December 2020

Master plan

Increasing metro capacity and reliability

In cooperation

Preface

According to the traffic, forecasts made by HSL in spring 2018 and updated in summer 2020. As the land use of the Helsinki metropolitan area develops, the number of passengers in the metro will exceed to its capacity during this decade. HKL, HSL, Länsimetro Oy and the City of Espoo has agreed to co-operate in the development of metro capacity and reliability. This master plan brings together the main measures to improve the situation.

In February 2020, in the morning rush hour, the busiest part of the metro was in the east between Sörnäinen and Hakaniemi, where there were about 8,400 passengers during rush hour. The load on the Vuosaari line was about 4,500 and on the Mellunmäki line about 3,900 passengers. However, the capacity of the metro's eastern branch will not be far enough into the future with the construction of Helsinki increase in land use in the metro's area affected by increasing passenger numbers. The timing for passenger demand exceeding the current metro capacity also depends on the construction of Östersundom area. However, the construction of the Östersundom area requires its own broader transportation review, which is outside the scope of this work. The completion of the Kruunuvuorenselkä tramway, estimated in 2026, will reduce the load on the metro, but higher capacity requirement is projected to be needed later.

According to traffic forecasts, with the introduction of the Kivenlahti extension of the Länsimetro and the development of land use in the area, the number of passengers on the line starting from Kivenlahti will exceed the maximum capacity on the Kivenlahti branch. The maximum capacity will exceed in a situation where one metro line turns as planned in Tapiola and the other in Kivenlahti and the metro interval is as current (300 seconds / line). According to the study, as land use and traffic pricing continue to develop, metro capacity may be exceeded by 2030.

At the planning stage, the 2020 pandemic (COVID 19) has posed challenges in estimating future capacity needs, creating uncertainty about the pace of the passenger growth, potential step changes in demand due to increased teleworking, at least temporarily, and other possible changes in travel practices. It is unclear which of these changes are temporary and which of these may become established practices in the future. In addition, a pandemic can have a significant impact on the urban economy and thus on the ability to fund a project. These factors have been taken into account in drawing up the master plan. However, there are uncertainties in the estimates of the changes, which may lead to an unsustainable congestion of the current system and a failure to react quickly enough. To prevent this risk, regular monitoring of traffic volumes and forecasts will be carried out.

There are many systems in use in the metro that have already been operational for a very long period, and their lifecycle is potentially coming to an end. It is critical for smooth traffic to ensure that these systems operate reliably as long as necessary.

The master plan defines the qualitative objectives for increasing the capacity and operating reliability, sets a ceiling price for the measures and describes the outcome of the project.

The master plan also summarizes the main results of the inquiries set out in the preliminary study and sets out the development path for the metro. Separate project plans will be drawn up for the projects recommended in the master plan, specifying their objectives and confirming their overall feasibility.

The preparation of the master plan has been supervised by a co-operation group formed by

HKL, HSL, the City of Espoo and Länsimetro Oy. The members have been:

HKL	**Espoon kaupunki**	**HSL**	**Länsimetro Oy**
Ville Lehmuskoski	Olli Isotalo	Tero Anttila	Ville Saksi
Artturi Lähdetie	Harri Tanska		

Participants in the preparation of the master plan and the collection of required information:

HKL
Heikki Viika
Julius Vuoriluoto
Salar Mohammad
Jukka Aholainen
Timo Ansamaa
Sanna Kuustie
Matias Heselius
Jaakko Heikkilä
Mauno Nurmela
Toni Kervinen
Teemu Niippa
Jussi Karjalainen
Kari Klemetti
Markku Laaksonen
Lasse Rosenholm
Arttu Kuukankorpi
Kimmo Reiman
Tuomo Pietilä
Juhana Hietaranta
Toni Jurva

HKL
Jukka Hämäläinen
Ella Etula
Sami Kellokoski
Anna Lonka
Hannu Koskela
Seppo Kasurinen
Harri Perkiö
Kalle Muilu
Tiia Vilhola
Rami Iiskola
Tero Lehtimäki
Mika Taavitsainen

HSL
Eeva Vesaoja
Johanna Wallin
Tuomas Piiroinen
Teuvo Syrjälä
Timo Virman

Länsimetro Oy
Raimo Kaunismäki
Jussi Utti
Mikko Piitulainen

Welado Oy
Erno Nieminen
Katja Tiihonen
Tommi Rytkönen
Jukka Niemelä

Proxion Oy
Heidi Sunnari
Janne-Joonas Mantsinen
Miiro Kokko
Simo Savolainen
Markus Parkatti

BCG
Kaori Uehigashi
Mari Ijäs
Vesa Leskinen
Teemu Ruska
Tuomas Eloholma

VTT
Perttu Peusa
Eetu Heikkilä
Risto Tiusanen
Risto Öörni

SWECO Oy
Jan Tiri
Jouni Kiviniitty

Ramboll Oy
Jyrki Rinta-Piirto
Eeva Elmnäinen

The preparation of the plan began in March 2020 and ended in November 2020.

During the preparation of the plan, ten separate studies were carried out, the results of which have influenced the plan. In addition, work packages have been opened for certain others and preliminary information has been obtained for general planning.

Statement	Subject	
Report 3:	Other capacity increase options	Study carried out together with HSL based on a service design survey conducted with Hellon
Report 4:	Capacity solutions at the western end of the metro	Länsimetro Oy has commissioned a study based on a commission from the City of Espoo.
Report 5:	The development potential of the current train control system will be investigated.	Extensive study carried out with the support of Welado, Sweco and Proxion.
Report 6:	Define the procurement and implementation model of the CBTC system.	The studies carried out taking into account the experiences of the participants in major projects.

Statement	Subject	
Report 7:	A more detailed cost estimate for the CBTC system will be prepared.	The estimated cost based on the price level of other projects.
Report 8:	A more detailed analysis of the benefits and costs of the automation rate of the metro.	Study carried out with the support of VTT. A well-liked high-risk workshop.
Report 9:	Impact of the project on metro operations.	Analysis of the potential disruption to metro services during the implementation of the project.
Report 10:	Use of M100 and M200 fleet in CBTC system	Examined the state of modern equipment with the support of HKL's equipment experts
Report 11:	Coordination of M400 fleet procurement.	Examined equipment requirements with the support of HKL's equipment experts
Report 12:	A risk management plan will be drawn up.	Preliminary risk management plan drawn up with the support of BCG. A well-liked high-risk workshop.
Report 13:	A study will be prepared on the scenarios for the development of land use and transport systems. Metro60-study.	A forecast based on maximum land use prepared together with the cities of Helsinki, Espoo and Vantaa and the municipalities of Kirkkonummi and Sipoo, led by HSL until 2060.
	Lessons learned from other projects	Interviewed several metros to gather experiences with BCG support.
	Communication requirements	Collected information on the communication requirements of the systems. A cybersecurity analysis of the traffic management system.
	System safety approval	Draft process for system safety approval.
	Project communication	Preliminary communication plan drawn up

In addition, several discussions were held with companies supplying metro traffic control systems. These were attended by six companies. Several rounds of separate, bilateral dialogues were held with the companies.

Master plan for increasing metro capacity and reliability

Content

Summary

A well-functioning public transport is a key part of a well-functioning, modern cityscape. It is a network consisting of several different modes of transport, and the metro serves as its backbone, providing a high-capacity and fast connection in an east-west direction. The popularity of the metro is reflected in the growing number of passengers, so maintaining the level of service requires an increase in its capacity. Increasing the metro's capacity will have a positive effect on the urban image of both cities. The higher capacity allows continuing construction in the metro's area of influence, providing sufficient capacity also for new passengers. In this way, increasing the capacity of the metro will alter the cityscape.

The number of metro passengers has grown strongly in recent years. From 2010 to 2019, the total number of metro users increased by about 62% and the peak load of the metro increased by about 14% since 2012. Most of the growth has come from the opening of the first stage of metro west extension in 2017. According to traffic forecasts made by HSL in spring 2018 and updated in summer 2020, with the projected land development in the Helsinki metropolitan area, the number of passengers in the metro will exceed its capacity during this decade.

As employment and population in the Helsinki metropolitan area will increase, bus traffic will not be enough to match the increase in passenger numbers, as the urban structure cannot withstand such large bus volumes. Projected in Metro60-study, the capacity of the light rail lines studied in the maximum scenarios for land use and transport system development in the sub-study is not sufficient to meet the full growth, but a high-capacity mode of transport is needed. Therefore, it is not easy to meet the growth of passenger demand by developing alternative modes of transport.

According to the metro's forecasts, the most significant effects of the metro capacity project will be on congested parts. Based on the forecasts of passenger growth and the development goals of the metro, the master plan has examined possible short- and long-term ways to provide sufficient passenger capacity based on the current situation of the metro. The document presents short-term development opportunities related to existing systems and operating models, as well as measures to streamline passenger flows.

The most important reform of the capacity project is the implementation of a new traffic control system, which will make it possible to increase train intervals from the current 2.5-minute interval in key sections first to 2-minute intervals, and later to 1 minute 40 s intervals. Thus, in a two-line operation, instead of the current 5 minutes interval, each line runs initially every 4 minutes and finally every 3 minutes for 20 s, shortening the average waiting times for passengers, and further increasing the attractiveness of the mode of transport.

Increased traffic will also reduce passenger volumes per train during peak times, further positively impacting the passenger experience. Of course, additional trains will also be needed to achieve more frequent intervals. The new traffic control system will

eventually also enable automation of operation, with a wide range of benefits and advantages. However, automation also requires investment in equipment and trackside infrastructure especially in the older sections of the metro.

Glossary and terms

Traffic control system	The overall system of metro traffic control, including a traffic control centre, interlocking device, data transmission system and several trackside controllable devices, such as light signals.
Traffic Management System, ATS	A system for managing, supervising and controlling metro train traffic through an interlocking device. The system monitors the location of trains and automatically routes their traffic, and allows for manual intervention to control the traffic.
Interlocking	Controls and monitors trackside equipment and monitors train safety.
Audio frequency track circuit	Identifies the presence of a train on the metro line, which is the same as the train's presence on the metro line. Monitored by a single device.
Forced stop system, Magnetic stop system	A system which gives a stop request with a magnetic field to a passing train, if the trackside magnetic field is not turned off. The field is picked up by an onboard device connected to the braking system of the metro train. The magnetic field is controlled off only when the signal associated with the trackside device shows a permissive aspect.
Automatic Train Protection, ATP	ATP is a system which continuously monitors the maximum allowed speed of the train and the distance to the point on the line where the train is authorized to proceed to. If the driver does not comply with the speed limit or the braking curve to the stop, the system train device automatically slows down the running of the train.
CBTC	Communications-based Train Control. ATP system that receives its information from trackside systems based on radio communication technology.
Greenfield project	A project targeting the new transport system under construction. For example, Länsimetro phase 2.
Brownfield project	A project targeting an existing transport system that updates existing equipment. For example, an interlocking system renewal.
Core Metro	Metro line east of and including Ruoholahti station

Länsimetro, Metro West	Metro line west of Ruoholahti station
GoA	Grade of Automation. Degree of automation of the rail transport system. The number is assigned to indicate the degree of automation.
GoA0	Level 0 means driving according to the driver's visual observations
GoA1	At level 1, the driver drives according to the colour light signals and typically the traffic control system has an ATP system in place.
GoA2	On level 2, semi-automatic driving is used, i.e. the driver's task is to close and, as a rule, open the doors and to give permission for departure of the train. Automation drives the train to the next stopping position.
GoA3	On the 3rd level, automatic driving is used, i.e. driver is not required. Automation drives the train to the next stopping position. However, the train is staffed by an operator for exceptional circumstances.
GoA4	On the 4th level, automatic driving is used, i.e. driver is not required. Automation drives the train to the next stopping position. The train does not normally have operator staff.
M100	Metro train fleet introduced between 1980 and 1984
M200	Metro train fleet introduced from 2000 to 2001
M300	Metro train fleet introduced in 2017–2018. A five train option will be delivered in 2022.
M400	The future metro fleet. The procurement has not yet been launched.
SIL	Safety Integrity Level. The level of safety of the device or system. Level 4 is the highest level defined for safety critical systems, level 0 is the lowest with only quality requirements.

1. Programme background

The metro is the backbone of the east-west axis of public transport in the Helsinki Metropolitan Area, on which very service-oriented and attractive passengers transport system is built. Therefore, the reliable operation of the metro and sufficient capacity are essential for the functioning of the public transport system in both Southern Espoo and Eastern Helsinki.

The advantage of the metro is its good average speed compared to other options. Only suburban train services offer the same average travel speed as the metro.

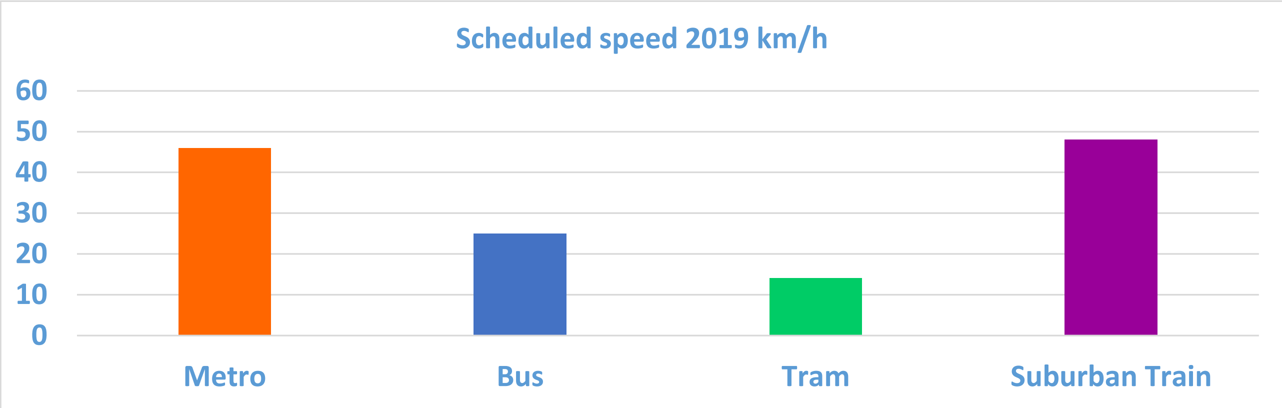


Figure 1 Scheduled speed of the mode according to the 2019 schedule

Metro passenger-kilometer production cost also differs in favour of other alternatives. The cost of a metro passenger-kilometer is less than half the cost of a passenger-kilometer of a bus or tram, Figure 2.

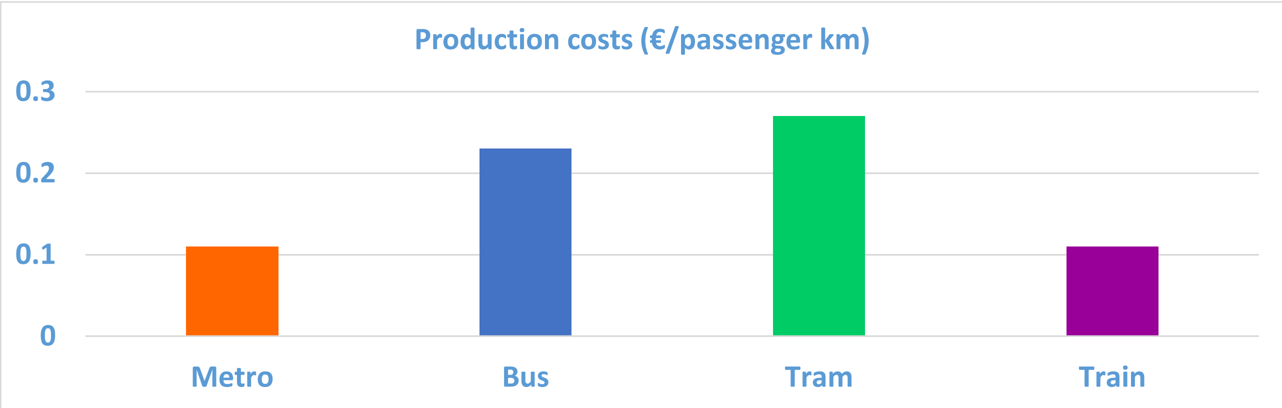


Figure 2 Passenger-kilometre production costs 2017

The metro is also in many ways an environmentally friendly mode of transport. Trains running on electric power without emissions carry a very large number of passengers using a relatively small amount of space which in significant portions is underground, Figure 3. Thus, metro traffic is able to significantly reduce surface traffic in a densely built downtown area

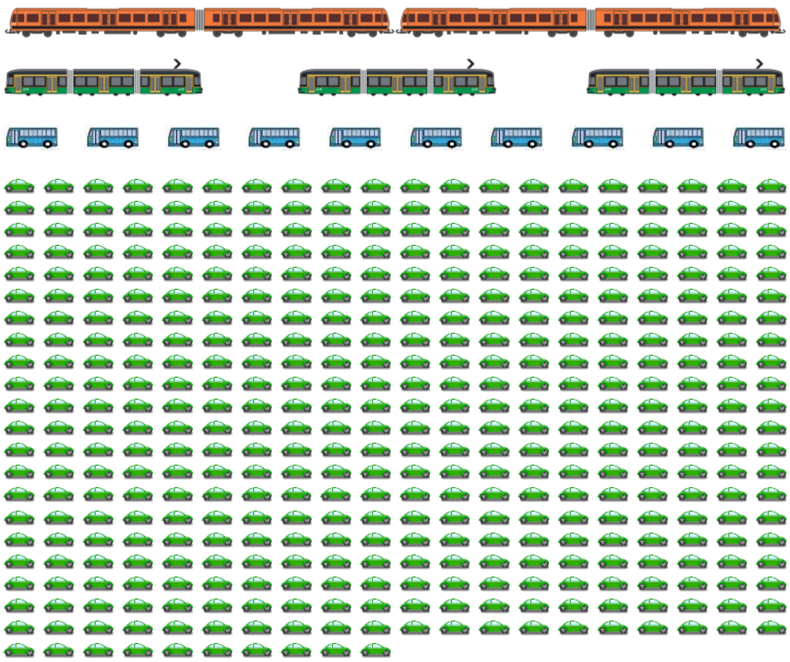


Figure 3 Metro capacity compared to other forms of urban transport

The largest recent development project for the metro system has been the extension of the metro to Espoo. The first phase of the extension from Ruoholahti to Matinkylä has brought eight new stations and significantly increased the number of passengers. The second phase of the extension, which will open in 2023 to Kivenlahti, will bring five more stations, and the number of passengers is expected to increase considerably. Residential and commercial real estate building has been significantly targeted at the new areas covered by the metro, increasing the number of passengers. This increase in passenger numbers, which is greater than initially anticipated, has brought with it the need to develop metro capacity.

In the preliminary study phase of the metro capacity development project, it has been identified that a significant increase in capacity requires a renewal of the metro's traffic control system. The principles of the new traffic control system differ significantly from the current one, which is why the implementation of the new system will have an impact on the entire metro's operating environment. A successful project requires a vision that takes into account future needs ranging from the need for traffic and maintenance to system ownership, metro passenger numbers, and the traffic contract. The success factors for the implementation of the new traffic control system have been determined by collecting and analysing experiences from several metro projects around the world.

To a limited extent, capacity can also be increased by developing existing operations as well as existing traffic control and other systems related to the operation and management of the metro. In addition, improving passenger flow will increase the efficiency of passenger capacity utilization.

1.1 Development of metro passenger numbers and metro load

The number of metro passengers has grown strongly in recent years. From 2010 to 2019, the total number of metro users has increased by about 62% and the peak load of the metro has increased by about 14% since 2012. Most of the growth has come from the opening of the metro west extension.

In February 2020, during the morning rush hour, the busiest part of the metro was in the east between Sörnäinen and Hakaniemi, where there were about 8,400 passengers per hour per direction (pphpd) during rush hour. The load on the Vuosaari line was about 4,500 and the load on the Mellunmäki line was about 3,900 pphpd. In the west, the busiest section was between Lauttasaari and Ruoholahti, where there were about 5,800 pphpd during peak hours. The load on the Matinkylä line was about 4,000 and on the Tapiola line about 1,800 pphpd. The highest load observed was 515 passengers on a single train.

Eastward the metro is loaded very unevenly, especially on the Espoo section. The Matinkylä line (M1) in Tapiola had more than five times the number of passengers compared to the Tapiola line (M2). In the western direction, the metro lines to Vuosaari and Mellunmäki are loaded quite evenly.

Figures Figure 4-Figure 5 shows the train-specific loads (maximum, 80th percentile and median) of the metro lines M1 Matinkylä-Vuosaari and M2 Tapiola-Mellunmäki when departing from the station at 8-9 in week 6/2020.

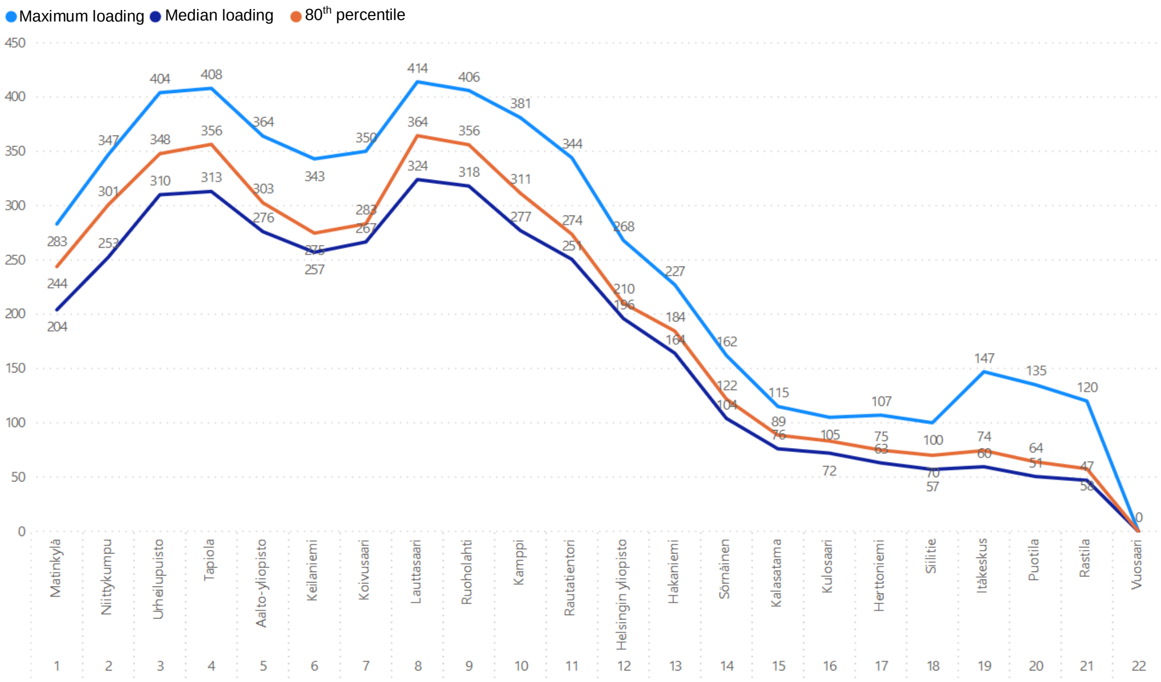


Figure 4 The metro line M1 Matinkylä-Vuosaari truck (maximum, 80th percentile and median) to the east from the station at 8-9 in week 6/2020

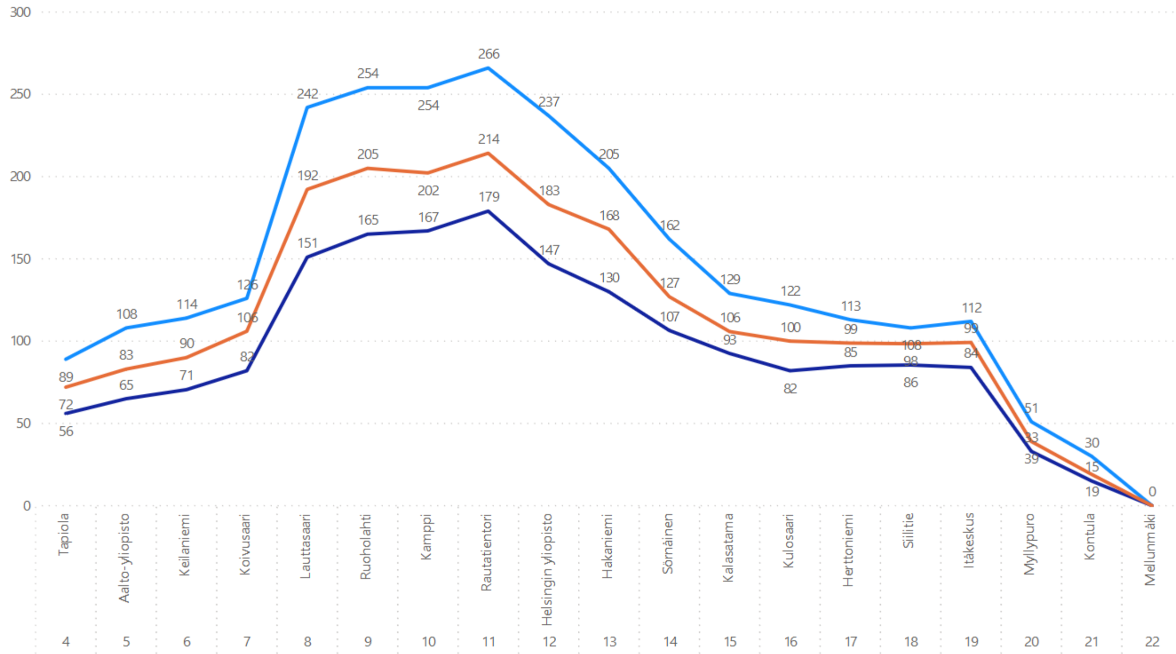


Figure 5 Metro line M2 Tapiola-Mellunmäki truck (maximum, 80th percentile and median) eastbound from the station at 8-9 in week 6/2020.

According to a forecast of the number of passengers in the metro prepared by HSL and the municipalities in the area affected by the metro, the metro's capacity is running out in the late 2020s. Based on these traffic forecasts, the share of the metro is between Kulosaari and Kalasatama, which has about 11,800 passengers per hour. According to the forecast, the number of passengers on the west side of Tapiola in 2030 will be approximately 9,300–10,500 passengers per hour, which clearly exceeds the capacity of the current metro. In the study, the number of passengers in the automated metro operating both lines at 200s intervals exceeds the number of passengers in the current metro, which means that there are about 12,700 passengers per hour between Kulosaari and Kalasatama. However, the capacity in this scenario is sufficient for the entire metro area.

Metro passenger numbers are affected by e.g. the development of land use in the area affected by the metro, changes in mobility habits and traffic pricing. Passenger demand will continue to grow after 2030. In order to have a clearer picture of the growth in passenger demand in the coming decades, HSL, in co-operation with the cities and municipalities in the metro area of Helsinki, Espoo, Vantaa, Kirkkonummi and Sipoo, has conducted a new comprehensive study of land use and transport system development by 2060. The report will be published in its entirety separately from this plan.

Scenario	Assumptions
Baseline scenario	Maximum land use potential developed by municipalities for 2060 (a total of 2.2 million inhabitants and 1.1 million jobs in the region) Based on the pricing of the MAL2019 plan and the traffic network of the MAL2050 ve1 scenario, which has been updated.
Current transport pricing	No congestion charges No ticket price reduction No changes to parking fees
Without Pisararata construction	Current type of train service without Pisararata (frequency min, morning/day/evening): E Kauklahti-Helsinki (7,5/10/7,5) K Kerava-Helsinki (7,5/10/7,5) I and P Ring Railway via airport (7,5/10/7,5)
Several different options were explored at the work to solve capacity challenges at the western end of the metro. *Report 4 of metro's capacity increase project has further explored the possibilities for solutions with different western end track layouts*.	Options explored: • Matinkylä turn-back • Kivenlahti turn-back • Saunalahti extension • Kauklahti extension (tunnel) • Kauklahti extension (surface)
New metro branch	→ Metro lines: Matinkylä--Majvik, Kivenlahti-Vuosaari, Kamppi-Sakarinmäki (new metro line) → No Pisararata It's a theoretical examination. The new metro connection has not been further planned or assessed in its feasibility in this work. The aim of the sensitivity analysis was to look at the demand for Kamppi-Pasila-Viikki-Itäkeskus corridor in question and to fork out its impact on the load on the existing metro corridor. There is actually no turn-back at Matinkylä, so it can't act as a terminus.
Development of tram connections	Tiederatikka tram Jokeri 0 tram Transverse trams lines Tiederatikka+Jokeri 0 Viikki-Malmi tram extension to Mellunmäki
Development of bus offerings	The sensitivity analysis has been prepared on the principle of increasing bus provision, where the metro load is high and/or thought that bus services could attract demand from the metro. The line is not planned in more detail, but the scenario seeks a magnitude of the impact of possible changes in bus offerings on metro demand.

In the baseline scenario, the most congested part of the metro in the morning peak hour in 2060 will be located on the Kulosaari Bridge, which has about 17,160 passengers per hour. The most congested section on the western section is between Lauttasaari and Ruoholahti, which has about 13,360 passengers per hour. In the basic scenario, the second line ends in Tapiola, so the highest load per line is located between the Sports Park and Tapiola, which has about 11,880 passengers per hour. The metro's load exceeds the maximum capacity of the new train control system between Niittykumpu and Tapiola. Figure 6 shows the metro load in the baseline scenario during the morning rush hour.

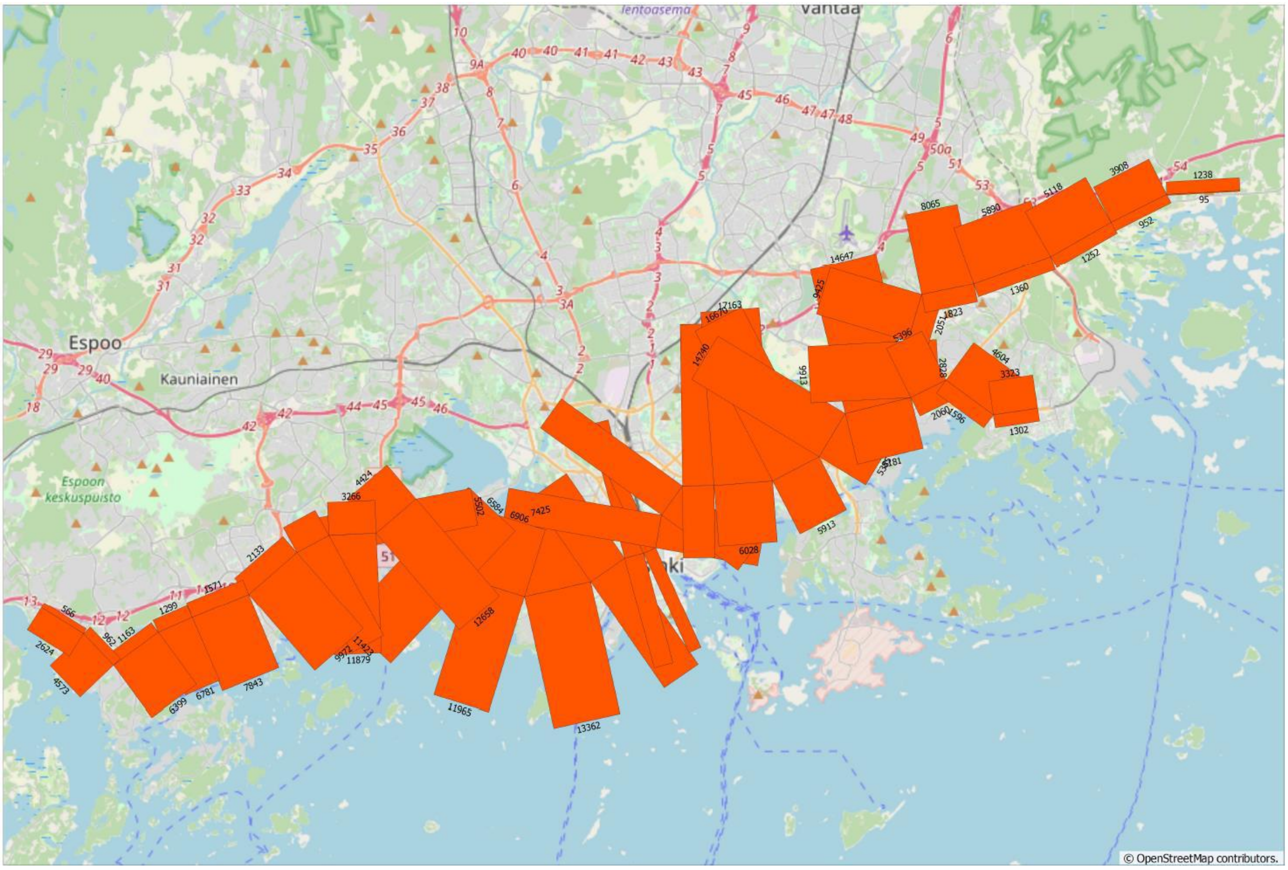


Figure 6 Metro passenger numbers by station interval in 2060 in the morning rush hour

In the baseline scenario, the metro lines are loaded very unevenly on the western part. The Kivenlahti line between Matinkylä and Kamppi is close to maximum capacity or overloaded, while the Tapiola line collects very few passengers. However, the potential for uneven loading in a situation where the extension from Matinkylä to Kivenlahti is in use is only modelled, and there is no real observation of this yet. The future load distribution also depends on how the connecting bus services are designed.

The Östersundom line to be built in Majvik in the future on the eastern section will be loaded more than the Vuosaari line and the number of passengers will be 93% of the maximum capacity of the metro system on the Kulosaari-Kalasatama section. Figures

Figure 7 - Figure 10 show the line-specific load of the metro by station interval in the baseline scenario during the morning peak hour.

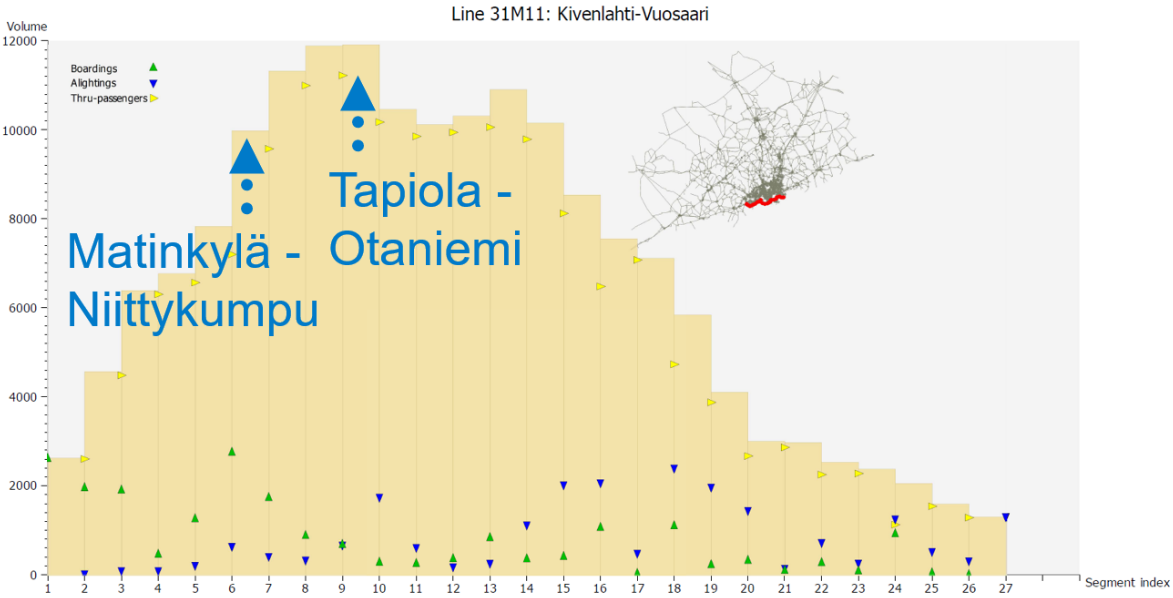


Figure 7 Load of metro line M1 in direction 1 by station interval in the baseline scenario 2060 in the morning peak hour

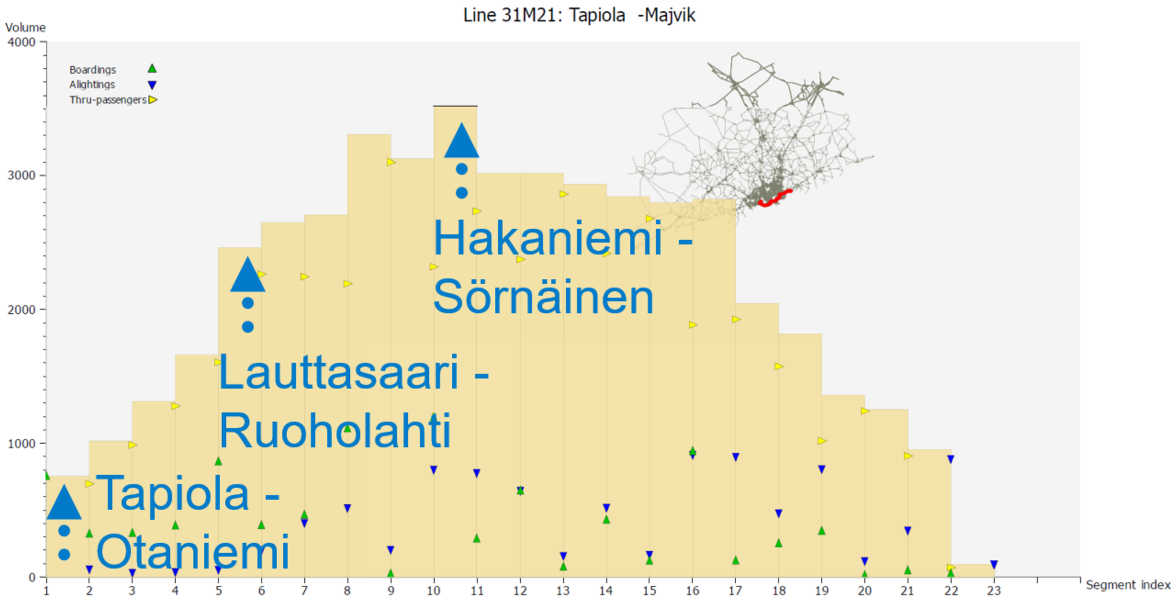


Figure 8 Load of metro line M2 in direction 1 by station interval in the baseline scenario 2060 in the morning peak hour

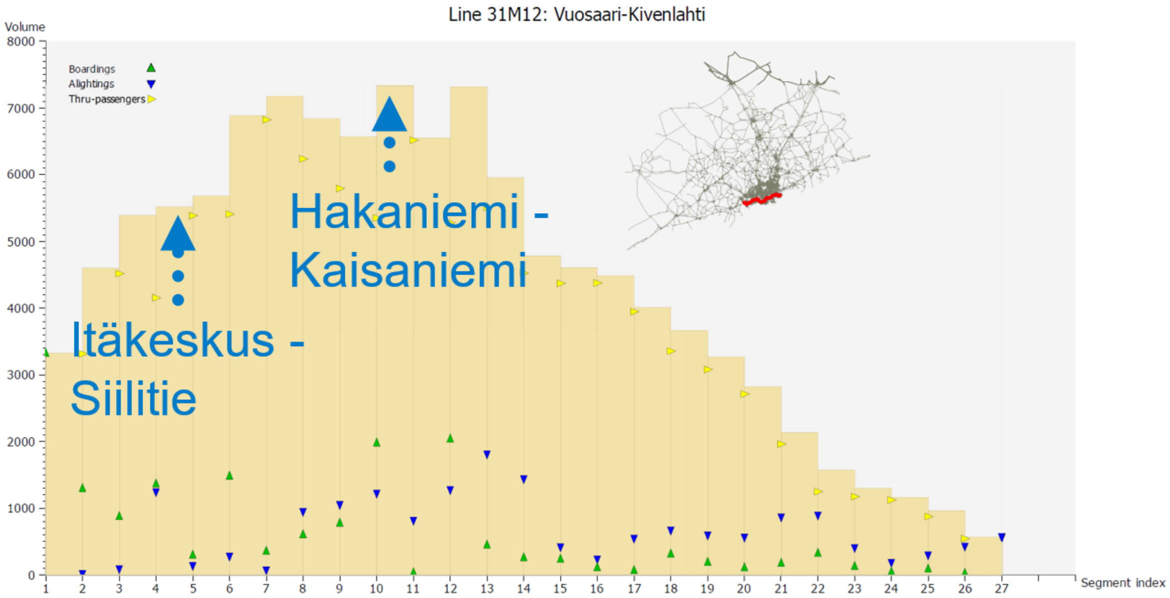


Figure 9 Metrolinjan M1 kuormitus suunnassa 2 asemaväleittäin perusskenaariossa 2060 aamuhuipputunnissa

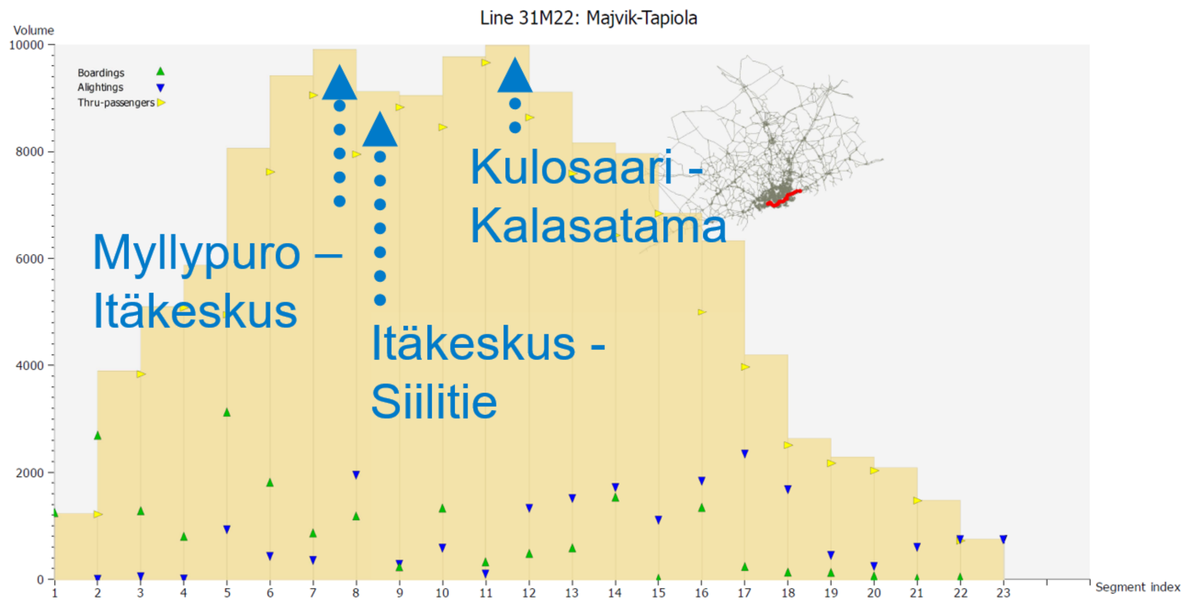


Figure 10 Load of metro line M2 in direction 2 by station intervals in the baseline scenario 2060 in the morning peak hour

In the baseline scenario, the Kivenlahti line between Matinkylä and Kamppi is close to maximum capacity or is congested, while the Tapiola line collects very few passengers. Even if the morning rush business trips were 10% lower than forecast (business travel development scenario), the capacity on the west side of Tapiola is 99% full.

Another critically loaded section of the metro line is the Majvik metro line between Myllypuro and Itäkeskus and Herttoniemi and Kalasatama, which is particularly affected by the increase in passenger numbers caused by a possible extension of the metro to

Östersundom. In the basic scenario, on the eastern section, the Östersundom line will be somewhat more congested than the Vuosaari line and will be more than 90% full on the Myllypuro-Itäkeskus and Herttoniemi-Kalasatama sections.

In the scenarios considered, the eastern part of the trunk line is more heavily loaded than the western part, except in the scenario with the new metro branch. The total occupancy rate of the lines varies between 64-82% in the east on the Kulosaari-Kalasatama section and between 57-64% in the west on the Lauttasaari-Ruoholahti section. In the metro branches, the occupancy rate varies in different scenarios between 82-97% for Myllypuro-Itäkeskus and between 100-111% for Urheilupuisto-Tapiola (excluding the potential changes at western end of the metro line).

The effect of the considered scenarios on the peak hour load of the metro varies depending on the observation point. In the scenarios considered, the differences in the share of the East are larger than the changes in the West. In the eastern part, the biggest differences are in the scenarios without Östersundom, the new metro branch and the development of the bus offering. In the West, the biggest impacts will be created by modifications for the western end of the metro, a new metro branch and the development of the bus offering. More permanent (or other systemic) changes in commuting can have a significant impact on outcomes.

The following table shows the number of passengers and bottlenecks identified in the metro in different forecasts. In addition, the table shows the number of passengers with a sensitivity analysis, in which the number of passengers has been reduced by 10% and 20%.

		Number of passengers / hour		
	Capacity	Model	-10%	-20%
URP 2020 (helmikuu toteuma)	7200	5800		
URP 2030 (MAL19)	9000	9600	8640	7680
URP 2060 (2020 perus)	10800	11900	10700	9500
KA - M1 2020 (helmikuu toteuma)	7200x2	10870		
KA - M1 2030 (MAL19)	9000	6300	5670	5040
KA – M2 2030 (MAL19)	9000	6400	5760	5120
KA - M1 2060 (2020 perus)	10800	7200	6480	5760
KA – M2 2060 (2020 perus)	10800	10000	9000	8000

URP = Urheilupuisto – Tapiola, KA = Kulosaari – Kalasatama linjaosuus

The table shows that the current metro capacity on the west side of Tapiola is not enough with the current system and traffic model at the end of this decade in 2030 or 2060 forecasts, even if demand decreases by 10% or 20%: Capacity will therefore have to be improved in all cases. If the system is developed to reduce the frequency to 120 seconds, a 10% reduction in forecasts of peak hour passenger numbers in 2030 would be sufficient to ensure sufficient capacity. On the other hand, then we are so close that it is probably best to prepare for the transition to a traffic model where more than every other train continues from Tapiola onwards. In the baseline scenario, the

Kivenlahti line between Matinkylä and Kamppi is close to maximum capacity or congested, while the Tapiola line collects relatively few passengers. The solutions considered at the west end of the metro eliminate capacity problems due to uneven loading. The other options considered are not sufficient to address the capacity challenges in the West, but in some scenarios the number of sections that are above or close to maximum capacity will decrease. The development of the bus offering scenario has the greatest impact. The development of tram connections also has an impact, and the Tiederatikka tram line has a greater impact on the load on the West than the Jokeri 0 tram line. In other scenarios, the problem locations in the West do not change compared to the baseline scenario. Even if commuting during the morning rush hour were 10% lower than forecast (scenario for the development of commuting), the capacity on the west side of Tapiola is 99% full.

On the east side of Kalasatama, capacity must be developed at the latest with the development of the Östersundom area and the Majvik line. In addition to the sensitivity analysis and the baseline presented here, several studies have been conducted in the study. Of the scenarios studied, excluding Östersundom, the new metro branch and the development of bus connections will reduce the load on the metro so that the eastern part will no longer be close to the maximum capacity of the metro system. If Pisararata is not built, Tiederatikka tram line and Jokeri 0 tram line will reduce the loading on the metro somewhat, but in these scenarios, the Östersundom line will still have over 90% loading on some sections. Of the scenarios, the solutions for the western end of the metro and the current pricing of traffic, in turn, slightly increase the sections in the East where demand is close to the maximum. The extension of the ViiMa tram line has no significant effect to metro passenger load. Based on the reviews made in the scenarios, the extension of metro to Vuosaari Port will not have significant effects on the morning congestion capacity problems.

1.2 Uncertainties related to passenger growth

Passenger demand is seen to grow in the future as the number of inhabitants and jobs in the Helsinki metropolitan area increase. At the same time, at the planning stage, the 2020 pandemic (COVID 19) has posed challenges in estimating future capacity needs, creating uncertainty about the pace of this growth, possible step changes in demand due to increased teleworking, at least temporarily, and other possible changes in travel practices, e.g. levelling and extension of morning rush hour. It is unclear which of these changes are temporary and which of these may become established practices in the future. According to traffic model experts, it may take 4 to 5 years before new travel practices can be modelled and updated models can be made based on traffic models.

However, the coronavirus pandemic has shown that ~ 50% of public transport trips take place even in the worst of the epidemic. With strong teleworking recommendations in force in August 2020, passenger numbers are only about 30-35% lower than at the same time in 2019. At this stage, it is recommended to use scenarios for sensitivity analysis where metro peak hours are reduced by 10% or 20% compared to current models. A reliable assessment of a possible change cannot be made, but in both cases it would be a significant change in the transport system and is therefore suitable as a sensitivity analysis.

In addition, the pandemic can have a significant impact on the urban economy and consequently on the financing the project. The implementation phase of the project may also be delayed by the recommendations made in the feasibility study, as the change in capacity needs is expected to slow down as a result of the change caused by the pandemic.

There are therefore uncertainties in the estimates, which can lead to a situation where the current system is congested in an unsustainable way and it is not possible to react quickly enough. To prevent this risk, regular monitoring of traffic volumes and forecasts will be carried out. The next more extensive review of this will be done in spring 2021, when preparations for the next round of MAL reviews will begin.

1.3 The current metro system

1.3.1 Metro Lines

The current Helsinki Metropolitan Area metro line consists of two lines: Vuosaari – Matinkylä at 5 minutes (300 s) and Mellunmäki – Tapiola at 5 minutes (300 s). The lines have share tracks between Itäkeskus and Tapiola, with an interval of 2.5 min (150 s).

Figure 11 Helsinki Metro map

The Helsinki metro began operating in August 1982 between Hakaniemi and Itäkeskus. The latest extension, the first phase of the Western Metro from Ruoholahti to Matinkylä, was opened to passenger traffic in November 2017. The second phase of the Western Metro from Matinkylä to Kivenlahti is currently being built. The estimated commercial operation start is in 2023.

Figure 12 Metropolitan area metro lines on the map. The dashed line marks the extension of the metro under construction from Matinkylä to Kivenlahti.

Since the metro started operating to Matinkylä, the average length of passenger journey has been 7.9 km. Prior to this the average length of trips was 6.3 km.

1.3.2 Track

The total length of the metro line is 35 km, it has 25 stations and one depot. Of the stations, 16 are underground and 9 are above ground. All above ground stations are located east of Sörnäinen. The Länsimetro western extension includes stations from Lauttasaari to Matinkylä, other stations are property of the City of Helsinki, and are known as core metro. The extension of the Länsimetro from Matinkylä to Kivenlahti brings seven km and five more stations to the metro line, as well as a new depot at Sammalvuori, which has reduced functions compared the current Roihupello metro depot. When the extension of the Länsimetro becomes operational, the total length of the metro line will be 42 km, with 30 stations, of which, 21 stations are underground and nine are above ground, and two depots.

The stations of the Länsimetro are built on shorter platforms than the core metro, and enable traffic on four-car metro trains. The stations have been dimensioned in accordance with the metro automation project underway at the design stage of the Länsimetro. The automation project at that time was to enable a 100-second interval already when the 1st phase of the Länsimetro was completed. Older metro stations allow a six-car train. Following the shift to four-car trains, the locations of the main signals at the core metro stations are no longer optimal.

The core metro power supply is currently implemented for a 150-second interval, but a metro power supply development plan has been made for a 100-second interval. Thus, when the power supply system is gradually renewed, it is upgraded towards shorter intervals. Länsimetro was originally designed for a 100-second interval in its entirety.

The load-bearing capacity of metro bridges has been a concern in the past as a possible limiting factor for capacity increase, but studies carried out in the context of general design show that the load-bearing capacity of bridges will not be a limiting factor for capacity.

If the tunnel sections of the core metro are to be developed in the direction of a fully automatic metro operation, considerable efforts must be made to develop the exits and emergency walkways.

1.3.3 Rolling Stock

The Helsinki Metropolitan Area metro is currently served by 45 metro trains, of which 36 are committed to operation during rush hours. There are three different fleets of trains: M100, M200 and M300. One metro train consists of one four-carriage M300 fleet train unit, of which there are 20, or two two-carriage M100 or M200 fleet train units. There are 39 M100 fleet train units and 12 M200 train units, thus making up 19 and 6 metro trains. Based on the option related to the purchase of M300 trains, 5 more four-car train units have been ordered for this train fleet. The delivery of the train units is scheduled for 2022, after which 50 metro trains will be available.

A new M400 train fleet procurement is being planned. Switching to the 120-second interval requires at least 10 new trains. This needs to be taken into account in the procurement schedule for the M400 train fleet. The future train fleet should also replace the older M100 and M200 fleet trains. The M400 trains will have two cabs per four carriages, while the M100 and M200 trains provide a metro service consisting of two two-car units, with four cabs per carriage. This will increase the space available to passengers by approx. 8 m2 and thus also the maximum passenger capacity by approx. 32 passengers / train, which with a four minute train interval corresponds to approx. 500 passengers per hour per direction on both metro lines.

Available trains per train series	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
M100	19	19	19	19	19	19	19	19	19	19	17	6				
M200	6	6	6	6	6	6	6	6	6	6						
M300	20	20	25	25	25	25	25	25	25	25	25	25	25	25	25	25
M400											17	29	35	35	35	35
Available total	**45**	**45**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**59**	**60**	**60**	**60**	**60**	**60**

Train availability	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Operation	35	35	35	39	39	43	43	43	43	43	53	53	53	53	53	53
Maintenance and	6	7	7	5	5	7	7	5	5	6	6	6	6	6	6	6
Total	**41**	**42**	**42**	**44**	**44**	**50**	**50**	**48**	**48**	**49**	**59**	**59**	**59**	**59**	**59**	**59**
Spare units	**4**	**3**	**8**	**6**	**6**	**0**	**0**	**2**	**2**	**1**	**0**	**1**	**1**	**1**	**1**	**1**
Usage rate	**78%**	**78%**	**70%**	**78%**	**78%**	**86%**	**86%**	**86%**	**86%**	**86%**	**90%**	**88%**	**88%**	**88%**	**88%**	**88%**

Note: **43** based on 3/4 operation to Kivenlahti **53** based on 2 min headway

Table 1 Number of trains available per train fleet and commitment of rolling stock

The total number of trains needed for 2020-2035 is based on preliminary estimates of future metro volumes. The number of trains per fleet is presented in Table 1 on the basis of the winter 2019/2020 version of HSL's traffic plan.

The adequacy of metro rolling stock for large-scale modifications is limited. When operating in Kivenlahti, the utilization rate of the fleet will be about 86% if one of the four trains turns in Tapiola while the others continue to Kivenlahti. With other factors such as corrective maintenance and periodic maintenance requiring the rolling stock to be out of service, the availability of trains for alterations is poor. In this case, the time required for changes to the trains as a whole may be too long. Table 1 is prepared with an assuption that ¾ traffic to Kivenlahti will start in 2025. However, no decisions have been made on this. Similarly, the timing of the acquisition of the M400 has been adjusted to correspond to a 120-second interval from 2030, with no decisions on the procurement of the fleet.

The oldest M100 fleet trains are from 1980 to 1984 and the M200 fleet trains from 2000 to 2001. These trains are state-of-the-art technology from their respective manufacturing times and their full automation proved challenging in a previous automation project. However, the M100 and M200 fleet are prepared to be kept operational until 2035, and a basic refurbishment project for these train fleets is currently underway.

The planned service life of a metro train is about 40 years. The remaining service life of the M100 and M200 trains thus estimated is shorter than the CBTC equipment that may be installed on them, which affects the return on investment. Converting trains to automatic can be cumbersome and expensive. The service life of the M100 fleet trains has previously been extended by a renovation carried out in 2003-2009. In 2017, HKL launched a project in which all M100 and M200 trains will be refurbished by 2023, e.g. in terms of commercial appearance. Wrong side door opening prevention will be implemented for all fleets with a project starting in 2021. However, M200 trains are coming to the end of their technical life in the 2030s, so their replacement is essential without some significant action. The M100 trains are mechanically very durable, so it is possible to refurbish them again. The use of such equipment is more cost-effective than new equipment, as the acquisition costs have been completely depreciated.

The newest, M300 fleet trains are from 2017–2018 and are well prepared for a fully automatic run according to the needs of the previous automation project. In the future, when switching to driverless metro, the cab of M300 trains can be removed. Five additional trains have also been ordered for the M300 fleet trains, which will be used for the need for additional trains required by the Länsimetro Kivenlahti extension. Delivery of the new trains is scheduled for 2022.

HKL now owns eight rail maintenance vehicles, the latest of which has been delivered this year (2020). All maintenance vehicles are different from each other and of different ages. A tamping machine from the Finnish Rail Administration's rail network is also used for track work about twice a year, in addition to which it also occasionally runs otherwise. HKL also has a contract for a rail wheel excavator that is used every night.

The maintenance vehicles are operated in accordance to the colour light signals and have magnetic stop devices. There is a lot to do in maintenance, working hours cannot be cut, so the maintenance vehicles leave the depot when the passenger traffic is ceasing. During the day, the vehicles are usually used only in the metro depot area.

Maintenance vehicles must also be prepared for the increasing need and the extended travel times to sites when the Länsimetro Matinkylä-Kivenlahti section opens. Ensuring the safety of maintenance vehicles in the metro system must be taken into account when renewing the systems.

The implementation of ATP equipment on existing trains and maintenance vehicles always requires a considerable amount of design and verification work, even before the challenges involved in installation and testing can be taken on.

The table below seeks to summarize the main findings of the fleet inventory related to the upgrade of trains to GoA2 semi-automatic running. If no automation is implemented, but only a continuous ATP system is installed, the interface to the equipment will be simpler. There is a separate document on the fleet inventory, where the findings presented below are discussed in more detail.

Fleet	Ease of installation of new ATP and ATO	Number of trains	Track based transition	Train based transition
M100	-	+	++	-
M200	- -	- -	++	- -
M300	+	++	+ -	+ -
Maintenance fleet	- -	- -	++	-

The fleet assessment has recommended a number of points to be clarified, which should be documented when a call for tenders for a new traffic control system is sent to potential suppliers, and in practice it is necessary to be documented at the latest when the contract with the selected supplier is drawn up.

1.3.4 Traffic Control System

The current metro system is a manually driven metro, which does not have a continuous ATP system to ensure compliance with speed limits. The interlocking device controls track-side magnets of the emergency stop system, which activate the train brake by means of an on-board device if the train passes a Stop signal. The train then stops on the overlap track provided by the interlocking device in connection with the train route. The tracks are divided by signals into fixed length sections, which can only be secured for the movement of one train at a time. Drivers drive trains from one signal to another on the basis of aspects provided by the signals. The aspects are generated and controlled by the interlocking device on the basis of the confirmed train routes.

The sections between the signals are further subdivided into track sections, where the location of the train is identified by the control devices with the granularity of the physical track section. Occupancy detection along the metro line is based on audio frequency track circuits, while axle counters are used in the metro depot area.

The traffic control system for the metro west extension has been acquired from Mipro Oy and is quite modern. In January 2019, Mipro's systems were also introduced in the core metro area, whereby the entire metro line now has a unified traffic control system. The same system is also being installed in the metro west extension phase 2 area.

The trackside equipment of the traffic control system in the Helsinki core metro area is mainly from the 1980s and the availability of their spare parts has deteriorated. Some devices are nearing the end of their life cycle and their failure frequency has grown, causing an increasing amount of traffic disruption.

The magnetic emergency stop system does not rely on the latest technology and does not allow shortening of intervals without compromising safety. This is, of course, not acceptable, so in terms of shortening the intervals, it is justified to develop the metro's traffic control, either by replacing the emergency stop system with continuous ATP or by installing a new traffic control system before shortening the train intervals.

1.3.5 Train frequency

The maximum train frequency of a metro is determined by the combined effect of the metro line, the metro trains and, most importantly, the metro's traffic control system. With the current traffic control system, the minimum possible theoretical interval of the metro is about 120 seconds, according to the most limiting factor. However, in order to enable traffic disruption management, the frequency of scheduled traffic must be greater. The most frequent train interval that is continuously achievable in practice for the Helsinki metro and Länsimetro is 150 seconds. To simplify this, this means that each train can afford to be only 30 seconds behind schedule before the following train has to wait for it. This recovery time is short and there are currently quite a few traffic disturbances in the metro.

The current train interval on the joint section of the metro lines cannot be shortened without updating the traffic control system. If the frequency were to increase without a train control update, trains would have less than 30 seconds to recover from disruptions. Such a small margin would have the metro traffic very easily disrupted and, for example, a passenger going between the closing doors of a metro could already cause significant traffic disruption. In addition, the current boarding and alighting of trains at stations should be significantly improved. This path of development is not realistic or the aim is to upgrade or renew the system for controlling metro trains in order to increase the frequency.

In the event of major disturbances, the disturbance is managed by abandoning the schedule and adopting a uniform headway, slowing down other trains by the delay of an individual train. In this case, a uniform train interval is maintained and station congestion can best be managed.

1.3.6 Passenger capacity and service level

The Public Transport Planning Guide (HSL 2016) guides passenger density in metro traffic. The instructions specify the number of seats in the vehicle in use and the permissible load levels. The targets set for travel space drive increasing departures when demand is increasing. According to the instructions, the capacity of the departures is dimensioned so that failure to be able to board a train is a rare exceptional situation. Outside peak periods, capacity is dimensioned so that, as a general rule, a seat is available in metro traffic. The maximum number of passengers per metro train is defined in the guidelines as 228 seats and 480 standing places, where the number of standing persons is 4 persons / m2. In long-term plans, capacity is dimensioned on an hourly basis and taking into account fluctuations in travel demand during peak hours. For this reason, 85% load factor is used to measure hourly capacity in traffic, ie 602 passengers / hour per metro train.

The current average load of the metro is significantly below the figures in the design guidelines presented above. However, HSL has repeatedly received feedback from passengers about excessive passenger numbers on the metro. For this reason, HSL will investigate the need for changes to the design guide in connection with the update of the design guide. The closer the passenger count is to the maximum design values, the greater the disturbances. A train delay at rush hour leads to 40% more passengers per minute, so regularity is a critical factor for traffic efficiency.

The length of the trip also has an effect on customers' wishes about travel space and seat availability. After the opening of the Länsimetro in 2017, the average distance in the metro increased from 6.3 kilometres to 7.9 kilometres (HSL ticketing surveys 2013 and 2018). The average distance is expected to increase further as the metro system expands further west and eventually also east.

The calculated passenger capacity of the current driver metro per metro line in five-minute (300 s) intervals, when half of the metro trains run from Tapiola to Mellunmäki and half from Matinkylä to Vuosaari, is about 7,200 passengers per hour.

Today, the service level of metro traffic is mainly good, but there is room for improvement, especially with regard to the regularity of traffic. The irregularity is often due to faults in the old signalling equipment and rolling stock as well as arising from passenger behaviour that cause delays. In signalling equipment, old track circuits and signals in the core metro are the most common cause of disruption, and for trains the most common interference is caused by door faults. Passenger activity can create disruption in many different ways, the most typical being the slow disembarkation and embarkation of passengers, standing between doors, and the actual disruptive behaviour such as malicious emergency handle pulling, moving on the track without permission, or exiting the train at the turn back area.

In addition, the effects of a disturbance can easily extend over a long period of time and large area due to the small disturbance recovery allowed by the system. The traffic control system does not actively support the implementation / restoration of a regular interval, but traffic controllers have to intervene manually to manage the situation.

There are very few missed departures, Figure 13. On average, the load factor is well below the service level targets of HSL's public transport planning guidelines, but the uneven loading of lines in the west and the irregularity of the intervals cause congestion experiences.

Metro traffic is currently run on a 35 km long line. When the 2nd phase of the metro west extension opens, the line length will increase by 7 km, which may increase the sensitivity of the metro line. As traffic intensifies and demand grows, the regularity of traffic will become even more important.

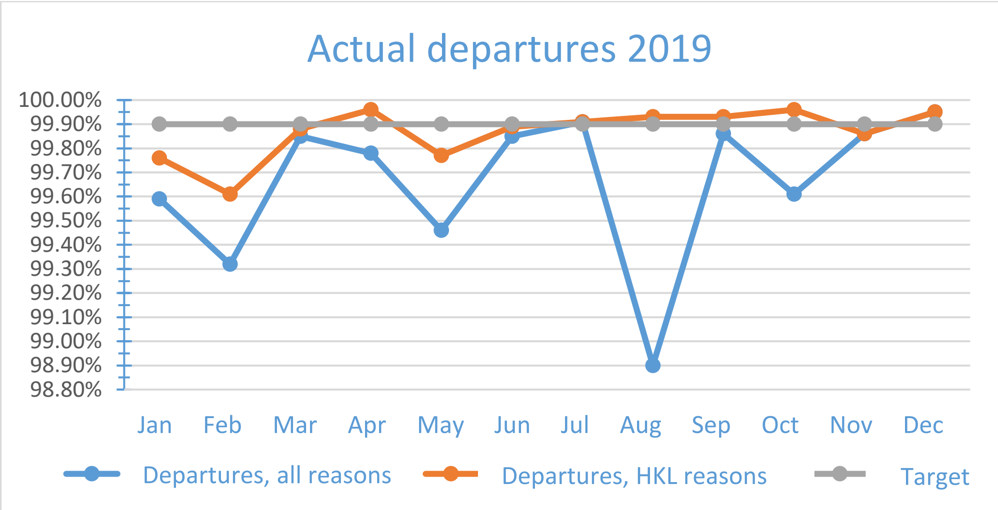


Figure 11 Actual departures in 2019

1.3.7 Ownership, maintenance and development

The infrastructure of the metro system east of Ruoholahti is owned, maintained and developed by the City of Helsinki (City of Helsinki Transport Authority, HKL). In addition to the track, this includes stations and technical systems. West of Ruoholahti, Länsimetro Oy has the ownership, maintenance and development responsibilities of the track, stations and technical systems. Länsimetro Oy is owned by the cities of Espoo and Helsinki. The shares of the cities are distributed so that Espoo's share of the Länsimetro is about 85 per cent and Helsinki's 15 per cent. The cities have agreed on the mutual sharing of construction costs in accordance with the principle of cross-border, i.e each pays the construction costs incurred in its own area. Länsimetro Oy has contracted HKL to maintain and operate the metro system in its area.

HKL owns the rolling stock and is responsible for the operation and maintenance of the metro equipment for the entire system.

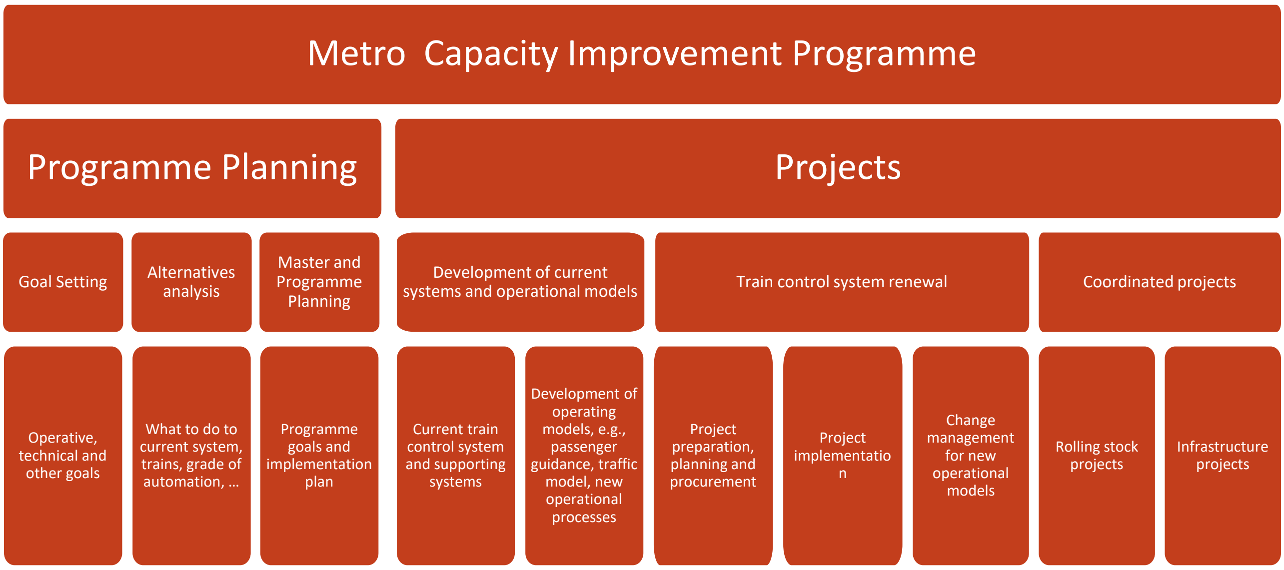
HSL as the regional public transportation operator plans and organizes public transport in its area of operation and, in addition to metro transport, also procures bus, tram, ferry and commuter train services.

2. Objectives

2.1 Project overview

With the completion of the master plan, the metro capacity project is moving from the planning stage to the implementation stage. In the planning phase, studies, pre-planning and supplier interviews have been used to assess alternative ways to improve the capacity and reliability of the system, and on this basis to set objectives for the project, which are brought together in this master plan. Based on these, several projects are planned for which separate project plans will be prepared.

The diagram below is an overview of the overall metro capacity project. This chapter is summarizing its objectives.



2.2 Capacity target

From the passenger's point of view, the essential goal is that the metro has sufficient capacity. Adequate capacity can be determined by the following indicators:

1. It is normally possible to board a train and not be left at a station due to an over-crowded metro train.
2. Station stopping times will not increase due to a large number of passengers and traffic speeds including stopping times will remain at a sufficient level, the target for dwell time is 20 sec.
3. Travel comfort does not suffer unreasonably due to full metro trains: Outside peak hours it is possible to sit, during peak hours up to 4 standing passengers per m^2.

The capacity of the current driver's metro is about 7,200 passengers per hour at 5 min (300 s) intervals, i.e on both line M1 and line M2. At present, both lines operate between Tapiola and Itäkeskus, with double capacity and train interval half of the above mentioned figures. If the metro is upgraded with a new radio-based traffic control system, its interval on both lines can be shortened to 200 seconds, giving a capacity of

10,800 passengers per hour. If a solution is reached in which the metro is equipped with a new ATP system and the line's signalling layout is optimized, it is possible to have an interval of 4 min (240s) on both lines.

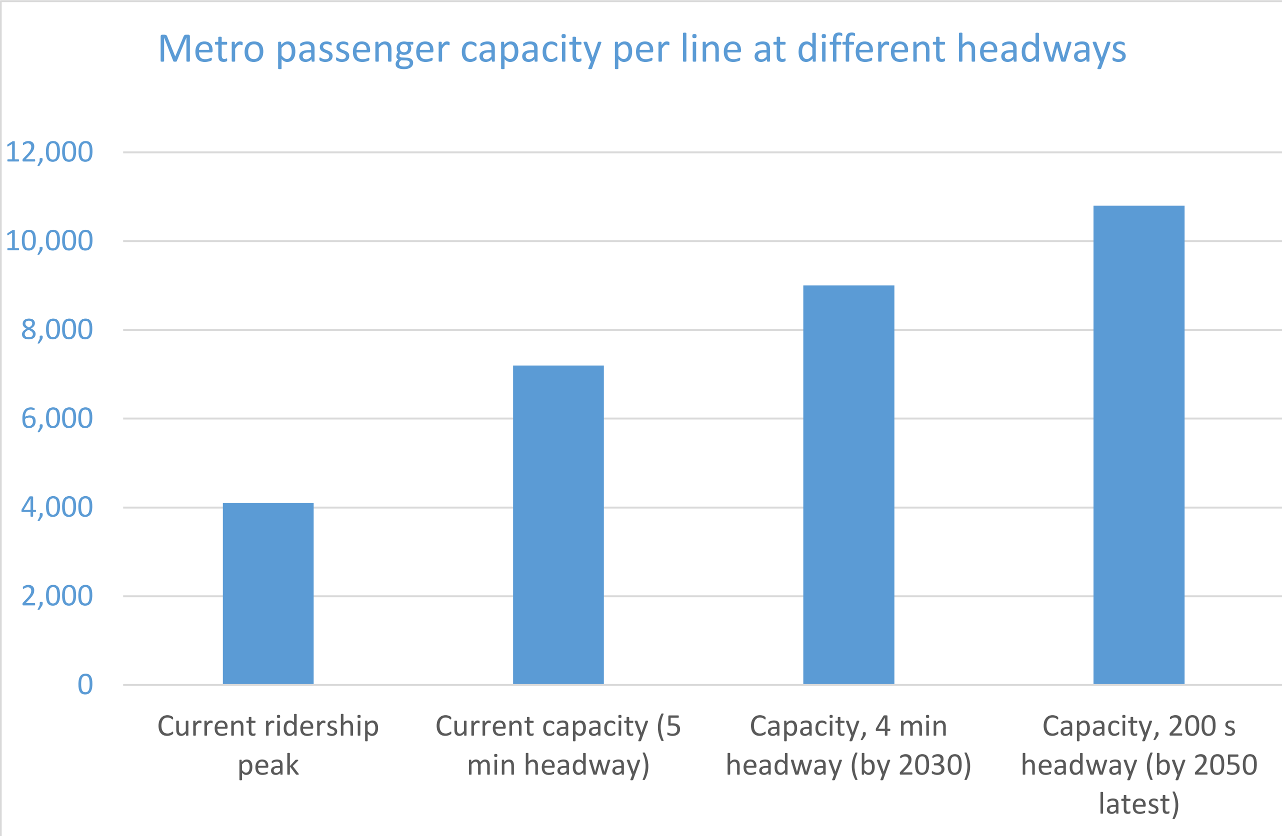


Figure 12 Metro passenger capacity at different train frequencies

According to the traffic model, even with the lower growth in passenger numbers as analysed in the sensitivity tests, the line west of Tapiola will be congested with the current traffic model by end of this decade. Therefore, increasing the capacity of this section of line is essential during this decade.

Congestion is forming slower on the east part of metro line, and it is strongly associated with the continuation of the metro to Majvik as the Östersundom area is built. According to the passenger volume survey carried out in connection with the preparation of the master plan, the surveyed high-speed tram lines Tiederatikka, Jokeri 0 and the extension of the Viikki-Malmi tramway to Mellunmäki do not remove enough passengers from metro to avoid congestion. At this stage, the metro and / or other public transport system components must be developed in order for public transport to be able to meet the growing demand.

2.3 Service level objective

The capacity of the metro system is determined by two things, the number of passengers and the level of passenger service. The two naturally have an effect on each other. The growing number of passengers makes it possible to run additional services economically, but on the other hand, the system has its limitations on how many additional services can be run. On the other hand, if the number of passengers is low, the economic train interval may be so long that the level of service deteriorates.

Therefore, in order to determine the level of service, it is necessary to assess how many passengers are predicted and what level of service they should have. The service level can also be measured by various measures measuring passenger satisfaction, but the service level indicators presented here are those that can be significantly affected directly by the implementation of the technical system.

The aim of the project is to continuously monitor the service level and implement measures to develop the service level, as well as to set ambitious but realistic service level targets for a possible renewal of the traffic control system.

The following table shows possible service level metrics:

Service level metric	The goal of the service level metric
Passengers per square meter	A metric that is closely linked to capacity
Non operated scheduled departures	A traditional, easily measurable thing that tells of a schedule change
Number of delays of more than 5 minutes	The number of delays measures how many train passengers have experienced delays on their metro journey
The longest delay of the day	The biggest delay of the day indicates whether there has been a significant, widespread traffic disruption during the day
Punctuality	An easily comparable figure that tells the proportion of arrivals to terminals up to 3 minutes late
The longest train interval of the rush hour	Describes the regularity of traffic
Number of passengers who could not fit in the metro from the station	Report exceedances of maximum capacity, but challenging to measure with existing systems and especially at trunk stations through which two lines pass
Metro load factor	Meter calculated from the change in the length of stopping times or the number of passengers that cannot fit on a full train
Accuracy and clarity of information provided to passengers	No metrics specified
Passenger flow efficiency	No metrics specified

Another goal of the service level is the disruptions caused by the project during the project implementation. The main objective of the metro capacity project is not to cause traffic disruptions or other disruptions to passenger traffic.

2.4 Life cycle cost targets

When developing a long life cycle system, it makes sense to focus not only on the investment cost, but on the life cycle cost of the system. This principle is also in line with HKL's cost-effectiveness objective. When estimating life cycle costs, the life cycle costs of the entire metro system should be taken into account, not just the costs of this project.

Lifecycle costs are particularly affected by system reliability and availability, maintainability, and lifecycle duration. The related objectives are outlined here as qualitative objectives.

Reliability is directly reflected in low maintenance costs of the system and high availability of the system reduces the need to use money-consuming exceptional solutions for the operation of the metro system. Therefore, when choosing the equipment and subsystems to be adopted for the system, attention must be paid to their reliability. When designing and implementing the structure of the system, the availability of the entire system must be taken into account. However, at the same time it must be ensured that equipment is not unnecessarily added, thus adding parts that may fail in the system. This balance should be kept in mind throughout the project.

The solutions made in the project must be maintainable in such a way that the opportunities to develop the operation of the metro that can be identified in the future can be utilized and the system faces e.g. the threats of component obsolescence can be countered. In addition, future extensions of the system must be cost-effective.

The life cycle of a system is not necessarily the same as the life cycle of its components and subsystems. If the structure of the system is carefully designed, it is possible to replace parts of the system throughout the life cycle of the system. In this way, a longer life cycle of the system can be achieved, and high system renewal costs can be avoided over a longer period of time.

2.5 Safety objective

The safety objectives for metro transport in the Helsinki Metropolitan Area have been selected as follows:

- Zero personal injuries in metro traffic as a result of a metro traffic accidents.
- Zero rail accidents.
- The level of safety during system development remains at least the same or better

To support the achievement of these objectives, it has been decided that according to EU standards, a SIL-4 target in accordance with the EN 50126 standard should be set for the signalling system itself. This is in line with and supports the achievement of metro safety objectives.

There is zero tolerance for occupational safety risks in the implementation of the system.

Co-operation with the safety authorities relevant to the passenger safety of the system, i.e the rescue services and the police, must be continuous in order to ensure the safety of the metro system when the operating models of the system are changed. Co-operation must begin with the preparation of the operational requirements for the system as project planning progresses and with the preparation of the tender documentation.

As the railway traffic safety authority in Finland, Traficom monitors the implementation of HKL's safety systems. During the project, it must be ensured that the processes used in the project are approved by Traficom. Traficom will also audit the processes of HKL and thus of this project.

2.6 Environmental objective

Increasing the metro's capacity and attracting passengers to the most environmentally friendly mode of transport is a key goal of the capacity project. Despite the fact that the metro is in itself an energy-efficient system, the aim of the project is to ensure that the design takes into account the additional possibilities for saving electricity and improving the energy efficiency of the system.

When making procurement and implementation, the environmental friendliness of the system to be procured. It must be ensured during the both manufacturing phase and during maintenance. When assessing the environmental impact of maintenance, the need for consumables and spare parts as well as the necessary transitions when performing maintenance operations must be taken into account.

The decommissioning of existing systems must ensure the environmentally sound recycling or destruction of discarded products.

When assessing environmental impacts, the radiation hazards / effects of radio networks must also be assessed and taken into account.

2.7 Security Objective

As cyber harassment and crime increase, the security goals must be set for critical systems.

The information security of the metro system must be developed in such a way that it is not possible for third parties to cause disturbances to metro traffic. The security level for the system will be defined in accordance with the security standard IEC 62443 developed for the automation industry and the security standard EN 50701 for rail traffic under development based on it.

The system must also meet the requirements published by Traficom for the security of rail traffic systems.

3. Comparison and selection of capacity development measures

3.1 The way forward

Capacity development is divided into two phases. The first phase aims at measures to improve existing systems and operating models and to safeguard their life cycle, so that by the end of this decade the capacity and reliability of the metro system will be sufficient to meet passenger demand. At the same time, definition of, project planning and procurement preparation of a traffic control system that satisfies future capacity needs and offers a higher level of driving automation will be taken forward. Once the preparations have progressed sufficiently and the current uncertainty about the development of passenger demand has been overcome and seen as additional capacity and / or a higher level of automation is needed, further development of the second phase of traffic control can be initiated for future needs.

The project must communicate the requirements caused by the increasing train density to HKL's asset management renovation projects, which may not be sufficient to maintain the current state. Examples include the adequacy of the track electrical system capacity, emergency exit arrangements, tunnel ventilation, building services systems (e.g., ventilation, smoke extraction, escalators, elevators) and pressure equalization. In addition, it must be ensured that the Maintenance Department is able to meet the growing need for maintenance with possibly smaller working hours and response times.

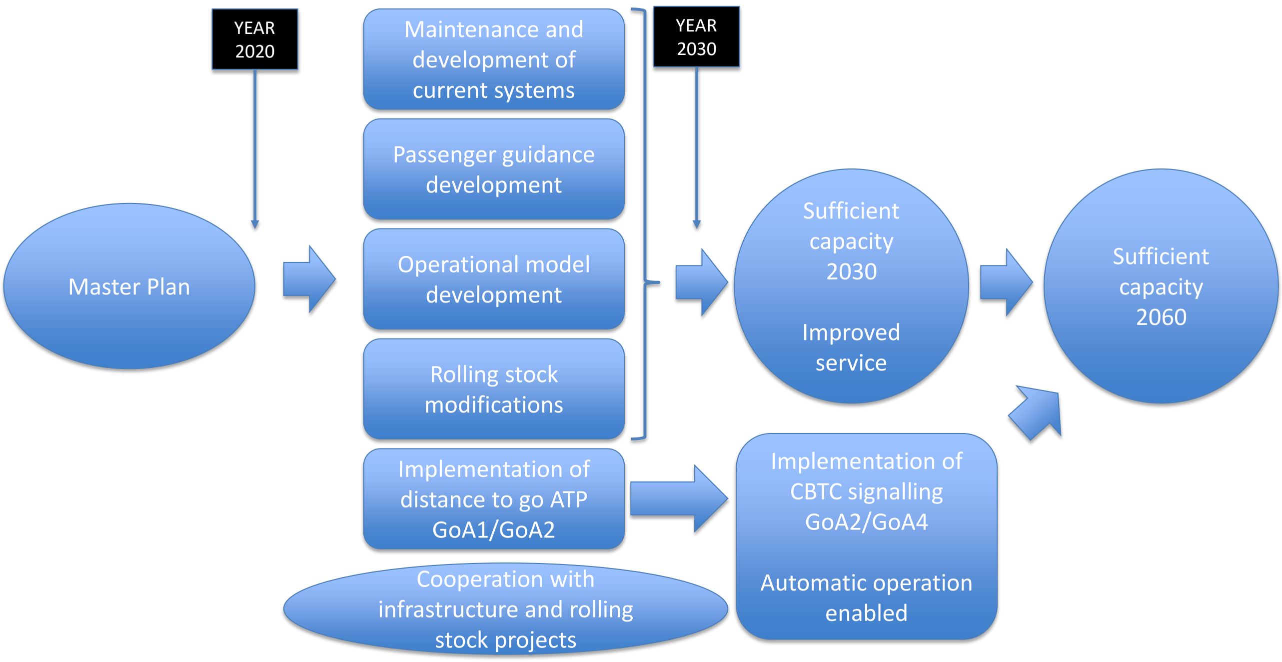


Figure 13 The roadmap of the capacity and reliability development project

3.2 Maintenance and development of existing systems

The development potential of the current system has been examined in the studies carried out during the preparation of the master plan. As a general rule, the identified development measures do not increase capacity in such a way that the train interval can be shortened, but they prevent the occurrence of disruptive situations and thus have a positive effect on the flow and punctuality of traffic.

The priorities for the development of the current system are:

- ensure that the reliability of the system is no longer deteriorating, the aim is to reduce disruption;
- develop the operation of existing signalling equipment and eliminate capacity and traffic bottlenecks in the system;
- develop operating models and traffic control system features so that track capacity is utilized more efficiently and metro disturbances can be managed more effectively and thus recover faster

Behind these priorities are several smaller measures that are described in this chapter. These measures can be used to improve the metro's disruption tolerance and punctuality, as well as to ensure the system's life cycle until the introduction of a new traffic control system.

However, some of the current subsystems of the core metro will require significant investment at the end of their life cycle. The production of the original metro's track circuits and the manufacturer's support have already ceased years ago. Also, faults in those occur frequently compared to similar new equipment used in the metro west extension. In the case of signals, the short life of the bulbs currently supplied and the risk to train safety due to failed red signal are particularly problematic.

The original plans were to maintain the service life of the above subsystems until the introduction of the CBTC system. There are significant reliability problems associated with the subsystems, which pose significant risks to train safety and traffic flow. If the commissioning of the CBTC system is significantly delayed, it is recommended to replace the emergency stop system with a continuous ATP system. If at the same time the signalling layout is improved, the train intervals can also be shortened.

3.2.1 Extending the life cycle of subsystems

There are many systems in use in the metro that have already very long operational period or their lifecycle is potentially already coming to an end. It is critical for smooth traffic to ensure that these systems operate reliably as long as necessary. There are several ways to prolong the life cycle, from which the most suitable ones must be mapped and selected.

Examples of the above-mentioned critical systems are the old metro track circuits (Siemens GLS 9/15) and filament signals (Siemens) as well as the M100 train magnetic emergency stop onboard system.

In addition to these, there are other important factors to consider when considering extending the life cycle of the current system. The spare parts and inventory management system can be used to ensure optimal spare parts management. It is also important to identify and possibly remove additional old cables from the tunnel areas of the core metro, which are a fire safety risk, as well as other equipment and systems that have become unnecessary.

Malicious pulls on the emergency handles of station platforms burden traffic control and disrupt traffic. In order to ensure smooth traffic, ways to significantly reduce unnecessary use should be identified and implemented.

Measures	Objective of the measure
Documenting the GLS 9/15 track circuit repair process and securing its life cycle	Reduces traffic disruptions caused by track circuit faults and ensures the adequacy of spare parts and a stable fault frequency at a tolerable level until the replacement of the traffic control system. Investigate the possibilities for preventing track circuit failures and implement measures. Analyse the root causes of the most failed track circuits and plan preventive measures, including the replacement of individual track circuits with a new free control system. Ensure the availability of spare parts until the replacement of the traffic control system.
Securing the life cycle of main line filament signals	Reduces traffic disruptions caused by filament failures and ensures the adequacy of spare parts and a tolerable failure rate until the replacement investment in the traffic control system. The condition of the signal structures and the effects of the deficiencies will be explained in more detail. Implementable measures to maximize the service life of filament signalling lamps, e.g. procurement of alternative products and possible support of the lamp supplier in development work.
Securing the life cycle of the M100 train emergency stop system	Ensures the availability of M100 trains with regard to emergency stop devices. Determining the availability and substitutability of spare parts and reviewing solution options with the equipment supplier (introduction of the next generation of magnetic stop devices in the M100 fleet).
Implementation of a traffic control system spare parts management system	Implements an up-to-date view of the spare parts situation, automatic definition of alarm and order limits, and connection to the SAP system.
Decommissioning of decommissioned cabling and components	Frees up space and eliminates unnecessary fire loads. Unused cabling and equipment will be identified and appropriate follow-up measures will be taken.
Development opportunities for point machines	Investigate the possibilities of increasing capacity at points and junctions by increasing the turning speed of point machines. Gaining experience in the operation of pneumatic and other faster point machines. The capacity benefit to be achieved as well as other advantages and disadvantages are determined.

Development of platform safety and vandalism prevention	Reduces malicious pulling of emergency handles and thus traffic disruption. Carry out a thorough risk analysis of the current state of the emergency handles, on the basis of which solutions to prevent malicious pulling will be implemented.

3.2.2 Modifications to signalling

Develop the current signalling by clarifying the problem areas of the current system and moving, adding or updating signals and other field devices. The end result is to increase the usability, reliability, traffic flow and life cycle of the current system.

Measures	Objective of the measure
Identifying bottlenecks in the current system	Identify network bottlenecks. Utilize ATS system stop and run times as well as other available data and simulation. Propose measures based on the results.
Signalling modifications at Itäkeskus area	Eliminates identified traffic bottlenecks. Itäkeskus station has been identified as a clear bottleneck (junction station) that limits passenger traffic capacity on the core metro side. Identify the possibilities and needs for changes in signalling in order to get rid of the factors limiting the operation of the station and assess the amount of investment required for the changes.
Signalling changes caused by platform signals	Eliminates network bottlenecks. Analyse the benefits of adding platform signals on a station-by-station basis, with a particular focus on bottlenecks. Define design principles and implement signalling plans. Utilize simulations as part of the final assessment.
Signalling changes at departure signals	To find out the capacity benefits and costs for changes that change the long platforms of the old metro in terms of signalling equipment placement to correspond to the lengths of the metro west extension platforms.

In the development of the current signalling system, it is essential to first make more detailed assessments of the bottlenecks in the current system and the effects of possible signal transfers / additions. These assessments should make use of simulations in order to detect the real effects of the measures, even outside the immediate vicinity of the change site, and to obtain a more comprehensive picture of the effects of the change. The actual signalling modifications would be carried out on the basis of these more detailed studies and simulations, once the extent and overall effects of the necessary changes are clear.

3.2.3 Accelerating the turning time

Reducing turnaround times at turnback at the ends of metro lines is a potential place to achieve time savings. Accelerating turnaround time would benefit traffic by creating more leeway to absorb various minor problem situations or delays. In addition, shortening turnaround times would help to recover from larger problem / fault situations and more generally increase flexibility during normal traffic. The reduction in turnaround times should therefore be used mainly to increase recovery margin and enable recovery from disruptions, as increases in line length, increasing traffic volumes and end-of-life systems will increase the likelihood and duration of traffic disruptions.

Measures	Objective of the measure
Speed increase at turning points	Raise the 20 km/h speed limit to 35 km/h at turn back. Add a signal and emergency stop magnet at the turning points as an end point of the route, and determine the overlaps for the routes ending in turns.
Utilizing an extra driver with turns	Determine the most appropriate operating model for the utilization of an additional driver at turn back and carry out an experiment, after which the benefits achieved in terms of capacity and immunity are assessed and a calculation of the effects of the operating model on operating costs is made.
Automatic turnback study	Prepare risk analysis and requirements specifications for automatic turn back. Based on the requirements specifications, an impact and cost assessment is made for the project plan.

Increasing the speed of the turn backs is a clear measure by which the turning times can be shortened. However, the time savings achieved in this way are limited, but this still increases the time margin available for disruption management. In addition, other possibilities for shortening turning times are being explored, such as the possible implementation of automatic turning for turning points. However, measures related to driver turning and automatic turning first require more detailed information on the benefits to be achieved and the level of costs of the measures.

3.2.4 Development of traffic control system functions

Develop the tools used in traffic control and the traffic control system itself in a direction that promotes smoother passenger traffic, training of traffic controllers and utilization of data available from current systems, e.g. traffic control and maintenance.

Measures	Objective of the measure
Piloting the connection of emergency handles and surveillance cameras in the core metro	Enables a faster response of the safety control room and traffic control as a result of emergency handles. Information will be provided on the pulling of Kontula's emergency handles into the camera surveillance system in control rooms in the most economically cost-effective way. A cost estimate is made to import all base metro emergency handle data into the camera surveillance system.
Swinging overlap	Shortens the effect of overlaps on capacity. Benefits of the swinging overlap feature in the ASL2 project will be monitored and other locations analysed to see where the feature is useful.

Optimization of interlocking functions in terms of capacity and safety	Increase capacity and make it easier to manage emergencies by changing access conditions. Possibilities for developing the operation of the interlocking device are studied, e.g.
Proactive point turning	Increase capacity at certain locations in situations where the train goes to a different branch of the point compared to the previous train. Implement in a controlled manner in the traffic control system a function in accordance with HKL's traffic rules with an indicator that turns the points to the correct position before the path can be secured.
Development of fault management tools	Allows you to maintain a steady interval in the event of disturbances using the ATS system. Implement more detailed definitions for the functions to be developed in the ATS system, potentially such as a train graph view and the manual and automatic schedule adjustment.
Further development of the ATS system and improvement of usability	Continue to identify development targets for ATS system functions and system updates with the system vendor.
Development of an ATS simulator	Improves the quality of traffic controller training. Ensure training in a space free of other distractions. The simulator is divided into two user interfaces, one for the trainer and the other for the trainee. It is possible to utilize the interlocking device simulator in the simulator of the ATS system.
Traffic management system data interface	Ensures the security and usability of the data produced by the traffic control system. Define the architecture and requirements for traffic control system data management and sharing.
Acquisition of an interlocking device simulator	Enables training of the interlocking system with the correct interlocking device and testing of the interlocking firmware at HKL's premises. Define more detailed implementation requirements and associated costs.

The development of traffic control systems achieves more flexibility and fault tolerance during normal traffic. In particular, the development of disruption management and solutions that bring more flexibility to traffic promote traffic in various fault or problem situations and recovery from them back to normal smooth traffic. The development of simulators, in turn, helps in the training of traffic controllers, in the testing and practice of various disturbances or traffic situations, and in the testing of new ATS or interlocking functions before they are brought into the final production environment.

3.3 Development of operational models

HKL has operated the metro for about 40 years, and the currently in used operational model has been developed for operating the metro. The model is documented as a metro functional guide (MTO).

However, evolving digitalisation offers opportunities to further develop these processes. Some of these opportunities can be developed into existing operations management systems, and some require investment in the development of new systems or the development of new functions in existing systems.

The right timing must be taken into account when developing these models for current or future system digitalisation, when making investment decisions. In general, however, in the case of moderate investments, the issue of time takes precedence over cost issues if the efficiencies are reasonably high, as this type of investment brings experience with new models and their use / digitalization, which in turn promotes further development.

When considering the implementation of a new traffic control system, the redefinition and development of functions must also take into account their functionality with new traffic models. The successful implementation of the traffic model when implementing automatic traffic requires significant changes in operating methods, which must be defined at least in outline already in the system requirements definition phase. For this reason, it is advisable to start defining current responsibilities, procedures and acquiring support systems well in advance of acquiring a new system. These measures to develop operating models for the new traffic control system will be carried out as part of the traffic control system implementation project, and this chapter will focus on measures to work with the current system. Some may also be relays after the traffic control has been renewed.

The recommended actions set out below do not increase the overall capacity of the metro system to a very large extent, but they can increase the efficiency of traffic and increase its reliability. The recommendations presented contain a number of challenging measures, the implementation of which requires further development and co-operation between different actors. Some of the proposed measures have been estimated to be cost-effective to implement, but their introduction may in some cases require new systems as well as a change in existing practices.

Measures	Objective of the measure
More detailed design of the 2/3 traffic model	Increase capacity at Tapiola's western stations. In co-operation with HSL, a schedule in accordance with the 2/3 model is planned, and the effects of the model on the need for equipment and drivers and on maintenance are determined. A decision will be made to switch to the new line structure, taking into account the effects of the commissioning of the Matinkylä-Kivenlahti section.
The effects of the line extension on the operation of transport services	Ensures uninterrupted traffic on longer lines. Define all changes and challenges caused by line extension (breaks, location of alternate drivers, spare keys, spare VIRVEs) for HKL's operational process. Update drivers' capabilities and guidance to operate on a longer line without increasing risks of disruption.

Updating emergency traffic cards for future traffic models and new line sections	Ensures that the traffic control system fault management instructions are up-to-date. The emergency traffic cards will be updated to correspond to the state after the commissioning of the Matinkylä-Kivenlahti section. Consider any schedule based on the e.g. 2/3 model. Emergency traffic cards are being tested in the factory testing phase of the metro west extension phase 2 project.
Development of drivers' job descriptions	Improves the well-being of drivers at work and ensures the attractiveness of driver training. Together with the staff, identify opportunities and needs to develop the driver's job description. Reduce the risk of driver shortages.
Determining the location of alternate drivers and interchanges when the extension of the Länsimetro opens	Improves the use of equipment and speeds up recovery from disruptions, depending on schedule planning. Preparing for the challenges posed by the extension of the metro line. Find out the appropriate locations and economically viable on-call time for alternate drivers.
Defining the train queuing process	Clarifies responsibilities and streamlines operations. Agree on the placement process, roles and tasks, and ensure adequate resources and skills for the job. Ensure ease of use of tools and appropriate communication.
Ensuring the interoperability of the train queueing list and the Mipro ATS system	Automate unnecessary work steps. Ensures the functionality of the tools for the automatic loading of the waiting lists into the ATS system. automation would also facilitate the work of traffic control
Track reservation process optimization and development	Enabling planned activities and facilitating the maintenance of an up-to-date situation. A track work process is defined that takes into account, in addition to HKL's maintenance and traffic needs, the needs of contractors outside HKL. In the process, e.g. risks, test traffic, power outages, different types of MTO permits and their pre-defined protections. Define the desired functionality for the system to be implemented in the ATS system for traffic controllers and other users outside it. A procurement project is launched.
Linking the schedule stop time and driving time to the actual ones	Connect the current situation and the schedules planned by HSL and enable monitoring. Determine the fractions to be monitored in the distribution of station stop times, the changes of which are monitored regularly. Respond as needed by updating the schedule.
Extension of the rush hour schedule	Operate at minimum intervals for a larger portion of the day. Due to the coronavirus pandemic, the peak of the peak period has levelled off and the measure has already been implemented, but at this stage it is temporary.

Analysis of the deeper integration of the DAS system	Improves driver situational awareness of emergency situations, track work and speed limits. Explore the potential benefits and safety risks of deeper integration between the DAS system and the traffic control system.
A tool for driver roster scheduling during traffic incidents	Facilitates, in exceptional situations, the design of a traffic-optimal solution that takes into account the boundary conditions of shift planning. The challenges of the current situation and the flexibility of shifts will be explained in more detail. Identify the needs for the development of information flow for drivers and traffic management. Determine the next steps.
Driver simulator	Reduces the need for driver training track capacity and enables driver training, driving training during the day. Ongoing project. Define scenarios related to disturbances and accidents, as well as entities related to signalling equipment in the driver simulator.

Some of the above measures have already been taken forward. For example, HKL is studying the utilization of more complex schedule structures with HSL and Länsimetro Oy, and finding out what would be the most optimal traffic model. The review also takes into account the challenges of the Kivenlahti turn and the connection to the Sammalvuori depot. In addition, Länsimetro Oy conducts a needs assessment for the development of track infrastructure.

The time window for a more frequent peak period has been temporarily extended since the beginning of the autumn timetable period 2020 as a means of combating the corona pandemic. However, consideration of this extension and other follow-up actions are needed. Other follow-up measures may include the digitization of the train decommissioning process, the development of a track reservation system and the updating of emergency traffic cards.

3.4 Development of passenger guidance at stations

The measures planned for the development of passenger guidance are based on a passenger survey conducted by HSL in cooperation with Hellon in September / October 2019, which examined passengers' experiences and views on the use of the metro, as well as their thoughts on possible improvements.

The goal of improving passenger flow at stations is to reduce congestion at stations, and thus develop the passenger experience in a positive direction. The measures are divided into four areas, which are the development of passenger guidance, the development of dynamic passenger guidance, the development of passenger flow at stations, and etiquette communication.

These recommendations contain a number of measures for which coordination and mutual timing are essential. Most of these measures need further development to form the concrete action. The effectiveness of the actions will be confirmed with the help of pilots before comprehensive changes to the entire metro system are performed. However, many of these measures are quite rapid and low cost compared to the other measures presented in this plan, and are therefore suitable as short-term development measures.

3.4.1 Development of a fixed passenger signage system

The further development of the metro's fixed guidance system to support the identified development needs will enable better control of the passenger flow. The aim of the development project is to improve the steady load factor of trains, and to speed up the embarkation and disembarkation of passengers. These measures aim to allow more even and even shorter stopping times, especially during peak times.

There are the following areas in the development of the passenger guidance system:

Measures	Objective of the measure
Development of platform guidance	Directing passengers more evenly to the entire platform area to wait; guidance on space for wheels, prams and large luggage. Consider a set of information, e.g.: announcements, physical signs, stickers, LED displays.
Boarding and alighting guidance	Acceleration of passenger change of trains. First out, then in. Where and how to wait. E.g.: floor stickers on platforms, markings on the train door and instruction stickers on the train walls.
Guidance for the metro stop location	Acceleration of passenger change of trains. Where the metro stops, where are the doors (e.g. handrail instead of “doesn’t stop here” tapes, marking on the wall, ceiling, study tape, floor); where is space for prams, bikes, and luggage. This also requires driver training on the importance of the stopping location.
Guide to the elevators	Guide the route to the lifts, e.g.: tapes, also for the visually impaired.
Strollers, bikes, rollers, luggage, etc. (size, weight, location, etc.)	Define the principles of transport for these and the communication that guides them.

The guidance system development project has been launched in autumn 2020 in cooperation between HKL and HSL.

3.4.2 Development of dynamic passenger guidance

The development of information provision on the traffic situation by the Passenger Information System aims to further improve the passenger experience and to distribute the passengers more evenly within the trains.

Measures	Objective of the measure
Communication on occupancy rate	At the platform, information on the load of the different cars of the incoming train, e.g. video image of the

	train's loading level at the previous station, indicator lights at the train doors, platform displays.
Countdown clock on the platform	Determining the effects: Would it help to distribute the passenger flow more evenly to the different cars/doors? Can it cause delays or dangerous situations, such as running to closing doors?
Switching station schedule screens	Additional real-time timetable screens, indicating the duration of the journey to the platform area and information on incoming trains. The information should be as clear as possible.
Development of schedule communication	Better information on delays and schedules, impact on arrival time.

The development of dynamic passenger guidance will start with the current systems. If positive experiences are gained from these, and it is expected that further development can further improve passenger flow management, development work can be continued by implementing new systems.

3.4.3 Improving station flow

By developing the flow of passengers at stations, it is possible to speed up the transition of passengers between the station level and the platform level. This reduces congestion on platforms, making it more efficient for passengers to leave and board trains, and as a result, stopping times can be better adhered to.

Measures	Objective of the measure
Escalator operation	Reorder: down from the centre allowing less intersecting passenger flow at the station platform
Escalator behaviour definition, followed by communication	Whether instructed to overtake or stand still? Studies show that maximum transport capacity is obtained when passengers are directed to stand side by side on the escalator. This, in turn, is a model that increases travel time for those passengers who would like to walk. An experiment in the effectiveness of these options, and the conclusions followed by the communication of the label e.g. paintings, stickers, announcements, lights.
Placement of ticket validation devices	New location without congestion
Placement of ticket machines	New location without congestion
Metros to the departure platform later at the terminals	This will help to distribute passengers more evenly over the length of the platform, but the effects of the measure on the capacity of metro turns should be verified before implementation.

A change in the order of the escalators and the escalator behaviour is planned to be implemented during year 2021 at Rautatientori station.

The implementation of these is the responsibility of HKL, but HSL will propose the changes.

3.4.4 Behavioural guidance

To support the measures listed above, behavioural communication is needed to make better use of both the passenger flow at stations and the capacity of trains. Communication topics have been devised and will be developed and implemented under the leadership of HSL Passenger Communications. HSL implements the campaigns in co-ordination with other development projects

3.5 Renewal of the traffic control system

3.5.1 Operating models for traffic control systems

The metro traffic control system can be developed either with automatic train protection system and fixed block technology, or with a continuous radio communication based technology between the train and trackside control systems, enabling a moving block system. Figures 14 and 15 show the difference between the systems.

Of the two, the radio-based moving block system offers higher capacity, but also has a higher investment cost. When measuring the cost level over the entire life cycle of the system (LCC, life cycle cost), the cost differences between the systems are evened out to some extent, as there are significantly more track-mounted equipment to be serviced on the track.

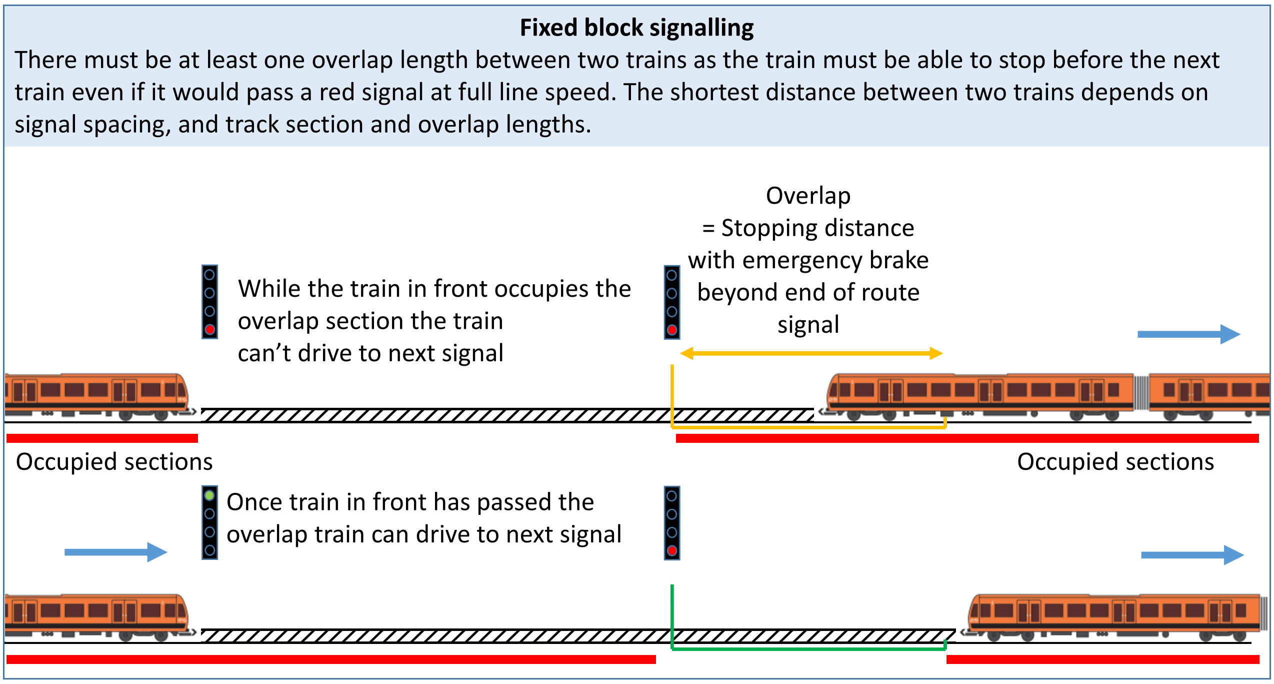


Figure 14 Fixed block system

Moving block signalling

The space between two trains must long enough for the train behind to be able to stop before the next train, added with a safety margin. The shortest distance between two trains depends on train's speed and its braking ability. If the distance is longer than braking distance the trains can drive at full speed, whereas with shorter distances the train behind will have a lower allowed speed.

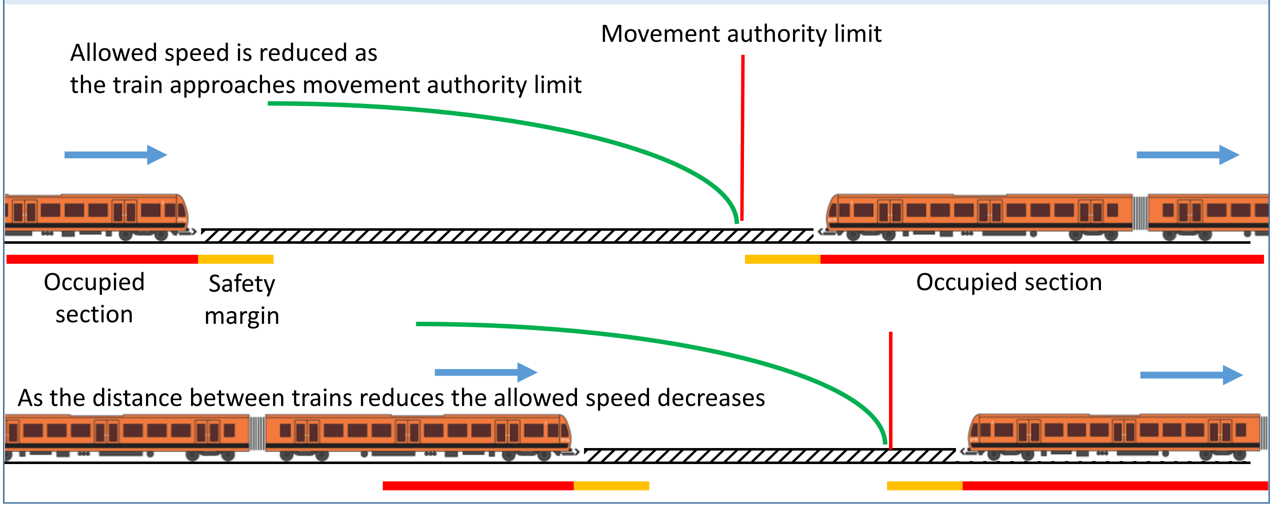


Figure 15 Moving block system

3.5.2 System automation level

Another factor to be decided in the renewal of a traffic control system is the degree of automation of the system. Internationally, the definition of automation levels according to Figure 16 is used.

Grade of Automation 1	Grade of Automation 2	Grade of Automation 3	Grade of Automation 4
Normal Train Operation NTO	Semiautomatic train operation STO	Driverless train operation DTO	Unattended train operation UTO
The driver drives the train according to the train control system indications	The train drives autonomously. The driver closes the doors and gives permission to depart. The driver is responsible for potential emergency situations as well as emergency braking	The train operates without a driver, but there is a member of staff who may be responsible for some operative tasks, and is responsible for acting in emergency situations.	Fully automated unattended train operation. Emergency situation response is initiated remotely or automatically.
The driver sits in the cab and is responsible for train safety		A member of staff who may have operational responsibilities is onboard and can take emergency action	There are no members of staff onboard routinely

Figure 16 Grades of rail automation

Of these levels, Grade of Automation (GoA) 1 is currently in use in Helsinki Metro. GoA2 or a higher level of automation requires a continuously operating ATP system.

Although a fully automated metro requires fewer staff on a train than a conventional metro, a smaller number of staff does not mean a reduction in staff costs in the same proportion (Cohen, J. et al, 2015). GoA3/4 needs more highly skilled staff, which usually also means better paid staff.

The authors cite the fact that the number of running metro trains is not directly related to the number of required drivers as a key feature of the fully automatic metro affecting the staff cost structure, so staff costs do not immediately limit the increase in train density if needed to increase service attractiveness. In a fully automatic metro, the energy needed to run a train rises to be the most important operating cost.

Average figures have been calculated for Keolis' metro business, based on a total of 13 GoA3 / 4 metro lines operated by Keolis with a total length of 168 km (Legay, P., 2017), cf. Figure 18. More detailed information on the calculations behind the summary is not provided.

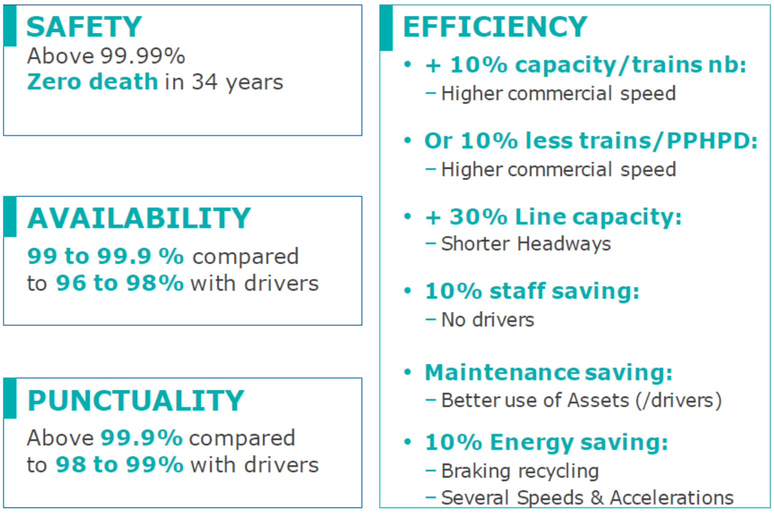


Figure17 Summary of Keolis' GoA3 / 4 metro line operating experience based on 13 lines with a total length of 168 km (Legay, P., 2017). PPHPD is Passengers per Hour per Direction.

UITP's information leaflet on fully automatic meters states that up to 15-30% operating cost savings are possible (Malla, R. et al, 2019). These are made up of many small things, of which the most clear is energy savings. A computer-controlled metro train is likely to follow the optimal acceleration-rolling-deceleration profile systematically more closely than a driver-controlled train. Keolis 'results also support UITP's estimates, based on energy savings, savings in maintenance, and a reduction in staff required for transportation.

Traffic automation also improves its reliability and timeliness. According to Keolis data, the accuracy improves from 98-99% above 99.9%. Automation also reduces disruption due to irregularities in drivers' shifts.

The implementation of extensive automation also affects the organization and personnel skills required for operations. In automated traffic, work roles are broader and, due to the technology of the system, tasks related to service and maintenance also require new skills from maintenance personnel. For this reason, preparations for automation must begin well in advance of implementation.

The full potential benefits of the automatic metro investment have been studied extensively, especially for high-capacity lines. A recent study (Canavan, S. et al, 2019) lists key ways to drive the line at a high level of performance:

- Unbranched metro line with a simple and consistent level of service
- Fast pace of operation of terminals, and / or ability to turn two trains simultaneously
- Short and consistent station stop times, supported by efficient platform management, as well as platforms on both sides of the train at the stations with the longest stop times
- Train running scheduled to the level of seconds
- Moving-block signalling, as well as the ability for GoA4 (UTO) operation
- High reliability and regularity
- High capacity through train with lots of wide doors

Scheduling with seconds level accuracy, as well as high reliability and regularity, are also well suited as Helsinki's means and are already in use in the metro. The seconds-level schedule helps to reduce the time between trains to a minimum, especially in situations of maximizing capacity, or as a reliability of the service experienced by the passenger. The fully automatic metro has been found to be more regular than the GoA1 / 2 metro both in station stops and in adherence to the train-to-train schedule (Cohen, J. et al, 2015). The results are based on information provided by automated metro operators from 23 different parts of the world on the actual schedules of the busiest stations during peak hours.

In the case of a fully automatic metro, it is possible to connect and disconnect the carriages automatically. This is not necessarily a technically difficult additional function for an automated train anyway, meeting the requirements of the safety regulations is probably a more demanding thing. A new function of this kind has also been designed for use in temporary transfers of trains stopped on the track (Legay, P., 2017). The concept, simply put, is that a new train comes to a broken train, connects to it (if the broken train's coupling function works), and then pushes it off. From the point of view of flexible control of the special situation, it is probably best that the movement and functions of the new train are handled remotely. The concept also makes it possible to increase the number of carriages of metro trains, for example during peak hours, and to reduce them for quiet times.

Maintaining a precise schedule timing means not only proactive maintenance, but also the means by which a failed train or infrastructure is repaired. GoA3 / 4 allows more flexible staff placement on the line. This applies in particular to service and maintenance personnel.

3.5.3 Renewal of traffic control with fixed block and with ATP system

Renewal of the metro's traffic control with fixed blocks and with a system operating with ATP will make it possible to shorten the metro's intervals and increase capacity by about 25%, depending on the system's operating principles and implementation.

Metro's current system operates at fixed blocks, so the biggest novelty of this implementation is the implementation of an ATP system. ATP replaces the magnetic stop equipment of the current system, and allows the fixed block sections to be rearranged so that the system can operate at shorter train intervals than at present. Increasing the number of trains is possible when the implementation of the ATP system makes it possible to significantly shorten the overlaps, the signals can be placed closer together, and the train can run at higher speeds on a large part of the network.

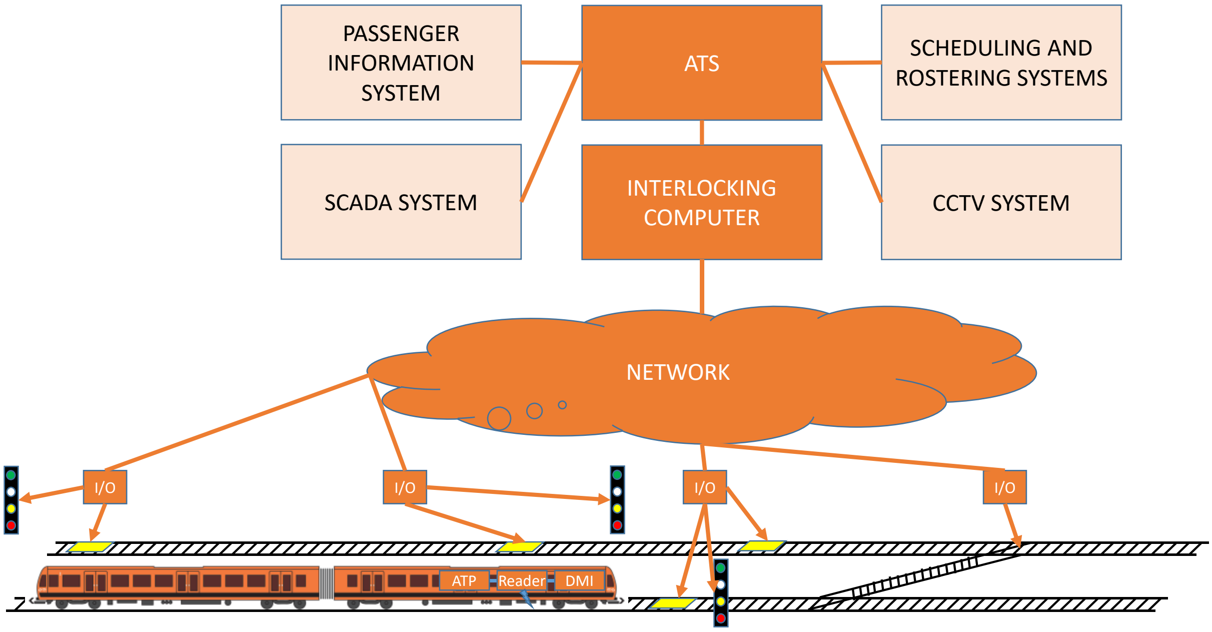


Figure 18 Structure of a system operating at fixed intervals

The systems consist of an automatic control centre (ATS), an interlocking system, a communication network, I / O units for control of track-side equipment, and an on-board Automatic Train Protection (ATP) system. The central traffic control system is typically associated with other systems required to manage the metro system, such as passenger guidance, security control systems, technical control room systems, and scheduling and shift management systems.

The communication between the interlocking device and the train ATP system typically takes place by means of a transmitter mounted between the rails. As the transmitter is based on transponder (balise) technology, it is only able to update the train's ATP computer when the train passes that transmitter. In this case, the train does not receive information about the more permissive traffic situation until it reaches the next data transfer point. The communication points also need light signals to support them so that the train driver knows when to move to the communication point if the train has received at the previous communication point an order to stop in front of the next signal / communication point. Repeater points for transmission can be made for the before the actual location, thus enabling an earlier update of the traffic situation for the on-board equipment. In some solutions, the repeater points are implemented with radio technology, which means that information can be obtained in a wider area.

3.5.4 Renewal of traffic control to a radio-based system

A radio-based system with a continuous communication link between the train and track-side control-command systems, enabling mobile protection intervals, allows the shortest intervals, and allows for a 50% increase in capacity from the current signalling system. As a general principle, in this type of system, the train positions are accurately updated as track kilometre data without fixed sections on the track and the braking curves determining the maximum train speeds as a function of location are updated practically without delay and without additional safety margin. In this context, the extra safety margin means the time that the train has to wait for the entire next guard interval to be released in the fixed guard system.

The systems of different suppliers are similar in this respect, but their other functionality and technical implementation vary significantly. For this reason, renewal must focus on the identification of operational requirements, and the actual technical implementation should be defined together with the supplier. This also poses challenges to the system's possible competitive evaluation criteria. Figure 19 shows a typical basic structure of a radio-based traffic control system, i.e. a CBTC system.

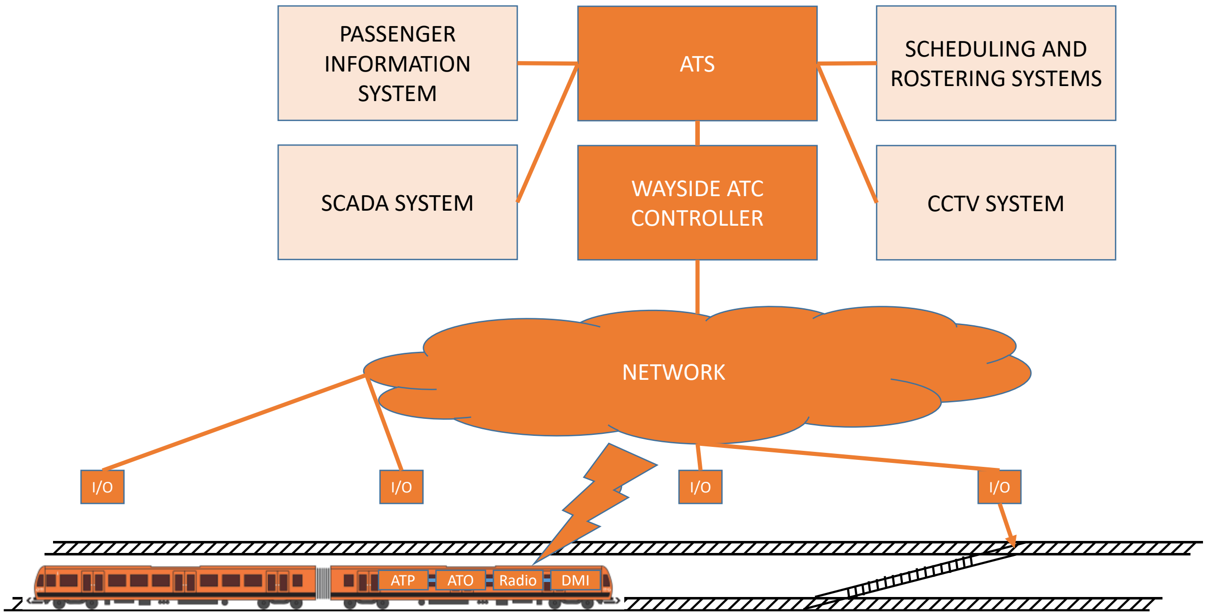


Figure 19 CBTC system structure

The systems consist of an ATS, a Wayside ATC (Automatic Train Control), a communication network, I / O units for track-side control, and an On-board Automatic Train Protection (ATP) and Automatic Train Operation (ATO) system. The central traffic control system is typically associated with other systems required for the management of the metro system, such as passenger guidance, safety control systems, and technical control systems and scheduling and shift management systems.

The data transmission between the trackside safety equipment system and the train protection system takes place via the radio network. As a continuous radio link, it is able to continuously update the train's equipment and the train protection system can allow the train to continuously maintain the maximum possible speed.

3.5.5 Vision for the Metro's future operational concept

The benefits of digitalisation brought about by the new traffic control system enable and require a significant development of the operational model in the direction where current operating methods can change considerably. The division of labour between maintenance, the train driver and the control room will even change considerably, which in turn will affect the skills needs of different groups of staff. The possibility to diagnose fault situations from the control room is improved, which enables better control of repairs in real time.

With the transition to fully automatic operation, the role of the train driver will disappear as it is, but the skills to drive a train will still be needed. In the future, however, the role may include expertise in, for example, repair or troubleshooting tasks, as well as possibly also customer service tasks.

As with all change situations, change comes with risks. The table below summarizes some of the key operational risks that raising the level of automation will bring.

GoA2 key risks	GoA3 / 4 key risks
The interfaces of the automatic and manual operation are prone to errors in both passenger traffic and maintenance operations.	The lack of driver detection increases the risk of collisions and makes it difficult to monitor the condition of equipment and infrastructure as well as to detect maintenance work.
Drivers' job satisfaction and motivation suffer in a new role.	The response time to respond to emergencies will be extended.
Maintaining the attention of drivers becomes more difficult in a supervisory role.	In emergencies, passenger control becomes more difficult (especially GoA4).
Maintaining the driver's skills becomes more difficult in a supervisory role.	Platform doors cause damage or reduce operational reliability.
	The skills or resources of the control room staff are not sufficient to manage the system.
	Susceptibility to disruptive passenger behaviour.

HKL must define a vision for the development of an operational model allowed by the digitalisation of the metro together with HSL. The concept defines a roadmap for raising the level of automation in the metro, and its effects on the organization, job descriptions, work tasks, competence and operating model. Based on this, a future business plan will be drawn up for HKL's future organizational structure, and it will be possible to define the operational requirements of the new traffic control system.

3.5.6 Objectives of the future traffic control system

The primary goal of the new traffic control system is to enable the metro capacity to be increased to the required level so that the level of traffic disturbance is low and operating costs do not increase.

The Helsinki Metropolitan Area metro is a key part of the public transport system. From a passenger perspective, the following reliability targets can be set:

- Minimize traffic disruption. At its worst, metro disruptions cause the passenger great difficulties in the absence of replacement connections.
- Disruptions cause as little inconvenience to passengers as possible. In the event of a disturbance, passengers must be able to be informed of the duration of the disturbance, the alternative connections and the cause of the disturbance.
- The system must enable traffic disruption management and rapid recovery from disruption. The difference between the technical and operational intervals must be large enough that reasonable delays, Ex: Due to passenger actions, do not cause increasing disruption to traffic.

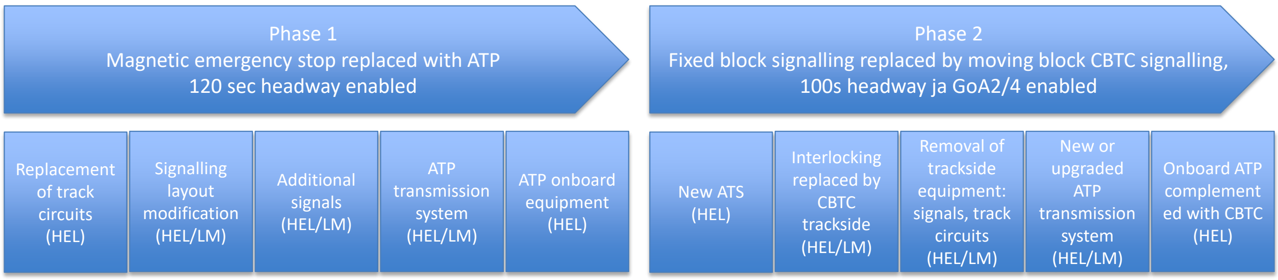
The life cycle target of the system is 30 years. This is a system-level goal, which means that the technical life and availability of individual system components may have a shorter life cycle. However, replacement, compatible components must be available for the life of the system. There should also be a reasonably limited cost for the availability of these parts, or other arrangement acceptable in terms of life cycle costs.

The goal of increasing capacity while reducing the susceptibility of traffic to disruption can be most effectively achieved by switching to the traffic control system to operate at the automation level GoA2, a semi-automatic operation. However, in order to ensure the future suitability of the system, it is expected to be able to run the metro without a driver (GoA3 / 4 level automation), if enabled by the rolling stock and other transport system. This will have a significant impact on the organization, skills and work tasks required.

If capacity is increased by implementing a new ATP system and enhancing fixed block layout, a lower capacity benefit is obtained. The effects of this change on the organization of metro maintenance and traffic will be considerably smaller, as the rolling stock will remain largely unchanged and drivers will continue to be responsible for operating metro trains. Thus, the effects on staff skills needs and organization are also minor. The risk with this option is that the capacity increase achieved will not be sufficient for the 30-year life cycle of the system, but will require a more efficient capacity increase measure before the end of the life cycle. This is expected to happen latest in the 2040s, but it is difficult to predict the time. This will be assessed in the preparatory work for the MAL round in spring 2021, when scenario studies will be carried out on the effects of the corona.

3.5.7 Tasks of the traffic control renewal project

The project will be implemented as a two-stage tiered project, which will reduce the risk caused by the system reform when the changes take place in stages. At the same time, the investment is spread over a longer period of time and the need to write down the residual value of current systems is reduced.



In the first phase of the project, the train and track-side equipment of the current magnetic emergency stop system will be replaced by an ATP system as shown in Figure 20. Renewable / new devices are marked in green in the figure. The goal is to enable a 120-second interval by 2030.

In this context, the condition of any obsolete track equipment is also reviewed and renewed as necessary. At the same time, the track circuits are shortened at selected points to allow more frequent train gaps. Tunnel sections may not need new track circuits, but they may need to be subdivided.

Some signals may also be moved or added to optimize train running times and frequencies, as described in Chapter 3.2.2.

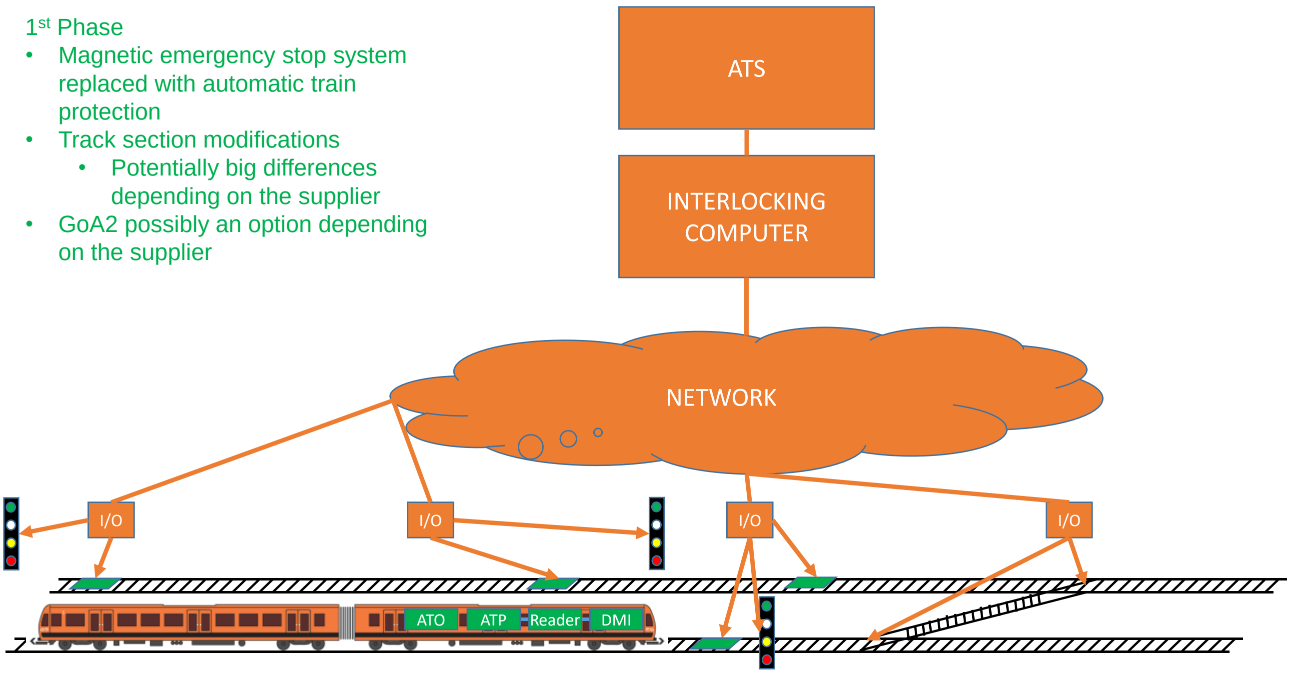


Figure 20 Phase 1 of the traffic control system renewal

In the 2nd stage of the system renewal, the radio-based protection is switched according to Figure 21. In this case, the current interlocking system is replaced by a radio-based traffic control track-side system (Wayside ATC Controller). The Central Traffic Management System (ATS) will also need to be upgraded to enable improved functionality of the entire system. In addition, the data transmission network will have to be developed to enable a very reliable radio connection for train control. The radio network can either be built as a stand-alone network, or if sufficiently reliable commercial / government networks with the necessary capacity are available, these can also be used.

After the implementation of step 2, an interval of 100 seconds is possible, and a semi-automatic run (GoA2). It will also be possible to implement a fully automatic operation (GoA4), but this is also affected by the limitations of the old rolling stock and infrastructure. These will require investment to improve or replace.

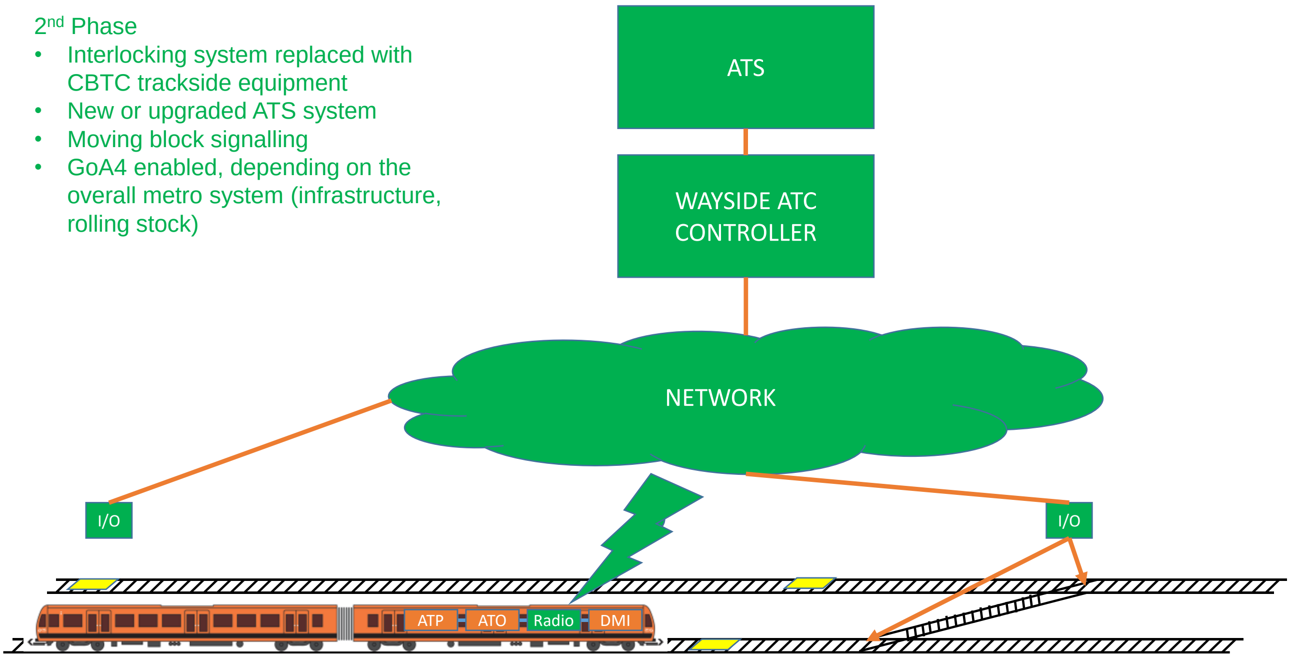


Figure 21 Phase 2 of the traffic control system renewal

3.5.8 Principles for the design and implementation of a new traffic control system

When designing a new traffic control system, the starting point must be the target state in accordance with the vision of the metro operation. The operating concept of the system in the normal mode and the management of fault states and abnormal situations shall be defined. The definition of these should take into account the design of human factors, especially with regard to the persons involved in operation and maintenance. For this reason, it is important that drivers, traffic controllers and system maintainers are involved in the definition and design work. This ensures the integration of traffic and implementation in the project, as they are of particular value in identifying risks and poor solutions.

When moving to more detailed functional planning, close cooperation with the selected supplier is essential to ensure, as far as possible, implementation in accordance with the supplier's basic system and to minimize product development risks from system changes and the development of new functions.

Operational risk management should be addressed in the project as part of the day-to-day implementation of the system, ensuring that measures designed to eliminate or reduce risks are implemented as part of the project implementation.

As part of risk management, potential risks to traffic during the implementation of the system must be addressed, and means must be planned for the implementation to avoid unplanned disruptions during the implementation of the system. The design also takes into account the minimization of the possibility of disruption during implementation.

Before a new system can be implemented, it must be ensured that the system integration is successful. The implementation path of the system comprises integration testing first in the laboratory environment, then on the test track, and finally the system is shadow tested on the metro track itself. This will ensure that the system has a required level of functionality and reliability, and that the metro system will operate reliably after commissioning.

3.5.9 Project gate model

To ensure the successful completion of the project, the project must have a clear plan of the project phases, and the objectives of each phase. The planning phase of the project specifies the division of phases. Preliminarily, the phases of the project and their objectives are as shown in the table below.

Step	Objectives
Principle design	Operating principles, definition of user requirements and initial approval
System design	Definition and review of system requirements
Preliminary design	System architecture definition and requirements partitioning, preliminary design review
System design and production	Critical design reviews, system operation and maintenance instructions
System testing	Laboratory testing, test track tests
System installation	System installation on track, trains and control centre
System integration	Integration testing, dynamic testing on the track, shadow operation
Approval and implementation	System approvals and deployment

When implementing the system, a high quality of work requirement must be considered as a key part of the project management system. Shortcuts taken during implementation usually lead to late changes and redesigns, thus increasing the cost and risk level of the project, and with it they are likely to prolong the schedule. Therefore, ensuring the high quality achievement of phase objectives pay for themselves during the project when the end-stage risk level is clearly lower than in a situation where the project would have been allowed to proceed based on uncertain or inaccurate definitions leading to changes at a late stage. This is illustrated in the picture Figure 22.

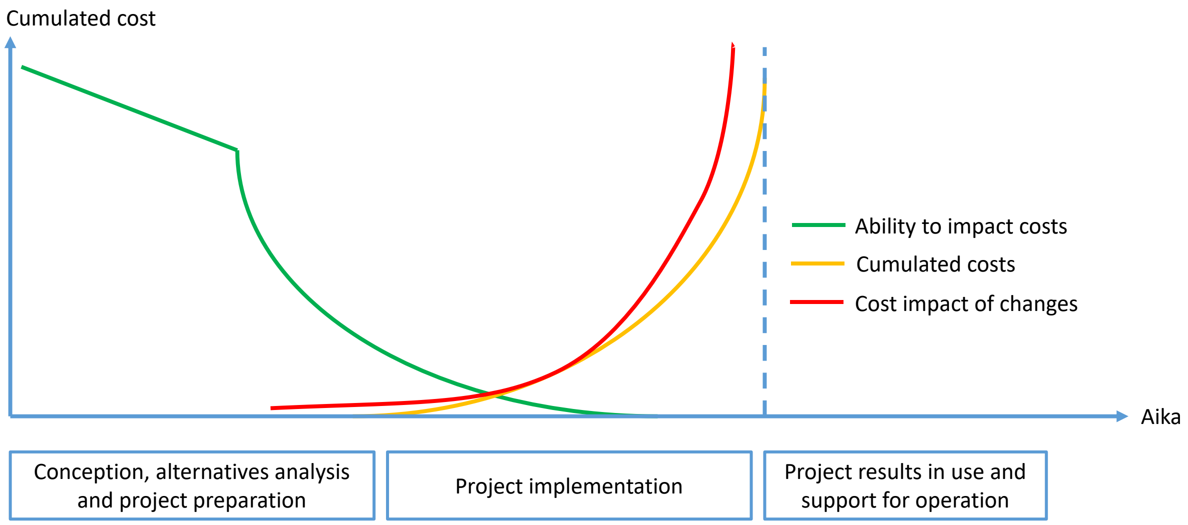


Figure 22 Determination of costs during the project life cycle

4. Project implementation

4.1 Procurement model

Delivery of a new traffic control system and services related to the system, such as e.g. system support, maintenance-related services and system extensions, will be put out to tender as public procurement above EU thresholds. The law on procurement and concessions of entities operating in the water and energy supply, transport and postal services sectors (1389/2016, hereinafter the Special Sector Procurement Act) applies to procurement.

This is a demanding system acquisition that also requires a reassessment of the customer's business processes. In addition, the procurement procedure chosen must make it possible to evaluate the various technical solutions of the suppliers, so that HKL can identify and define the requirements that can best meet future needs.

In practice, the procurement can be carried out either as a negotiated procedure pursuant to section 38 of the Special Sector Procurement Act or as a competitive negotiated procedure pursuant to section 39. As the project has identified the need to negotiate not only the terms of the contract but also the possibilities of utilizing different technical solutions and thus the means to best achieve the goal of securing the metro's capacity in the future, the procurement is proposed in a competitive negotiated procedure.

4.2 Contract model

Based on international experience and market consultations, a cooperation model-type solution (for example, an alliance) is recommended as the procurement model. The risk profile of this type of sourcing model is lower than that of the completely traditional customer-supplier model.

As this is the acquisition of a large-scale system consisting of data communications and information technology components, part of the costs are likely to be fixed costs (such as radio frequency license fees), which, however, can be borne entirely by the customer.

The advantages of the cooperation model include:

- Suitable for projects with challenging technical solutions and risks that are not fully known in advance and for the management of which the input of all parties is essential.
- The parties (customer, supplier) have common goals. In addition, the parties will be involved in genuine cooperation. It is quite certain that changes will have to be made during implementation. In this case, the best alternative to the solutions is sought together.
- Collaborative models usually have a development phase at the beginning, where determinations are made together and a target price is set. Only after the development phase, it is decided to implement the project. At the same time, the target price is also binding on all parties. In addition, a breakdown of cost

underruns and overruns has been agreed. It is not known that the alliance would be dismantled in metro automation projects after the development stages. The outputs of the development phase can be defined as assets and utilized by the customer, even if the alliance is dissolved after the development phase.
- Only the actual costs are paid, and the suppliers are rewarded for extraordinary performance. In addition, contracts must be drafted skilfully and ensure functional remuneration models in line with the customer's objectives.

Therefore, the contract model will be developed on the basis of the alliance agreements used by the City of Helsinki, taking into account the need for changes in order to draw up an agreement suitable for the technical implementation of the traffic control system. In addition, the following points must be taken into account when drafting a contract:

- Decision-making processes and responsibilities must be clear (who owns the decisions). Decisions that come too late are also often a problem. Indeed, the vagueness and slowness of the decision-making process would seem to be at least part of the cause of the problems of many projects. It is recommended that the risk be borne by those who are best placed to influence it.
- Delivery acceptance steps and processes must be carefully defined.
- If the train control system has systems from several different service providers, then there are also many interfaces between different actors. Service providers easily blame each other and do not take responsibility for what they do. It must be possible to secure responsibilities by contract. It is clearest if one service provider clearly has overall responsibility for the whole system, even if the subsystems supplied by the others are included.
- The working time gaps used by the service provider must be clearly agreed, and there must be a clear process for agreeing on changes to them, which takes into account the financial and operational implications of the changes. Working time gaps play a very important role in the project implementation schedule. Working time gaps can be extended, for example, by allocating additional hours at night, by cutting off traffic completely, for example on Sundays, or by cutting off traffic completely during summer time.
- HKL must provide the service provider with facilities to carry out the installations, etc. A test track for prototypes is recommended. A 500-600 meter track is required to test the functionality.
- The life cycle of the train control system is about 30 years. Extensions and changes to the system must be included in the contract. Flexibility is important for these. There will be a lot of changes in 30 years and there will also be new trains, for example. It should be noted that if the system is introduced in 2030, it will still be operational in 2060.
- It is a good idea to include a 24/7 maintenance contract in the service agreement, taking into account the needs of the entire system life cycle. The content

depends a lot on what tasks the subscriber wants to keep to himself. These still need to be investigated before the request to participate is published.

4.3 Project management model

The strategic goals of the programme must be monitored and guided, ensuring that the goals set for the project by the Helsinki Metropolitan Area and each municipality can be achieved, and that they are guided in a timely manner according to developments.

The programme must be managed as a project portfolio to ensure that the objectives are achieved. The programme is divided into separate projects with designated project managers.

The projects follow a gate process designed to ensure that the project minimizes the risk of re-doing and implements well-defined results. The manager of each subproject is responsible for managing the gate process to ensure project compliance. The project managers of the sub-projects are responsible for managing changes and risks within the limits of the powers assigned to them.

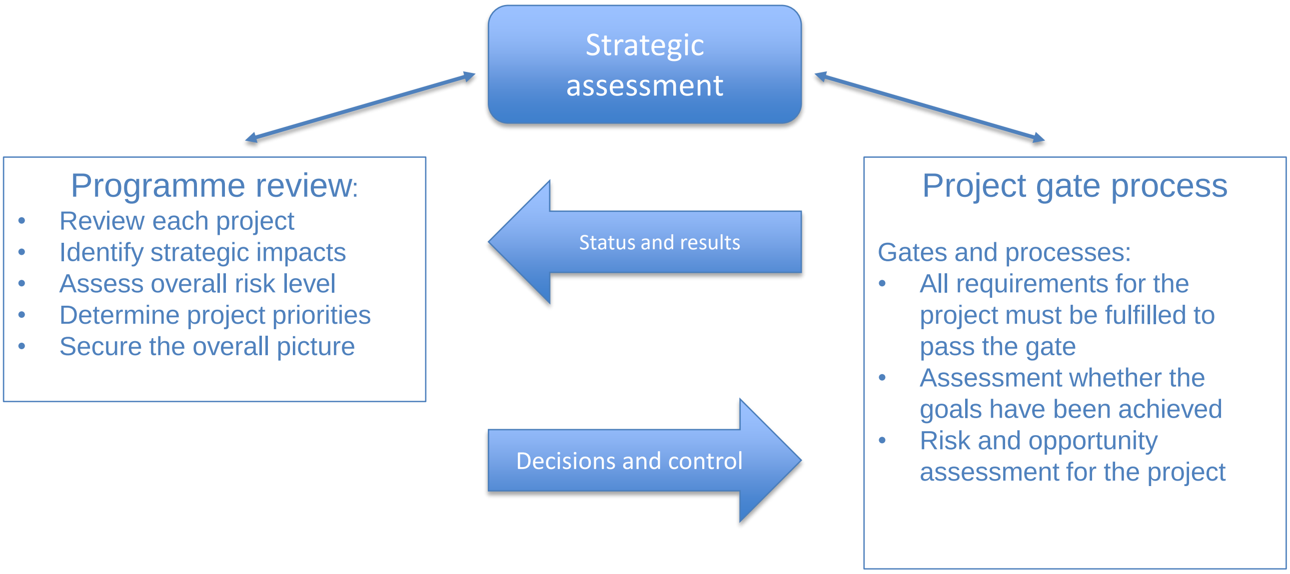


Figure 23 Capacity project management model

4.4 Organization and resourcing

Increasing capacity and improving the reliability of traffic require the cooperation of many organizations: HKL, Länsimetro Oy, Espoo, Helsinki and HSL, and it includes measures under the responsibility of various parties. According to the study, the starting point is to increase capacity. It is natural to combine this with increasing the reliability of traffic.

Due to the multi-stakeholder nature of decision-making, a high level Joint Committee on Capacity Building and Transport Reliability (METKA YHRY) has been set up, with membership consisting of direct reports for decision making political bodies as members. The activities of the co-operation group play a very central role, as the parties responsible for funding are represented and different parties may have different interests. The main task of the co-operation group is to define the objectives and resources for capacity increase and traffic reliability improvement, as well as the tasks, responsibilities and authorities of the Programme Director for Metro Capacity Increase and the Project Manager of the traffic control system project.

The Programme Director is responsible for the entire capacity increase. A key measure in increasing capacity is the development of a traffic control system. This has many commonalities with infrastructure construction and fleet development. Cooperation between these projects is very important. The Programme Director is responsible for the functionality of the whole.

The Programme Director reports on the progress of the project portfolio and programme to the capacity building cooperation group METKA YHRY. The co-operation is determined by the co-operation agreement signed between the City of Espoo and HKL on programme planning and development, as well as other current and future agreements on implementation projects and cost sharing.

The project manager supervises the implementation of the capacity programme projects led by their respective project managers, and coordinates the implementation of infrastructure and equipment development projects closely related to the project in line with the project objectives.

The organization of the capacity project is shown in Figure 24.

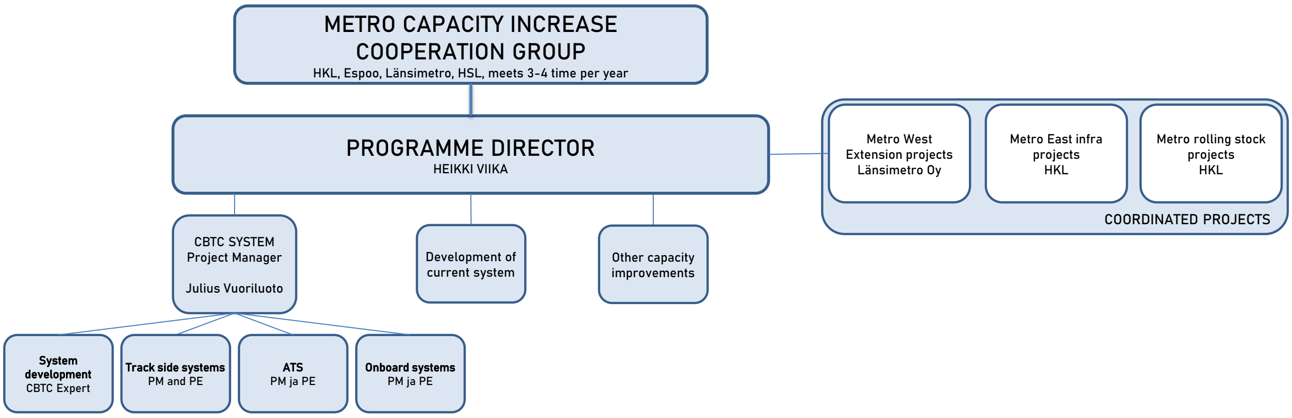


Figure 24 Organization of the metro capacity project

4.5 Project schedule

The most important project of the Metro's capacity project is the development of a traffic control system with a new ATP system. Figure 25 shows a preliminary schedule for the implementation of the new traffic control phase 1.

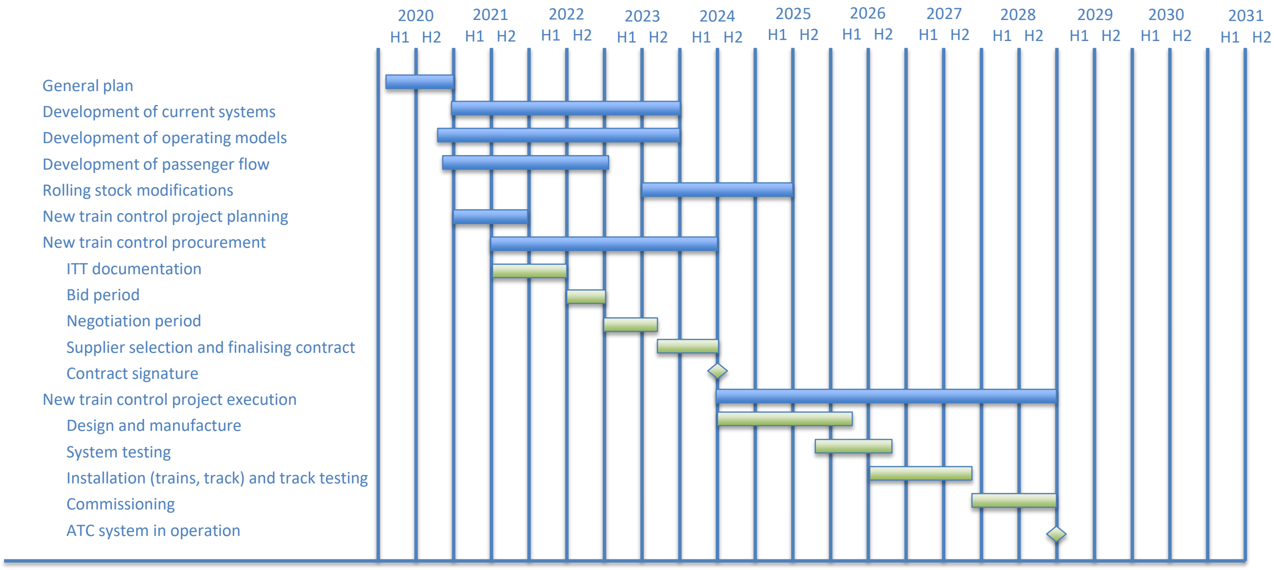
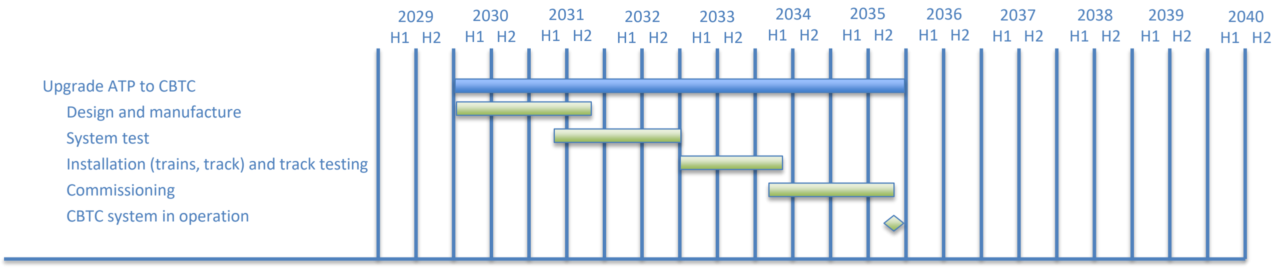


Figure 25 Indicative timetable for the new traffic control system

The timetable for the second phase is tentatively as follows



4.6 Risk management

The following objectives have been set for project risk management.

Zero tolerance for safety risks

- Minimize the probability of safety risk events as the highest priority in risk management.

Completion of the project on time and within budget, delivering the required functionality.

- Comprehensive risk management leads to cost and schedule discipline, and enables project completion as planned
- Timetable and budgetary constraints must not prevent the implementation of the required functionality.

Risk-conscious project management

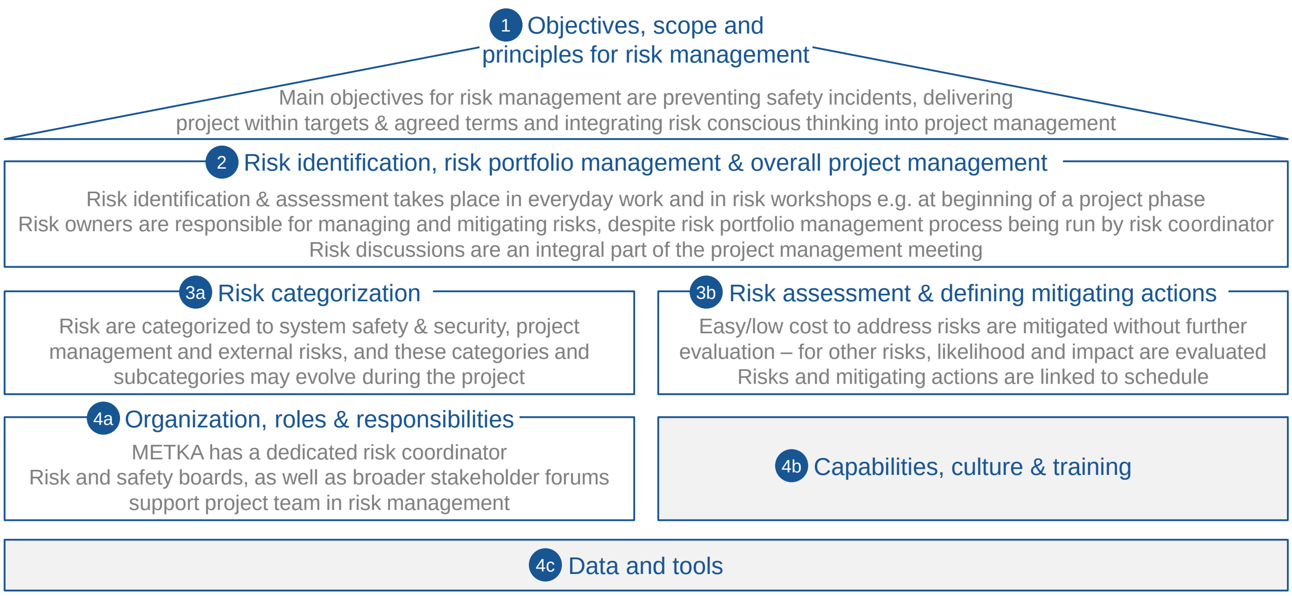
- Risk thinking is a key part of project management and risks are taken into account in decision-making.

The key goal is to identify risk management as a key process related to day-to-day operations.

Risk management must be planned. However, drawing up a risk management plan is only half the battle - getting it into day-to-day work is the most challenging part. The following principles have been developed for project risk management.

1. **Risk management is a key objective for all**
   - Risk management is a key goal for project management and all members
2. **Project management promotes proactive and transparent risk identification**
   - Risks are tackled proactively rather than reactively, open exchange of information is encouraged and bad news is encouraged.
   - The assessment of risks, their probability and possible consequences are in everyone's.
3. **Risk management is part of all project management processes**
   - Discussion is more important than the report - risk management must not be a bureaucratic process separate from project management

Based on these objectives and principles, a project risk management model has been developed in accordance with the structure below.



Risks are identified as part of daily work, as well as in risk workshops. Risk workshops are organized as needed, for example at the start of a new project phase, and involve both the project, stakeholders such as HKL's wider organization, and supplier personnel. An electronic channel will be set up to record the risk considerations observed in day-to-day work in the risk management system.

Project risks are divided into categories to facilitate their management. Preliminary main categories are safety, project management and external risk. These can be updated as the project progresses. Categorization is used to manage the risk portfolio and to determine the risk management model for each risk, to determine the sub-portfolio of risks and those responsible for the sub-portfolio, to decide on risk discussion forums and to report on risk.

Risk assessment is a three-step process in a project:

1. Rough assessment of the ease and cost of risk prevention
2. Assessing the severity of the risk in terms of impacts, likelihood of occurrence and risk-related schedule activities if prevention is difficult or costly
3. Determining the mode of response (accepting the risk, transferring the risk to another party, for example by insuring, limiting the impact of the risk or minimizing the likelihood by corrective measures, or avoiding the risk) and preventive measures

In assessing the severity of the risk, several different types of impacts are taken into account in addition to costs and schedule effects, such as environmental impacts and the impact on the overall project schedule.

4.7 Communication

Project stakeholders are regularly informed about the progress of the project.

Stakeholder	Method of communication	How often
Urban decision makers	Information at the meeting	Once a year
METKA YHRY	Information at the meeting	Four times a year
Other projects closely related to METKA	OHRY, TERY	Once a month
HKL, HSL, Länsimetro Oy employees	Releases	Regularly every two to three months, and when there are significant events
METKA Project team	Monthly info	Once a month
International cooperation forums, eg UITP	Presentations, project releases	Depending on the occasion
The press, the general public	Press releases	In connection with significant events and otherwise a couple of times a year
Key personnel groups affected by the project	Regular discussion, driver meetings	Several times a year / quarterly

4.8 Project coordination with related projects

4.8.1 Coordination model

The Programme Director is responsible for the entire capacity increase. A key measure in increasing capacity is the development of a traffic control system. This has many commonalities with infrastructure construction and fleet development. Cooperation between these is very important. The Programme Director is responsible for the functionality of the whole.

The Programme Director supervises the implementation of the projects included in the capacity project under the leadership of their project managers, and coordinates the implementation of infrastructure and equipment development projects closely related to the project in line with the project objectives.

Coordination between capacity-building projects and other metro-related projects must be maintained in order to avoid conflicts between projects and to prevent possible sub-optimization. Coordination is ensured through regular project steering group meetings, where the timeliness of project interfaces is ensured and the timing and content of tasks can be coordinated. The steering group includes the project manager, project managers and the necessary experts.

4.8.2 Rolling Stock projects

4.8.2.1 Renovation projects

The renovation project of the existing M100 metro fleet will be implemented in 2019-2022. In the project, the trains will have new lighting and an overall look, they will be equipped with a video surveillance system, and their interior, cab and passenger information system will be renewed. In this context, some of the train vestibules are also widened to facilitate and speed up the entry and exit of passengers.

The age of the trains is relatively high, as the oldest train units have now been in use for more than 40 years. No significant mechanical problems related to the car body and bogie structure have been detected in the trains. However, there is a risk that, e.g., previously unknown problems will be found in the renovation, but this is not considered probable based on the experience of the renovation so far. Minor availability problems with certain electronic components have been identified in connection with train maintenance.

The refurbishment of the 12 metro trains in the M200 train fleet is scheduled for 2022-2023, giving them new lighting and an overall look. Trains will be fitted with e.g. video surveillance system, train electronics and interface are being renewed and floors are being renewed.

4.8.2.2 Modifications to fleets

The fleet changes include both proposals for changes to the current fleet and recommendations for the design of future M400 trains. These fall into two areas: making better use of train capacity and developing in-passenger passenger flows.

Measures to make better use of train capacity

Measures	Objective of the measure
Improving air quality	Air conditioning / ventilation improvement / reliability / regulation / maintenance, determination of suitable indoor temperature. The M100 train has been tested for enhanced ventilation, but this was found not to significantly improve comfort. The M200 train pilot will be implemented when the refurbishment work begins.
Changes to passenger support points	For different types of rolling stock: Placement, addition, model, accessibility (height, loops, colour, etc.). The sizing review has found that M300 fleet trains should have more support points for standing passengers, for which a pilot is planned for 2021.
Checking the space requirements of the design guide	The passenger space requirements will be investigated (e.g. impact on stop times, customer needs). The review of passenger space has been carried out in principle, and the related documentation will be completed by the end of 2020.
Considerations for the design of the M400 fleet	More spacious vestibules and corridors, reclining folding benches, more support points and more detailed planning of placement, review of placement and number of benches.

Measures to develop the internal flow of passengers on board the train

Measures	Objective of the measure
Announcements on trains	Timing of stop announcements, functionality of announcement devices, increase of announcements: walk further to stand in corridors, give space to those leaving, etc.
Identity of the arrival station	Some of the following: Station signs lower / more visible, stations with their own sound world, more screens for trains, stations with clear visual identifiers, alert development.
Guidance for exit side at stations	Design a guidance package so that the passenger will know on which side the doors open at which station and where to wait. E.g. arrows on the train station display, announcements on the train and at the platform. Punctual communication at Kalasatama and Itäkeskus that the stations are different from others -> e.g. announcement on the train or in the platform area + illustration element.
Content and placement of on-board displays	Visible from entire coach, more varied content (e.g. exchanges, map of arrival station). This will determine the possible implementation of cabling as part of the renovation project.

4.8.2.3 Procurement of M400 trains

The M100 and M200 fleets will eventually reach the end of their technical life in the 2030s, and their replacement by a new train fleet is technically and economically necessary at that stage. With increasing passenger numbers and higher train frequency, it is also necessary to increase the number of trains.

Planning for the acquisition of a new train fleet, the M400 trains, was scheduled before the corona pandemic. Essential for cost-effective procurement of both the train control system and new trains is that projects are carefully coordinated and procurement phasing is in place and workable.

The draft budget 2021-2030 includes a provision for the purchase of 35 four-car train units (i.e. a shift). It was estimated that the first payment for the signing of the contract is 2027, and deliveries are from 2030 onwards. However, the M400 project has moved back and forth somewhat in terms of timing, and the corona pandemic may again affect the procurement.

Fleet sizing is based on 4 minutes train interval on both lines so that the M100 and M200 trains are replaced and there is a need for ten additional shifts. In the capacity project, the metro interval is to be shortened further, so 35 trains will not be enough later. When purchasing M400 rolling stock, an option covering the possible additional trains can be taken into account.

When planning the procurement, it can be assessed e.g. from the point of view of procurement law and strategically, whether these two major projects (M400 and the new traffic control system) will be implemented as two separate or joint procurements.

If the procurement of trains and the traffic control system is carried out together, it can be assumed that the customer integration risk is reduced especially for M400 trains. Large system integrators are able to provide both trains and a CBTC system. However, when assessing joint procurement, it must be assessed whether the joint procurement will lead to the exclusion of suppliers who are only suppliers of train or traffic control systems to the detriment of the customer.

4.8.3 Infrastructure development

4.8.3.1 Maintenance and development of existing infrastructure

This master plan sets out a number of measures to be taken in connection with the maintenance and / or development of existing infrastructure. With regard to these measures, the metro's capacity project will work in close co-operation with HKL's asset management and Länsimetro Oy. When creating project plans for development projects, they are reviewed to ensure that the projects are consistent with the goal of increasing capacity.

4.8.3.2 Länsimetro Phase 2 Matinkylä-Kivenlahti extension

HKL has appointed a project coordinator to ensure good communication in HKL's organization during the implementation of Phase 2 of the Länsimetro. The Project Coordinator reports to the Programme Director of the capacity programme. The Länsimetro Phase 2 Deployment Project Manager is responsible for receiving and commissioning the section. The implementation of the Phase 2 interlocking project is also monitored as part of the metro capacity increase project and the Project Manager reports to the Programme Director.

4.8.3.3 New metro infrastructure projects

New metro infrastructure projects will be coordinated if they are launched.

5. Impacts

5.1 Starting points for the evaluation

The impact assessment of the metro capacity project has been based on the objectives set for the project. The capacity project as a whole consists of several separate projects, for each of which a separate project evaluation must be prepared. In assessing these, the objectives set out in this master plan can be used and how each individual project will contribute to them.

In connection with the master plan preparation, several studies have been done. Observation and findings made in them have been taken into account as well as possible when preparing the general plan. The studies have dealt with e.g. the following topics:

- Urban infrastructure development of the metro area affected
- Growth in public transport demand and its market share of mobility
- Lessons learned from other similar projects around the world, and avoiding risks based on them
- Challenges of forecasting the future and uncertainty caused by the corona pandemic
- System life cycle costs
- Technical condition of the current traffic control system
- Options for investing in a new traffic control system or in an existing system and other supporting systems

Based on these, a master plan has been drawn up.

5.2 Main Impacts

“The most functional city in the world” is the city of Helsinki vision and “Espoo is a responsible and humane pioneering city” is the City of Espoo vision of what kind of experience each city wants to offer to people.

A well-functioning public transport is a key part of a well-functioning, modern cityscape. It is a network consisting of several different modes of transport, and the metro serves as its backbone, providing a high-capacity and fast connection in an east-west direction. The popularity of the metro is reflected in the growing number of passengers, so maintaining the level of service requires increasing its capacity. Increasing the metro's capacity will have a positive Impact on the urban image of both cities. The higher capacity allows continuous construction in the metro's area of influence, when the capacity is also sufficient for new passengers. In this way, increasing the capacity of the metro will shape the cityscape.

According to the metro's forecasts, the most significant impacts of the metro capacity project will be on congested parts, especially on the west side of Tapiola and between Herttoniemi-Kalasatama and Myllypuro-Itäkeskus. In all cases, Tapiola will have to move to a new timetable model during this decade as the number of passengers exceeds capacity. Kruunusillat project will reduce the load on the eastern metro by about

11% from 2025, which will slightly delay the time when shorter train intervals are needed to the east. Without the Kruunusillat project, passenger numbers will reach maximum capacity by 2030.

The most important renewal of the capacity project is the implementation of a new traffic control system, which will make it possible to reduce train intervals from the current 2.5-minute interval in key sections first to 2-minute intervals, and later to 1 second to 40 s intervals. Thus, in a two-line system, instead of the current 5 minutes interval, each of the lines runs initially every 4 minutes and finally every 3 minutes for 20 s, shortening the average waiting times for passengers, and further increasing the attractiveness of the mode of transport. Increased number of trains will also reduce peak passenger numbers per train during peak times, further positively impacting the passenger experience. The new traffic control system also enables the automation of driving, which has a wide range of advantages and benefits.

The safety level of the metro can be improved with a new traffic control system. Helsinki Metro has been operating for nearly forty years without serious accidents. There have been some cases classified as “near misses”. A very low level of incidents has been achieved due to the good operation of the staff and the previously good level of technology reliability.

However, there is a need to improve the level of safety in the future, as an accident in a significant transport system often has major consequences. When renewing the train control system, the new technology provides an opportunity to significantly increase the level of safety. Statistically, with the current model, the risk frequency of traffic is 10-3 (1 malfunction / 42 days) and with the automated metro 10-9 (1 malfunction / 14.2 years), i.e the frequency of risk situations will be reduced significantly.

5.2.1 Increased revenue and social benefits from the development of metro traffic control system

Travel times will be shortened in public and passenger car traffic

Wait and change times at stations will be reduced. Using the metro becomes more effortless and faster even at the end sections of the network. There is no need to look up schedules. At a value of 10 euros / hour, the benefit in 2030 would be about 3.5 million euros per year at 120 s intervals, and 5.9 million euros at 100 s intervals.

As the metro expands, travel time benefits will increase in proportion to passenger numbers.

The investment would also benefit motorists in terms of travel time savings and reduced on-net costs.

The use of public transport is growing

As travel times become shorter, the use of the metro and all public transport will increase. Some of the new passengers transfer from light transport modes and passenger car users. Some of the trips are new trips that are attractive as distances and travel times shorten. Some, on the other hand, are new metro users who are switching to a faster route from other forms of public transport.

Based on the model review, the daily metro ridership will increase by 2.3% in the 2030 scenario when the interval decreases to 120 seconds (compared to the 2030 150 KIL scenario) and by 3.7% when the interval decreases to 100 seconds (compared to the 2030 150 KIL scenario).

As the size of the metro network grows, the number of new passengers could more than double from that shown above.

Ticket revenue is growing

The increase in passenger numbers will bring more ticket revenue. With the current extent of the metro network and the current level of ticket prices, the additional revenue in 2030 would be about 1-1.6 million euros.

In 2050, the additional income would be estimated at 2.4 million euros / year.

Savings on road and street investments, environmental and accident costs

As the attractiveness of public transport increases, growth in passenger car transport will level off. This reduces the need to invest in increasing the transmission capacity of the road and street network.

The benefits of metro automation have been examined in terms of revenue increases and societal savings. Table 2 shows the annual calculated monetary benefits of automation for 2030 and 2050. The single largest benefit item is the time benefits for public transport passengers in the comparison situation.

Income increases are calculated as:

- Growth in public transport ticket revenue as determined by the number of journeys predicted by the Helmet 3.1 transport model.
- Growth in rental and advertising revenues, which can be thought of as commensurate with the growth in the number of metro rises.

The most significant social impacts include:

- Time and service level benefits for public transport passengers, both for reference passengers and for new passengers in transit. The travel time and travel resistance performances have been calculated using the Helmet 3.1 model, and the time values according to the Finnish Rail Administration's project evaluation guidelines for track projects (approx. 10 € / h) have been used. (Finnish Transport Agency, 2013)
- Time cost savings in road traffic due to declining car traffic have been calculated using the Helmet 3.1 model, and the time values used are the time values according to the Finnish Rail Administration's project evaluation guidelines for rail projects (approx. 10 € / h for passenger cars and approx. 33 € / h for truck trips). (Finnish Transport Agency, 2013)

- Road accident costs determined by the type of kilometers and accident rates produced by the Helmet 3.1 model. The price of the personal injury accident is € 598,899 / accident according to the Finnish Rail Administration's project evaluation guidelines for track projects. (Finnish Transport Agency, 2013)
- CO_2 emission costs for road transport, which have been determined on the basis of the kilometer performance of road transport produced by the Helmet 3.1 model and the unit emission factors calculated on the basis of VTT's ALIISA and LIISA models. VTT's estimates of CO2 unit emission factors for 2030 are 93 g / km (HA) and 560 g / km (KA). The emission factors for 2050 are 46 g / km (HA) and 408 g / km (KA). (VTT, 2020).

	Compared to 2030 150s 2030		**Compared to 2050 120s** 2050	
Mill. €	120s	100s	100s	100s GoA4
Increased income				
Increased ticket revenue	0.98	1.65	1.76	1.65
Increased lease income	Not yet assessed			
Increased advertising revenue				
Increased income total	**0.98**	**1.65**	**1.76**	**1.65**
Social Impacts				
Time benefits for public transport passengers	3.55	5.93	6.36	5.93
Service level benefits for public transport passengers	1.70	2.97	3.24	2.97
Time cost savings in road traffic	0.69	1.21	1.19	1.21
Road accident costs	1.08	1.90	1.95	1.90
CO_2 emission costs for road transport	0.02	0.03	0.03	0.03
Transport route construction savings	Not yet assessed			
More compact urban structure				
Increased ticket revenue (negative for social impact)	-0.98	-1.65	-1.76	-1.65
Social impact and increased income total	**7.04**	**12.04**	**12.77**	**12.04**

Table 2 Benefits of increasing metro capacity - income increases and social impacts

5.2.2 Savings from the development of metro traffic control

Energy savings

Energy is saved when the metro's need for electrical energy decreases, because automatic driving reduces the need for traction electricity by 20-25%. On the other hand, some of these savings are already achieved today through the driver assistance scheme, so the net benefit is estimated at 8-13%.

Metro train maintenance costs are reduced

If you switch to semi- or fully automatic driving, metro trains will run more smoothly, and wear on both brakes and wheels will be reduced, reducing maintenance costs by about 20%.

Savings on metro operation costs

If the metro is fully automated, drivers can be abandoned. This also reduces administrative costs. On the other hand, more staff are needed at stations and on touring trains. The total savings from this are estimated to be about 10% savings in personnel costs.

5.3 Cost estimate

The cost estimate is divided into the steps of the system development path as follows. During the implementation of the first phase of the traffic control development, the ageing and less efficient parts of the current system will be renewed, and a new ATP system will be installed. The costs of the first phase have been estimated at approx. 98-125 million. €. The costs accruing during the acquisition are estimated at approx. EUR 4 million. €.

In the second phase, a new radio-based traffic control system will be implemented, with a cost estimate of EUR 125-148 million. €. The costs accruing during the acquisition are estimated at approx. EUR 4.5 million. €. The train borne ATP equipment acquired in the first phase is to be utilized also at this stage; installing or upgrading radio equipment. The additional investment in existing equipment on rolling stock represents only about 7% of the cost estimate for the second phase. The cost of infrastructure development is the largest single item of implementation expenditure and is about 50% of the total cost of the phase. The third major investment is the radio network to serve communication-based train control. Today the investment would be about € 10 million, but as there is still is quite a long time to implementation, it is not yet possible to predict the radio network technology at the time, and therefore the costs cannot be estimated accurately. It will also be possible to outsource the radio network.

If the second phase implements a fully automatic metro (GoA3/4), the cost is estimated at approx. € 100-200 million including platform doors and modifications to metro platforms. In addition to this, it is likely that there will be additional costs for the changes needed to improve passenger safety, especially in tunnel areas, however these change needs have not been identified. No detail assessment has been made at this stage, as the timing of the measures is far in the future. When moving to fully automatic traffic, existing M100 and M200 fleet trains must be replaced by newer train units, which must be equipped with automatic train control equipment. The cost estimate of these ATP devices for 25 train units is approx. € 12-14 million. These costs become part of the cost of acquiring the rolling stock and have not been taken into account in this cost estimate. In the procurement of equipment, they will replace the emergency stop devices currently estimated in the cost of the M400 project.

At the initial stage, 20% of the estimated acquisition costs have been calculated as a risk provision for the project. The remaining 15% of the cost estimate is reserved e.g. project plan, inflation, personnel and other running costs. The total cost estimate for the project is given in Table 3 below.

The project will be financed and the costs will be shared in a separate agreement between Helsinki and Espoo.

Mill. €	Stage 1 ATP	Stage 2 CBTC	Full automation implementation
Procurement cost	4 - 5	4 - 5	2 - 4
Project costs	16 - 18	19 - 23	4 - 8
System supply	65 - 85	85 - 100	80 - 160
Risk provision	13 - 17	17 - 20	16 - 32
Total	**98 - 125**	**125 - 148**	**102 - 204**

Table 3 Estimated cost of implementation

In the assessment of profitability, the investment cost has been taken into account as depreciation over a period of 20 years.

5.4 Assessment of profitability

In assessing profitability, the revenue increases and social impacts identified at this stage have been taken into account. Investment costs have been taken into account according to the highest value of the forecast. In the valuation, the investment cost has been taken into account as depreciation with a depreciation period of 20 years as straight-line depreciation. The profitability assessment can be seen in Table 4.

Mill. € p.a.	Compared to 2030 150s 2030		Compared to 2050 120s 2050	
	120s	100s	100s	100s GoA4
Social Impacts				
Time benefits for public transport passengers	3.55	5.93	6.36	5.93
Service level benefits for public transport passengers	1.70	2.97	3.24	2.97
Time cost savings in road traffic	0.69	1.21	1.19	1.21
Road accident costs	1.08	1.90	1.95	1.90
CO_2 emission costs for road transport	0.02	0.03	0.03	0.03
Transport route construction savings	Not assessed yet			
More compact urban structure				
Increased ticket revenue (negative for social impact)	-0.98	-1.65	-1.76	-1.65
Social impact and increased income total	**6.06**	**10.39**	**11.01**	**10.39**
Increased income				
Increased ticket revenue	0.98	1.65	1.76	1.65
Increased lease income	Not assessed yet			
Increased advertising revenue				
Increased income total	**0.98**	**1.65**	**1.76**	**1.65**
Cost benefits				
Energy saving	0.50	0.60	0.60	0.60
Reduced driver costs	0.10	0.10	0.00	11.40
Savings on surface traffic	Not assessed yet			
Maintenance of current train control	0.30	1.50	1.50	1.50
Cost benefits total	**0.90**	**2.20**	**2.10**	**13.50**
Benefits total (mill. € p.a.)	**7.94**	**14.24**	**14.87**	**25.54**
Cost increases				
Train supervisors	0.00	-0.08	0.00	-9.12
Maintenance of new train control	-0.30	-1.00	-1.00	-1.00
Change in depreciations	-6.23	-11.00	-7.40	-10.15
Cost increases total	**-6.53**	**-12.08**	**-8.40**	**-20.27**
Impact on operating income	**-4.65**	**-8.23**	**-4.54**	**-5.12**
Social impact and change in operating income total	**1.42**	**2.16**	**6.47**	**5.27**

Table 4 Impact assessment

Upgrading the system to 120 second intervals will bring € 1.0-1.5 million impact on the annual operating and social economy. This change is reflected in the Phase 1 system update. When phase 2 is implemented, 6.0 - 6.5 million euro will be obtained in 2050 additional annual impacts on the operating and social economy.

Switching to a 100-second interval will have an impact of about 2 million on the annual operating and social economy from 2030 onwards. This would be made possible by the immediate implementation of a radio-based traffic control system, assuming that passenger numbers would increase at the rate indicated in the surveys. However, the corona pandemic has raised doubts about passenger growth, so a more cautious, step-by-step implementation path is recommended.

Additional benefits of switching to fully automatic driving (GoA4) include due to driver savings do not cover investments made for this purpose if these exceed EUR 75 million. EUR. In the transition to the implementation of Phase 2, this review will, of course, have to be repeated.

5.5 Impacts of non-implementation

As employment and population in the Helsinki metropolitan area increase, bus traffic will not be enough to match the increase in passenger numbers, as the urban structure will not withstand such large bus volumes. Also, the capacity of the light rail lines studied in the Metro60 work is not enough to meet the total growth, but a high-capacity mode of transport is needed, so it is not easy to meet the growth in passenger demand by developing alternative modes of transport.

If the capacity of the metro is not increased, the metro will become congested. Situations where it is not possible to fit on the first train are increasing. The increase in passenger numbers also has a direct link to passenger safety, especially at stations during peak times, where congestion at station platforms can lead to dangerous situations or accidents. Congestion also reduces the attractiveness of the metro, and transfers passengers to use their own car, and thus affects environmental issues by increasing carbon emissions.

Today, the metro's traffic control uses different generations of systems and a diverse fleet of equipment is installed, which is already challenging to maintain for the oldest equipment, and whose failure rate is increasing. Therefore, investment in the survival of the current system is essential if the traffic control system is not to be renewed now. Alternatively, the increasing failure rate of old equipment will increase traffic inaccuracies and the number of traffic disruptions. In the event of equipment failures, the metro will have to operate under emergency arrangements, the level of safety of which is never as good as in normal operating models, so safety risks will also increase.

6. Conclusion

The alternatives for increasing the metro's capacity have been extensively analysed in this plan. The plan has identified a number of measures that require immediate small investments, and their implementation will be taken forward as appropriately grouped smaller projects as part of the Metro's capacity project portfolio. In addition, the renewal of the traffic control system has been assessed as a key part of the project, and a preliminary project assessment has been carried out.

The modernization of the traffic control system is clearly a value-added and profitable investment that improves the public transport in the area it serves. Both the implementation model, which proceeds step by step to a higher degree of automation, and the direct implementation of a new traffic control system enabling automation are profitable investments.

The step-by-step implementation model has a higher total cost than the one-time implementation, but on the other hand allows the investment to be spread over a longer period of time. This also makes it possible to adjust the timing of investments in line with the development of passenger numbers. However, the full economic benefits of the investment will not be achieved until the system is fully implemented.

The immediate renewal of the entire traffic control is lower in total costs, but the investment would be realized in a total of about five years. If this is done immediately, it would also cause a write-down of the current traffic control, leading to a peak in operating costs. The benefits of this path may not materialize at the pace of the investment, as there are doubts about the increase in passenger numbers due to the corona pandemic.

The third option is, of course, the “do nothing” option. This option cannot be recommended due to the e.g. due to the risks of an aging system. There are threats in this option, e.g. the rapid increase in metro disruptions, and the threat of a metro accident cannot be ruled out. In addition, the presented alternatives have a positive economic impact compared to this alternative.

The plan recommends starting a step-by-step implementation model by starting project planning for the further development of the traffic control system as an extension of the preparation of the master plan. Project planning for the other measures presented in this plan is also proposed to be launched.

The plan also recommends monitoring the actual passenger load of the metro and regularly updating the forecasts to ensure the appropriateness of the solutions to be implemented. The first major review will come with the MAL Round in spring 2021. This is a good time before the new traffic control system project plan is completed and will be affected by the project plan presented to the Implementation Plan. This is well in advance of the completion of the new traffic control system procurement plan and will affect the implementation plan presented in the project plan.