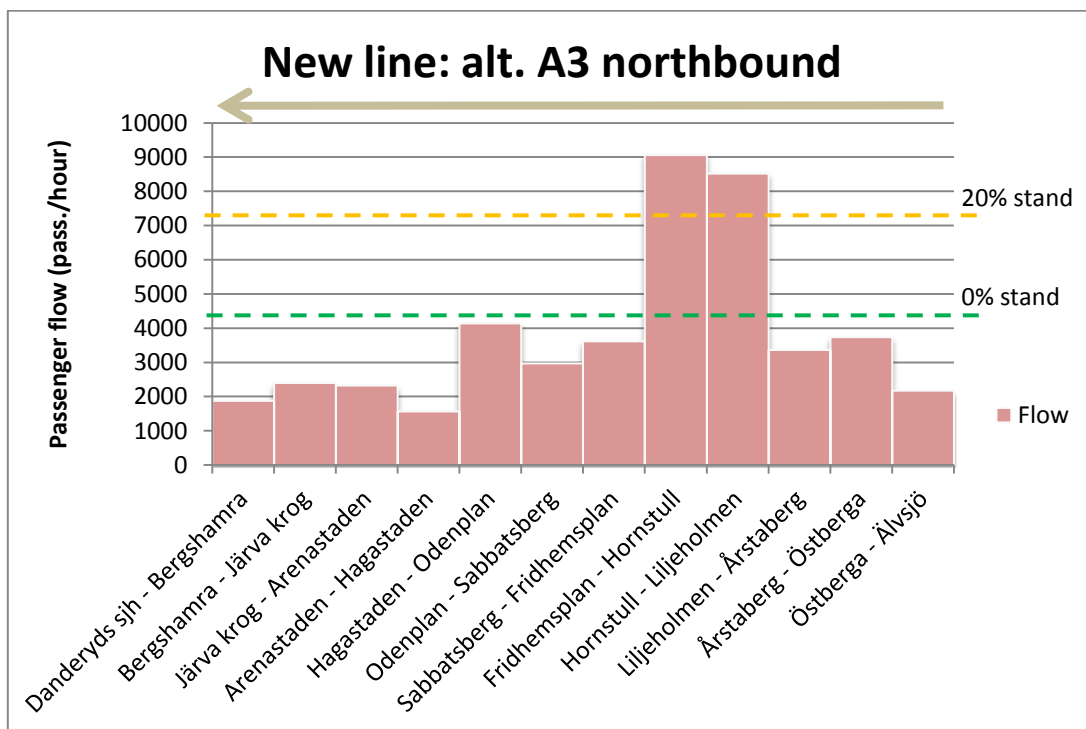
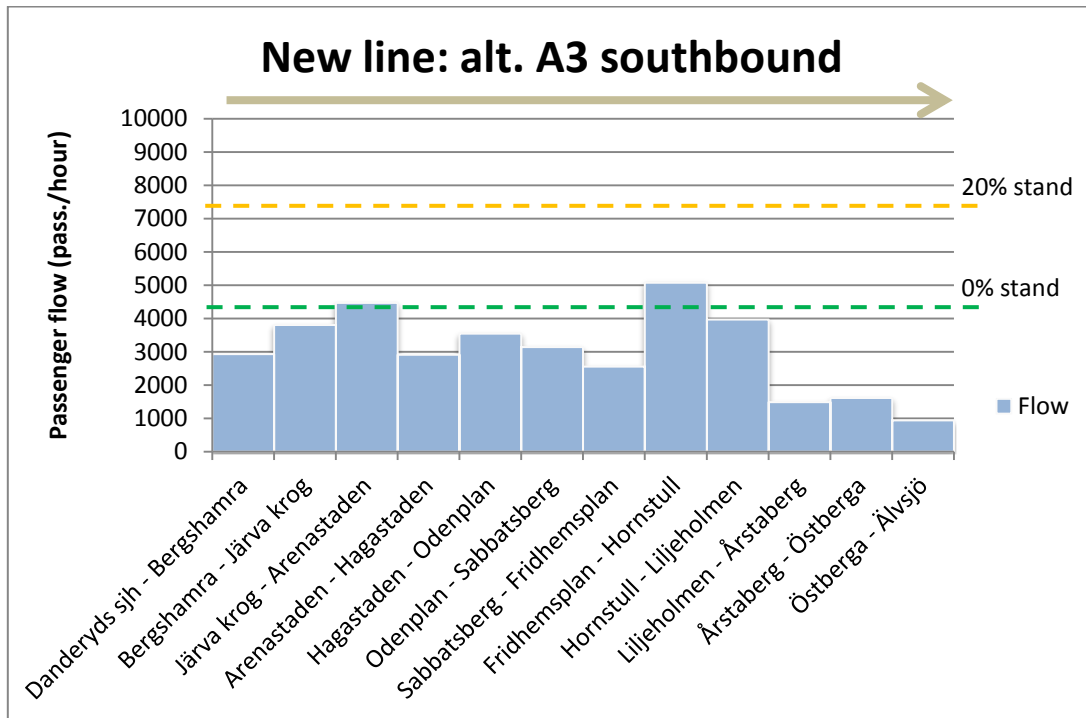
### Passenger flows for the new Metro line with alternative A2 in 2030

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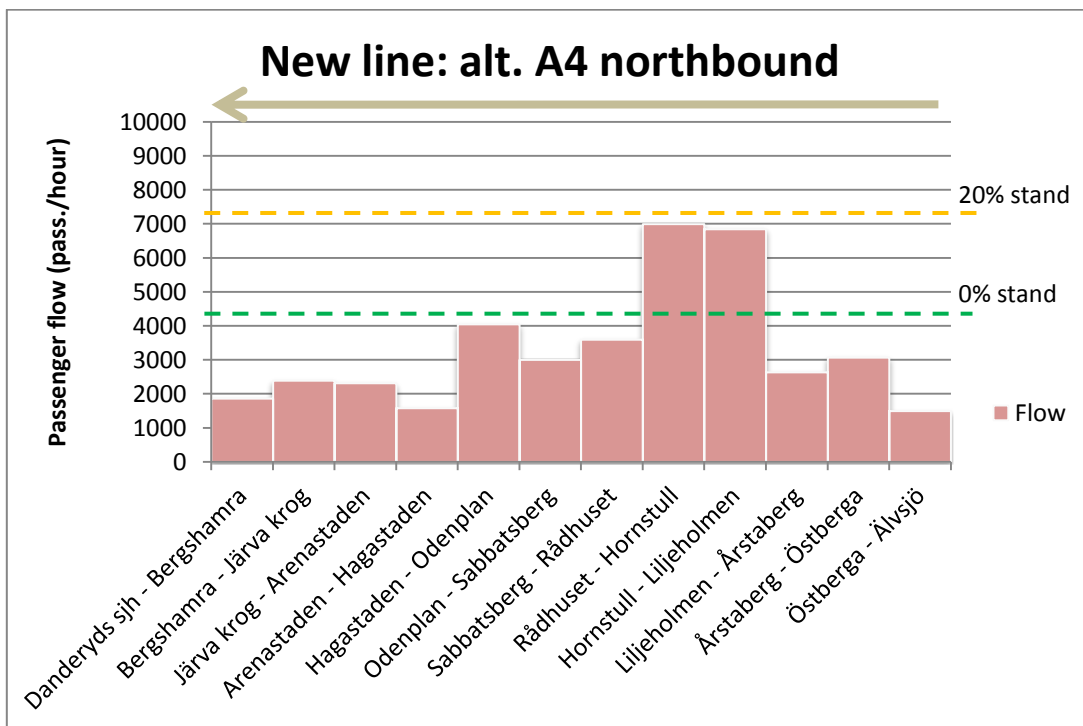
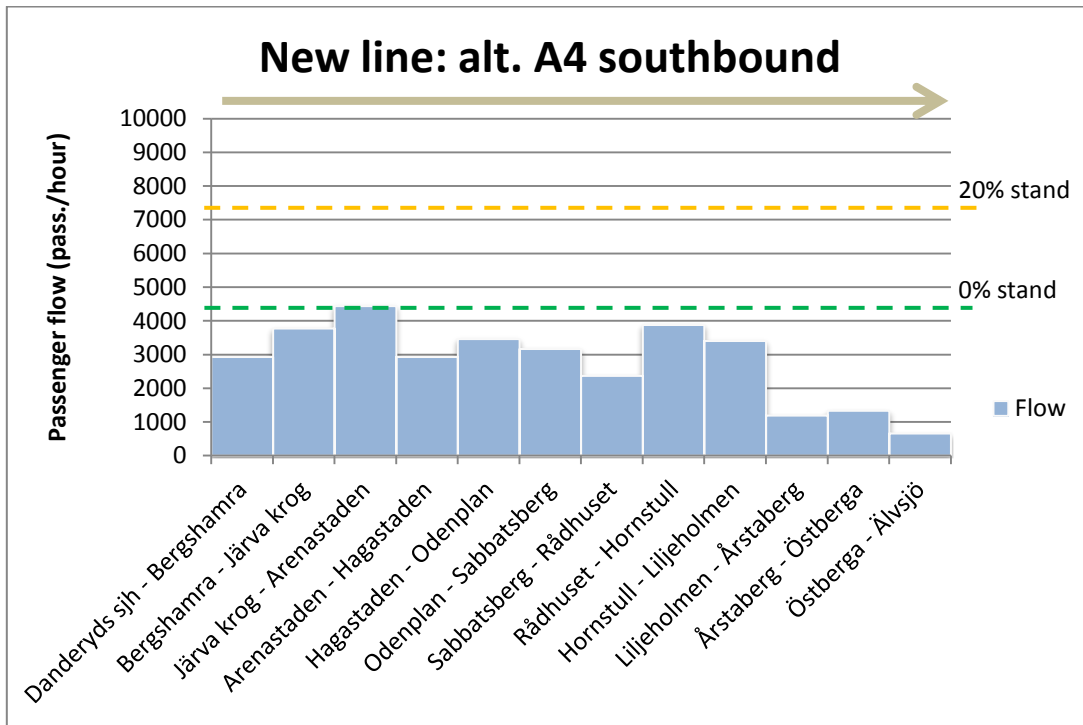
**Passenger flows for the new Metro line with alternative A3 in 2030**

Simulation made with a 4-minute headway in the morning peak hour between 07:30 and 08.30.



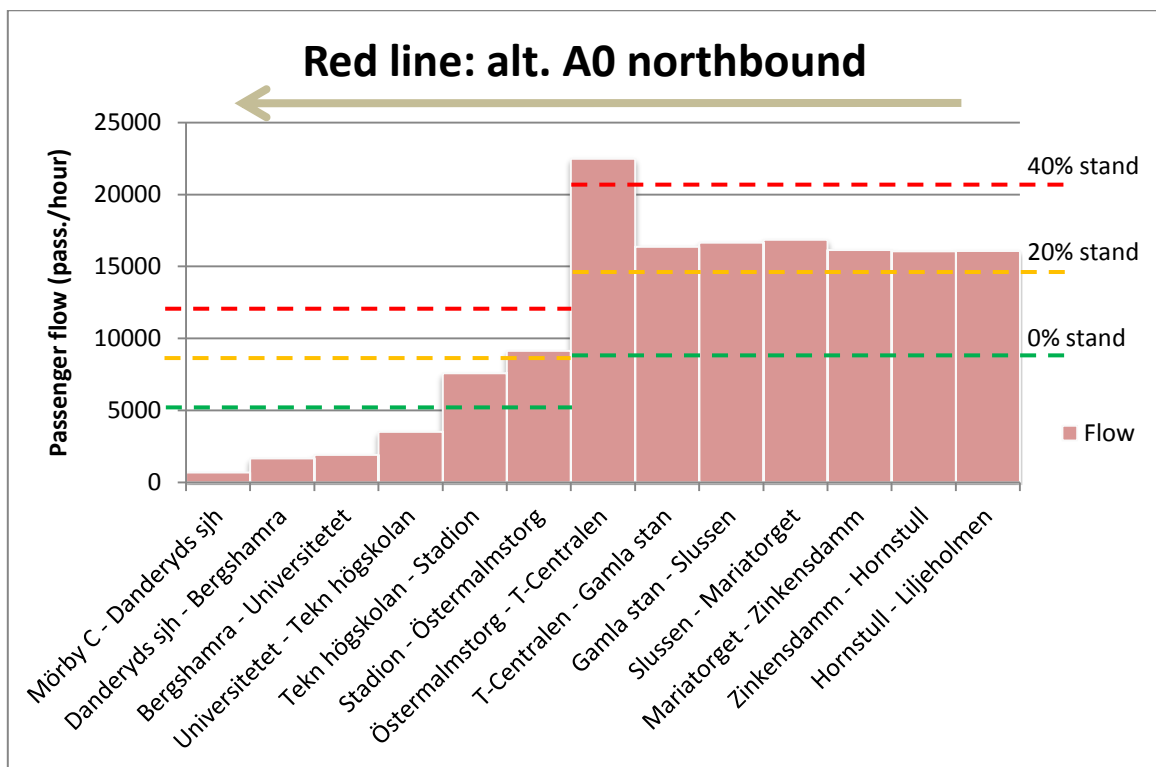
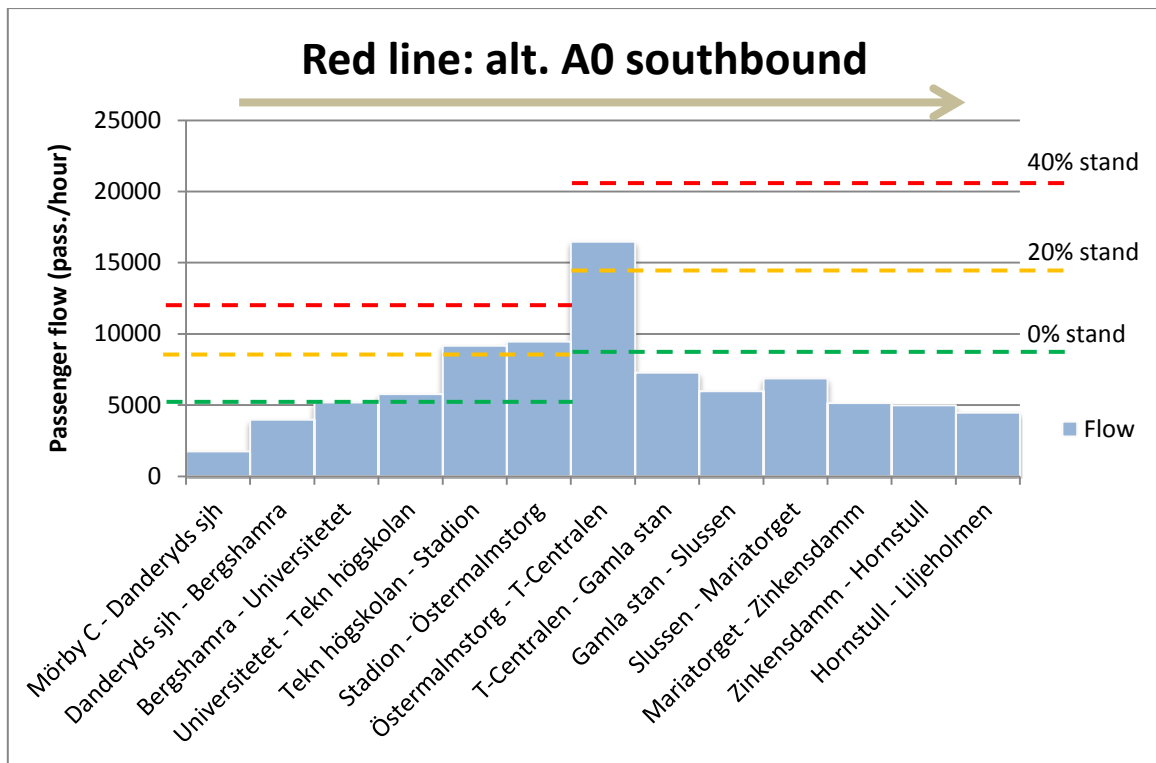
### Passenger flows for the new Metro line with alternative A4 in 2030

Simulation made with a 4-minute headway in the morning peak hour between 07:30 and 08.30.



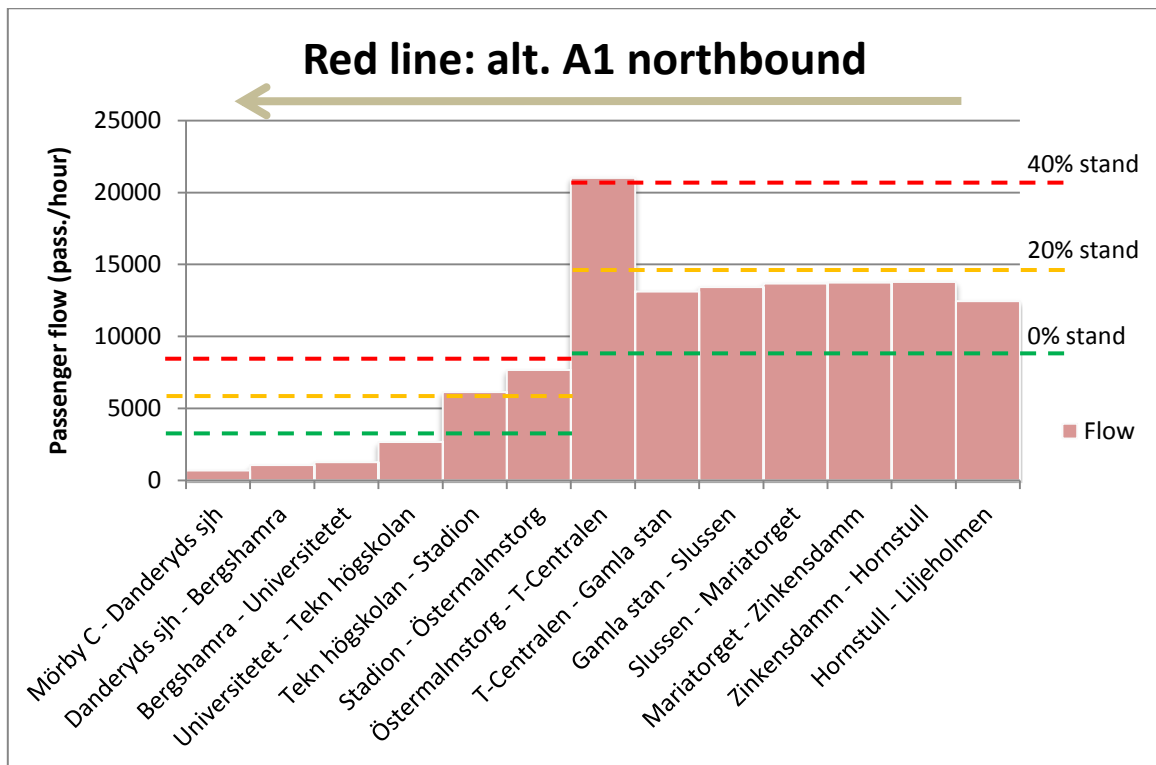
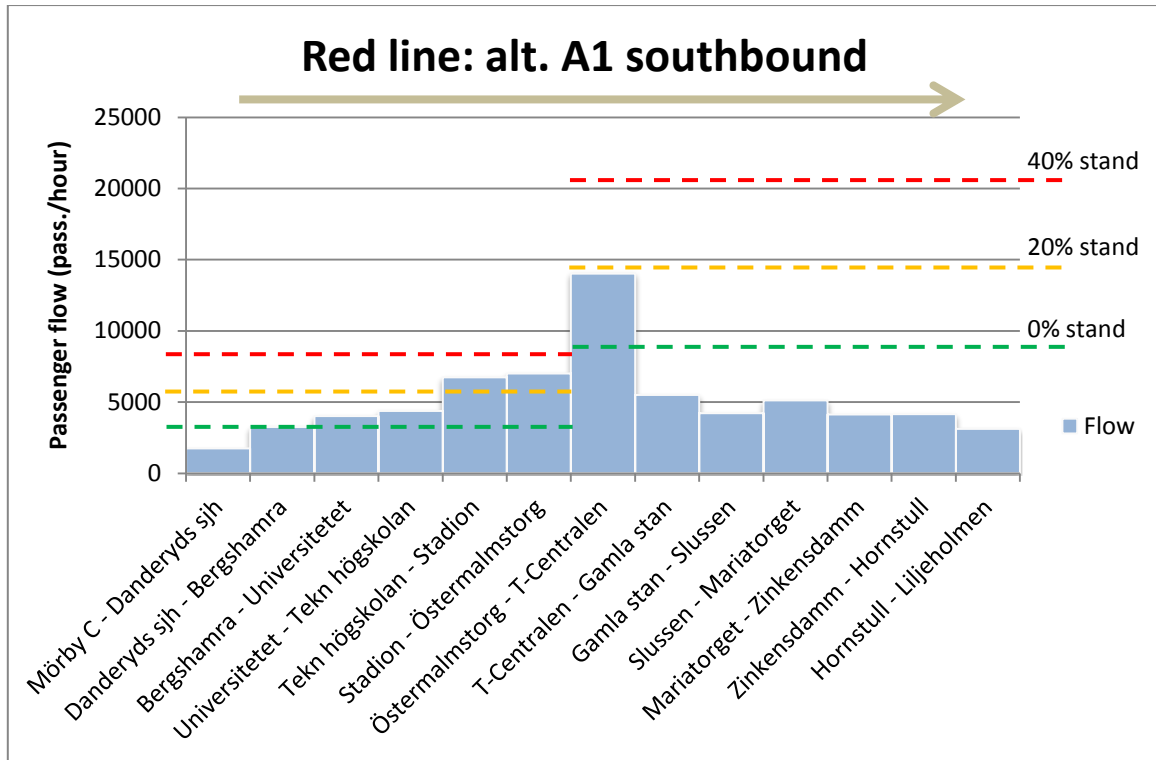
### Passenger flows for the Metro red line with alternative A0 in 2030

Simulation made with a 3,3-minute headway for Mörby C – Östermalmstorg and a 2-minute headway for Östermalmstorg – Liljeholmen in the morning peak hour between 07:30 and 08:30.



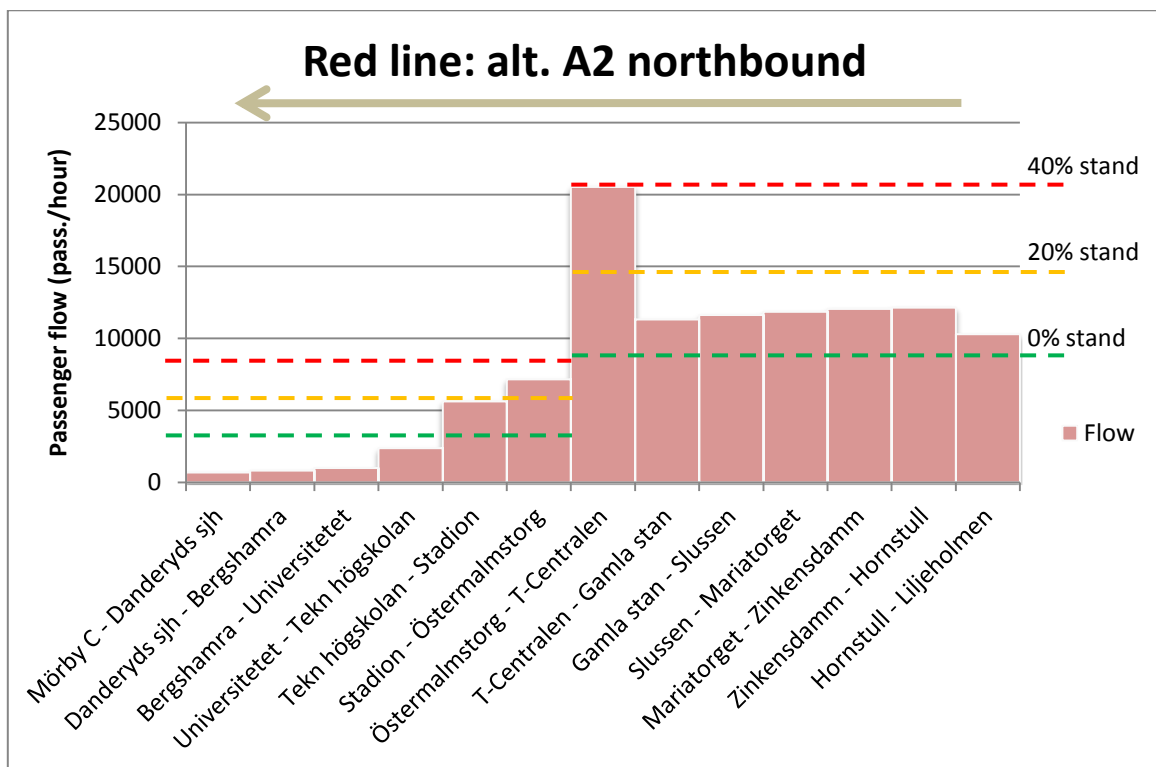
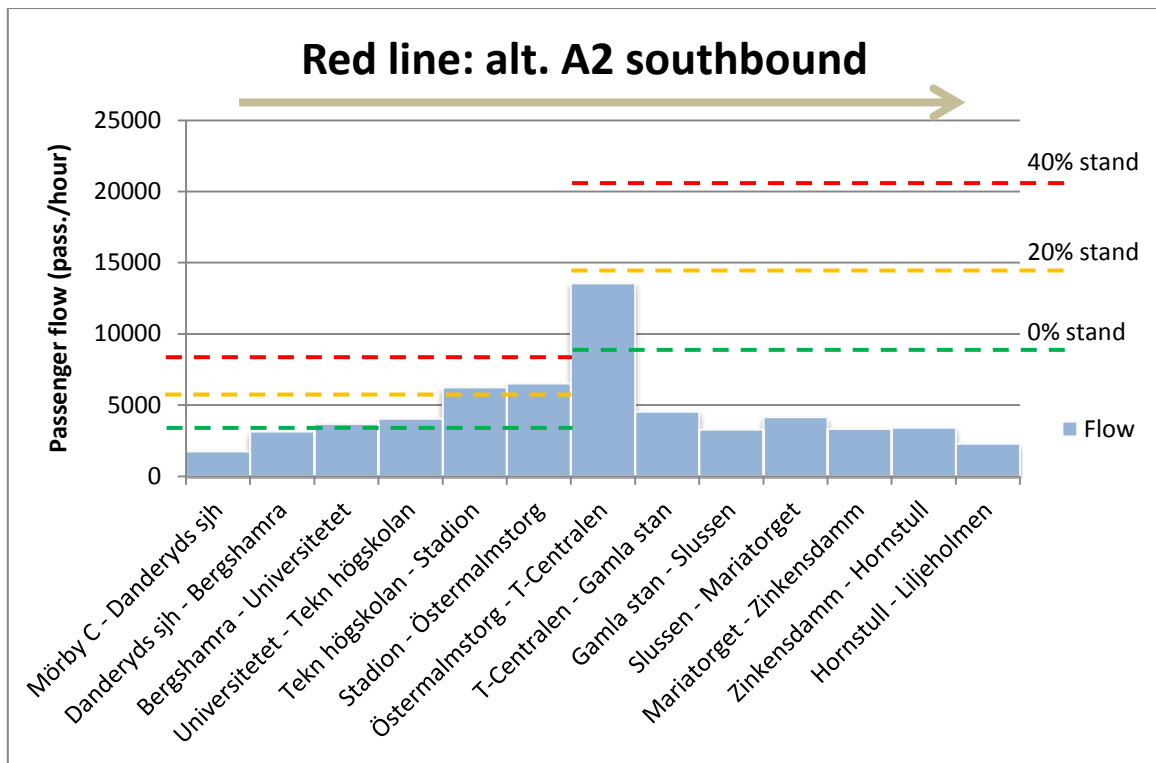
### Passenger flows for the Metro red line with alternative A1 in 2030

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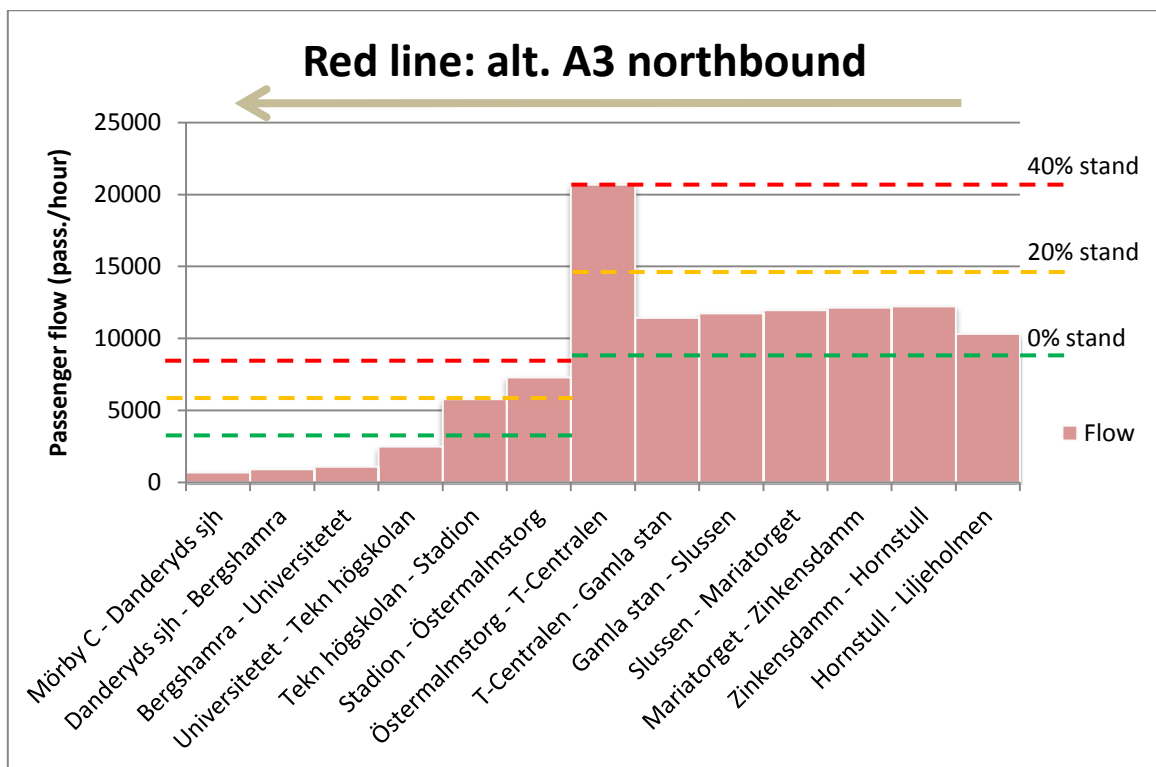
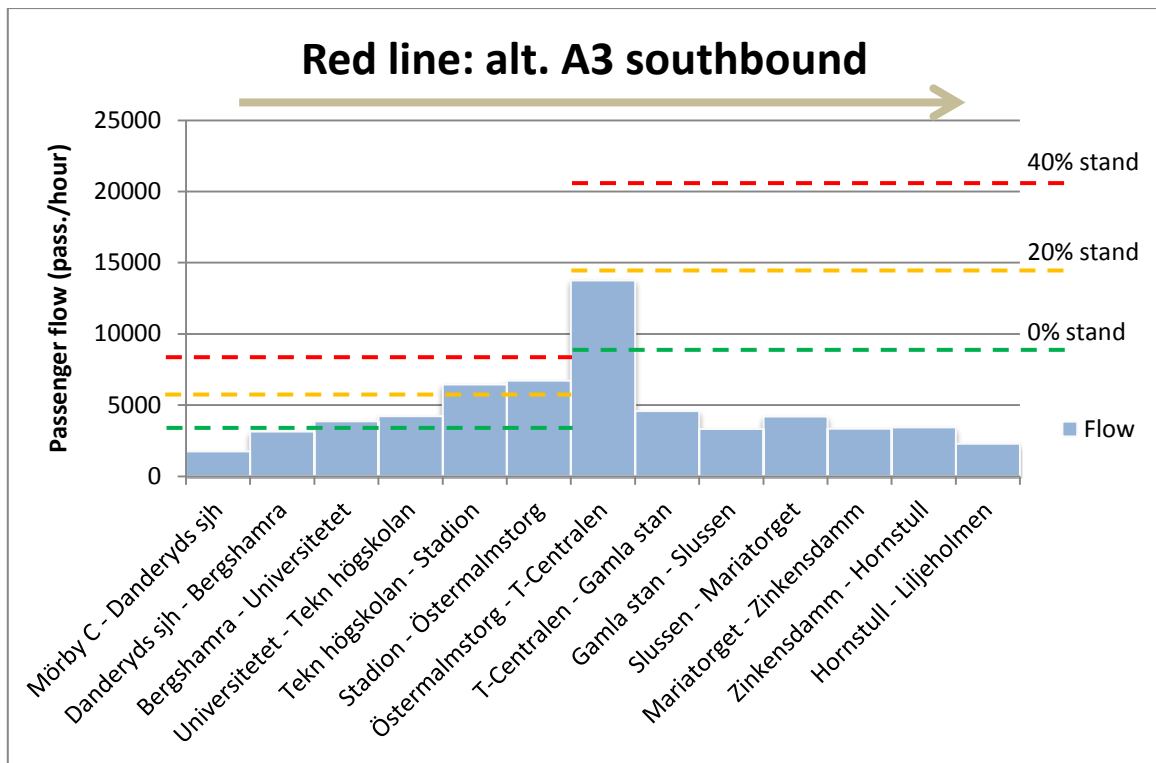
### Passenger flows for the Metro red line with alternative A2 in 2030

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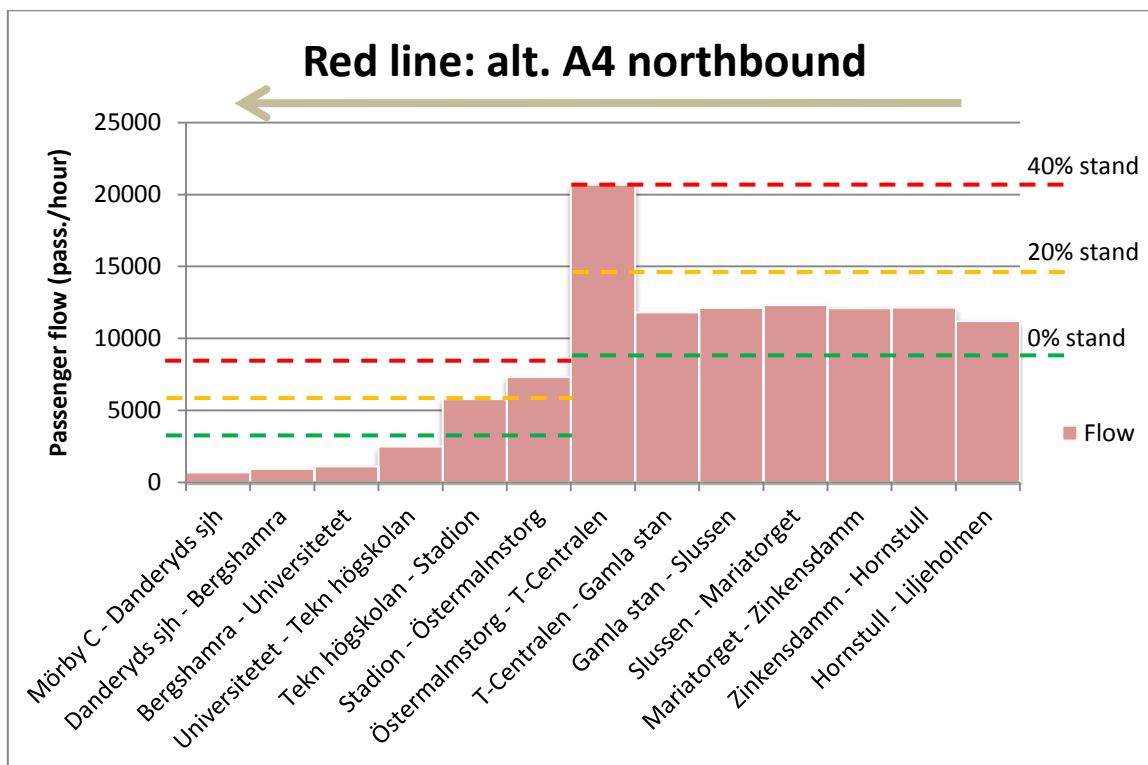
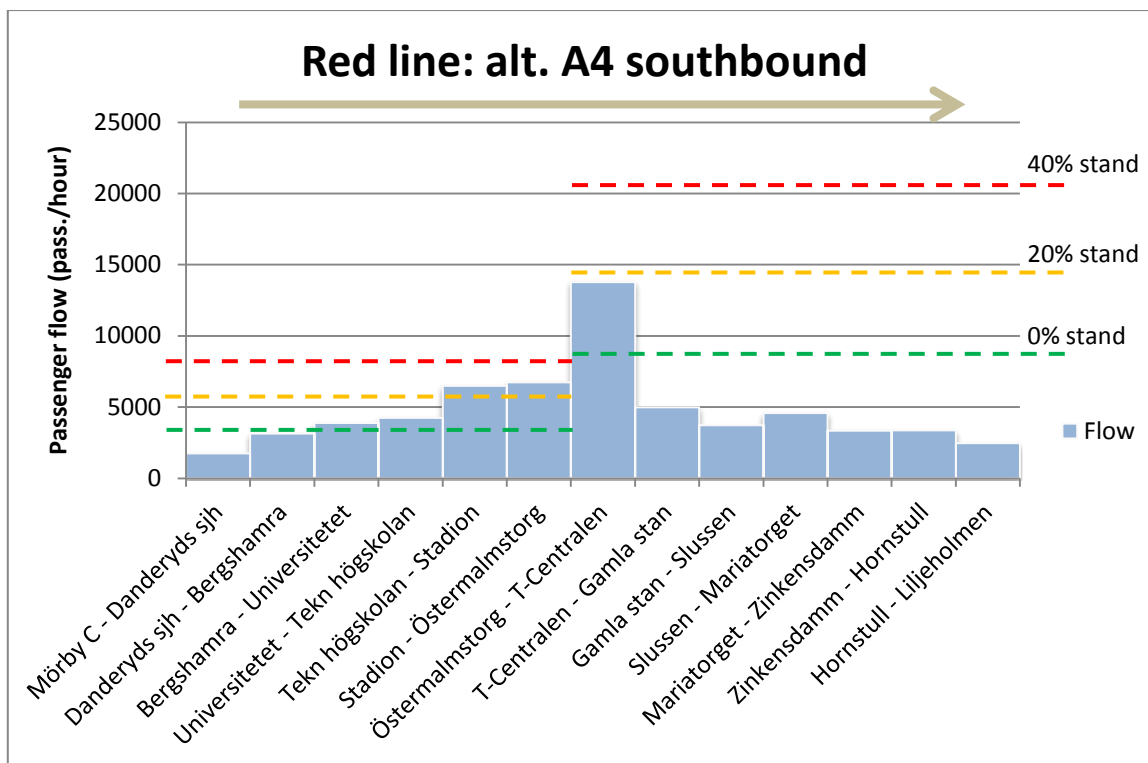
### Passenger flows for the Metro red line with alternative A3 in 2030

Simulation made with a 5-minute headway for Mörby C – Östermalmstorg and a 2-minute headway for Östermalmstorg – Liljeholmen in the morning peak hour between 07:30 and 08.30.



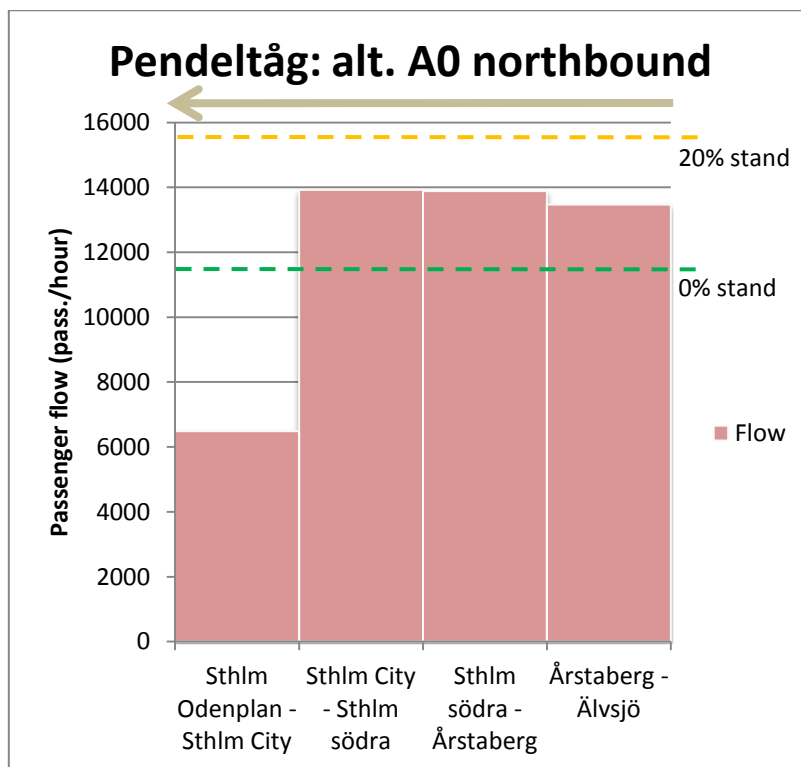
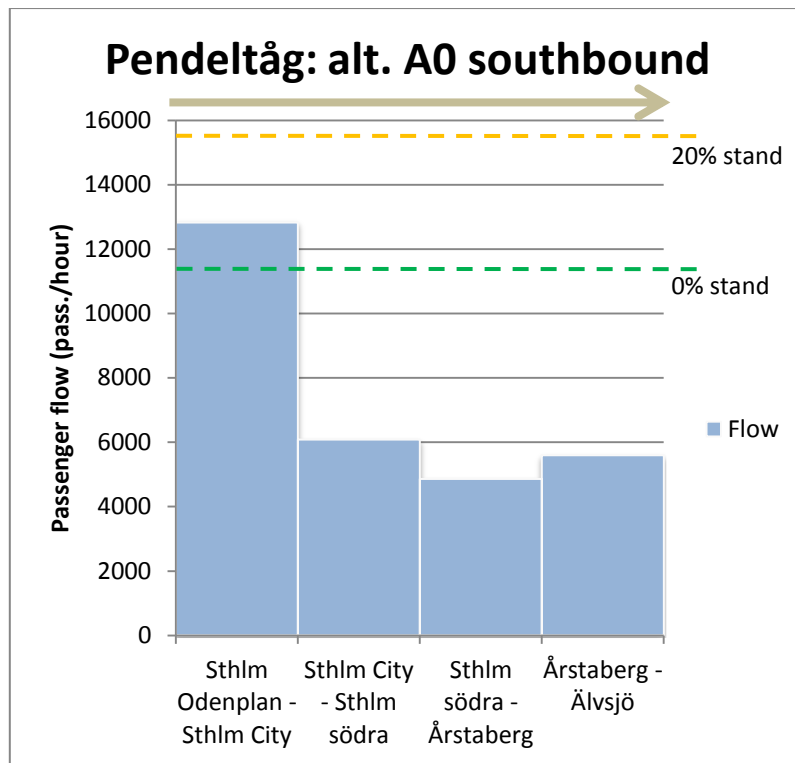
### Passenger flows for the Metro red line with alternative A4 in 2030

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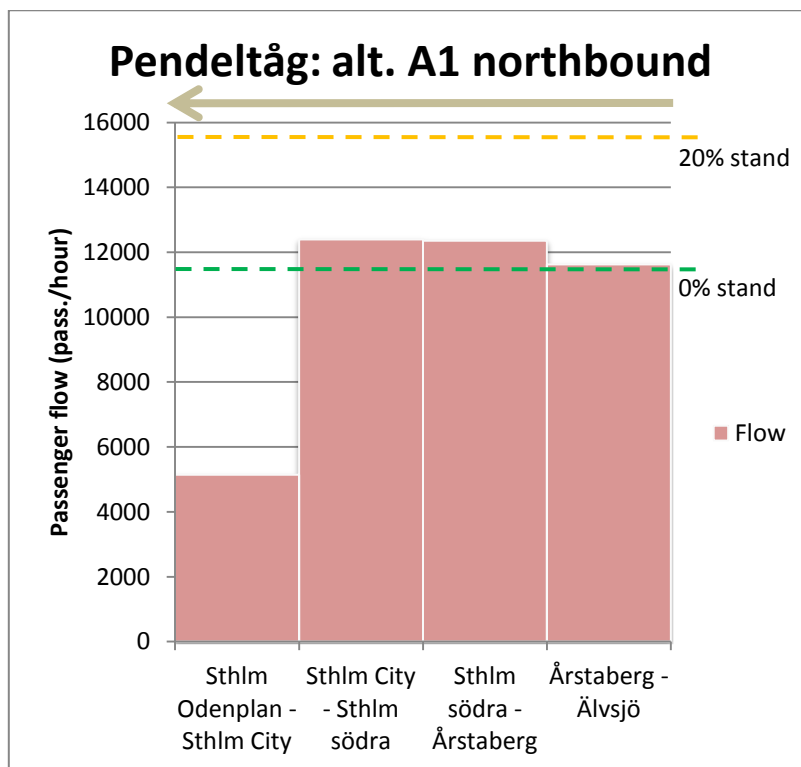
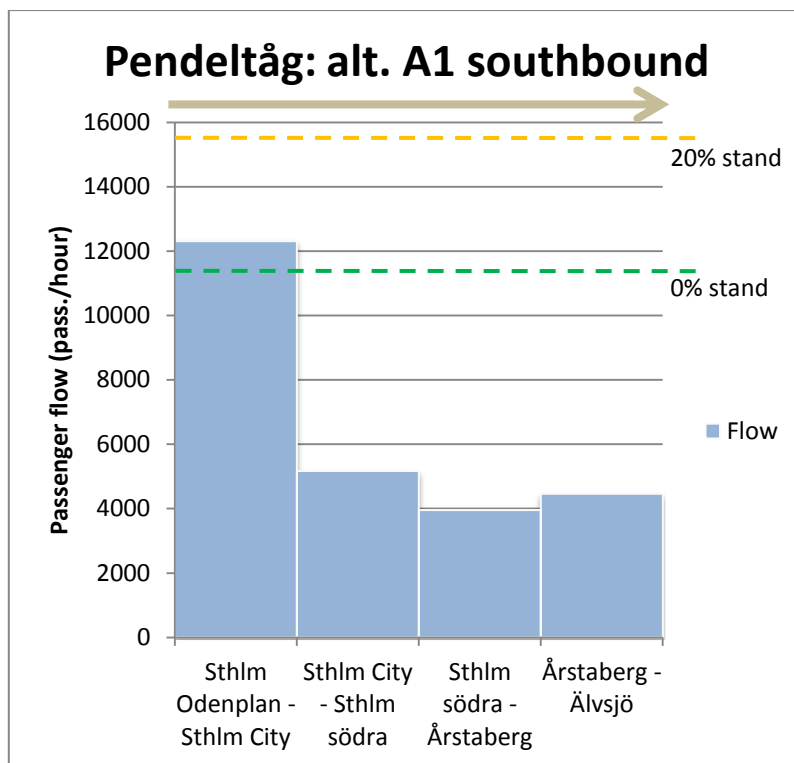
### Passenger flows for the commuter train (Pendeltåg) with alternative A0 in 2030

Simulation made with a 4-minute headway for Stockholm Odenplan – Älvsjö (in both directions) in the morning peak hour between 07:30 and 08:30.



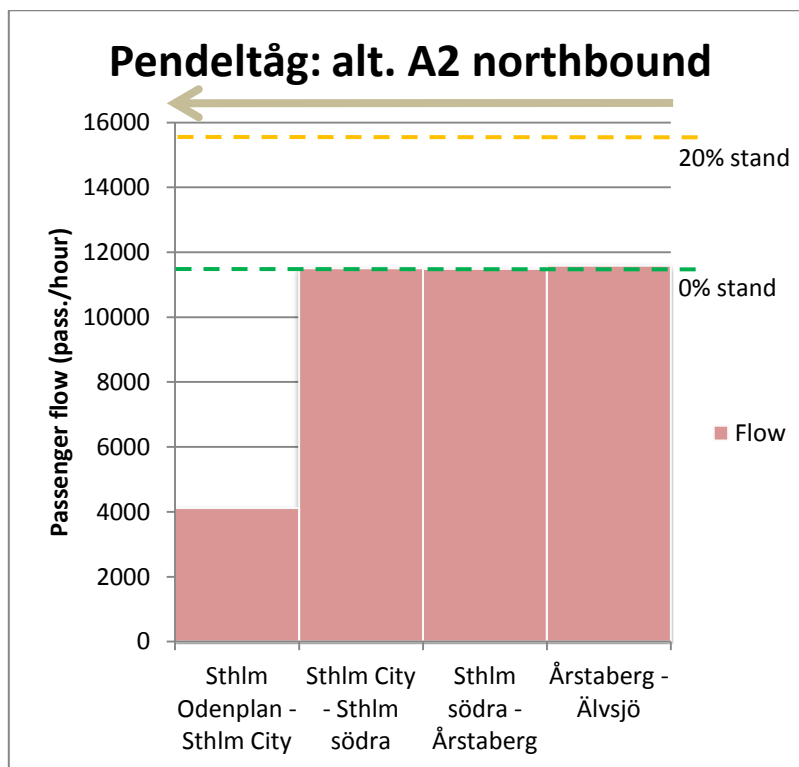
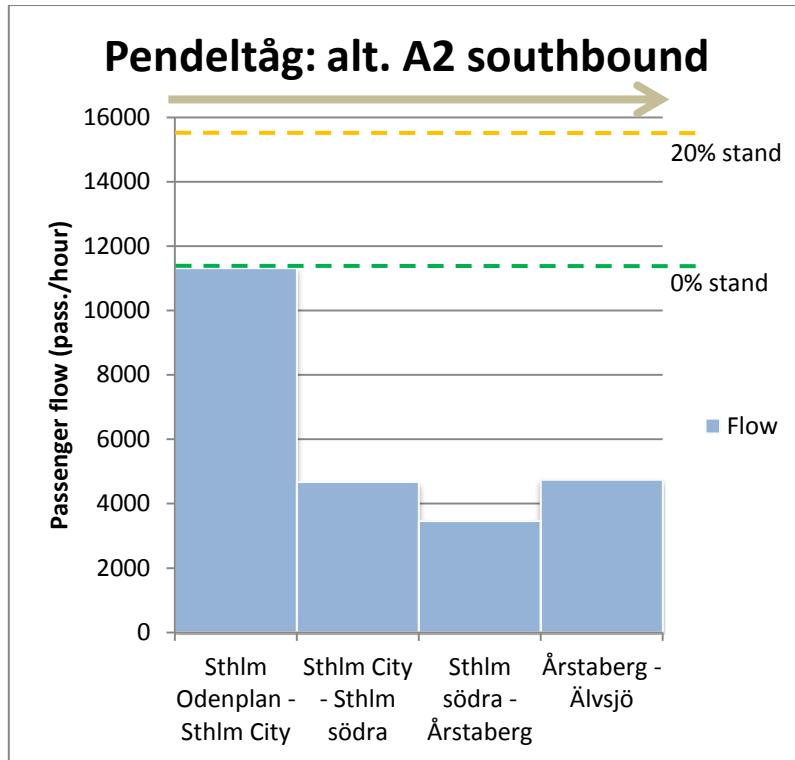
### Passenger flows for the commuter train (Pendeltåg) with alternative A1 in 2030

Simulation made with a 4-minute headway for Stockholm Odenplan – Älvsjö (in both directions) in the morning peak hour between 07:30 and 08:30.



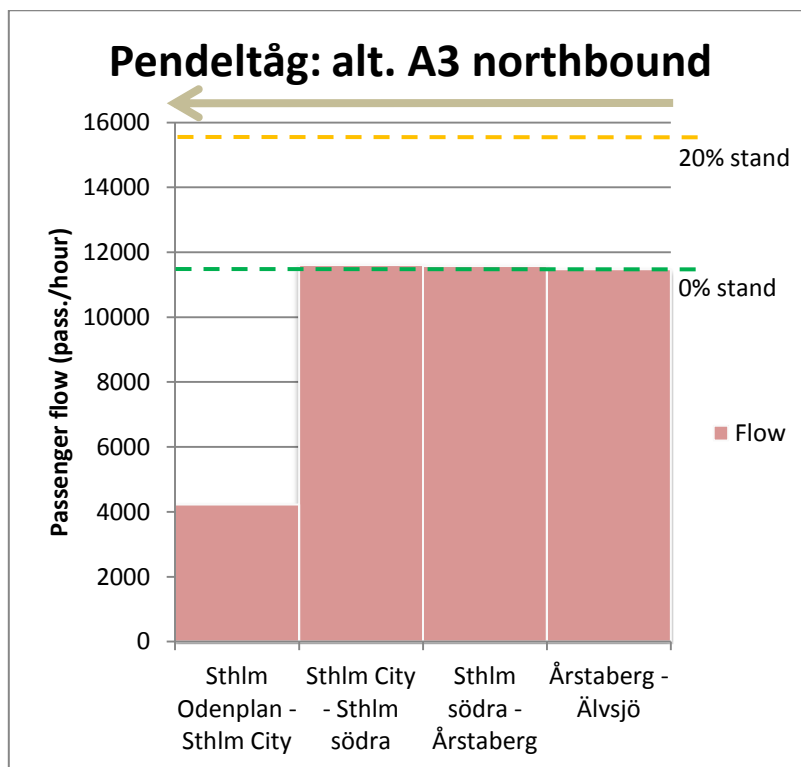
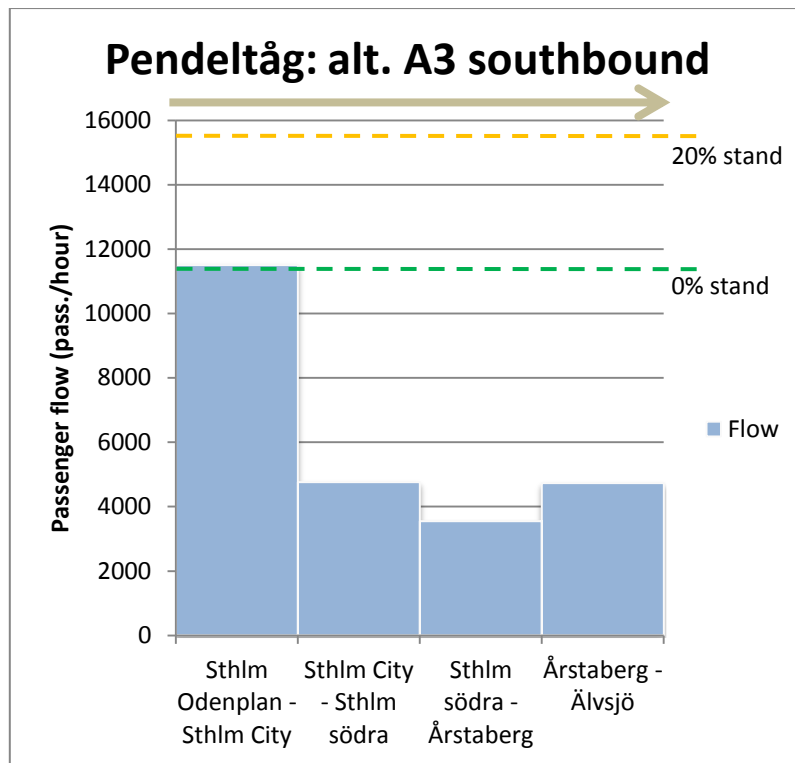
**Passenger flows for the commuter train (Pendeltåg) with alternative A2 in 2030**

Simulation made with a 4-minute headway for Stockholm Odenplan – Älvsjö (in both directions) in the morning peak hour between 07:30 and 08:30.



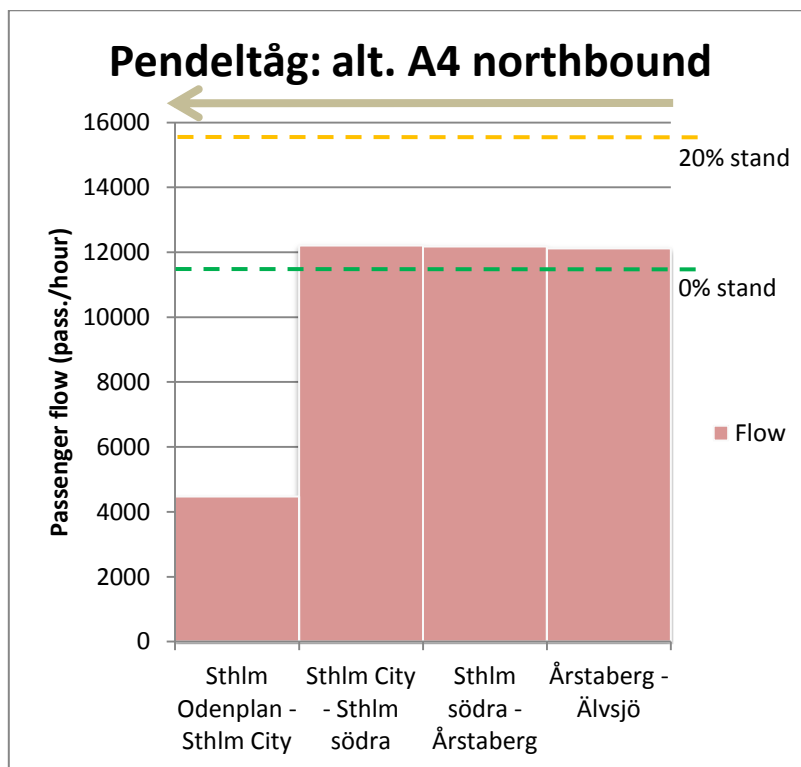
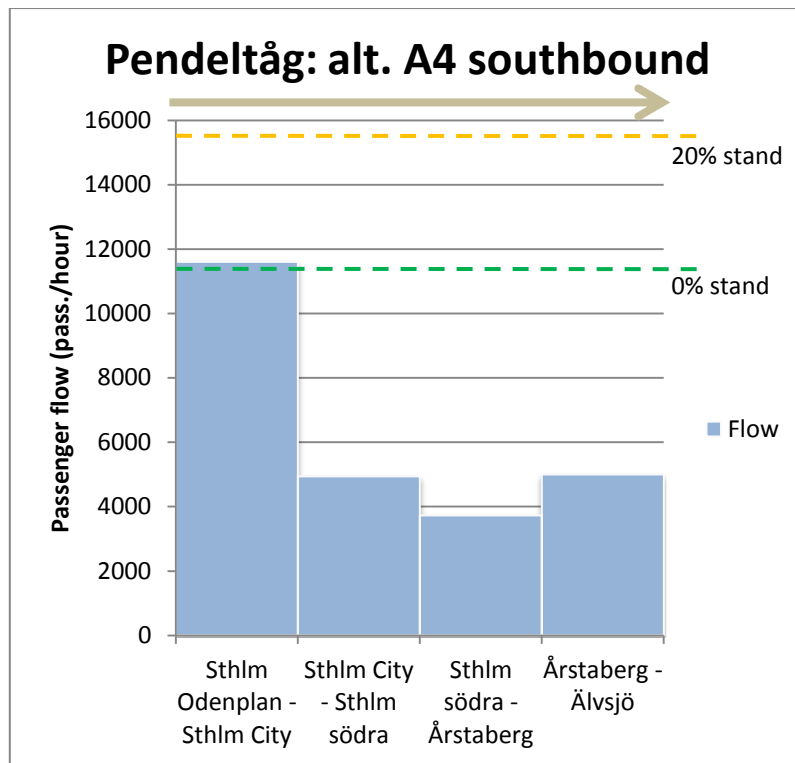
**Passenger flows for the commuter train (Pendeltåg) with alternative A3 in 2030**

Simulation made with a 4-minute headway for Stockholm Odenplan – Älvsjö (in both directions) in the morning peak hour between 07:30 and 08:30.



### Passenger flows for the commuter train (Pendeltåg) with alternative A4 in 2030

Simulation made with a 4-minute headway for Stockholm Odenplan – Älvsjö (in both directions) in the morning peak hour between 07:30 and 08:30.



### Vehicle capacity (passenger/hour) depending on the frequency (1/3)

**Red:** 100% seating, 100% standing (maximum capacity). **Orange:** 100% seating, 40% standing (bad comfort). **Yellow:** 100% seating, 20% standing (fairly good comfort). **Green:** 100% seating, 0% standing (good comfort).

		Saltsjöbanan/Tvärbanan/Nockebybanan				Lidingöbanan/Spårväg	
		1 x A32	2 x A32	1 x A35	2 x A35	1 x A36	2 x A36
Length (m)		29,7	59,4	30,8	61,6	40	80
Width (m)		2,65	2,65	2,65	2,65	2,65	2,65
Max speed (km/h)		80	80	90	90	90	90
Number of seats		78	156	72	144	104	208
Standing pass.		133	266	203	406	246	492
Total capacity		211	422	275	550	350	700
Headway							
30 min	2 trains/h	422	844	550	1100	700	1400
20 min	3 trains/h	633	1266	825	1650	1050	2100
15 min	4 trains/h	844	1688	1100	2200	1400	2800
12 min	5 trains/h	1055	2110	1375	2750	1750	3500
10 min	6 trains/h	1266	2532	1650	3300	2100	4200
7/8 min	8 trains/h	1688	3376	2200	4400	2800	5600
6 min	10 trains/h	2110	4220	2750	5500	3500	7000
5 min	12 trains/h	2532	5064	3300	6600	4200	8400
4 min	15 trains/h	3165	6330	4125	8250	5250	10500
3,3 min	18 trains/h	3798	7596	4950	9900	6300	12600
3 min	20 trains/h	4220	8440	5500	11000	7000	14000
2,5 min	24 trains/h	5064	10128	6600	13200	8400	16800
2 min	30 trains/h	6330	12660	8250	16500	10500	21000
30 min	2 trains/h	262	525	306	613	405	810
20 min	3 trains/h	394	787	460	919	607	1214
15 min	4 trains/h	525	1050	613	1226	810	1619
12 min	5 trains/h	656	1312	766	1532	1012	2024
10 min	6 trains/h	787	1574	919	1838	1214	2429
7/8 min	8 trains/h	1050	2099	1226	2451	1619	3238
6 min	10 trains/h	1312	2624	1532	3064	2024	4048
5 min	12 trains/h	1574	3149	1838	3677	2429	4858
4 min	15 trains/h	1968	3936	2298	4596	3036	6072
3,3 min	18 trains/h	2362	4723	2758	5515	3643	7286
3 min	20 trains/h	2624	5248	3064	6128	4048	8096
2,5 min	24 trains/h	3149	6298	3677	7354	4858	9715
2 min	30 trains/h	3936	7872	4596	9192	6072	12144
30 min	2 trains/h	209	418	225	450	306	613
20 min	3 trains/h	314	628	338	676	460	919
15 min	4 trains/h	418	837	450	901	613	1226
12 min	5 trains/h	523	1046	563	1126	766	1532
10 min	6 trains/h	628	1255	676	1351	919	1838
7/8 min	8 trains/h	837	1674	901	1802	1226	2451
6 min	10 trains/h	1046	2092	1126	2252	1532	3064
5 min	12 trains/h	1255	2510	1351	2702	1838	3677
4 min	15 trains/h	1569	3138	1689	3378	2298	4596
3,3 min	18 trains/h	1883	3766	2027	4054	2758	5515
3 min	20 trains/h	2092	4184	2252	4504	3064	6128
2,5 min	24 trains/h	2510	5021	2702	5405	3677	7354
2 min	30 trains/h	3138	6276	3378	6756	4596	9192
30 min	2 trains/h	156	312	144	288	208	416
20 min	3 trains/h	234	468	216	432	312	624
15 min	4 trains/h	312	624	288	576	416	832
12 min	5 trains/h	390	780	360	720	520	1040
10 min	6 trains/h	468	936	432	864	624	1248
7/8 min	8 trains/h	624	1248	576	1152	832	1664
6 min	10 trains/h	780	1560	720	1440	1040	2080
5 min	12 trains/h	936	1872	864	1728	1248	2496
4 min	15 trains/h	1170	2340	1080	2160	1560	3120
3,3 min	18 trains/h	1404	2808	1296	2592	1872	3744
3 min	20 trains/h	1560	3120	1440	2880	2080	4160
2,5 min	24 trains/h	1872	3744	1728	3456	2496	4992
2 min	30 trains/h	2340	4680	2160	4320	3120	6240

### Vehicle capacity (passenger/hour) depending on the frequency (2/3)

**Red:** 100% seating, 100% standing (maximum capacity). **Orange:** 100% seating, 40% standing (bad comfort). **Yellow:** 100% seating, 20% standing (fairly good comfort). **Green:** 100% seating, 0% standing (good comfort).

		Tunnelbana				Pendeltåg		
		1 x C20	2 x C20	3 x C20	1 x C30	2 x C30	1 x X60	2 x X60
Length (m)		46,5	93	139,5	70	140	106,5	213
Width (m)		2,9	2,9	2,9	2,9	2,9	3,26	3,26
Max speed (km/h)		90	90	90	90	90	160	160
Number of seats		126	252	378	146	292	374	748
Standing pass.		288	576	864	490	980	526	1052
Total capacity		414	828	1242	636	1272	900	1800
Headway								
30 min	2 trains/h	828	1656	2484	1272	2544	1800	3600
20 min	3 trains/h	1242	2484	3726	1908	3816	2700	5400
15 min	4 trains/h	1656	3312	4968	2544	5088	3600	7200
12 min	5 trains/h	2070	4140	6210	3180	6360	4500	9000
10 min	6 trains/h	2484	4968	7452	3816	7632	5400	10800
7/8 min	8 trains/h	3312	6624	9936	5088	10176	7200	14400
6 min	10 trains/h	4140	8280	12420	6360	12720	9000	18000
5 min	12 trains/h	4968	9936	14904	7632	15264	10800	21600
4 min	15 trains/h	6210	12420	18630	9540	19080	13500	27000
3,3 min	18 trains/h	7452	14904	22356	11448	22896	16200	32400
3 min	20 trains/h	8280	16560	24840	12720	25440	18000	36000
2,5 min	24 trains/h	9936	19872	29808	15264	30528	21600	43200
2 min	30 trains/h	12420	24840	37260	19080	38160	27000	54000
30 min	2 trains/h	482	965	1447	684	1368	1169	2338
20 min	3 trains/h	724	1447	2171	1026	2052	1753	3506
15 min	4 trains/h	965	1930	2894	1368	2736	2338	4675
12 min	5 trains/h	1206	2412	3618	1710	3420	2922	5844
10 min	6 trains/h	1447	2894	4342	2052	4104	3506	7013
7/8 min	8 trains/h	1930	3859	5789	2736	5472	4675	9350
6 min	10 trains/h	2412	4824	7236	3420	6840	5844	11688
5 min	12 trains/h	2894	5789	8683	4104	8208	7013	14026
4 min	15 trains/h	3618	7236	10854	5130	10260	8766	17532
3,3 min	18 trains/h	4342	8683	13025	6156	12312	10519	21038
3 min	20 trains/h	4824	9648	14472	6840	13680	11688	23376
2,5 min	24 trains/h	5789	11578	17366	8208	16416	14026	28051
2 min	30 trains/h	7236	14472	21708	10260	20520	17532	35064
30 min	2 trains/h	367	734	1102	488	976	958	1917
20 min	3 trains/h	551	1102	1652	732	1464	1438	2875
15 min	4 trains/h	734	1469	2203	976	1952	1917	3834
12 min	5 trains/h	918	1836	2754	1220	2440	2396	4792
10 min	6 trains/h	1102	2203	3305	1464	2928	2875	5750
7/8 min	8 trains/h	1469	2938	4406	1952	3904	3834	7667
6 min	10 trains/h	1836	3672	5508	2440	4880	4792	9584
5 min	12 trains/h	2203	4406	6610	2928	5856	5750	11501
4 min	15 trains/h	2754	5508	8262	3660	7320	7188	14376
3,3 min	18 trains/h	3305	6610	9914	4392	8784	8626	17251
3 min	20 trains/h	3672	7344	11016	4880	9760	9584	19168
2,5 min	24 trains/h	4406	8813	13219	5856	11712	11501	23002
2 min	30 trains/h	5508	11016	16524	7320	14640	14376	28752
30 min	2 trains/h	252	504	756	292	584	748	1496
20 min	3 trains/h	378	756	1134	438	876	1122	2244
15 min	4 trains/h	504	1008	1512	584	1168	1496	2992
12 min	5 trains/h	630	1260	1890	730	1460	1870	3740
10 min	6 trains/h	756	1512	2268	876	1752	2244	4488
7/8 min	8 trains/h	1008	2016	3024	1168	2336	2992	5984
6 min	10 trains/h	1260	2520	3780	1460	2920	3740	7480
5 min	12 trains/h	1512	3024	4536	1752	3504	4488	8976
4 min	15 trains/h	1890	3780	5670	2190	4380	5610	11220
3,3 min	18 trains/h	2268	4536	6804	2628	5256	6732	13464
3 min	20 trains/h	2520	5040	7560	2920	5840	7480	14960
2,5 min	24 trains/h	3024	6048	9072	3504	7008	8976	17952
2 min	30 trains/h	3780	7560	11340	4380	8760	11220	22440

### Vehicle capacity (passenger/hour) depending on the frequency (3/3)

**Red:** 100% seating, 100% standing (maximum capacity). **Orange:** 100% seating, 40% standing (bad comfort). **Yellow:** 100% seating, 20% standing (fairly good comfort). **Green:** 100% seating, 0% standing (good comfort).

		Roslagsbanan		Buss			
		1 x X10p	2 x X10p	MAN LC G	MAN LC L	MAN LC C	MAN LC S
Length (m)		59,7	119,4	18	14,7	13,7	11,98
Width (m)		2,6	2,6	2,5	2,5	2,5	2,5
Max speed (km/h)		80	80	90	90	90	90
Number of seats		232	464	51	48	42	36
Standing pass.		118	236	103	68	66	56
Total capacity		350	700	154	116	108	92
Headway							
30 min	2 trains/h	700	1400	308	232	216	184
20 min	3 trains/h	1050	2100	462	348	324	276
15 min	4 trains/h	1400	2800	616	464	432	368
12 min	5 trains/h	1750	3500	770	580	540	460
10 min	6 trains/h	2100	4200	924	696	648	552
7/8 min	8 trains/h	2800	5600	1232	928	864	736
6 min	10 trains/h	3500	7000	1540	1160	1080	920
5 min	12 trains/h	4200	8400	1848	1392	1296	1104
4 min	15 trains/h	5250	10500	2310	1740	1620	1380
3,3 min	18 trains/h	6300	12600	2772	2088	1944	1656
3 min	20 trains/h	7000	14000	3080	2320	2160	1840
2,5 min	24 trains/h	8400	16800	3696	2784	2592	2208
2 min	30 trains/h	10500	21000	4620	3480	3240	2760
30 min	2 trains/h	558	1117	184	150	137	117
20 min	3 trains/h	838	1675	277	226	205	175
15 min	4 trains/h	1117	2234	369	301	274	234
12 min	5 trains/h	1396	2792	461	376	342	292
10 min	6 trains/h	1675	3350	553	451	410	350
7/8 min	8 trains/h	2234	4467	738	602	547	467
6 min	10 trains/h	2792	5584	922	752	684	584
5 min	12 trains/h	3350	6701	1106	902	821	701
4 min	15 trains/h	4188	8376	1383	1128	1026	876
3,3 min	18 trains/h	5026	10051	1660	1354	1231	1051
3 min	20 trains/h	5584	11168	1844	1504	1368	1168
2,5 min	24 trains/h	6701	13402	2213	1805	1642	1402
2 min	30 trains/h	8376	16752	2766	2256	2052	1752
30 min	2 trains/h	511	1022	143	123	110	94
20 min	3 trains/h	767	1534	215	185	166	142
15 min	4 trains/h	1022	2045	286	246	221	189
12 min	5 trains/h	1278	2556	358	308	276	236
10 min	6 trains/h	1534	3067	430	370	331	283
7/8 min	8 trains/h	2045	4090	573	493	442	378
6 min	10 trains/h	2556	5112	716	616	552	472
5 min	12 trains/h	3067	6134	859	739	662	566
4 min	15 trains/h	3834	7668	1074	924	828	708
3,3 min	18 trains/h	4601	9202	1289	1109	994	850
3 min	20 trains/h	5112	10224	1432	1232	1104	944
2,5 min	24 trains/h	6134	12269	1718	1478	1325	1133
2 min	30 trains/h	7668	15336	2148	1848	1656	1416
30 min	2 trains/h	464	928	102	96	84	72
20 min	3 trains/h	696	1392	153	144	126	108
15 min	4 trains/h	928	1856	204	192	168	144
12 min	5 trains/h	1160	2320	255	240	210	180
10 min	6 trains/h	1392	2784	306	288	252	216
7/8 min	8 trains/h	1856	3712	408	384	336	288
6 min	10 trains/h	2320	4640	510	480	420	360
5 min	12 trains/h	2784	5568	612	576	504	432
4 min	15 trains/h	3480	6960	765	720	630	540
3,3 min	18 trains/h	4176	8352	918	864	756	648
3 min	20 trains/h	4640	9280	1020	960	840	720
2,5 min	24 trains/h	5568	11136	1224	1152	1008	864
2 min	30 trains/h	6960	13920	1530	1440	1260	1080





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