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ERTMS/ETCS LEVEL 2 CAPACITY BENEFITS ON THE CITY LINES OF THE HELSINKI REGION

Alex Landex, Lars Wittrup Jensen, Anne Jokiranta, Maija Musto

ERTMS/ETCS level 2 capacity benefits on the city lines of the Helsinki Region

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Finnish Transport Infrastructure Agency
P.O. Box 33
FI 00521 HELSINKI
Phone +358 (0)295 34 3000

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Key words: capacity, urban railway tracks, ERTMS/ETCS

Abstract

The objective of the study was to analyse capacity benefits enabled by ERTMS/ETCS level 2 on the Finnish city lines. ERTMS (European Rail Traffic Management System) and its ETCS (European Train Control System) are adopted by the European Union, aiming for an interoperable rail network in Europe, and the standard has since been adapted by many other countries outside Europe. Worldwide more than 95 000 km of tracks and 12 500 vehicles are contracted to be equipped with ERTMS/ETCS. The continuous supervision system ERTMS/ETCS level 2 has traditionally been used for new high-speed lines, but an increasing number of conventional and suburban lines are being equipped with it.

In the study the capacity differences between the automatic train protection systems; ATP-VR/RHK (JKV), ERTMS/ETCS level 1 and level 2 were studied on the city lines between Helsinki and Leppävaara as well as between Helsinki and Kerava. With ERTMS/ETCS level 2 it is possible to have shorter block sections and the location of block sections is more flexible as signal visibility is not required. This impacts the capacity and hence improved block sections has also been analysed for ERTMS/ETCS level 2.

The evaluation of the results was done by comparing the minimum headways and capacity consumption between JKV and ERTMS/ETCS levels 1 and 2 with existing block section and ERTMS/ETCS level 2 with improved block sections. The capacity analyses are based on blocking times.

With the existing block sections the headway times for ERTMS/ETCS are generally slightly longer than JKV due to the system delays. However, when block sections are improved, there is a significant improvement in capacity with ERTMS/ETCS level 2. The improvement in minimum line headway for the main line towards Kerava is on average 28% from Helsinki and 36% towards Helsinki. For the Coastal line (Rantarata), the average improvement from Helsinki is 24% and towards Helsinki 14%. A general capacity improvement is expected with Level 2 due to continuous update of the movement authority for both existing and improved block sections. The continuous update provides more flexibility in the operation especially when delays occur. To gain significant capacity benefits, more and shorter block sections are needed which typically require a refurbishment or renewal of interlocking. ERTMS/ETCS level 2 allows for much shorter block sections than ERTMS/ETCS level 1 and JKV (even if JKV is improved). Operation with shorter block sections has therefore, and due to time restrictions, not been analysed for ERTMS/ETCS level 1 and JKV. It is therefore to be expected that ERTMS/ETCS level 1 and JKV capacity can be improved with shorter block sections, although not to same level as ERTMS/ETCS level 2. Cost-benefit analysis between ERTMS/ETCS level 1 and 2 has not been part of the project.

One of the findings of the analysis was, that between Helsinki and Hiekkaharju the service can be operated with 3.75 minute planned headways all hours, keeping the capacity consumption below the recommendation of the International union of railways UIC (Fr. "Union Internationale des Chemins de fer"), 70%, during off-peak hours. Between Helsinki and Huopalahti the capacity consumption is higher, but still below 85% which is UIC's recommendation for the maximum capacity consumption in peak hours.

In the analysis it was found, that for existing block sections, the main bottlenecks arise from long block sections with one or more stops in each as well as long approach times. Furthermore, Helsinki is limiting the capacity with ERTMS/ETCS level 2 and improved block sections due to the conflicting movements of trains at Helsinki and longer dwell times. Further improvements at Helsinki could improve capacity, especially for Coastal line (Rantarata) trains.

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Avainsanat: kapasiteetti, kaupunkirata, ETCS

Tiivistelmä

Selvitystyön tavoitteena oli tarkastella ERTMS/ETCS-tasolla 2 saavutettavia kapasiteettihyötyjä kaupunkiradoilla. ERTMS (eurooppalainen rautatieliikenteen hallintajärjestelmä, engl. European Rail Traffic Management System) ja sen ETCS (eurooppalainen junien kulunvalvontajärjestelmä, engl. European Train Control System) ovat Euroopan unionin ajamaa liikennepolitiikkaa, jolla pyritään yhtenäiseen eurooppalaiseen rautatiealueeseen, mutta vastaavia järjestelmiä on otettu käyttöön myös muissa maissa Euroopan ulkopuolella. ERTMS/ETCS-järjestelmiä tilattu yli 95 000 ratakilometrille maailmanlaajuisesti ja yli 12 500 veturia on tilattu ERTMS/ETCS-varusteluilla. Jatkuvatoimisen kulunvalvonnan järjestelmä ERTMS/ETCS taso 2 on käytössä pääosin suurnopeus radoilla, mutta myös joillain kaupunki- ja sekaliikenneradoilla. Nykyään ERTMS/ETCS tason 2 käyttöönottoja suunnitellaan myös tavanomaisille radoille ja kaupunkiradoille.

Tutkimuksessa tarkasteltiin kapasiteettieroja eri junien kulunvalvontajärjestelmien välillä; nykyisen junien kulunvalvonnan JKV:n, ERTMS/ETCS-tason 1 ja tason 2 välillä kaupunkiradoilla Helsingistä Leppävaaraan ja Keravalle. ERTMS/ETCS tasolla 2 on mahdollista saavuttaa lyhyemmät suojastusvälit ja niiden sijoittelu on joustavampaa, sillä opastimien näkyvyys ei ole välttämätöntä. Tästä johtuen kapasiteettia tutkittiin myös lyhennetyillä suojastusväleillä ERTMS/ETCS tasolla 2.

Tulosten arviointi tehtiin vertaamalla minimijunaväliä ja kapasiteetin käyttöä JKV:n ja ERTMS/ETCS tasojen 1 ja 2 välillä olemassa olevilla suojastusväleillä sekä parannetuilla suojastusväleillä tasolla 2. Kapasiteettiä analysoitiin junaväliaikalaskennan avulla.

Olemassa olevilla suojastusväleillä ERTMS/ETCS-tason 2 junavälit ovat tyypillisesti hieman pidemmät kuin JKV:lla järjestelmäviiveiden vuoksi. Kun suojastusvälejä parannetaan, saadaan kapasiteettia lisättyä huomattavasti ERTMS/ETCS tasolla 2. Minimijunaväli paranee pääradan kaupunkiraiteilla keskimäärin 28 prosenttia Helsingistä Keravalle ja 36 prosenttia Helsinkiin päin kuljettaessa. Rantaradan kaupunkiraiteilla keskimääräinen parannus Helsingistä poispäin on 24 prosenttia ja Helsinkiin päin kuljettaessa 14 prosenttia. ERTMS/ETCS tason 2 mahdollistaman jatkuvan kulunvalvonnan avulla saadaan lisähyötyjä sekä olemassa olevilla että parannetuilla suojastusväleillä. Jatkuvatoiminen kulunvalvonta mahdollistaa joustavuutta operointiin erityisesti häiriötilanteissa. Jotta hyödyt olisivat merkittävät, tulee suojastusvälejä parantaa ja optimoida, mikä edellyttää myös asetinlaitemuutoksia ja -uudistuksia. Taso 2 mahdollistaa lyhyemmät suojastusvälit kuin taso 1 tai nykyinen JKV, vaikka nykyisiä opastinvälejä olisi optimoitu. Projektin ajallisten rajoitteiden vuoksi liikennöintiä lyhennetyillä suojaväleillä ei analysoitu JKV:n ja ERTMS/ETCS tason 1 osalta. Voidaan olettaa, että myös niiden kapasiteettia voitaisiin parantaa opastinvälien lyhentämisellä, mutta ei yhtä merkittävästi kuin tasolla 2. Kustannus-hyötyanalyysi tasojen 1 ja 2 välillä ei kuulunut projektiin.

Analyysissä todettiin, että Helsingin ja Hiekkaharjun välillä voidaan liikennöidä tavoitellulla 3,75 minuutin vuorovälillä niin, että kapasiteetin käyttöaste on koko vuorokauden alle 70 prosenttia. Tämä on kansainvälisen rautatieliiton UIC:n (ransk. "Union Internationale des Chemins de fer") suositus kapasiteetin käyttöasteelle ruuhka-aikojen ulkopuolella. Helsingin ja Huopalahden välillä kapasiteetin käyttöaste on korkeampi, mutta alle 85 prosenttia, mikä on UIC:n suositun kapasiteetin käyttöasteelle ruuhkatunteina.

Analyysin tuloksena saatiin, että olemassa olevilla suojastusväleillä suurimmat pullonkaulat ovat pitkät suojastusvälit, joissa on yksi tai useampi pysähdys ja pitkät lähestymisajat. Lisäksi Helsingissä suojastusvälien sijoittelu ERTMS/ETCS tasolla 2 on rajallista junien risteävien kulkuteiden ja pidempien asemapysähdysaikojen vuoksi. Lisäjärjestelyt Helsingissä voisivat parantaa kapasiteettia erityisesti Rantaradan liikenteessä.

Alex Landex, Lars Wittrup Jensen, Anne Jokiranta och Maija Musto: Kapacitetsnyttan av ERTMS/ETCS nivå 2 på stadsspår inom Helsingforsregionen. Trafikledsverket. Helsingfors 2019. Trafikledsverkets publikationer 43/2018. 66 sidor och 3 bilagor. ISSN 2490-0745, ISBN 978-952-317-722-2.

Sammanfattning

Syftet med utredningsarbetet var att granska kapacitetsnyttan av ERTMS/ETCS nivå 2 på stadsbanor. ERTMS (det europeiska trafikstyrningssystemet för järnvägen, eng. European Rail Traffic Management System) och ETCS (dess europeiska tågövervakningssystem, eng. European Train Control System) är trafikpolitik som förs av Europeiska unionen i syfte att skapa ett enhetligt järnvägsområde i Europa. Motsvarande system har införts också i andra länder utanför Europa. ERTMS/ETCS-system har beställts för mer än 95 000 bankilometer globalt och mer än 12 500 lok har beställts med ERTMS/ETCS-utrustning. Systemet ERTMS/ETCS nivå 2 för tågkontroll i kontinuerlig drift används huvudsakligen på banor avsedda för högre hastighet, men också på vissa stads- och blandtrafikbanor. Nuförtiden planeras införande av ERTMS/ETCS nivå 2 också på sedvanliga banor och stadsbanor.

I undersökningen granskades skillnader i kapacitet mellan tågkontrollsystem på olika tåg; det nuvarande tågkontrollsystemet av tåg mellan JKV, ERTMS/ETCS nivå 1 och nivå 2 på stadsbanorna från Helsingfors till Alberga och Kervo. Med ERTMS/ETCS nivå 2 är det möjligt att nå kortare blocksträckor och det går smidigare att placera ut dem, för det är inte nödvändigt att signalerna syns. På grund av detta undersöktes kapaciteten även på förkortade blocksträckor ERTMS/ETCS nivå 2.

Av resultaten gjordes en utvärdering genom att jämföra det kortaste tågintervallet och kapacitetsutnyttjandet på blocksträckor mellan JKV och ERTMS/ETCS nivå 1 och 2 samt förbättrade blocksträckor på nivå 2. Kapaciteten analyserades med hjälp av en beräkning av tågintervaller.

På existerande blocksträckor var tågintervaller enligt ERTMS/ETCS nivå 2 normalt en aning längre än enligt JKV på grund av systemförseningar. I och med att blocksträckorna förbättras, kommer kapaciteten att öka avsevärt enligt ERTMS/ETCS nivå 2. Det kortaste tågintervallet förbättras på stadsspåren på huvudbanan med i genomsnitt 28 procent från Helsingfors till Kervo och med 36 procent i riktning mot Helsingfors. På Kustbanans stadsbanor är den genomsnittliga förbättringen i riktning från Helsingfors 24 procent och i riktning mot Helsingfors 14 procent. Med hjälp av den kontinuerliga tågkontroll som ERTMS/ETCS nivå 2 erbjuder får man ytterligare fördelar såväl med existerande som med förbättrade blocksträckor. Tågkontroll i kontinuerlig drift möjliggör flexibilitet i agerandet i synnerhet i störningssituationer. För att nyttan ska vara betydande, bör blocksträckorna förbättras och optimeras, vilket även förutsätter att ställverk ändras och förnyas. Nivå 2 möjliggör kortare blocksträckor än nivå 1 eller nuvarande JKV, även om nuvarande signalsträckor skulle ha optimerats. På grund av tidsmässiga begränsningar med projektet analyserades inte trafik med förkortade blocksträckor i fråga om JKV och ERTMS/ETCS nivå 1. Man kan anta att även deras kapacitet kunde förbättras med en förkortning av signalsträckor, men inte på ett lika betydande sätt som på nivå 2. En kostnadsnyttoanalys mellan nivåerna 1 och 2 ingick inte i projektet.

I analysen konstaterades att man mellan Helsingfors och Sandkulla kan trafikera med en önskvärd turtäthet på 3,75 minuter, så att kapacitetsutnyttjandet ligger under 70 procent under hela dygnet. Detta är internationella järnvägsunionen UIC:s (fr. "Union Internationale des Chemins de fer") rekommendation om kapacitetsutnyttjande utanför rusningstider. Mellan Helsingfors och Hoplax är kapacitetsutnyttjandet högre, men under 85 procent, vilket är det kapacitetsutnyttjande som UIC gynnar under rusningstimmar.

Resultatet av analysen utvisade att de största flaskhalsarna i fråga om existerande blocksträckor var långa blocksträckor med ett eller flera uppehåll och långa retardationstider. I Helsingfors är dessutom placeringen av blocksträckor enligt ERTMS/ETCS nivå 2 begränsad på grund av gångvägar som korsar tågen och längre stationsuppehåll. Tilläggsarrangemang i Helsingfors kunde förbättra kapaciteten i synnerhet i trafiken på Kustbanan.

Prologue

The Finnish Transport Infrastructure Agency (FTIA) carried out a previous related study: "*Capacity benefits of ERTMS/ETCS Level 2 on double-track lines*" back in 2018. It revealed that the ERTMS/ETCS level 2 is not a philosopher's stone in increasing capacity in mix freight and passenger traffic typical on Finnish double track lines. As the city commuter traffic is more homogeneous in terms of speed, the need for studying further the capacity benefits was recognised. Especially Helsinki Region Transport (HSL) was eager to study this subject, so this study was launched in late 2018.

Due to the limitations of time, this study does not contain comparable results with all train control systems the JKV, the ERTMS/ETCS level 1 and 2, but instead it studied the improved block sections only for the ERTMS/ETCS level 2, which has most flexible possibilities for them. Somewhat similar capacity improvements can be realised for JKV by using shortened block sections and additionally for ERTMS/ETCS level 1 by using infill functionalities.

The main writers of the study were **Alex Landex** (Chief Consultant Capacity Analysis at Rambøll Danmark), **Lars Wittrup Jensen** (Consulting Engineer at Rambøll Danmark), **Anne Jokiranta** (Project Manager at Ramboll Finland) and **Maija Musto** (Team Leader at Ramboll Finland). At the FTIA the study was steered by **Aki Härkönen** (Head of Railway Maintenance Services). As the availability of persons writing the study changed during the project, it was agreed, that the report is exceptionally written in English.

During the study, several workshops were arranged, and they had active participants from HSL, Finrail, FTIA, Rambøll, VR Group and VR FleetCare.

Helsinki, October 2019

Finnish Transport Infrastructure Agency
Maintenance department, Railway Maintenance Services

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Definitions

ATO: (Automatic Train Operation) ATO provides partial or complete automatic train piloting and driverless functionalities. Different not standardized ATO systems are subdivided into different grades of automation, see GoA.

ATP-VR/RHK (Automatic Train Protection): Supplier and product neutral name of the current Finnish automatic train protection system (JKV). Automatic train protection or control ensures the following of speed limits and signals in rail traffic. If the driver does not react on speed limit or stopping signal on time, the ATP will do it automatically. System consists of on-board and track equipment.

Balise: an electronic transponder placed between the rails. It is used for sending messages from the track-side automatic train control to the onboard equipment.

CBTC: A CBTC system is a "continuous, automatic train control system utilizing high-resolution train location determination, independent of track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and trainborne and wayside processors capable of implementing Automatic Train Protection (ATP) functions, as well as optional Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) functions.", as defined in the IEEE 1474 standard.

DMI: Driver Machine Interface is the display and control panel in the train.

EoM: End of Mission is a term used in ETCS to define when the train driver logs of the DMI to either shutdown the train or hand it over to another driver.

ERA: European Union Agency for Railways. Formerly known as European Railway Agency. Founded 2004. The purpose of the agency is to form the technical specifications of interoperability, including ERTMS, and to promote the efficient operation of a uniform and borderless railway within Europe. The main tasks are to unify, register and supervise the technical specifications in the European railway network and define common safety requirements for the entire area.

ERTMS: European Rail Traffic Management System. A European industrial project which aims for replacing of the national rail traffic management and automatic train control systems by a uniform interoperable system. The ERTMS has two basic parts: ETCS and GSM-R or in the future FRMCS.

ETCS: European Train Control System, which will replace national train control systems in Europe.

EVC: European Vital Computer is the on-board computer for ERTMS/ETCS.

FRMCS. Future Railway Mobile Communication System is a worldwide railway telecommunication system designed by the UIC, in cooperation with the different stakeholders from the rail sector, as the successor of GSM-R.

GoA: Grade of Automation: GoA 0: Manual operation, GoA 1: Non-automated operation (NTO), GoA 2: Semi-automatic operation (STO), GoA 3: Driverless operation (DTO), GoA 4: Unattended operation (UTO)

GSM-R: Global System for Mobile Communications – Railway. Radio system based on common GSM technology which uses frequencies reserved for railway traffic. GSM-R is used for creating a voice and data transfer connection between a train and its environment.

JKV: The conventional national automatic train protection system used in Finland (Finnish Junien kulunvalvonta).

LEU: Lineside Electronic Unit, encoder.

MA: Movement Authority, a permission given to cross one or more block sections on the line.

Marker board: In ETCS Level 2 marker boards replace conventional main signals. The position of the marker board defines the beginning of a block section. The signal aspect is only shown in the DMI.

RBC: Radio Block Centre. Part of ERTMS/ETCS systems of levels 2 and 3. The task of RBC is to transmit permit to drive from interlocking to trains moving inside the area of the RBC.

SoM: Start of Mission is a term used in ETCS to define when the train driver logs on the DMI to prepare the train for departure at the origin station.

STM: Specific Transmission Module. An on-board equipment integrated into the EVC for reading the information supplied current national ATC or ATP system to the ERTMS/ETCS.

TETRA: Terrestrial Trunked Radio; formerly known as Trans-European Trunked Radio. TETRA is a European Telecommunications Standards Institute (ETSI) standard.

UIC: International union of railways, (Fr. Union Internationale des Chemins de fer).

VIRVE: A TETRA (Terrestrial Trunked Radio) radio system used in Finland that has replaced GSM-R for railways.

1 Introduction

The current Finnish automatic train protection system (JKV) is planned to be replaced by the European Rail Traffic Management System (ERTMS) and its European Train Control System (ETCS). The main purpose of the ETCS is to implement a common European railway area, which that can open the rail signalling supply market and ease cross-border rail traffic within Europe. ERTMS/ETCS can be implemented in three different levels (level 1-3), where level 1 is the simplest level most like today's signalling and level 3 is the most advanced system providing the most capacity. Level 3 is not yet fully commercialized as available products.

In Finland the JKV system will be reaching the end of its lifecycle during 2020's, which is the key driver to consider ERTMS/ETCS implementation in Finland [52]. In addition, ERTMS/ETCS has been considered as one possible solution to help increasing the capacity on the railways especially in the Finnish capital area.

The aim of this work is to study the differences in capacity between the following systems on the city lines round Helsinki:

- The current JKV system with the current signalling layout
- ETCS level 1 with the current signalling layout
- ETCS level 2 with the current signalling layout
- ETCS level 2 with improved signalling layout

The analyses are carried out on the city lines between Helsinki and Leppävaara as well as between Helsinki and Kerava where the benefits of ERTMS/ETCS is assumed to be high due to trains of the same type operating with the same stop pattern.

Analysing the same signalling layout shows the differences in performance between the different systems. The ERTMS/ETCS level 2 makes it possibe to improve the signalling layout hence the capacity gain of improved block sections is analysed too for ERTMS/ETCS level 2 only. Due to the lack of time in the project, similar shorter block sections were not studied for the JKV and ERTMS/ETCS level 1. The results will be analysed and the main reasons causing variation between the systems will be described.

2 ERTMS/ETCS rollout

2.1 ERTMS/ETCS on suburban rail networks

There are altogether 95 589 km of ERTMS/ETCS equipped track contracted worldwide and 12 590 vehicles equipped with ERTMS/ETCS on-board systems [56]. While ERTMS/ETCS level 2 is mainly used for new high-speed lines, an increasing number of conventional and suburban lines are being equipped with ERTMS/ETCS level 2 to benefit from the capacity improvements it brings.

Suburban networks in operation today with ERTMS/ETCS level 2 include the Thameslink Core area in central London. The Core area comprises five stations with a capacity of 24 trains per hour in each direction on the central part between Blackfriars and St. Pancras. ERTMS/ETCS level 2 operation has been introduced concurrently with new rolling stock on the network. [56] [57]

In Spain a line of the Barcelona suburban network (Rodalies de Catalunya), a 56-kilometre-long section between L'Hospitalet de Llobregat and Mataró has been fitted with ERTMS/ETCS level 2. [56] [58]

While there are not that many suburban lines (or mixed traffic lines with suburban traffic) with ERTMS/ETCS level 2 in operation today, several are planned or under implementation. Among others:

- AUSTRALIA. Brisbane Suburban Network: 10.2 km new line across the river equipped with ERTMS/ETCS level 2 to be ready by 2024 [59]. Furthermore, the core part of the existing network is to be resignalled with ERTMS/ETCS level 2 between Milton and Northgate, a section with 11 stations. With the resignalling the capacity is increased by 20% (eight trains per hour). [60]
- AUSTRALIA. Sydney Trains: Resignalling of the suburban network with ERTMS/ETCS level 2. The network consists of nine lines covering 813 kilometers of track and 175 stations. First lines to complete migration in the early 2020's. [63]
- UNITED KINGDOM. London: ERTMS/ETCS level 2 overlay to existing signalling Paddington-Heathrow/West Drayton under the Crossrail Project. ERTMS/ETCS signalling to be extended later to Maidenhead, Reading and Bristol. When Crossrail opens, trains are to operate under CBTC east of Paddington through central London. [56] [61] [62]
- UNITED KINGDOM. ECML (East Coast Main Line): Resignalling of mixed traffic route. One of the first lines to be resignalled is the Moorgate branch that exclusive has suburban or metro traffic.

Several of the resignalling projects on the abovementioned suburban lines also include plans for ATO, e.g. Thameslink and Sydney Trains.

2.2 ERTMS/ETCS in Europe

Europe comprise the highest proportion of ERTMS/ETCS installations worldwide with 46% of the ETCS/ERTMS trackside contracts and 66% of vehicle onboard installations.

ERTMS/ETCS level 1 is already or is planned to be in operation in the following European countries: Austria, Belgium, Bulgaria, Croatia, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg (full coverage of the network), North Macedonia, the Netherlands, Poland, Romania, Slovakia, Spain, Sweden, Switzerland (full coverage of the network with ERTMS/ETCS level 1 Limited Supervision). [19]

ERTMS/ETCS level 2 is already or is planned to be in operation in the following European countries: Austria, Belgium, Czech Republic, Denmark, France, Germany, Italy, the Netherlands, Norway, Poland, Romania, Slovakia, Spain, Sweden, Switzerland, United Kingdom. [19]

The ERTMS European Deployment Plan has set deadlines for ERTMS/ETCS implementation along the main European rail routes. The Commission Implementing Regulation (EU) 2017/6 lays down timetable for ERTMS/ETCS deployments on nine core network corridors (CNC) connecting European cities to each other. These corridors are shown in figure 1. Finland is in two of the CNC's; in Scandinavian-Mediterranean (SCM) and in North Sea- Baltic (NSB) corridor. [20]

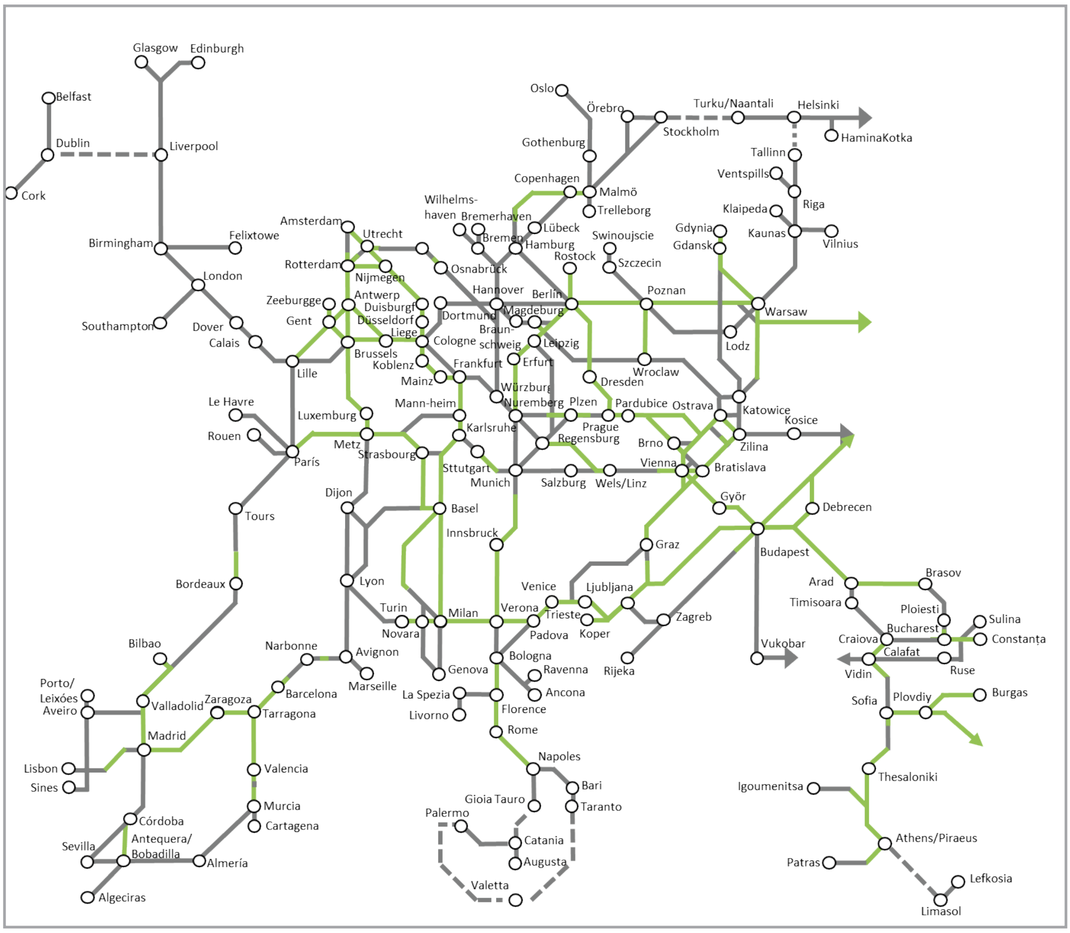

Figure 1 The Core Network Corridors [20].

2.3 Implementation of ERTMS/ETCS Level 2 in the Nordics

2.3.1 Sweden

The Swedish National Implementation Plan for ERTMS/ETCS does not include which level of ERTMS/ETCS for the deployment strategy [64]. Level 2 technology has been chosen for the whole of Sweden, with exceptions of Level 1 being deployed at larger stations and railway yards with extensive shunting movements [12]. The first Swedish ERTMS/ETCS line was implemented to Bothnia line in 2010, altogether 190 km of new railway, with 140 bridges and 25 km of tunnels. Most of Swedish lines are expected to be equipped by 2035. [11].

A report "*Nytt signalsystem för järnvägen – effektiviteten i införandet av ERTMS*" was published in August 2018 by the Swedish National Audit Office Riksrevisionen [13]. The costs of the implementation have been much higher than anticipated. Previously the improvement of capacity was one of the key objectives of the project but the promised increase in capacity has not been realized. It has been found out that the same capacity improvements could be achieved with ATC system, although with greater cost. The results do indicate of increased reliability with ERTMS/ETCS. [13]

2.3.2 Denmark

Denmark has had challenges from many different and old train control systems, leading to an insufficient capacity and lack of knowledgeable maintenance staff. Therefore, the state-owned rail network infrastructure manager Banedanmark has decided to replace all the legacy systems with ERTMS/ETCS level 2, expecting to reach possible 25 % reduction in maintenance costs and 80% reduction on the signal-related delays. [14, 15]

The first regional passenger services with ERTMS/ETCS level 2 started to operate between Lindholm (just north of Aalborg) and Frederikshavn on 21st October 2018 and is operated by Nordjyske Jernbaner. Banedanmark aims to complete the ETCS roll out by 2030. [16]

Denmark has experienced problems rolling out the on-board equipment in the trains due to several stakeholders (operator, infrastructure manager and supplier) with different interests in the roll-out. It has furthermore, been more difficult than expected to equip the older trains with ERTMS/ETCS on-board system due to lack of space for the on-board equipment and variations within the same train types.

2.3.3 Norway

In Norway, the ERTMS/ETCS signalling system will be implemented to the main railway lines and Oslo S. The whole programme is due to be completed around 2034. The driver for the new signalling system is to update their current relay-based systems and a desire for early deployment of a country-wide Traffic Management System. The Norwegian rail network infrastructure manager Bane NOR has suggested a sequential ERTMS level 2 Baseline 3 implementation. [17, 18]

2.4 ETCS in Finland

2.4.1 Functional requirements specifications

The Finnish Transport Infrastructure Agency maintains the national functional requirements specifications for the ERTMS/ETCS. The latest publication was in 2018. The document presents the main operating principles for ERTMS/ETCS Level 1 on-board and trackside command, control and signalling subsystems in Finland. It has been determined that ERTMS/ETCS system in Finland shall conform to ERA's most recent and up-to-date definition, the ERTMS/ETCS baseline 3 requirements [3]. However, although information is not conclusive, it appears that Finland is the only country that foresees to equip only ERTMS/ETCS level 1 in the network [64], which is the same strategy as Luxemburg has already implemented [19].

On-board equipment shall have all ERTMS/ETCS train and axle load categories available. The data transmission distances in the ERTMS/ETCS system is determined to be equivalent to the ones used in the current train control system JKV. Regarding the trackside requirements, it is stated that the transition border between JKV and ERTMS/ETCS train control systems should be located within a line section in such a way, that another speed restrictive element after the transition balise group is avoided. Pantograph or line interrupter control will not be automated by trackside equipment in Finland. In the specification following has been stated: "ERTMS/*ETCS on-board equipment to be used on Finnish railway network shall have a function that does not require air intake data as train data*." Also loading gauge train data is not required as train data in Finnish railway network. The technical maximum speed limit for Staff Responsible mode for ERTMS/ETCS on-board equipment is 80 km/h. However, the national maximum speed in Staff Responsible mode is 50 km/h. [3]

2.4.2 National values

The Finnish national values for ERTMS/ETCS are presented in Finnish national ERTMS/ETCS parameters FTA guideline 20/2015 [4]. As a background of defining Finnish National Values, applications and values of ERTMS/ETCS system being used in other European countries have been examined.

Finnish national values are determined based on ERTMS/ETCS braking curves reasonably well match the JKV braking curves with weather value 2 "normal weather". The other values are value 1 "good weather" and 3 "bad weather".

In the Finnish railway network the weather value will be allowed to be set by the driver in ERTMS/ETCS, as it is currently allowed also in JKV. Setting the weather values for ERTMS/ETCS is challenging especially for the freight trains since there is one weather value to be set, to match both loaded and empty trains. In Finland it is crucial also to consider the snow conditions, which will decrease the deceleration value. [4]

2.4.3 Implementation plans

The first official Finnish ERTMS/ETCS implementation plan was prepared for the European Commission in 2006. The strategy for the implementation was to start with the locomotive equipment and to continue later with the track equipment when there would be enough rolling stock equipped with ETCS. The plan proposed implementation of GSM-R in rolling stock during 2008–2012, development and introduction of specific transmission module in 2013 as well as first sections to be equipped with ERTMS/ETCS during 2019–2025. [5]

The new Finnish implementation plan of the ERTMS/ETCS was published in 2017 according to the Commission Regulation (EU) 2016/919, which obligates the Member States to draw up a national implementation plan, describing their actions to comply with the technical specification for interoperability (TSI). According to the Finnish national implementation plan of ERTMS/ETCS the deployment for railway network was due to begin with pilots during 2020–2023. After that the network would be equipped during 2024–2038 in six stages. Additionally, there was a plan to equip the remaining rolling stock with ERTMS/ETCS during 2025–2037. There were no binding decisions for the proposed timetable or the funding of the project. The strategy was to begin implementation with ERTMS/ETCS level 1 for less occupied lines and then study the benefits of the level 2 before implementing ERTMS/ETCS to the busy main lines in 2030s. [6]

In 2019 the current Finnish implementation plan of the ERTMS/ETCS is being re-evaluated by a new study project launched by Minister of Transport and Communications in Finland with a more broad scope of digitalization. The study will be published in early 2020.

2.4.4 On-board equipment of Rolling Stock

Specification of the control, command and signalling, prepared by the Finnish Transport and Communications Agency Traficom, steers for early equipment of rolling stock. All the new operations have to follow 2016/919/EU Set of Specifications: Technical specification of the interoperability of control, command and signalling, meaning ERTMS Baseline 3 + GSM-R. The Traficom has prepared a regulation for the implementation of the ERTMS/ETCS equipment as follows:

- new rolling stock orders after 1.7.2015
- rolling stock refurbishments ordered after 1.1.2017 and
- new or refurbished track equipment, which has been ordered after 1.1.2022 or implemented after 1.1.2025, must be equipped with ERTMS/ETCS. [7]

VR Group Ltd introduced the first locomotives equipped with ERTMS/ETCS in 2017. Locomotives of type Sr3 have been equipped with ERTMS/ETCS and STM, so they can be used in lines equipped with ERTMS/ETCS and JKV trackside systems. [8]

Finnish Transport Infrastructure Agency (FTIA) built a test section on Kerava–Lahti line for the approval of rolling stock equipped with ERTMS/ETCS in 2015-2017. Test section is equipped with both ERTMS/ETCS level 1 and JKV. The section was given a permission from Traficom to test drive ERTMS/ETCS level, but not to operate commercial ERTMS/ETCS traffic on it. [9]

2.4.5 Data transfer network

In Finland the railway radio system GSM-R has been replaced by VIRVE network, which is based on TETRA technology. The shutdown of GSM-R is due to issues railway radio network has caused to the commercial radio networks, and vice versa. After the shutdown there is no separate radio network for railway traffic in Finland. [10]

3 Capacity on ERTMS/ETCS

3.1 Definition of capacity

Capacity is a complex concept related to infrastructure, train timetables and rolling stock. Generally, capacity describes how many trains can be operated on a railway line during a given time period with a given quality or stability, see figure 2. Capacity of a line section is rarely equal to the capacity of stations, and therefore one or the other defines the capacity of a line.

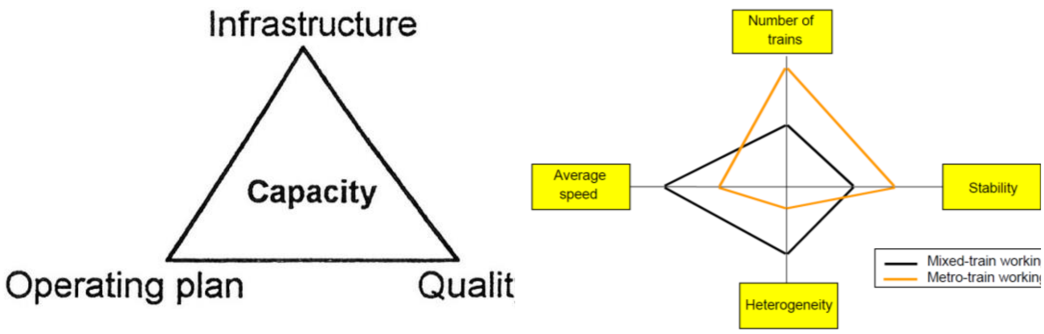

Figure 2 UIC definitions of capacity [49] left and [50] right.

The railway capacity evaluation standards are based on analytical models (e.g. UIC 406 formula [50] and optimization processes). These theoretical methods will analyze the maximum number of trains that can be scheduled, and are dependent by infrastructure, traffic features and operating requirements.

Maximum capacity can be used to define the theoretical maximum number of trains. In practice it can be challenging to define an exact value for maximum capacity because the heterogeneity of traffic and the stability of timetable structure affect the capacity crucially.

There is a distinction between a theoretical and practical capacity. In practical capacity, the reliability and operational aspects are included. In operational management the economically optimal level of capacity is to be determined, since the theoretical maximum capacity is not viable in practice (Figure 3). [25]

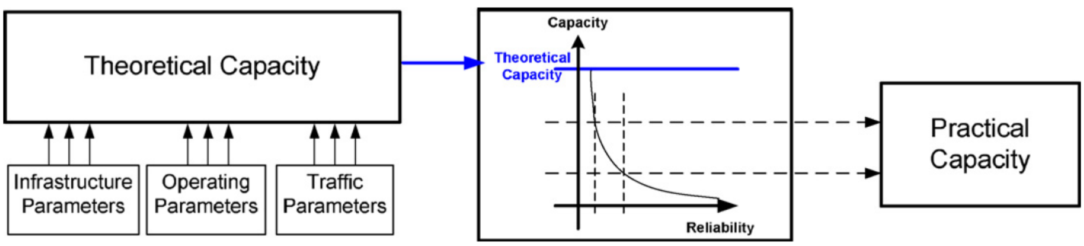

Figure 3 Reliability is the most influential parameter between theoretical and practical capacity.

This report investigates the differences related to capacity between JKV and ERTMS/ETCS level 1 and level 2. There are several other aspects related to capacity, but this work considers only the capacity features that cause variation in capacity. These features are signal distances, braking curves and response times of the system.

3.2 Differences of ERTMS/ETCS levels 1, 2 and 3

Main differences of ERTMS/ETCS levels are related to the update of the movement authority (signal aspect). Level 1 has discrete update while level 2 has continuous update of the movement authority (signal aspect). In levels 1 and 2 the movement authority is based on fixed block sections. In ERTMS/ETCS Level 3, train monitors its own position and integrity continuously, introducing a “moving block” technology. [21]

ERTMS/ETCS level 1 is similar to the current JKV system of Finland. In level 1 the movement authority of a train is updated discretely when train passes Eurobalises. The system requires visible signals and detection of track section occupation (figure 4). The on-board computer (EVC) continuously monitors and calculates the maximum speed and the braking curve from this data. The movement authority is given to the train by Eurobalises, making data transmission non-continuous. The main benefit with ERTMS/ETCS level 1 is the interoperability between suppliers and countries. [22]

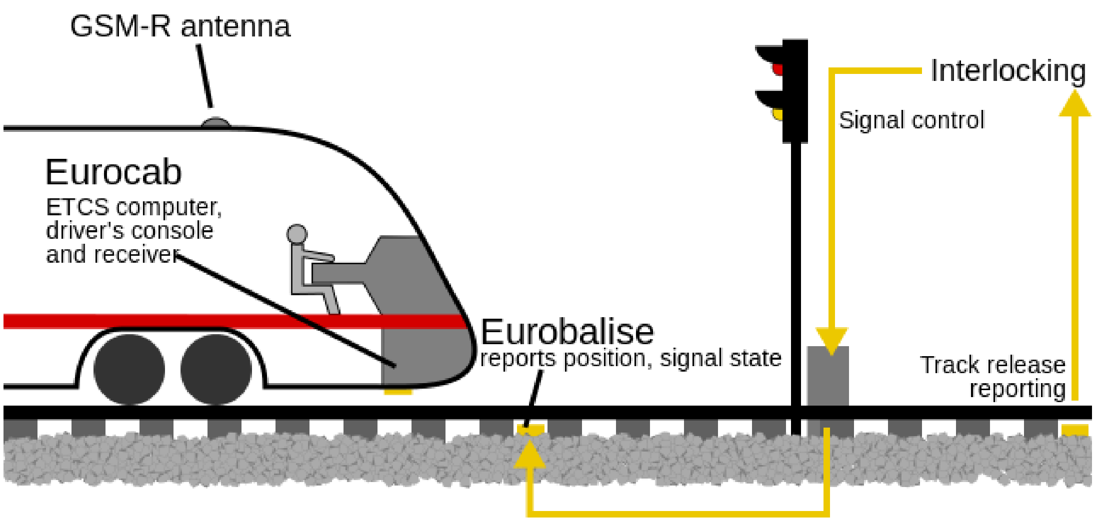

Figure 4 Visualization of operation of ERTMS/ETCS level 1 [23].

In ERTMS/ETCS level 2 the movement authorities are transmitted continuously from a radio block center (RBC) using the GSM-R network or similar like FRMCS (Figure 5). The system also requires detection of track section occupation using for example axle counters, but there is no need for visible signals. Balises are used to transmit fixed messages, relating to e.g. location, speed limit, gradient etc. Continuous data transfer allows improved capacity to discrete update of the movement authority in level 1, allowing the train to reach its optimal speed maintaining a safe braking distance. [21, 22]

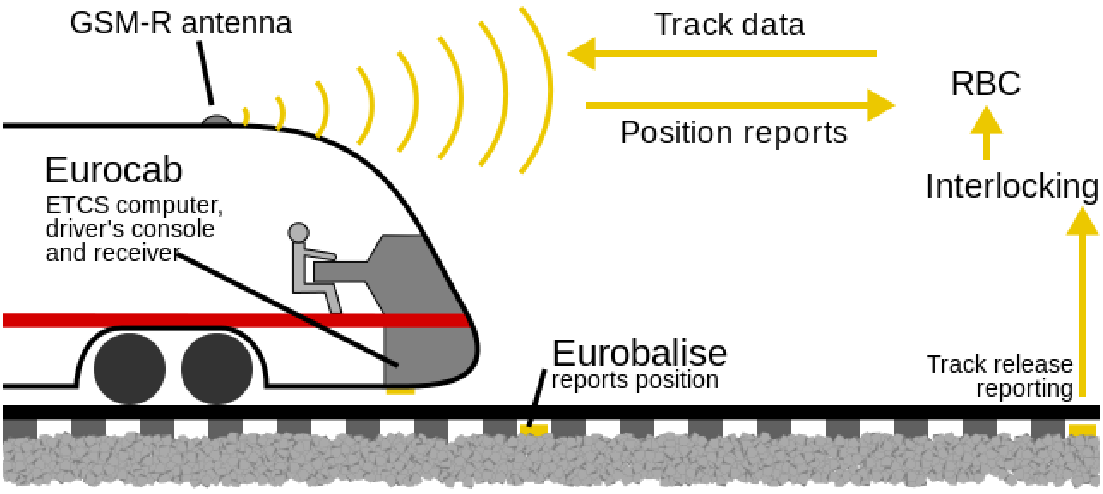

Figure 5 Visualization of the operation of ERTMS/ETCS level 2 [23].

ERTMS/ETCS level 3 has also continuous train control like level 2. The significant difference is that there are no fixed blocks monitored using track circuits or axle counters. Thereby a single train forms its own moving block allowing increased capacity compared to level 2. The position of the train is reset by Eurobalises and odometer inside the train and this information is transmitted to the central control (Figure 6). ERTMS/ETCS level 3 needs reliable radio communication and a train integrity system to ensure the train is complete. These requirements have prevented implementation of pure ERTMS/ETCS level 3 systems. ERTMS/ETCS level 3 is not considered in this study. [21, 22]

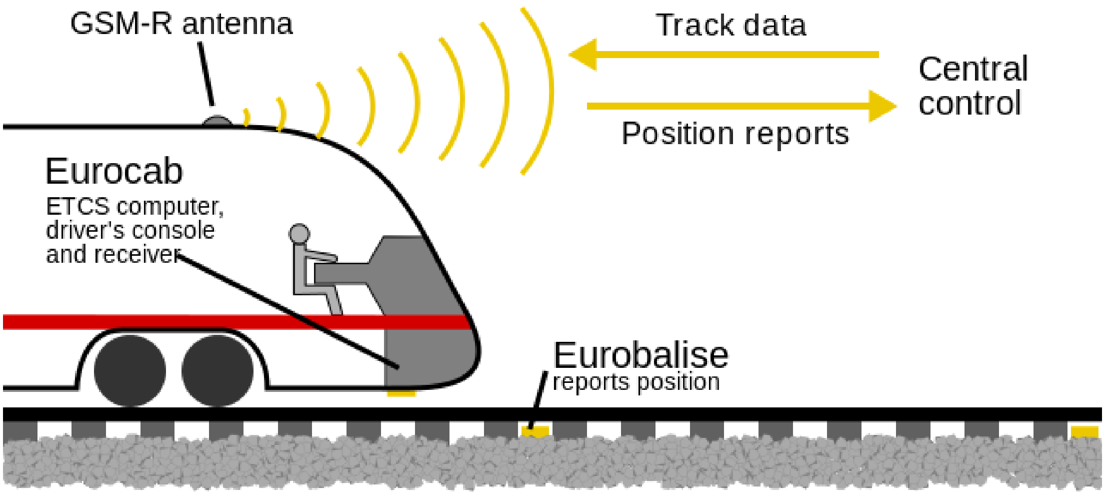

Figure 6 Visualization of the operation of ERTMS/ETCS level 3 [23].

An overview of different functionalities for ERTMS/ETCS levels 1, 2 and 3 is presented in table 1. [24]

Table 1 Comparison of ERTMS/ETCS levels 1, 2 and 3 [24].

	Level 1	**Level 2**	**Level 3**
Minimum block length	Short	Short	“No” blocks
Communication	Discrete*	Continuous	Continuous
Signal visibility	Usually needed	Not needed	No signals
Train detection in track	Needed	Needed	Limited (on train and switches)
Train integrity	Not needed	Not needed	Crucial
Position known	Block section	Block section**	“Exact” position
Gap in communication	–	Possible	Possible***

* *Infill possible*
** *To some extent also to the exact balise*
*** *Will result in longer headways*

3.3 Capacity benefits of ERTMS/ETCS

UIC has engaged the RWTH Aachen University to study about influence of ERTMS/ETCS on line capacity. The results of the capacity analysis were based on UIC 406 and STRELE-formulas.

A clear increase in capacity between ERTMS/ETCS levels 1 and 2 was observed in the case of high-speed lines with homogenous fast passenger traffic. There was only a slight increase in capacity compared to ERTMS/ETCS level 1 with level 2 in all cases; in high-speed line, conventional main line and regional line. It is stated that ETCS level 2 with 400 m block sections and ETCS level 3 have a high potential for capacity increase (Figure 7). [1]

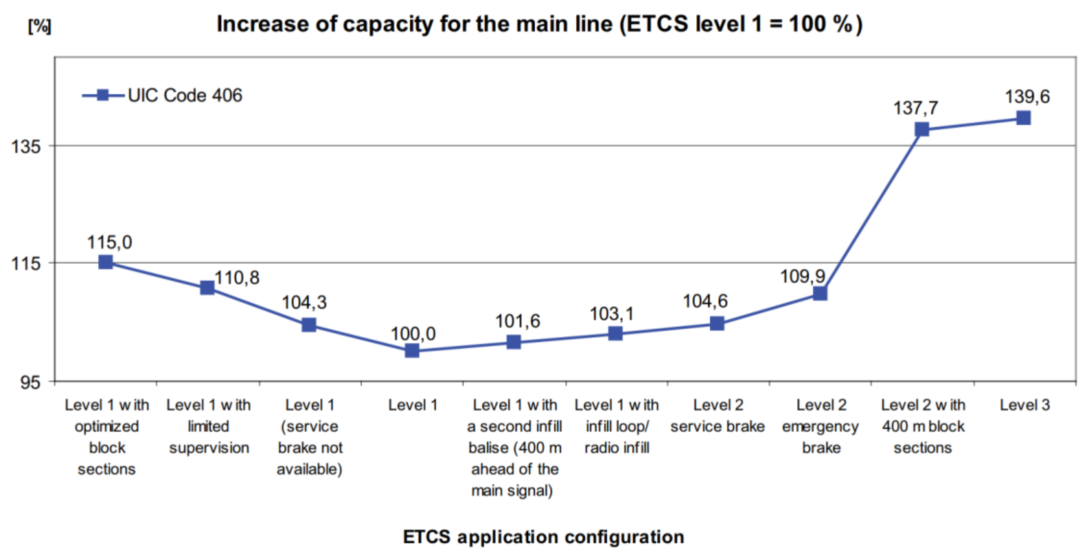

Figure 7 Increase in capacity for the conventional main line.

FTIA studied in 2018 the possible benefits of ERTMS/ETCS level 2 solutions in double track railway lines, where the capacity benefits were assumed to be the greatest. Capacity differences between ERTMS/ETCS levels 1 and 2 were examined in two case studies. The selected line sections were Riihimäki–Tampere and Kerava–Lahti.

In the study it was concluded, that the more homogenous traffic is, the greater the capacity benefits are with ETCS level 2 (Figure 8). In Finland homogenous traffic, and possibly the greatest capacity benefits can be found on the city line tracks to Kerava and Leppävaara, and on the Ring Rail Line Huopalahti–Hiekkaharju. In the study it was also stated that capacity benefits can be enhanced by optimizing block sections for the braking curve. [2]

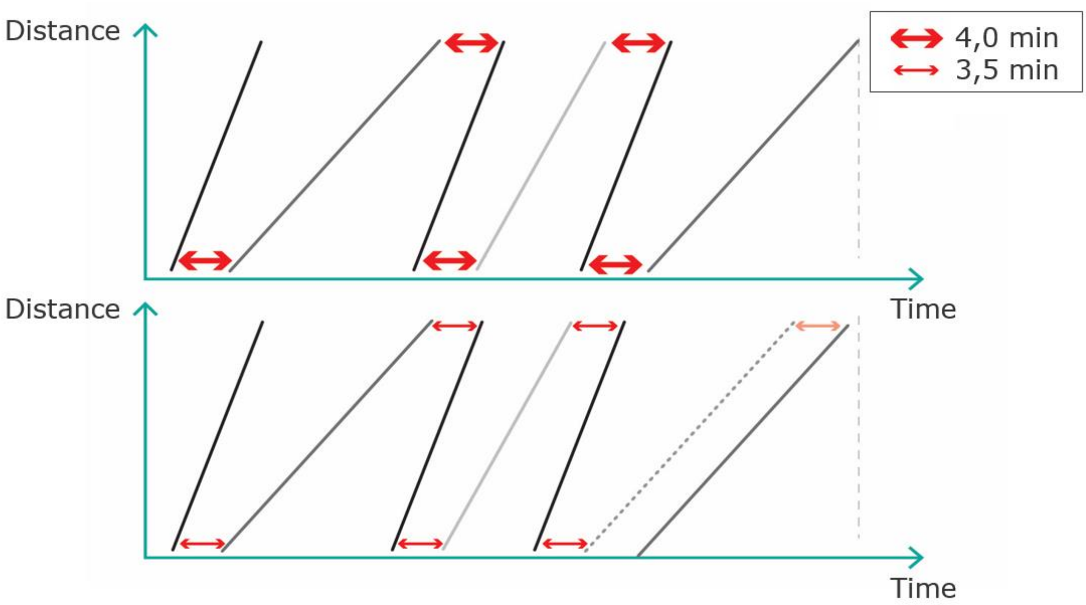

Figure 8 Possibility to increase the amount of trains by decreasing the minimum headway in homogenous traffic [2].

3.4 Factors affecting capacity

3.4.1 Signal distances

Main differences related to capacity between JKV and ERTMS/ETCS are caused by the signal distances and how the braking distances of the trains fit to the them. Generally, distances between signals are adapted based on the braking distances, but this can be challenging on railway lines with heterogenic traffic where the trains can have very different braking curves. Figure 9 demonstrates the correlation of signal distance and braking distance in ERTMS/ETCS level 1. Because the train receives an updated braking curve only by the balises it can happen that the train brakes unnecessary early with respect to an approaching signal or marker board.

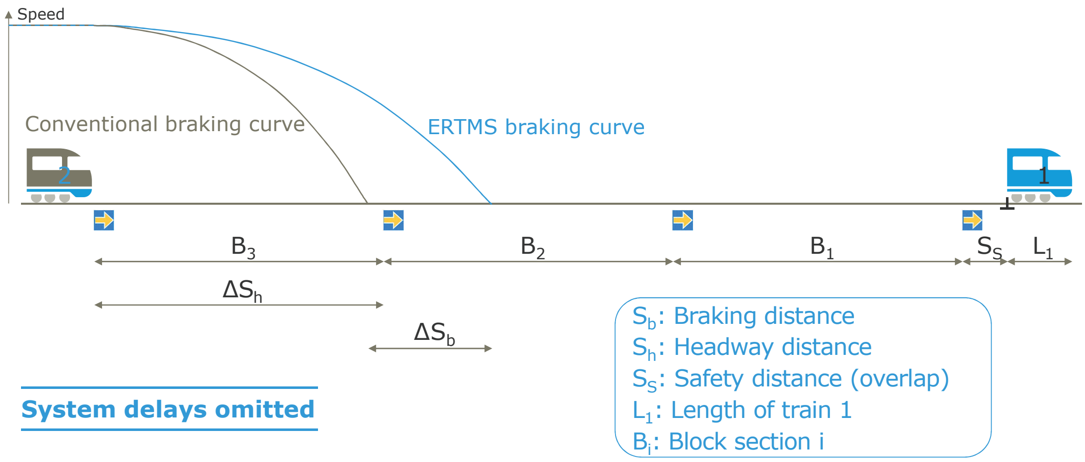

Figure 9 Correlation of signal distance and braking distance in ERTMS/ ETCS level 1.

Conclusions about the correlation of signal distance and braking distance are summarized in figure 10 where the effect of continuous and discrete train control on train (time) headway is demonstrated using a theoretical example. When the total block distance is constant, the more equal the systems are the higher is the number of signal blocks. Generally, train headways are longer for discretely updated movement authority (JKV and ERTMS/ETCS level 1) compared to continuously updated systems (ERTMS/ETCS levels 2 and 3). In situations where signal distance and braking distance are equal, the minimum train headway is the same for the same type of system i.e. ERTMS/ETCS levels 1 and 2 (ignoring system delays, which in practice influences the outcome).

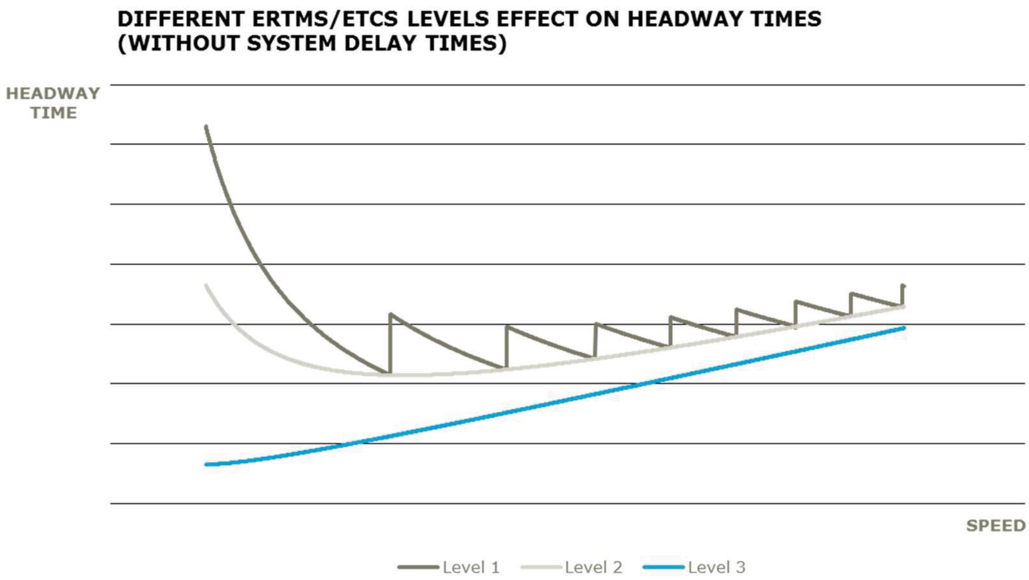

Figure 10 Minimum train headway by continuous and discrete update of movement authority [Modified from 26].

3.4.2 ERTMS/ETCS Braking curves and comparison with JKV

As a part of the implementation of ERTMS/ETCS, the braking curves of the trains are equalized in order that there is no need for interfaces or software for several national practice and braking curves. In ERTMS/ETCS the braking curve is called EBD (Emergency Brake Deceleration) which depends on properties of both rolling stock and infrastructure. Based on EBD and the velocity of the train the ERTMS/ETCS computes the stopping distance many times per second taking also into account the uncertainty of the actual velocity and the eventual rise of velocity caused by acceleration. EBD-curves offer diverse control points for computing the braking curve to support driving and ensure smooth ride as possible. These points are indication (I), permitted speed (P), warning (W), service brake intervention (SBI) and emergency brake intervention (EBI). Figure 11 demonstrates the properties of EBD-curve and control points related to it. ERA has published an introduction to ERTMS/ETCS braking curves and defines the locations of the curves as follows:

- For the “I” supervision limit: leave the driver enough time to act on the service brake so that the train does not overpass the Permitted speed, when this latter will start to decrease. Without the indication it would not be possible for the driver to perform a transition from ceiling speed supervision to the target speed supervision without over-passing the Permitted speed.
- For the “P” supervision limit: in case of overspeed, to leave the driver an additional time to act on the service brake so that the train will not overpass the point beyond which ETCS will trigger the command of the brakes.
- For the “W” supervision limit, to give an additional audible warning after the Permitted speed has been overpassed.
- For the “SBI” supervision limit, to take into account the service brake build-up time so that the EBI supervision limit is not reached after the command by ETCS of the full service brake effort. The SBI supervision limit is facultative and can be implemented on-board the train in order to avoid too frequent emergency braking, which can be damaging for both the rolling stock and the track.

Same braking curves are used in both ERTMS/ETCS levels 1 and 2, but the effect of the braking curves on capacity is different because of the discrete or continuous train control. [27]

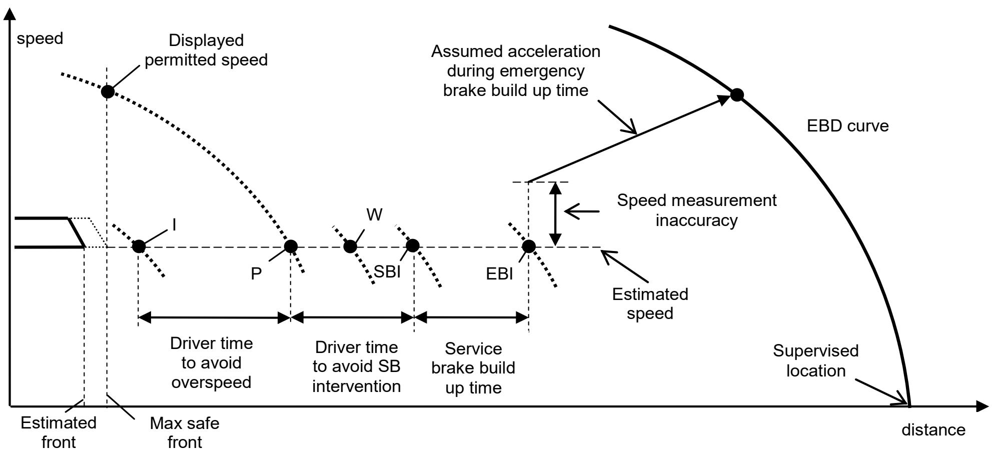

Figure 11 *EBD curve and its related supervision limits [27].*

Two different methods are used to calculate braking curves depending on the available data for the train. The more detailed calculation method is called Gamma method. For Gamma method, a number of predefined compositions like the nominal deceleration profiles, corresponding rolling stock correction factors and the brake build up time are required for the train.

For the Lambda braking curve calculation method, the braking performance is calculated as a brake weight percentage, which is converted into deceleration data. The method is purely mathematical, being based on an algorithm developed by UIC's extensive field tests with a large variety of train types. [27] An overview of the Gamma and Lambda braking curve calculations is presented in table 2.

Table 2 *Overview of Gamma and Lambda braking curves.*

Type	**Lambda**	**Gamma**
Precision	Low/limited	High
Number of parameters	Few	Many
Generally used for	Freight trains as exact braking parameters are not known	Train units as braking performance is well-defined

Current Finnish Automatic Train Protection system, JKV, has five braking curves; Warning (A), alarm (B), application curve for service brake (C), service brake (D) and emergency braking curve (E) (Figure 12). The functionality of the curves is as follows:

- On the curve "A" the driver will get the first input on the stop sign ahead. The system recommends the driver to start braking.
- If the driver has missed the recommendation to start braking on the curve A, or is not braking enough, the curve "B" triggers a warning to the driver to start braking
- On the curve "C" the service brake is applied and will continue as long as the train reaches the supervised speed. The driver cannot change the braking of the train at this point.
- Curve "D" is a basic curve, which is used to calculate the other curves.
- Curve "E" applies an emergency brake. The braking continues until the speed is zero.

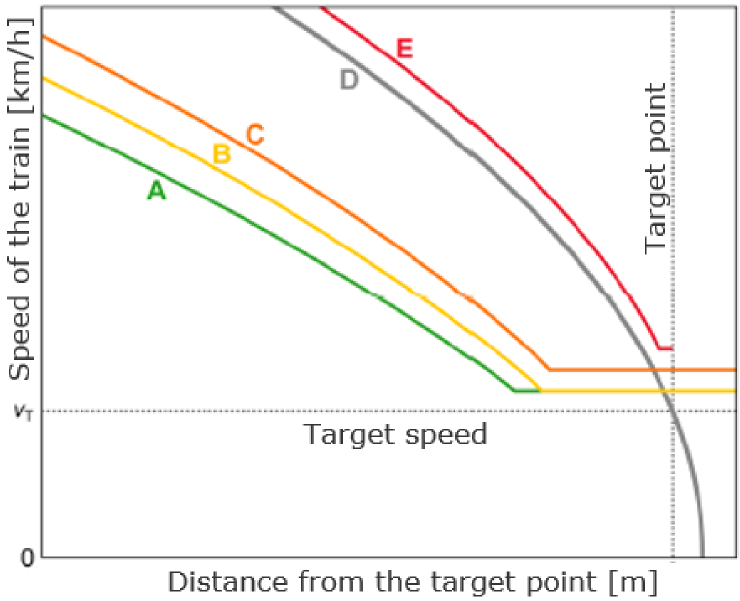

Figure 12 JKV braking curves and related supervision limits [28].

The maximum speed the driver sets to the system is based on the maximum speed received from the traffic control. Traffic control will base the maximum speed value on the braking ability requirements, track features, the maximum speed for the rolling stock and timetable circumstances. [29]

The calculation methods between JKV and ERTMS/ETCS braking curves differ from each other. The calculation for ERTMS/ETCS is more precise and covers more uncertainties. For ERTMS/ETCS, the emergency braking curve is calculated to the target point at or behind the signal (to supervised location SvL). For JKV the emergency braking curve is calculated ending to the signal (End Of Authority EOA). [29]

The emergency brake is applied for ERTMS/ETCS before in JKV system, due to the different philosophy of the systems. The service brake for JKV is safety critical whereas the emergency brake is only precautionary. In ERTMS/ETCS the emergency brake is safety critical brake, and service brake is introduced nationally. [29]

3.4.3 Response times

Response time means the time that is spent for the data transfer between different systems. Generally, it must be secured in any train control system that the response times do not become too high and therefore do not affect rail traffic safety negatively.

ERTMS/ETCS level 2 response time is longer than response time of level 1. Level 2 has more systems and interfaces which leads to longer time of data transfer. International union of railways (UIC) has estimated the response times for ERTMS/ETCS levels 1 and 2 in report influence of ERTMS/ETCS on line capacity [1]. Response times of ERTMS/ETCS level 2 have also been evaluated by FTIA in the study: "*Implementing the Interface of Future Rail Traffic Management System (ERTMS) to Present Railway Signalling Systems*", *Research reports of* *the Finnish Transport Agency (47/2012)* [30]. Estimated response times are presented in table 3.

Table 3 ERTMS/ETCS level 1 and level 2 response times estimated by UIC and FTA [1, 30].

	Response time (s)		
Functionality	**Level 1**	**Level 2**	**Level 2 by FTA**
*LEU**	0.70	-	-
*EVC+DMI***	1.00	1.00	-
Interlocking	-	-	1.50
Interface computer	-	-	1.00
Interlocking to RBC	-	0.05	-
RBC	-	1.50	0.50
RBC to train	-	1.10	0.50
Remote control	-	-	0.50
Total	**1.70**	**3.65**	**4.00**

**LEU = Lineside Electronic Unit*
***EVC = European Vital Computer DMI = Driver-Machine-Interface*

Differences between response times of different systems affect the time spent for ensuring train paths and therefore the minimum headway.

3.5 Transition between ERTMS/ETCS levels

Transition between ERTMS/ETCS levels needs to be considered before rolling out the system, as transitions may not be possible everywhere and it can limit capacity. This is regardless of changing between ERTMS/ETCS and conventional signalling or between levels of ERTMS/ETCS.

The transition from e.g. level NTC (National Train Control i.e. conventional signalling) to ERTMS level 2 (with GSM-R or FRMCS) can take place over a long distance before the radio network has been registered, the radio connection established, the Movement Authority (MA) received, and a train that has not received a movement authority has been braked safely, see figure 13.

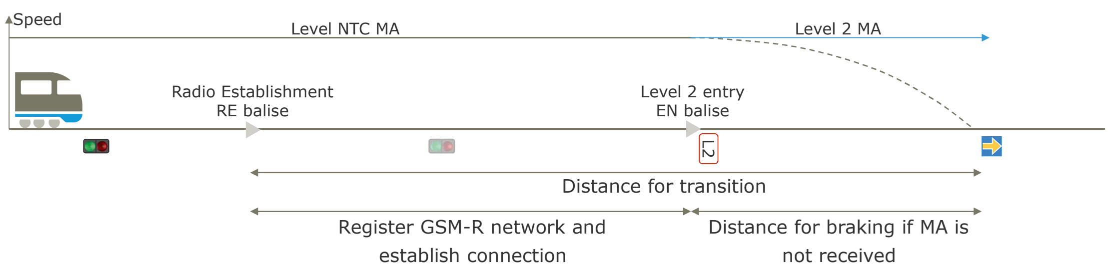

Figure 13 Example of transition from Level NTC (conventional signalling) to ERTMS level 2.

The distance for the transition depends on the transition time parameters that vary from system to system but to some extent is stated in the ERTMS/ETCS requirements in various subsets. An example of parameters that can be included in a transition is given in table 4.

Table 4 Example of transition times from Level NTC (National Train Control, conventional signalling) to ERTMS/ETCS level 2.

Event	**Time**	**Reference**
Read and process RE balise group	1.5s	Subset-041
Register with the GSM-R network	40s	Subset-037
Set up connection with RBC	40s	Subset-093
Exchange information train-RBC	10s	Estimate
Process train by TMS	15s	Estimate
Issue MA to train, and report this to legacy interlocking system	2s	Estimate
Update signal and class B system	2s	Estimate
Present signal aspect to driver	4s	Subset-026
Total (minimum)	**~115s**	**+ braking**

If a train is operating with 60 km/h, the transition distance is (based on the example values table 4) about 2 km plus time for the train to brake safely before the first marker board if the movement authority has not been received correctly[1]. The transition and the safe braking distance can limit the capacity of the railway line in the transition zone, and transition zones hence have to be located in areas where it will not affect the train operation.

In these analyses, it is assumed that the entire infrastructure uses the same signalling why transitions between ETCS levels is not considered.

[1] If Movement Authority (MA) has not been received correctly, the train driver must perform the Start of Mission (SoM) procedure manually before the train can continue.

4 Case studies

4.1 System description

Helsinki Region Transport (HSL) operates the city lines between Helsinki and Kerava, and Helsinki and Leppävaara. In addition, there is a Ring Rail Line on a route Helsinki–Hiekkaharju–Airport–Huopalahti–Helsinki, going also to the opposite direction. City line services have their dedicated infrastructure separated from other tracks and they are the lines where trains stop in each commercial station: A, P, I and K lines. In addition, lines L and T uses city line tracks on the sections from Leppävaara (L-line) and Kerava (T-line) towards Helsinki.

Services on all lines have a peak-hour headway of 10 minutes. Sections between Helsinki and Huopalahti as well as Helsinki and Hiekkaharju has a peak-hour headway of five minutes as these sections are operated both by Ring Rail Line and trains to Kerava or Leppävaara. During the peak-hour turnaround time on Leppävaara station is 6 minutes and in Kerava 7 minutes. The current system is presented in figure 14. This study considers lines from Helsinki to Kerava and Helsinki to Leppävaara as well as Helsinki main station rail yard. The Ring Rail Line is excluded from the study.

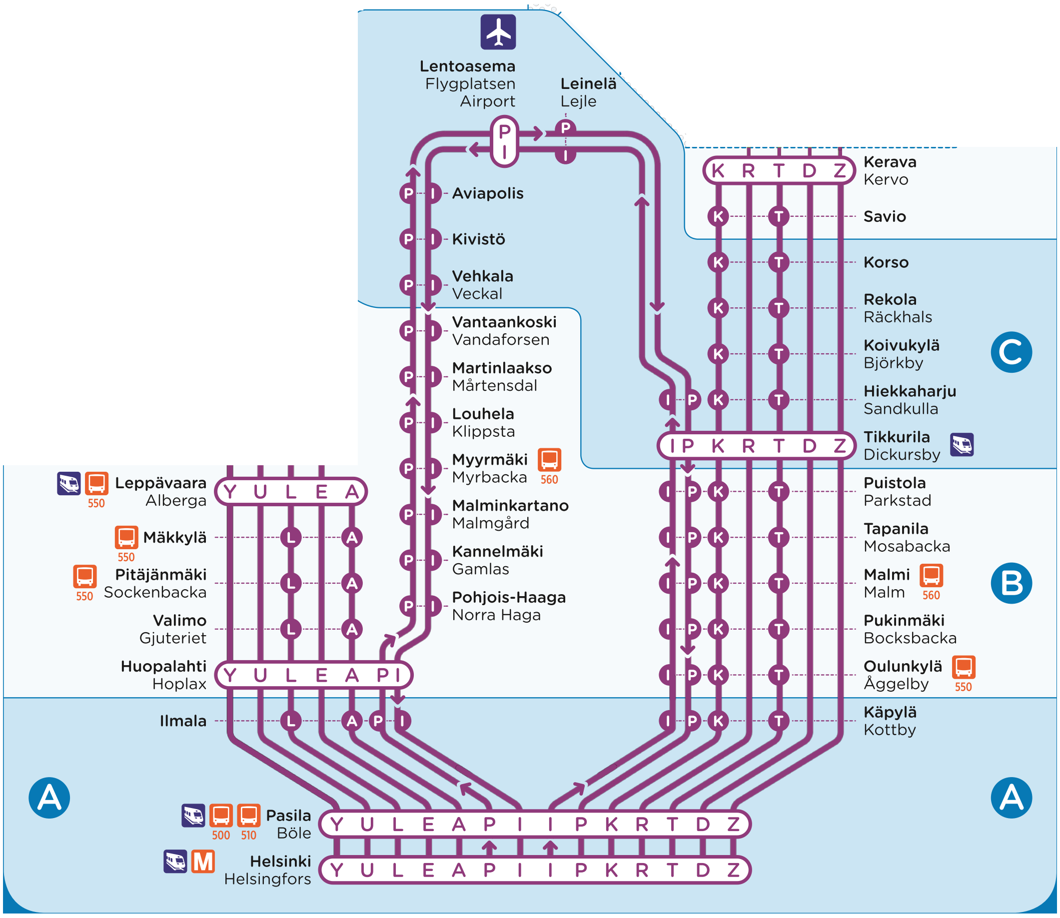

Figure 14 *Finnish city line tracks and Ring Rail Line [modified from 31].*

4.1.1 Helsinki–Kerava

Line section from Helsinki to Kerava has 13 intermediate stations (Figure 15). The length of the section is 28.7 kilometers and the scheduled driving time of the trains is 34 minutes. The longest signal distance between Helsinki and Kerava is 2 525 meters and the shortest 283 meters.

Figure 15 Helsinki–Kerava line map [32].

4.1.2 Helsinki–Leppävaara

Line section from Helsinki to Leppävaara has six intermediate stations (Figure 16). The length of the section is 10.8 kilometers and the scheduled driving time of the trains is 17 minutes. The longest signal distance between Helsinki and Leppävaara is 2 020 meters and the shortest 254 meters.

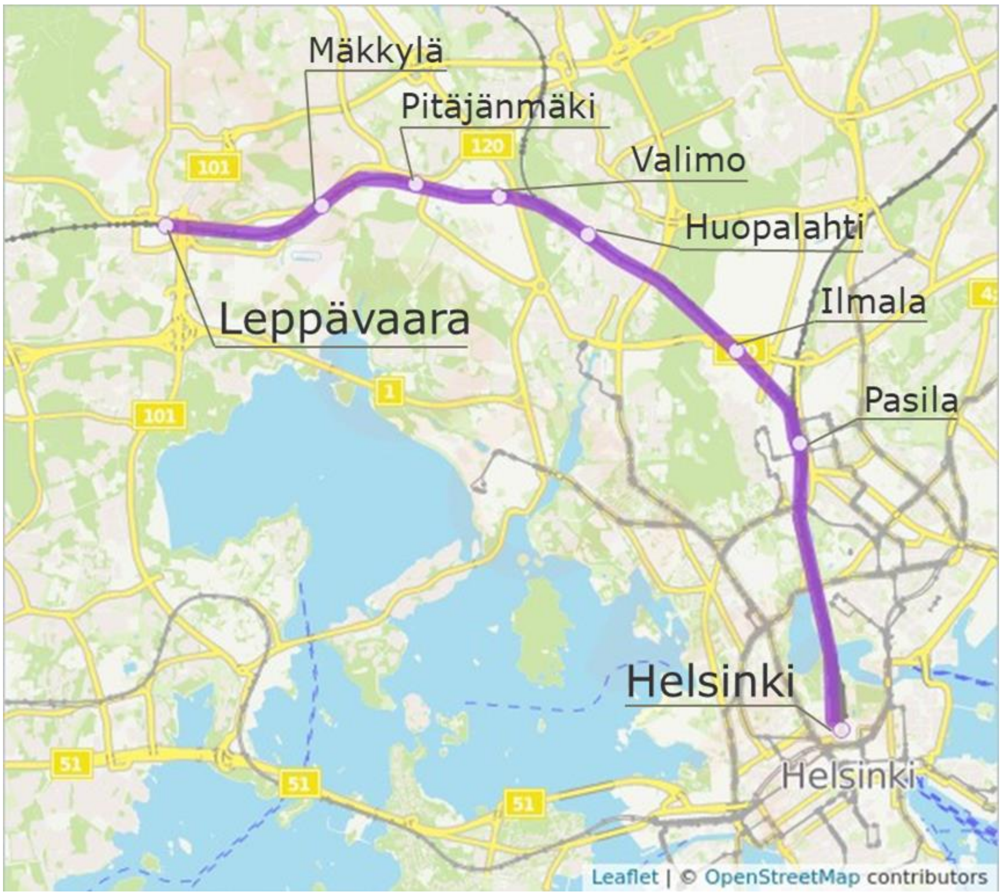

Figure 16 Helsinki–Leppävaara line map [32].

4.1.3 Helsinki railway yard

Helsinki railway yard is the most important hub for the Finnish rail network. The majority of the passenger trains goes via Helsinki and Pasila stations. Nowadays there are over 70 trains running during the peak hours. In the future capacity and disruption recovery will need to be enhanced, to make sure that the stations can meet the growing capacity needs. The traffic in Helsinki and Pasila affects to the whole train traffic in Finland. The development of Helsinki-Pasila has been considered in many studies. Currently an additional track is being built to Pasila. In the same platform level there is no more room for other tracks or platforms in Pasila. There is also a project called HELRA on-going, which aims to improve the functionality and increase the disruption recovery means of the Helsinki railway yard. The additional track and the actions to be undertaken in HELRA project will enable traffic for 90 trains per hour.

There are 19 platform tracks on Helsinki main station. The commuter trains are on the outermost platforms. The trains to Kerava and Ring Rail Track to the counter-clockwise direction departure mainly on tracks 1-3, and the trains to Leppävaara and Ring Rail Track to the clockwise direction departure mainly from the tracks 16-19. The Main line and Direct rail line (Oikorata) long distance and commuter trains are mainly on tracks 4-10. The tracks 11-15 are used by Coastal Railway. However, there is some flexibility on these principles.

There are eight line tracks between Helsinki and Pasila. The four tracks on the east side are used by main track and the four tracks on the west side are used by Coastal Railway. In the middle there are two service tracks to Ilmala. In this study only the tracks being used by city trains are being analysed, meaning two easternmost tracks and two westernmost tracks.

4.2 Preconditions, assumptions and exclusions

4.2.1 Infrastructure

All scenarios and systems are assumed to use today's speed profile that can be seen in figure 17 and 18. Controlled repeater balises are modelled according to FTIA's Rail Data Extranet [35]. No infill, which could improve the performance and the capacity, has been used for ERTMS/ETCS Level 1 analysis. For release points, only relevant ones for switch release have been modelled (first signal in opposite direction). [36]

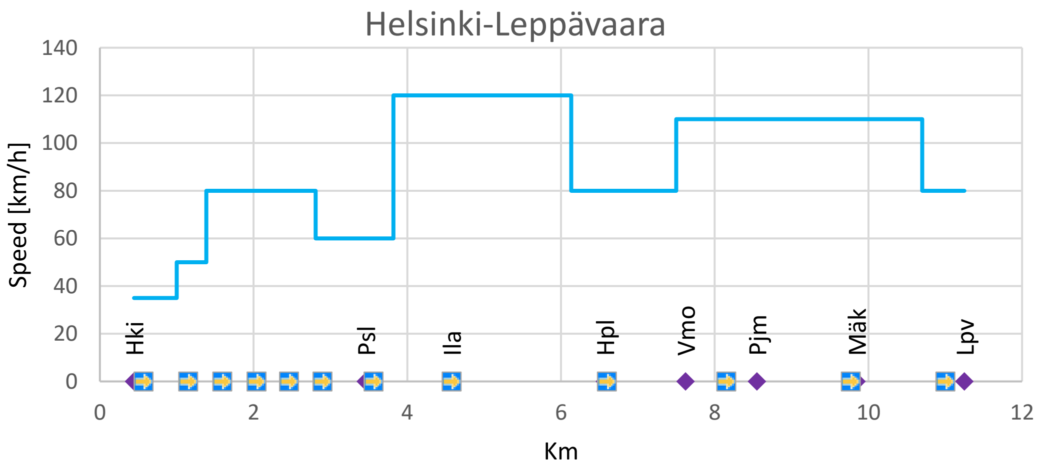

Figure 17 Speed profiles for Helsinki–Leppävaara with existing signal/ marker board positions.

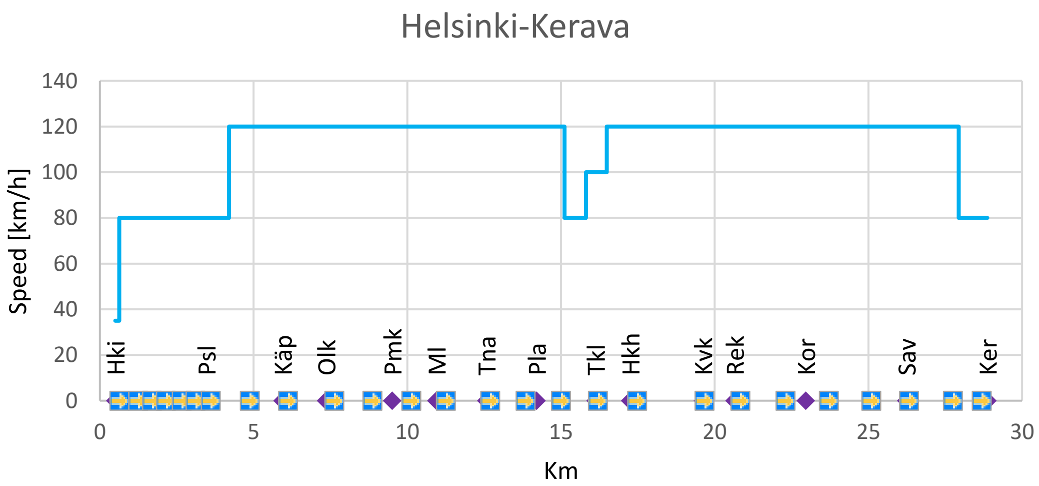

Figure 18 Speed profiles for Helsinki–Kerava with existing signal/marker board positions.

Main signal positions are modelled as in the existing situation for the analyses of JKV, ERTMS/ETCS levels 1 and 2. The signal positions have been retrieved from the FTIA's Rail Data Extranet [35]. For level 2 an additional analysis with improved block sections has been made using additional block sections as described in section 4.3.3.

4.2.2 System delays

System delays generally vary depending on the local setup (design, equipment and supplier) but can also vary over time. For this study, the system delay times stated in table 5 are used. For ERTMS/ETCS, the system delays are based on the response times estimated by UIC [1] (see section 3.5), while the response time by JKV and route set and release times is based on expert assessment.

Table 5 System delay times for the study.

	JKV	Level 1	Level 2
Response times	0 seconds	1.70 seconds	3.65 seconds
Route set time	9 seconds (without switches)		
Extra time for switches[*]	+ 5 seconds		
Route release time	3 seconds		

[*] *In the model, the extra route setting time for switches is included regardless if the switch is changing position*

It should be noted, that there are uncertainties in the system delays, and they will vary depending on location and time.

4.2.3 Rolling stock

The study has been made using Sm5 train, since it is the only train in service on the city line tracks currently. It is also expected that if new rolling stock would be bought in the near future, it would be very similar with Sm5 train type. The length of Sm5 train unit is 75 202 mm, weight in working order 131.6 t, total laden weight 174 t, axle load 13.2 t and maximum speed 160 km/h. [37]

For train driver deceleration towards open Movement Authority a value of 0.6 m/s^2 has been used. The value of 1.2 m/s^2. has been used for starting acceleration. For the running time estimations timetable supplements recommended by UIC [53] have been included.

4.2.4 Braking Curves

As described in Section 3.4.2 , there are two ways to calculate braking curves – Lambda and Gamma. The values to calculate the most accurate Gamma braking curves for Sm5 were not available. The less accurate Lambda method was therefore used to calculate the braking curves using a 158% brake weight percentage for the emergency brake and 135% for the service brake (Lambda model limitation).

For calculation of ERTMS/ETCS, service brake interface was used and the Permitted (P) braking curve. For braking curve calculation ERA calculation tool was used and Finnish national values were applied in the tool, based on the publication "*Suomen kansalliset ERTMS/ETCS-parametrit*" [28].

For JKV, the values presented in Table 6 were used for Sm5 trains in the analysis.

Table 6 JKV parameters for Sm5.

JKV Parameter	Value
Brake weight percentage	158 %
Safety factor	1
System delay	1 s
Acceleration delay	5 s
Braking time	3 s
Braking curve	B- curve

4.2.5 Human Factors

Human factors are not considered in the study. Migrating to the ERTMS/ETCS environment will impact train drivers and train operation, which may change the way they operate the system, affecting the capacity. [38]

4.2.6 Dwell times

Dwell times vary depending on the station, line and time of the day. In this analysis, a dwell time of 30 seconds is used for all stops between Helsinki and Kerava & Leppävaara respectively.

4.2.7 Technical turnaround times in ERTMS/ETCS

Technical times (without coupling times, brake tests and walking times) for ERTMS/ETCS, based on Danish empirical values, are stated in Table 7.

Table 7 Approximate technical times in ETCS level 1 and 2 when trains turn around for train units with automatic couplers.

Parameter	Emperical value
End of Mission (EoM)	5 seconds
Start of Mission (SoM)	
- Turnaround without coupling/decoupling	90-130 seconds
- Turnaround with coupling	100-140 seconds
- Turnaround with decoupling	90-130 seconds (for first train)
- New engine driver	+ 10 seconds
- Unknown position	+ 90 seconds

It is assumed the technical times in Table 7 are similar to JKV or only slightly higher. On condition that the on-board ERTMS/ETCS unit remember the train's position, it is thus presumed that today's minimum layover times can be kept. In case the buffer time (as part of the layover time) is changed, it can affect the punctuality. However, an assessment of the punctuality is not part of this study.

4.3 Method

4.3.1 Blocking time method

Train headways are calculated using the so-called blocking time method. The same method is used for example by OpenTrack simulation software. The blocking time method is based on calculation of the time that a train reserves a single train path and the train path is blocked from other train traffic. Blocking time consists of following time intervals for each block in a train path (see Figure 19):

- Route set time (interlocking, switch and possible communication)
- Time spent by driver for monitoring a signal
- Time spent by train approaching a signal (time it takes to cover the required braking distance)
- Running time between signals (time in block section)
- Block clearing time
- Signal clearing time (route release time)

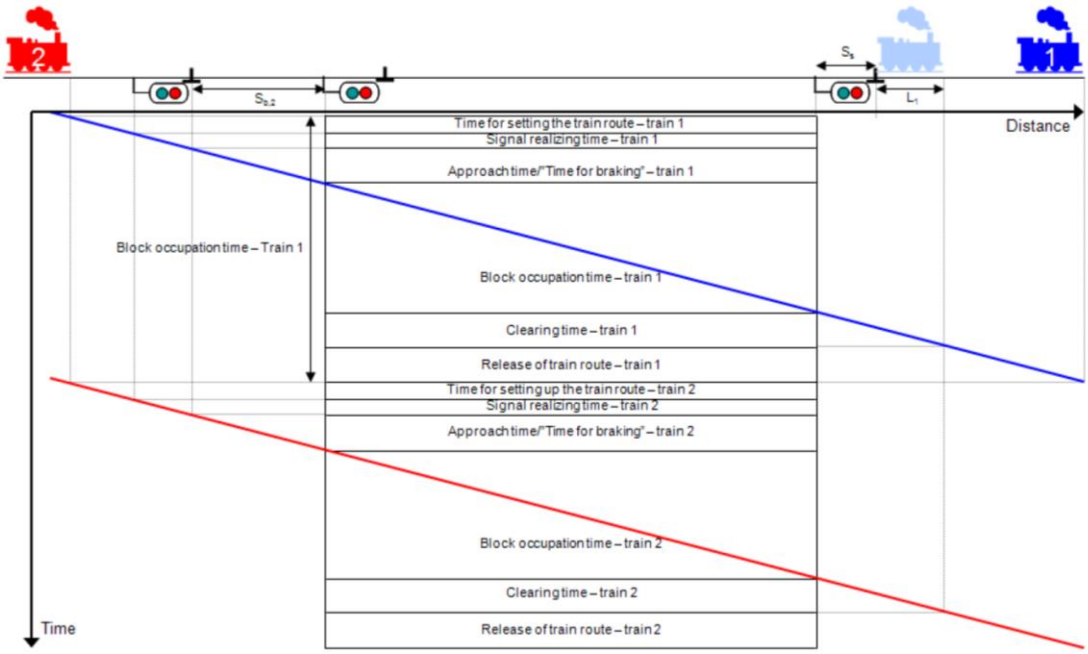

Figure 19 Defining of train headway and blocking time of train path [48]

Calculation of block occupation time takes also into account the acceleration and deceleration of trains as well as dwell time at stations in the block running time.

In ERTMS/ETCS level 1, train headways are defined by the same method as in traditional train control systems, so based on visible signals. ERTMS/ETCS level 2 systems do not necessarily have visible signals and the braking curves are updated continuously which may allow shorter headways than level 1. Response times of radio block centres and other data transfer delays are added to the blocking time (route set time).

4.3.2 Model

Ramboll has developed a model that uses the blocking time method described in Section 4.3.1 to calculate minimum headways between trains based on:

- Signal positions
- Switches and release points
- Speed profile of the line
- Rolling stock charecteristics
- Signalling dependent braking curves (ERTMS/ETCS or JKV)
- Route set and release times as well as communication delays

The minimum headway forms the basis for the capacity estimation. The line headway between trains is derived as described by Pachl [54]. To estimate the time spent by a train in each block, we use the running time estimation model described by Jensen [55]. This model takes acceleration, braking and the speed profile into account based on the rolling stock characteristics. ERTMS/ETCS braking curves are calculated using ERA's braking curve tools and fed into the model. JKV braking curves are likewise precalculated and fed into the model.

4.3.3 Improved Block Section layout

Two marker boards (or main signals for conventional signalling) demarcate a block section. There can be only one train at the time in a block section to ensure safety on the railways. In the UIC study [1], it is stated that improved block sections lead to significant higher capacity.

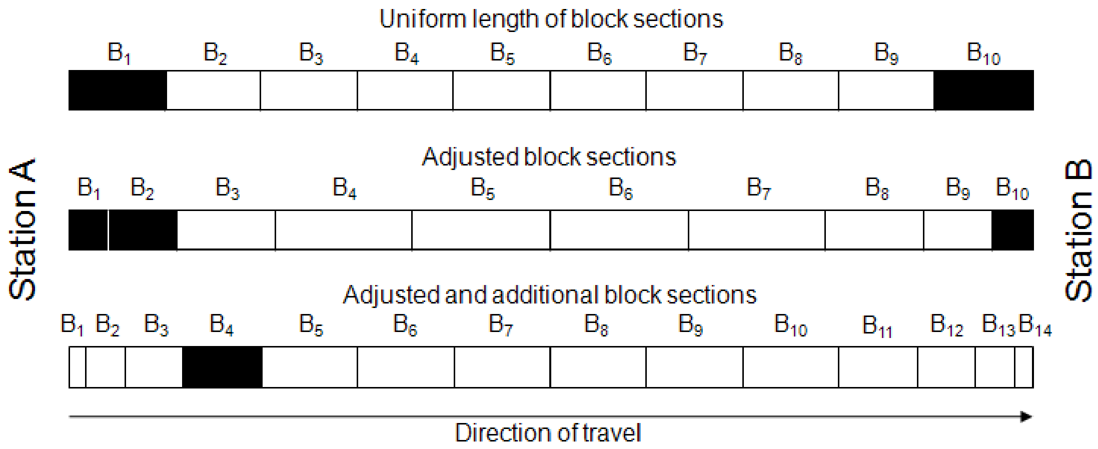

Figure 20 Critical block sections marked black for trains travelling from station A to B with stop at both stations [49]

The length of the block sections on a line can be determined by the fastest trains with longest stopping distances. This prevents trains with shorter stopping distances to travel closer together. If the block sections are optimised for the trains with shorter stopping distances to improve the capacity on the line, reduced speed is required for the trains with longer stopping distances for safety reasons. By improving the block section layout to fit better with train types, braking curves, infrastructure and schedule on the line, more capacity can be gained. [41]

Besides improving the block sections as shown in Figure 20, the impact of critical block sections at the stations can be reduced by shorter dwell times or by improved acceleration and braking capabilities of future trains. Both ways, the block section at the stations will be occupied for shorter time and hence be less critical.

ETCS has the possibility to look more block sections ahead than the conventional Finnish signalling system. Furthermore, ETCS braking curves are different to the current JKV braking curves. It gives the possibility to increase capacity by improving the length of the block sections and adding more block sections. Improvement of the block sections (from the current conventional signalling layout) has been carried out for the case study in the following steps:

1. Locate marker boards at existing signals
2. Add extra block sections between stations
    a. Generally, at least 300-meter long block sections
    b. Shorter block sections if larger improvement expected
3. Add extra block sections on selected stations respecting location of switches

This method uses the current location of conventional signals as the starting point. Replacing the entire signalling system, there is potential for further improvement of the capacity if marker boards can be located freely. On the other hand, longer block sections may be preferred to reduce cost. Furthermore, changes in national values and braking curve parameters is expected before the ERTMS/ETCS is implemented on the city lines round Helsinki. The improved capacity based on the improved block sections is hence only indicative.

4.3.4 Evaluation

The JKV, the ERTMS/ETCS levels 1 and 2 and the ERTM/ETCS level 2 with improved block sections are compared and evaluated based on headways and capacity consumption calculated using the blocking time model.

The calculated headways are evaluated and compared as both minimum line headways and headways between crossing movements at the terminal stations (Helsinki, Kerava, Leppävaara). The minimum line headway times express the ability of the signalling system to carry as many trains as possible following each other. While the minimum headway times between crossing movements express the signalling system and the position of switches to allow a certain amount of trains entering and leaving the terminal stations.

Given the headways calculated and a given order of train, the capacity consumption is calculated for different operational frequencies. Trains alternate between a train going to the airport and to Kerava or Leppävaara. The minimum frequency tested is 3.75 minutes on the common sections Helsinki–Hiekkaharju or Helsinki–Huopalahti yielding a 7.5 frequency to the airport and Kerava or Leppävaara respectively.

4.4 Analysis part 1 – Verifying parameters for the analysis

4.4.1 ERTMS/ETCS and JKV braking curves

Based on the assumptions described in Sections 4.2.3 and 4.2.4 , the braking curves of ETCS and JKV have been calculated for Sm5 (see 21 and Figure 22).

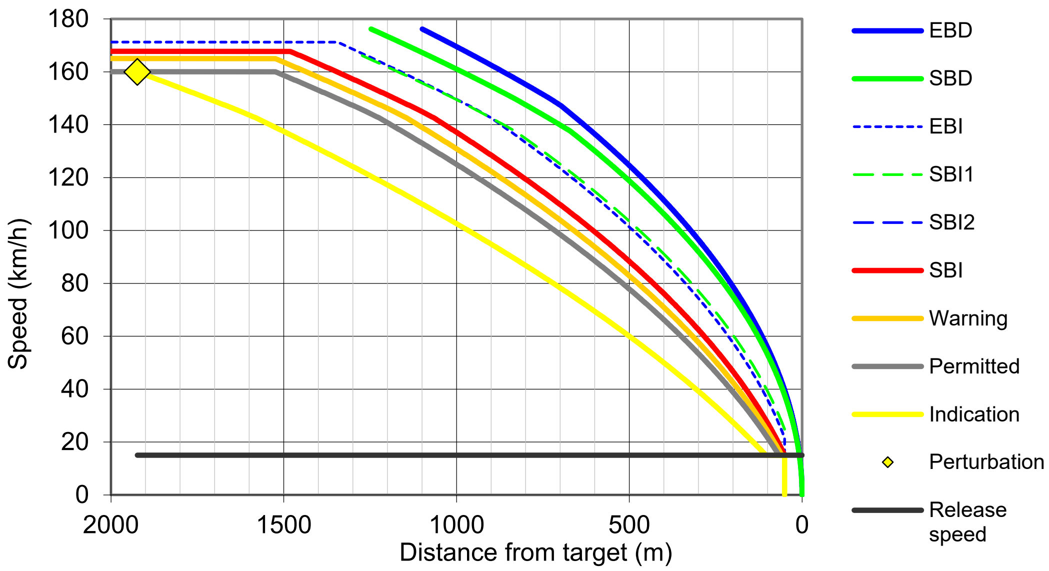

Figure 21 ETCS braking curves for Sm5.

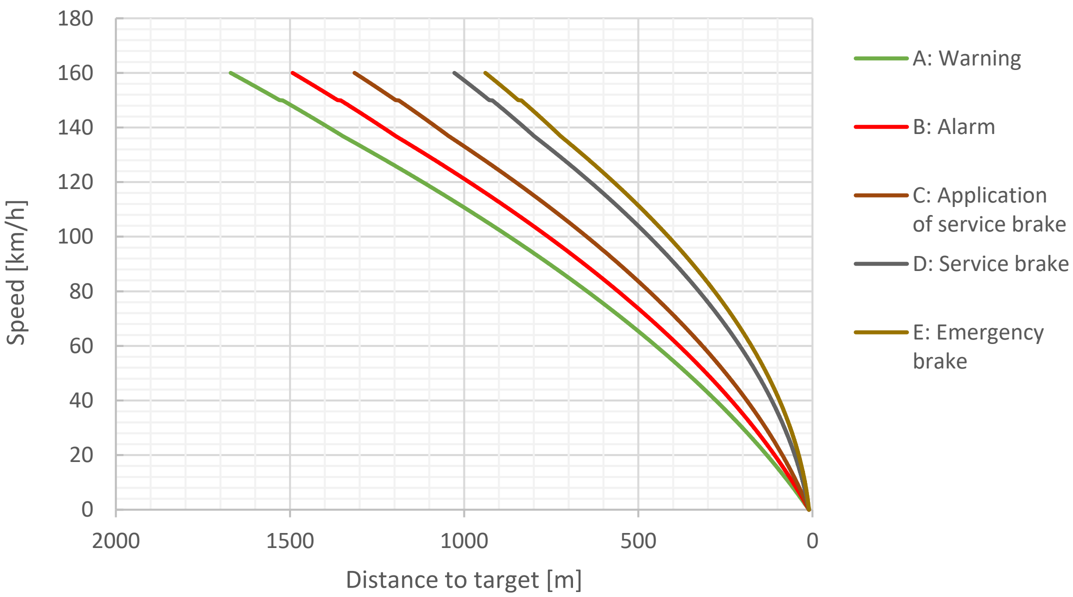

Figure 22 JKV braking curves for Sm5.

Figure 23 shows a comparison of the ERTMS/ETCS and JKV braking curves used for the capacity analyses. As the Figure shows the ERTMS/ETCS curve is longer than the JKV curve when braking from the maximum speed of the Sm5. From approximately 150 km/h, the JKV curve is marginally longer than the ERTMS/ETCS curve. As the maximum speed on the city tracks is 120 km/h to Kerava and Leppävaara, the JKV curve is always longer than the ERTMS/ETCS curve in relation to the case studies carried out in this report.

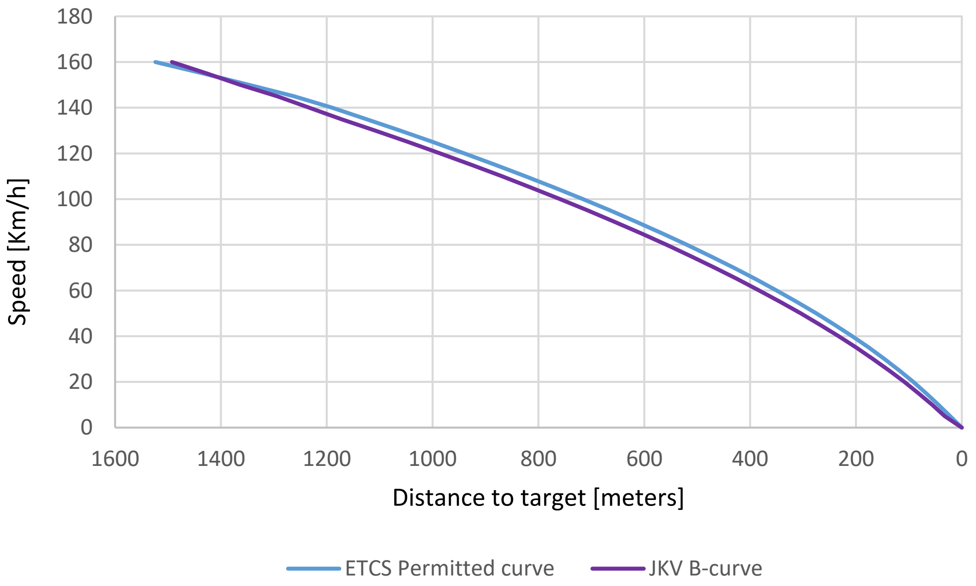

Figure 23 Comparison of ERTMS/ETCS and JKV braking curves for Sm5 used for the capacity analyses.

4.4.2 Release speed

The Finnish national values for ERTMS/ETCS operates with a release speed of 15 km/h [29] which is lower than the default values of 40 km/h [29]. A lower release speed results longer braking time and hence reduced capacity, see Figure 24.

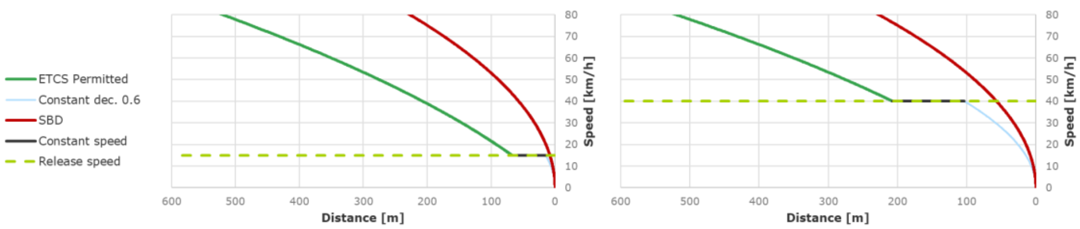

Figure 24 Difference between release speeds (left: 15 km/h and right: 40 km/h).

With release speed of 15 km/h time to brake from 80 km/h to 0 km/h takes 58 seconds, whereas with 40 km/h release speed it takes 47 seconds. With Sm5 trains with the characteristics described in Section 4.2.3 , the braking time can be reduced by 11 seconds if the release speed is increased from 15 to 40 km/h.

The total braking distance remain the same, but the required time to cover braking distance changes at is possible to initiate harder braking sooner. For the following case studies, a release speed of 15 km/h (similar to the Finnish national values for ERTMS/ETCS [29]) is used.

4.4.3 Arrive on red/green – effect on headway and running times

In ERTMS/ETCS, trains can either arrive at stations on "green" meaning the Movement Authority (MA) goes past the station or on "red" meaning the MA ends at the end of the block section where the train stops. When the trains arrive on "green", trains generally arrive faster at stations as the train driver can brake harder than the ERTMS/ETCS P-braking-curve. While trains arriving on "red" will have to reserve the station block section for longer time – including the dwell time at the station, see table 8 and Figure 25.

Table 8 Comparison of movement authority, approach time and braking when arrive on red or arrive on green is used.

	Arrive on red	Arrive on green
Movement authority	Ends at end of block section where trains stop	Can continue further than the station
Braking	Generally follows the P-curve	Driver can brake freely (when movement authority is longer)
Reservation of station block	"Long" as braking takes longer time	"Short" as driver can brake freely
Approach time for following block section	"Short" as block can be reserved later	"Long" as the block is reserved sooner (and will include dwell time)

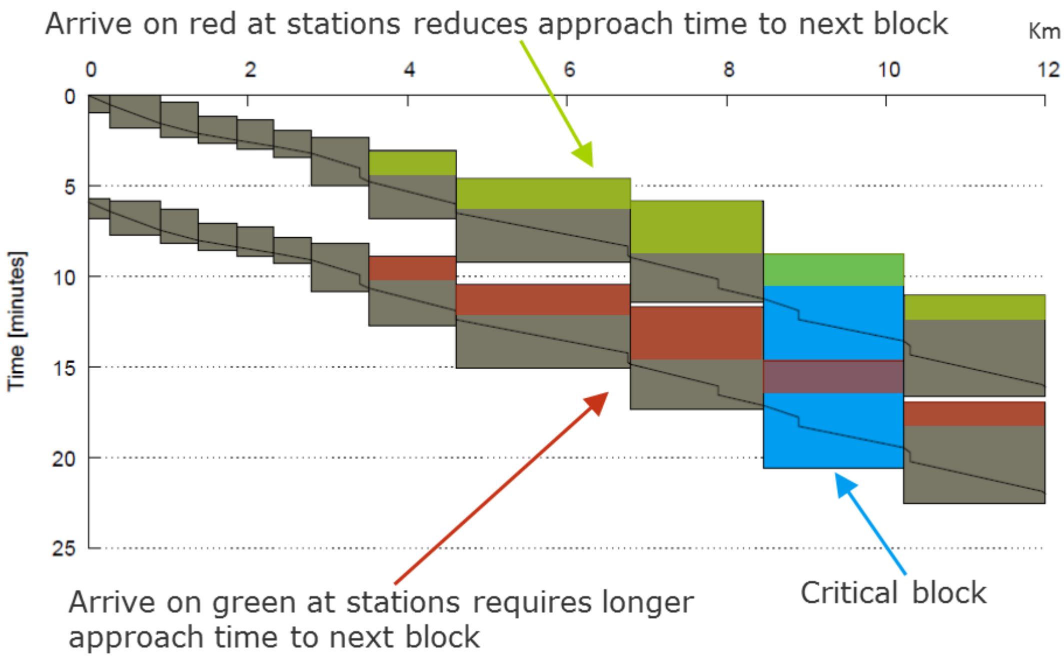

Figure 25 Difference arriving with continuous movement authority (green) or movement authority ending at the end of the block section (red).

Generally, the extended approach time arriving on “green” is longer than the extended arrival time to the station following the P-curve when arriving on “red”. Therefore, arrival on “red” where the MA ends at the end of the block section where the train stops, generally has the highest possible capacity (shortest headway times). Additionally, the P-curve may only restrict the braking towards a stop if the marker board is sufficiently close when the train is arriving on “red”. As an example, braking is only restricted for three out of 14 stops between Helsinki and Kerava with arrive on “red” and a release speed of 35 km/h (see Figure 26). Note that a lower release speed, e.g. 15 km/h, will result in more restrictions. The difference in capacity thus depends on the exact location of marker boards, release speed as well as train types, speed profile and gradients round the stops.

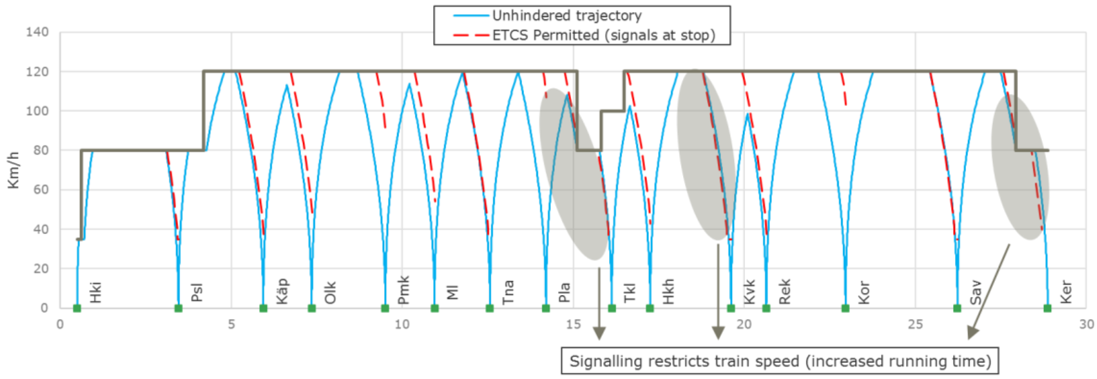

Figure 26 Signalling restricts (braking curves) braking increasing running times towards a stop.

For the following analyses, arrival on ”red” where the MA ends at the end of the block section where the train stops, is therefore used as it generally results in the highest potential capacity.

4.5 Analysis part 2 Case studies – minimum headways and capacity consumption

4.5.1 Minimum headway

Minimum headway times have been calculated for the following scenarios for the city lines between Helsinki and Kerava or Leppävaara:

- As-is with JKV
- ERTMS/ETCS level 1 with existing block sections
- ERTMS/ETCS level 2 with existing block sections
- ERTMS/ETCS level 2 with shorter and improved block sections

For JKV, the calculation of minimum headway times has been based on the JKV B-braking-curve while the other scenarios are based on the ERTMS/ETCS P-braking-curve. As described in Section 4.3.4 for each scenario, blocking stairs and minimum headway times have been calculated for all combinations of train courses on the two lines. E.g. trains between Helsinki and Kerava and trains between Helsinki and the airport as well as to and from different tracks at Helsinki, Kerava, and Leppävaara. Figure 27 shows the combination of a train from Helsinki to Kerava and Helsinki to the Airport via Hiekkaharju. Detailed headways are listed in Appendix 3.

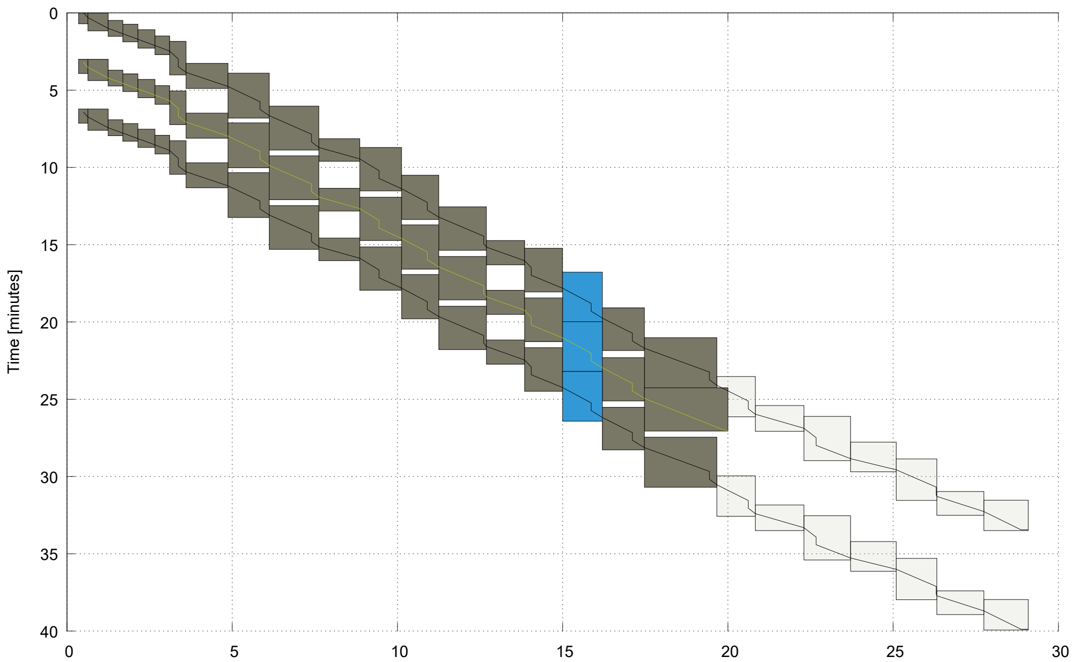

Figure 27 *Blocking stairs for a train to Kerava followed by a train to the airport and then another train to Kerava in Level 2 with existing block sections.*

Without changing the block sections, it is (in Figure 28 and Appendix 3) seen that the line headway times for ERTMS/ETCS generally is slightly longer than JKV due to more system delays in ERTMS/ETCS. In some cases, ERTMS/ETCS is a bit better than JKV as the JKV braking curve is slight longer than the ERTMS/ETCS curve. Furthermore, arrival on "red" where the MA ends at the end of the block section where the train stops for both JKV and ERTMS/ETCS generally result in improved capacity compared to arrival on "green" meaning the Movement Authority (MA) goes past the station. However, at this is also done with JKV, there are no additional benefits when comparing JKV and ERTMS/ETCS.

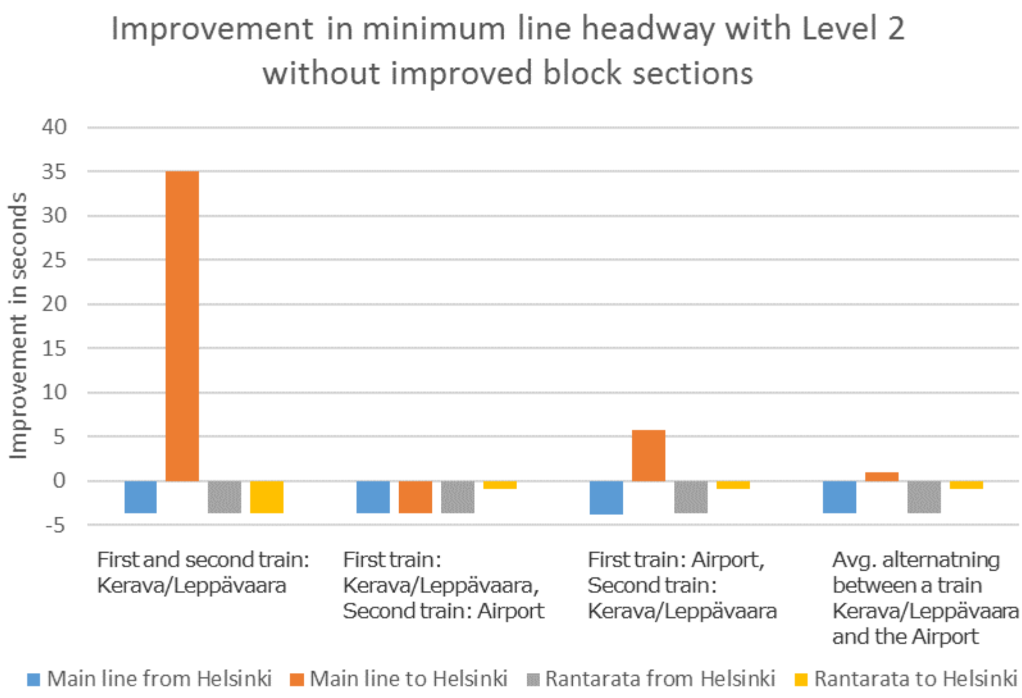

Figure 28 Improvement in minimum line headway time for level 2 (without improved block sections) compared to JKV.

Following the P-curve towards the stop at the station has the effect that level 1 lose less capacity than level 2 due the shorter system delays in the optimal situations in the model. However, in real-life operation, the difference is so small it will not be noticeable. Level 2 may even perform better in case the train in front is delayed as the driver has continuous update of the train's movement authority.

For the lines between Helsinki and Kerava or Leppävaara respectively, it is in Figure 30 seen that the ERTMS/ETCS levels 1 and 2 with the same block sections generally have round the same capacity (little loss) compared to JKV. Adding more block sections in ERTMS/ETCS Level 2 results in significant capacity gain as seen in Figure 29 and Figure 30. The short block lengths used in ERTMS/ETCS level 2 would not be fully achievable with the JKV system due to signal visibility requirements and as the block sections need to be coordinated with the braking distance of the trains.

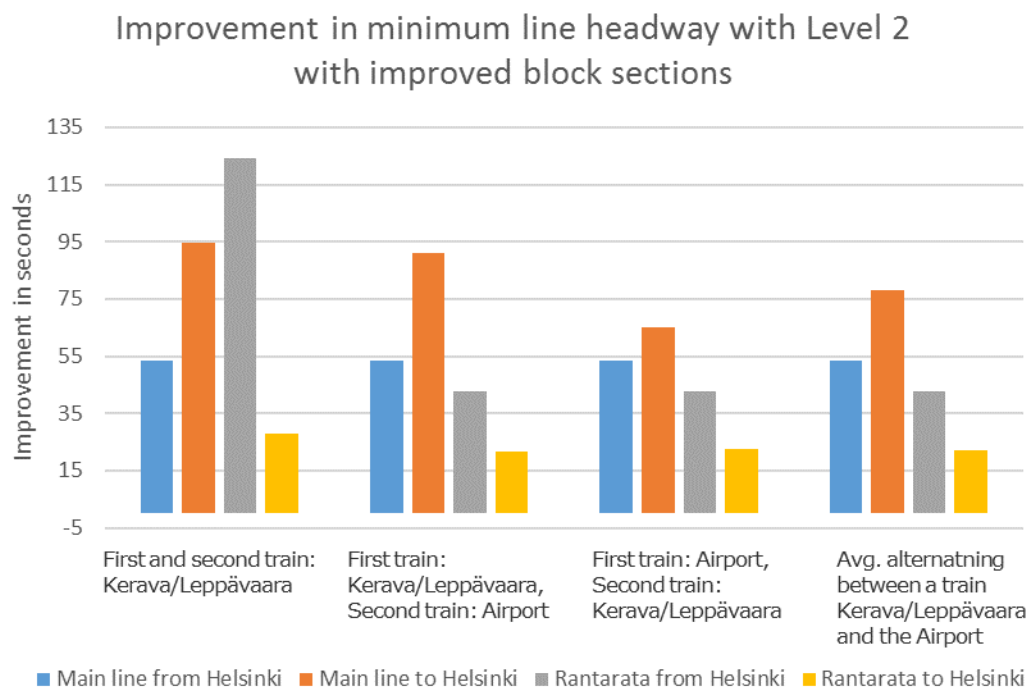

Figure 29 Improvement in minimum line headway time for level 2 with improved block sections compared to JKV.

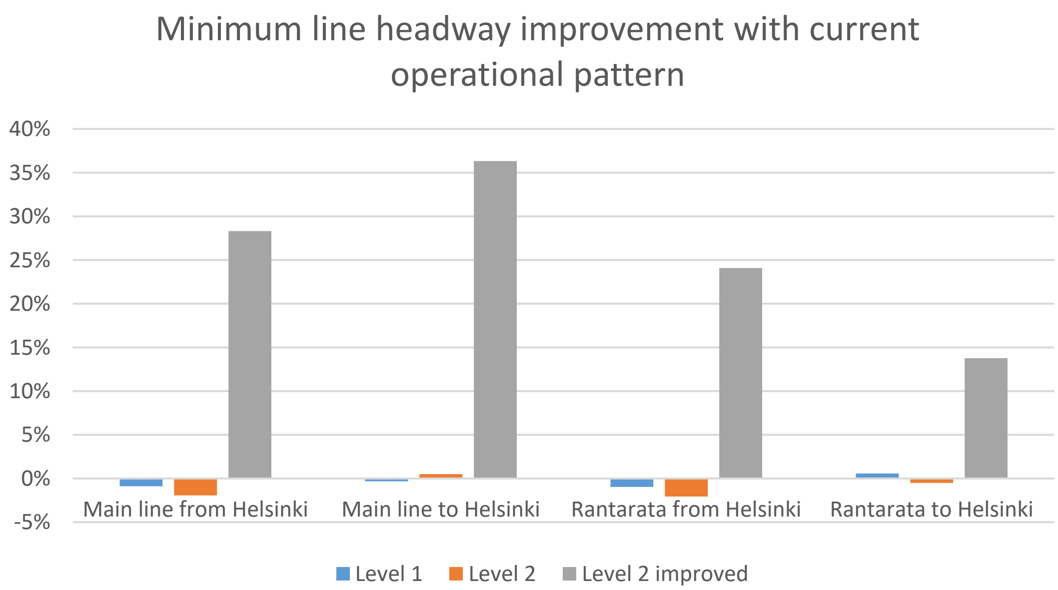

Figure 30 Minimum line headway improvement in percent compared to JKV.

4.5.2 Capacity consumption

The ERTMS/ETCS Level 2 allows for more block sections than the JKV, even if the JKV signalling layout is improved as well. Using the extra improved block sections results in a significant capacity gain allow operating more trains. The base 5-minute service within the common lines Helsinki–Huopalahti and Helsinki–Hiekkaharju (equal to 10-minute service on each line) has the following capacity consumption (Table 9):

Table 9 Capacity consumption for the base 5-minute service within the common lines between Helsinki and Huopalahti or Hiekkaharju.

	JKV	Level 2
Helsinki–Kerava, Existing block sections	67%	65%
Helsinki–Kerava, Improved block sections	–	50%
Helsinki–Leppävaara, Existing block sections	70%	68%
Helsinki–Leppävaara, Improved block sections	–	61%

The reduced capacity consumption for level 2 with improved block sections open up for increasing the frequency of the services. Figure 31 shows the capacity consumption for the two services with different capacity. Here the Helsinki–Kerava service can operate with 3.75-minute planned headways all hours between Helsinki and Hiekkaharju (7.5-minute service on the entire line Helsinki–Kerava) as the capacity consumption is below 70% which is UIC's recommendation for the capacity limit in off-peak hours [50]. The Helsinki–Leppävaara service can operate with 3.75-minute headways during peak hours between Helsinki and Huopalahti (7.5-minute service on the entire line Helsinki–Leppävaara) as the capacity consumption is above 70% but below 85% which is UIC's recommendation for the capacity limit in peak hours [50]. For all-day service, the section between Helsinki and Huopalahti should not exceed 5-minute frequency.

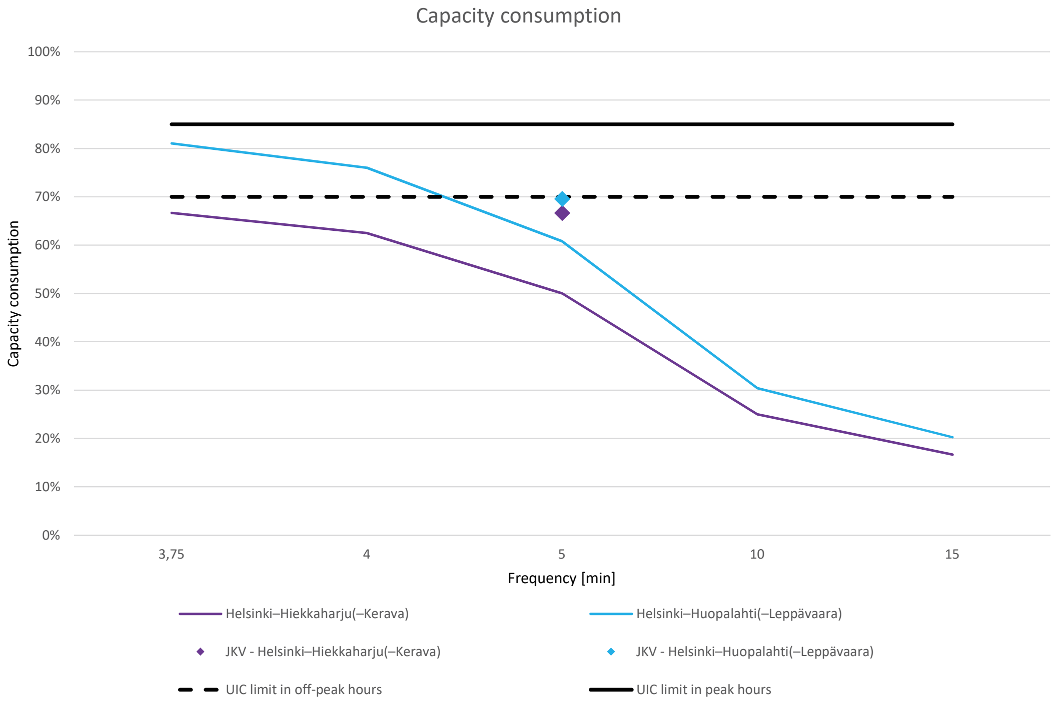

Figure 31 *Capacity consumption for the common section between Helsinki–Huopalahti and Helsinki–Hiekkaharju with ERTMS/ETCS level 2 and improved block sections. Capacity consumption numbers for JKV at 5 minutes frequency for reference.*

During the peak hours, the following headway times can be achieved in both directions when the UIC recommendation of 85% is used [50]:

- Helsinki–Hiekkaharju(–Kerava): 176 seconds (equal to 2.9 minutes)
- Helsinki–Huopalahti(–Leppävaara): 215 seconds (equal to 3.6 minutes)

The capacity limiting bottleneck is Helsinki due to conflicting movement of trains in the two directions and longer dwell times due to the trains turning around. This is also a problem in Kerava and Leppävaara, however as half of the trains go the airport, Helsinki is the main bottleneck. With a further improvement of marker board positions, partial release points and block sections at Helsinki the capacity is likely to increase even more, especially on the line to Leppävaara.

4.5.3 Bottlenecks limiting the operation

Figure 32 shows the main bottlenecks from the headway analyses for the existing blocks using either JKV, ERTMS/ETCS levels 1 or 2. The bottlenecks arise from two facts:

- Long block sections with one or more stops in each (e.g. Tikkurila, Hiekkaharju, Huopalahti, Mäkkylä)
- Long approach times (e.g. Oulunkylä, Savio)

Long block sections are an issue for all cases (JKV, ERTMS/ETCS levels 1 and 2). Long approach time is only an issue on JKV and ERTMS/ETCS level 1 as the continuous update reduces the approach times in ERTMS/ETCS Level 2. In addition to Oulunkylä and Savio, other blocks are also restrictive in some cases with JKV and ERTMS/ETCS level 1 due to long approach times (e.g. Pasila and Ilmala).

In general, there are less restricting block sections in ERTMS/ETCS level 2 due to the continuous update. This is expected to result in less delays although the critical block might be the same across the different signalling systems (resulting in the same minimum line headway) with the same block sections.

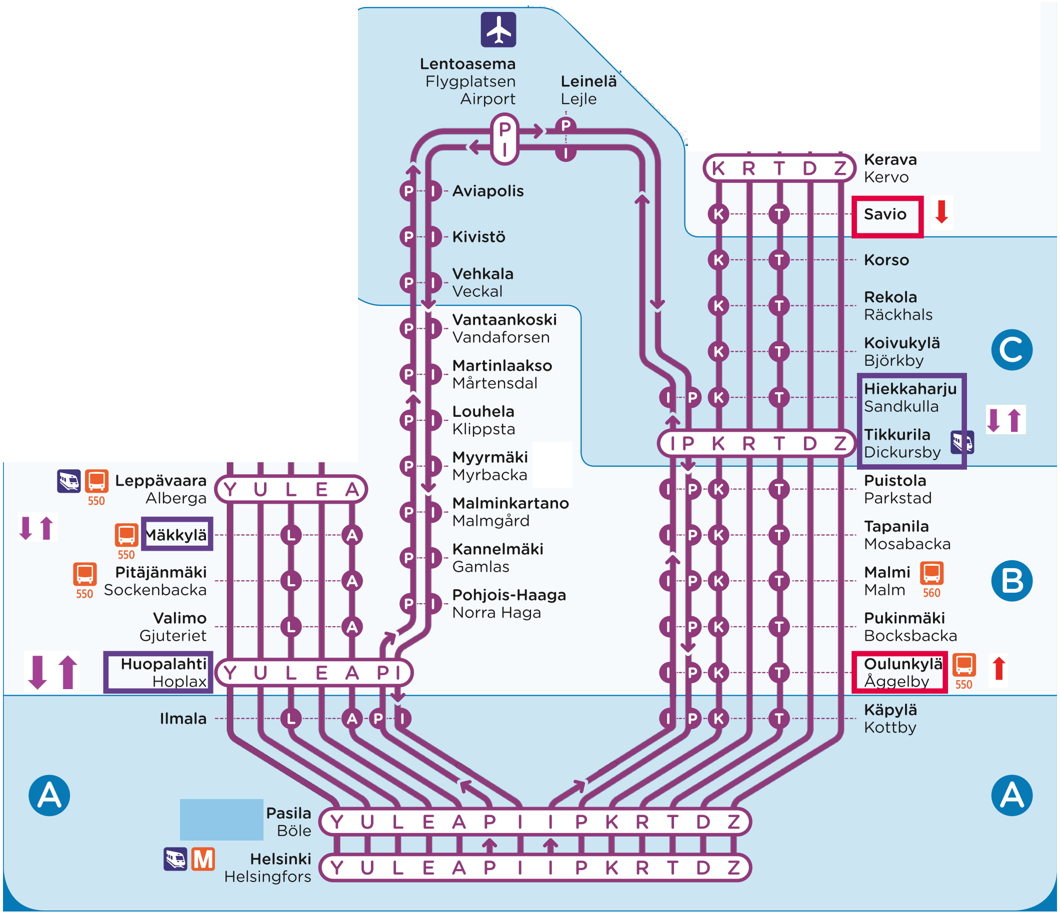

Figure 32 *Main bottlenecks in JKV, ERTMS/ETCS levels 1 and 2 (marked purple) with existing block sections. Bottlenecks only applicable for JKV and ERTMS/ETCS level 1 are marked as red.*

When the block sections are improved the bottlenecks are reduced to all block sections with stops in ERTMS/ETCS level 2. Thus, the dwell time is restricting the minimum line headway possible. This is shown in Figure 33 where two trains from Helsinki to Kerava follow each other. As seen in the Figure, all block sections with stops are restricting the minimum line headway, while the blocks in-between stops are non-restrictive acting as buffer.

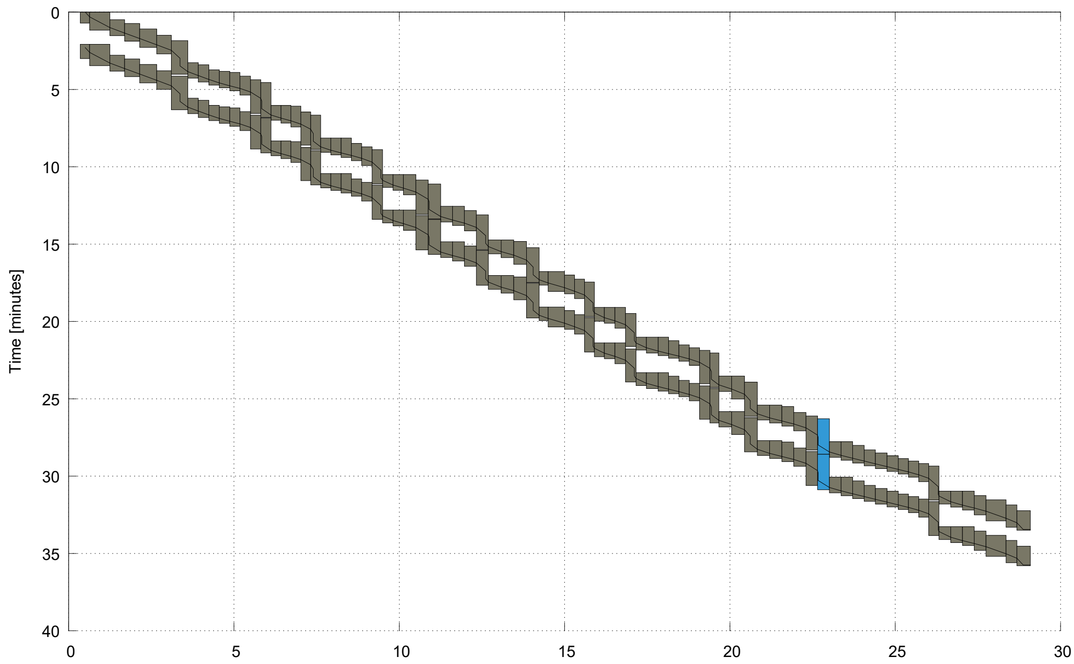

Figure 33 Blocking stairs of two trains Helsinki–Kerava for level 2 with improved block sections.

To improve the line headway further, even shorter block sections could be used and measures to speed-up passenger exchange can be carried out to reduce the dwell times. In addition to dwell times and blocks with stops being bottlenecks, Helsinki is also a bottleneck due to crossing movements between trains as mentioned in Section 4.5.2 Further improvement can be done here, e.g. additional marker boards and release points, to improve capacity even further.

5 Additional strategies to improve capacity

5.1 Factors impacting to the capacity

In addition to the train control systems, there are other factors which impact to the capacity. The most important factors being dwell times, radio or loop infill in ERTMS/ETCS level 1, block section design, automatic train operation and timetable planning are factors, which can improve the capacity of a railway traffic.

5.2 Timetable

In principle, timetable planning is allocating railway capacity for the trains and infrastructure maintenance. Timetable planning impacts on multiple factors on railway travel; punctuality, connections, regularity of the schedule, travel time and frequency. In addition, the objectives of timetable planning often conflict; e.g. punctuality might increase travel time. [45, 46]

Railway traffic is sensitive to disruptions due to the interdependencies between trains. One delayed train might delay other trains on the line and crossing lines. To gain some flexibility, buffer time is included in the timetable. Therefore, often this idle capacity cannot be used to operate more trains. [45, 47]

In the study *Railway Operation* by A. Landex, published in 2006 following is stated: "*A regular interval timetable, where all the trains are assigned a fixed departure interval, will often result in bad capacity utilization, as it is not possible to bundle trains with same driving behaviours*." In the figure 34 this situation is shown. If there is a lack of capacity on the line, it might be necessary to plan waiting time to the line to slow down fastest trains or add stops to their route to homogenize the operation. [46, 47]

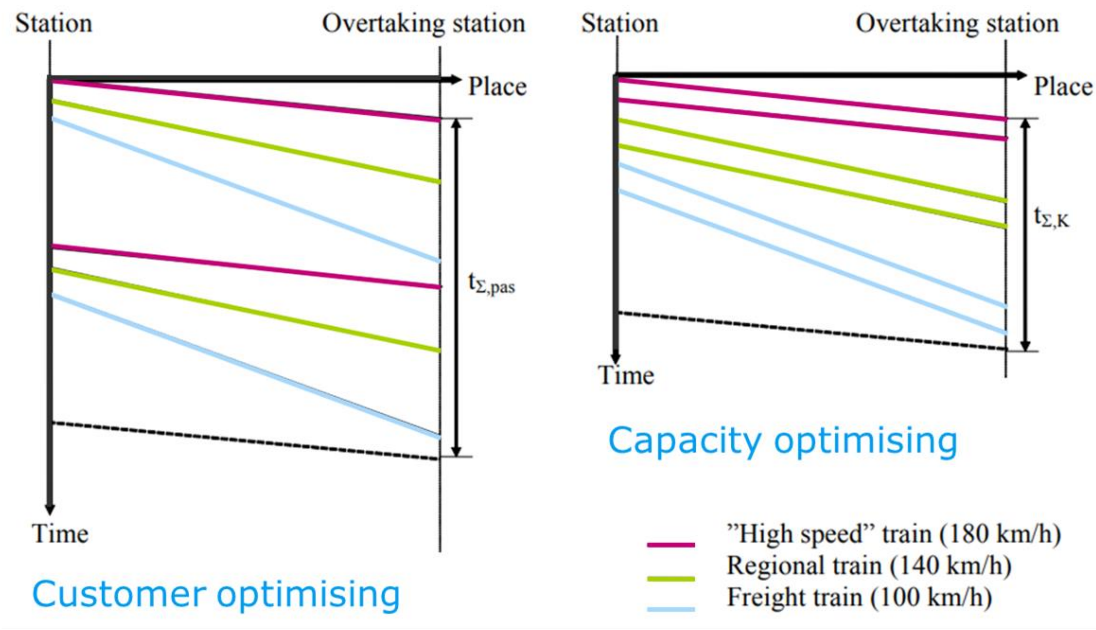

Figure 34 Customer and capacity optimisation of the timetable [modified from 46].

The right side of figure 34 shows that trains with similar speed driving after each other results in less consuming traffic operation, since $t_{\Sigma,pas} > t_{\Sigma,K}$. However, implementing this kind of schedule will lead to irregular departure interval, which might not align with the requirements of the clients. [46, 47]

5.3 Dwell times

Dwell time describes the time required for passengers to enter and leave the train. The factors affecting dwell times can be categorised to passenger volume, passenger profile, train design, station design and operational factors. If the dwell times are extended, it will lead to longer train and passenger journeys. [39]

Many factors affect the dwell time, e.g. door opening and closing time, departure procedures and the passenger interchanges (see figure 35). [40] However, the main factor affecting to the dwell time is generally the number of passengers coming out and getting in to the train. The more passengers are standing in the train the slower the alighting and boarding is. Passenger profile impacts the boarding and alighting as well; passengers with luggage or passengers requiring special assistance will in average take longer to get in and out of the train. Regular passengers are likely to alight faster than those who travel less regularly or are unfamiliar with the stations.

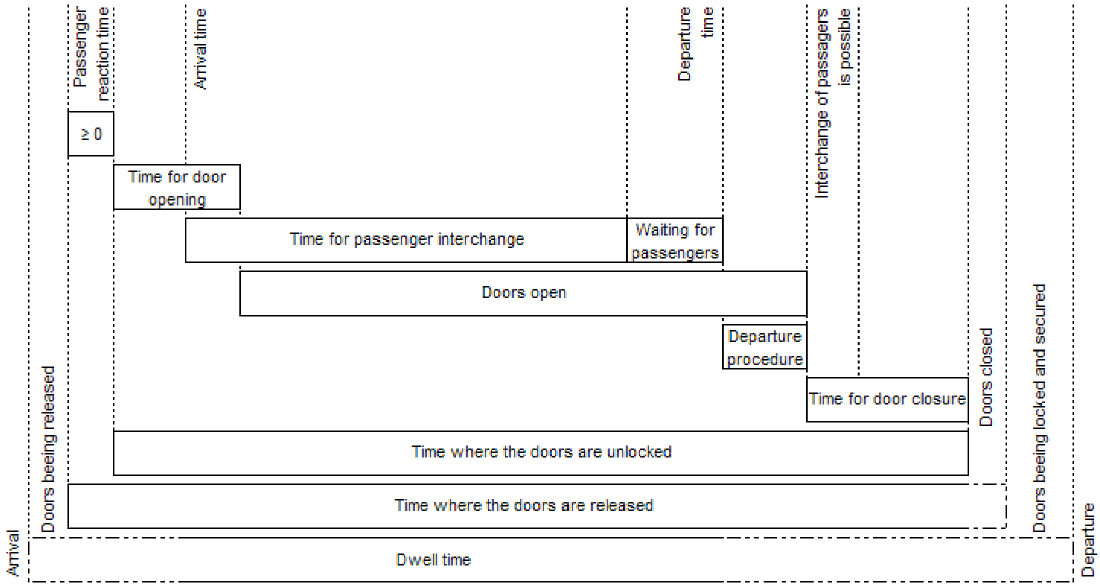

Figure 35 Time elements affecting the dwell time [40].

Dwell time is also affected by the train design. Passengers can board and alight faster when the doors are wider. However, too wide doors might transfer the congestion further into narrow sections in the train. Other factors impacting dwell time is the time required for acceleration and braking of the train, the gap between train and the platform and the number of steps required to get in and out of the train. [39] However, it should be noted that there are no steps in the Sm5 trains analysed in the case study.

Dwell times can be impacted also by ticketing system. If the ticketing machines are scattered along the wagon and platform instead of next to the doors, passengers can move forward on the isles and not form queues stamping the tickets near the door, obstructing other passengers to board. Similarly, a possibility to buy tickets beforehand will prevent queues and increased dwell time. The factors affecting to the capacity on the stations are the width of the platforms and number, capacity and location of stairs, escalators and lifts [39].

An operational factor impacting the dwell time is the timetable. The Dwell time increases if train arrives early, and if it is not allowed to departure before the scheduled time. Similar situations can occur with connecting trains, which need to wait for the passengers from another train to board. Irregular dwell times will lead to irregular headways. [39, 40]

5.4 Infill as a capacity increaser for ERTMS/ETCS level 1

In ERTMS/ETCS level 1 capacity can be improved by updating movement authority before the signal and marker board with infill. This will increase capacity and allow a smoother train ride. Infill can be implemented by infill balises, infill loops or radio.

When more balises are installed to the track, more discrete updates of Movement Authority will be gained. One way to get continuous update on Movement Authority is to install infill loops near signals or use GSM-R/radio communication. There is a limited number of suppliers producing infill loops, which might reduce the competition between suppliers.

In figure 36 the principle of capacity improvement with infill is presented. The potential capacity increase with infill, compared to Level 1 without infill, is 3.1 % according to the UIC study in 2008 (Figure 7) [1].

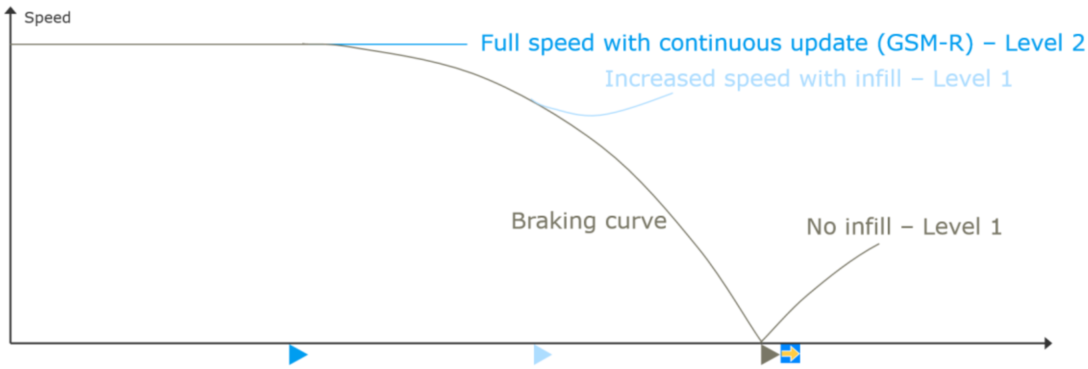

Figure 36 Principle of infill balises for ETCS Level 1 compared to ETCS Level 2.

To decide on infill in ERTMS/ETCS level 1, the capacity gain should be analysed. The largest capacity gains with infill are expected in the areas of the bottlenecks and on lines operated by trains with different braking performance. As part of the assessment, the system delay times for the different infill methods should be analysed and it should be mapped which solutions the different suppliers can provide.

5.5 Automatic Train Operation (ATO)

Automatic Train Operation can increase capacity on the railway. This is achieved by optimized driving which enables reduced headways. With ATO higher punctuality can be reached by using the line data and real-time information, but higher capacity on increased communications is required. [42]

Automatic Train Operation is divided into four grades of automation, as shown in table 10 and in figure 37. From GoA 0 to GoA 3 human involvement is required for driving, whereas GoA 4 is fully unattended. Only on GoA 3, where there is an attendant and no driver, infrastructure changes are required. [42, 44].

Table 10 Grades of Automation.

Grade of Automation	Train operation	ATP system	Starting	Driving & stopping	Door closure	Operation during disruption
GoA 0	Manual	No	Driver	Driver	Driver	Driver
GoA 1	Non-automated (NTO)	Yes	Driver	Driver	Driver	Driver
GoA 2	Semi-automatic (STO)	Yes	Driver/ Automatic	Automatic	Driver	Driver
GoA 3	Driverless (DTO)	Yes	Automatic	Automatic	Attendant/Automatic	Attendant
GoA 4	Unattended (UTO)	Yes	Automatic	Automatic	Automatic	Automatic

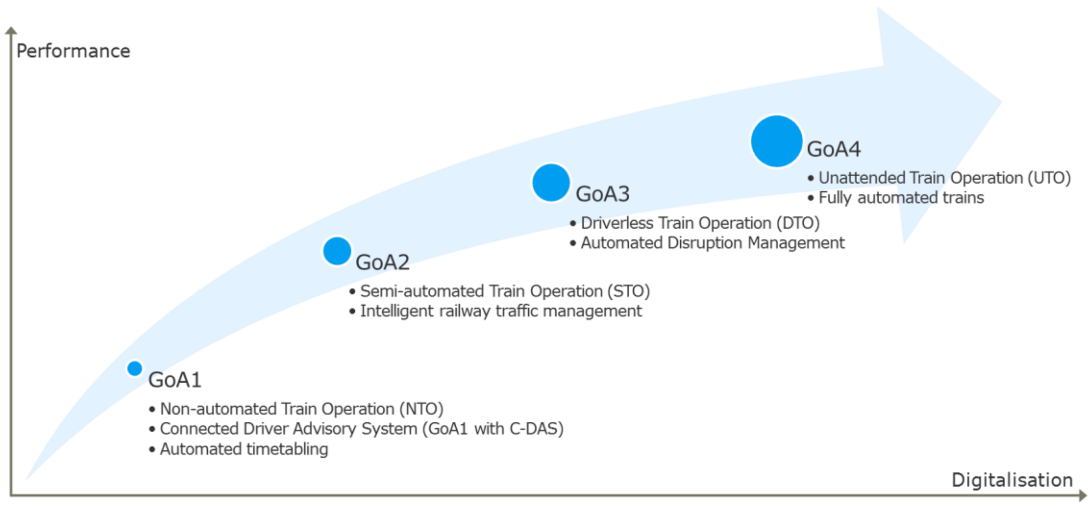

Figure 37 Performance and Digitalisation of ATO Grades.

There exists ERTMS/ETCS level 2 lines (e.g. Thameslink in London) that are running GoA 2. To reach level GoA 4, video and infrared cameras and sufficient image processing system will need to be linked to the braking system for emergency brake function. Remote control is also required to the video circuit, and evolved data transmission system. The possibilities of adding ATO on top of ERTMS/ETCS is presented in a conceptual level on figure 38. [43]

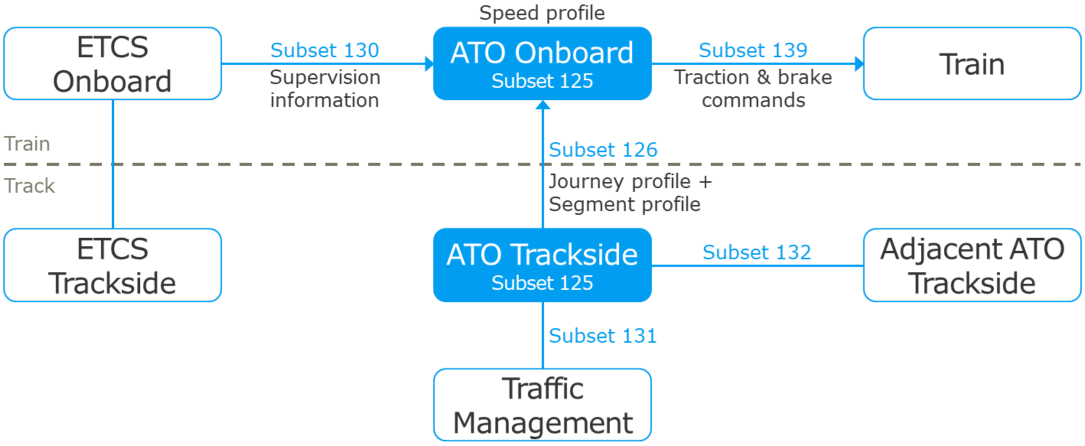

Figure 38 ERTMS/ETCS-ATO communications chart.

In metros unattended operation is already being used e.g. in Amsterdam, Copenhagen, Lausanne, Lille, Malaga and Milan. Generally, UTO is based on Communications Based Train Control technology (CBTC) but can also be used on other control systems. It has been stated that "moving block" technology will be introduced to CBTC in the future, increasing capacity even further. This technology is comparable with ETCS level 3 technology.

However, railway traffic is more complicated than metro traffic. There are often different types of rolling stock, timetables and stopping patterns. There are also several tracks in bigger stations and solving conflicts is not as straight forward than in an underground environment. [44] In Copenhagen, studies for GoA 4 are made for the suburban railway lines [e.g. 51]. For the Copenhagen suburban railway lines (that in many ways are similar to the city line system in Helsinki) four challenges are increasing the complexity of GoA 4 compared to more traditional metro systems:

1. The network structure is different from metro networks with more branches meeting towards the central part of the network.
2. The maximum speed of 120 km/h is higher than other metro systems.
3. Different train sizes that will result in need for automatic coupling and decoupling.
4. Operation above ground with increased impact from the weather (leaves, frost, snow etc) and risk that people cross the tracks.

6 Summary and conclusions

6.1 Summary

The ERTMS/ETCS comes in three levels 1, 2 and 3. Level 1 is the most similar to the current Finnish signalling and Automatic Train Protection (ATP) system with block sections and discrete update of the train's Movement Authority (MA). ERTMS/ETCS level 2 still has block sections but can result in more capacity due to continuous update of the train's Movement Authority (MA) while the future development system, the not yet commercially available level 3 operates with moving blocks and hence can result in even more capacity. This work has analysed the capacity differences between the conventional Finnish signalling and Automatic Train Protection (ATP) system and ERTMS / ETCS level 1 and 2 by analysing the following scenarios:

- As-is with JKV
- ETCS level 1 with existing block sections
- ETCS level 2 with existing block sections
- ETCS level 2 with shorter or improved block sections

The capacity analyses performed in this study are divided into general analyses and case studies for the urban railway lines between Helsinki and Kerava/ Leppävaara. These lines are chosen due to high capacity consumption and the plans to operate even more trains in the future. Besides, the urban railway lines with homogeneous operation is expected to result in the highest capacity benefits if changing from JKV to ERTMS /ETCS.

6.2 Conclusions

The case studies show only smaller capacity and line headway differences between JKV, and ETCS level 1 and 2 when the existing block sections are used. For JKV (and ETCS level 1) signal visibility limits the signal locations, and the lengths of block sections need to be coordinated with the braking distance. ERTMS/ETCS level 2 does not have the same limitations, why it is possible to have shorter block sections that can improve the capacity significantly. The case studies show that the minimum line headway can be reduced by 14% to 48%. The capacity consumption with the current operational pattern can be reduced from 67% with JKV to 50% on the Helsinki–Kerava line and from 70% to 61% on the Helsinki–Leppävaara line. The reduced capacity consumption with ERTMS/ETCS level 2 and improved block sections allows for a reduction in planned headway from 5 minutes to 3.75 minutes in the peak hours.

With the improved block sections, the capacity limiting bottleneck the conflicting train movements in opposite directions at Helsinki central station, especially for trains to and from Leppävaara. This is to some extent also a limiting factor at Kerava and Leppävaara, however as half of the trains go the airport, Helsinki is the main bottleneck. With a further improvement of the block sections and partial release points at Helsinki central station, the capacity is likely to increase even more, especially on the line to Leppävaara.

The case study assumes trains arrive on “red” at stations (Movement Authority ending at the station). At the stations, where the signal or marker board is located close to the stopping location, this can result in extended arrival time as the driver is following the ERTMS/ETCS braking curve instead of braking freely. Arriving on “green” at stations (Movement Authority past the station) would allow faster approach to the station but with total longer block occupation times. Thereby, arriving on “red” (Movement Authority ending at the station) results in the highest capacity for high-density lines.

In Finland the JKV and the ERTMS/ETCS braking curves used are very similarly. This is a main reason for the small capacity differences between JKV and ERTMS/ETCS level 1 when using the same block sections – when the block sections are adapted for JKV, the differences to ERTMS/ETCS level 2 are also minor if the block sections remain unchanged – however shorter or improved block sections can increase the capacity as described previously. A difference between JKV and ERTMS/ETCS is the release speed in braking curve for ERTMS/ETCS. Finland has decided a national value for the release speed of 15 km/h while the default value is 40 km/h. The analyses show the approach time to the stop of Sm5 trains can be reduced by 11 seconds if the release speed is raised to 40 km/h.

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Recommendation for further studies

Speed profile

Conventional signalling and ATP systems may limit the speed of certain or all train types. This may be caused by a limited amount of block sections that can be supervised in front of the train resulting in restrictions on speed to decrease braking distance. Speed restrictions may also be caused by reduced signal visibility. With ERTMS/ETCS level 2, and to some extent ERTMS/ETCS level 1, such speed restrictions may be removed to allow faster running times. Further studies in to ERTMS/ETCS and line speed profiles will uncover which speed restrictions may be removed or relaxed on existing lines.

Optimised block sections

With further improvement of block sections, release points and possibly different release speeds, even higher capacity may be possible on the lines to Kerava and Leppävaara studied in this project. Furthermore, some block sections are not critical or restricting and can be longer to save cost. Further studies into marker board positions and block sections will result in a more detailed design revealing detailed benefits and costs related to block sectioning.

Cost-Benefit analysis

Replacing an already functional signalling system has a cost that must be offset by the benefits with the new system such as running time reductions, increased frequency and less delays resulting in reduced travel time, as well as reduced maintenance cost and increased safety. A cost-benefit analysis to uncover the cost and benefits is thus recommended for further studies.

Human Factors

As the ERTMS/ETCS gives more information on movement authority than a conventional signalling system, the driver may be able to drive the train more optimally (e.g. not braking too early). This is not captured by capacity simulation software why the benefit in ERTMS/ETCS level 2 compared to JKV may be underestimated in some situations. A suggestion for further studies is therefore to study the driving behaviour of train drivers for both JKV and ERTMS/ETCS level 2 (in a simulator) as well as collecting experience from other countries to reveal how human factors affect the driving under JKV and ERTMS/ETCS.

ERTMS/ETCS Level 1 optimising block sections and using infill possibilities

ERTMS/ETCS level 1 with improved block sections may result in capacity benefits compared to JKV and is therefore a suggestion for further studies. Similarly the usage of infill can improve capacity.

ERTMS/ETCS Level 3 and hybrid Level 2/3

Compared to ERTMS/ETCS level 2 or 3 or a level 2/3 hybrid may yield an additional capacity increase. A hybrid system may be used for the long-distance tracks where trains such as freight trains will operate under ERTMS/ETCS level 2 (as train integrity cannot be guaranteed under level 3) and certain passenger trains (e.g. multiple units) may be operated under level 3. In the city line tracks, level 3 may be used. Further studies of other ERTMS/ETCS levels may therefore reveal additional benefits to be achieved compared to a pure level 2 implementation.

Block sections

Existing blocks

Helsinki–Kerava

From Km	To Km	From Signal	To Signal
0.349	0.632	HKI_T1	P001
0.349	0.632	HKI_T2	P002
0.349	0.632	HKI_T3	P003
0.16	0.599	HKI_T4	P004
0.632	1.244	P001	P222
0.632	1.244	P002	P222
0.632	1.244	P003	P222
0.599	1.244	P004	P222
1.244	1.691	P222	P281
1.691	2.147	P281	P411
2.147	2.662	P411	P431
2.662	3.106	P431	P487
3.106	3.602	P487	P441
3.602	4.873	P441	591p
4.873	6.12	591p	P501
6.12	7.62	P501	P541
7.62	8.86	P541	583p
8.86	10.125	583p	P073
10.125	11.25	P073	P003Ml
11.25	12.693	P003Ml	063p
12.693	13.846	063p	P083
13.846	14.995	P083	P273
14.995	16.2	P273	P205
16.2	17.475	P205	P263
17.475	19.665	P263	P283
17.475	20	P263	Lento1
19.665	20.83	P283	P493
20.83	22.3	P493	P473
22.3	23.711	P473	P443
23.711	25.093	P443	P463
25.093	26.322	P463	P573
26.322	27.745	P573	P613
27.745	29.088	P613	KE_T5
27.745	29.088	P613	KE_T6

Kerava–Helsinki

From Km	To Km	From Signal	To Signal
29.088	28.682	KE_T5	E605
28.682	26.322	E605	E614
29.088	28.682	KE_T6	E606
28.682	26.322	E606	E614
26.322	25.093	E614	E574
25.093	23.711	E574	E464
23.711	22.3	E464	E444
22.3	20.83	E444	E474
20.83	19.665	E474	E494
19.665	18.151	E494	E284
18.151	16.757	E284	E264
20	17.981	Lento2	E286
17.981	16.757	E286	E264
16.757	15.823	E264	E206
15.823	14.5	E206	274e
14.5	13.16	274e	E084
13.16	11.961	E084	E064
11.961	10.747	E064	004e
10.747	9.729	004e	E074
9.729	8.585	E074	E584
8.585	6.948	E584	540e
6.948	5.657	540e	E500
5.657	4.729	E500	E480
4.729	3.161	E480	E440
3.161	2.753	E440	E486
2.753	2.328	E486	E430
2.328	1.92	E430	E410
1.92	1.443	E410	E280
1.443	1.01	E280	E220
1.01	0.344	E220	HKI_T1
1.01	0.344	E220	HKI_T2
1.01	0.344	E220	HKI_T3
1.01	0.16	E220	HKI_T4

Helsinki–Leppävaara

From Km	To Km	From Signal	To Signal
0.312	0.566	HKI_T19	P019RR
0.312	0.566	HKI_T18	P018RR
0.312	0.566	HKI_T17	P017RR
0.312	0.571	HKI_T16	P016RR
0.566	1.147	P019RR	P231RR
0.566	1.147	P018RR	P231RR
0.566	1.147	P017RR	P231RR
0.571	1.147	P016RR	P231RR
1.147	1.591	P231RR	P419RR
1.591	2.036	P419RR	P423RR
2.036	2.459	P423RR	P429RR
2.459	2.894	P429RR	P489RR
2.894	3.56	P489RR	P449RR
3.56	4.576	P449RR	P274RR
4.576	6.596	P274RR	P204RR
6.596	8.15	P204RR	P264RR
8.15	9.77	P264RR	P354RR
9.77	11.415	P354RR	LPV_T4
9.77	11.415	P354RR	LPV_T3

Leppävaara–Helsinki

From Km	To Km	From Signal	To Signal
6.596	8.24	P204RR	P152RR
11.415	11	LPV_T4	E304RR
11.415	11	LPV_T3	E303RR
11	9.3	E304RR	E353RR
11	9.3	E303RR	E353RR
9.3	8.15	E353RR	E283RR
8.15	6.84	E283RR	E243RR
6.84	6.3	E243RR	E203RR
6.3	5.31	E203RR	E213RR
5.31	4.277	E213RR	E273RR
4.277	3.149	E273RR	E448RR
3.149	2.689	E448RR	E488RR
2.689	2.266	E488RR	E428RR
2.266	1.828	E428RR	E422RR
1.828	1.393	E422RR	E418RR
1.393	1.027	E418RR	E230RR
1.027	0.294	E230RR	HKI_T16
1.027	0.294	E230RR	HKI_T17
1.027	0.294	E230RR	HKI_T18
1.027	0.294	E230RR	HKI_T19
9.06	7.56	E111RR	E151RR
7.56	6.3	E151RR	E203RR

Improved blocks

Helsinki–Kerava

From Km	To Km	From Signal	To Signal
0.349	0.632	HKI_T1	P001
0.349	0.632	HKI_T2	P002
0.349	0.632	HKI_T3	P003
0.178	0.599	HKI_T4	P004
0.632	1.244	P001	P222
0.632	1.244	P002	P222
0.632	1.244	P003	P222
0.599	1.244	P004	P222
1.244	1.691	P222	P281
1.691	2.147	P281	P411
2.147	2.662	P411	P431
2.662	3.106	P431	P487
3.106	3.602	P487	P441
3.602	3.920	P441	
3.920	4.238		
4.238	4.555		
4.555	4.873		591p
4.87	5.18	591p	
5.18	5.50		
5.50	5.81		
5.81	6.12		P501
6.12	6.42	P501	
6.42	6.72		
6.72	7.02		
7.02	7.32		
7.32	7.62		P541
7.62	7.93	P541	
7.93	8.24		
8.24	8.55		
8.55	8.86		583p
8.86	9.18	583p	
9.18	9.49		
9.49	9.81		
9.81	10.125		P073
10.125	10.5	P073	
10.50	10.875		
10.875	11.25		P003Ml
11.25	11.61	P003Ml	
11.61	11.97		
11.97	12.33		
12.33	12.693		063p
12.693	13.08	063p	
13.08	13.46		

Helsinki–Kerava

From Km	To Km	From Signal	To Signal
13.46	13.846		P083
13.846	14.23	P083	
14.23	14.5		
14.50	14.995		P273
14.995	15.30	P273	
15.30	15.60		
15.60	15.90		
15.90	16.2		P205
16.2	16.52	P205	
16.52	16.84		
16.84	17.16		
17.16	17.475		P263
17.475	17.83	P263	
17.83	18.143		
18.14	18.456		
18.46	18.769		
18.77	19.081		
19.08	19.394		
19.39	19.665		P283
17.475	17.83	P263	
17.83	18.1		
18.10	18.42		
18.42	18.8		
18.80	19.12		
19.12	19.43		
19.43	19.75		
19.75	20		
19.665	20.05	P283	
20.05	20.44		
20.44	20.83		P493
20.83	21.20	P493	
21.20	21.57		
21.57	21.93		
21.93	22.3		P473
22.3	22.65	P473	
22.65	23.01		
23.01	23.36		
23.36	23.711		P443
23.711	24.06	P443	
24.06	24.40		
24.40	24.75		
24.75	25.093		P463
25.093	25.40	P463	
25.40	25.71		
25.71	26.01		

Helsinki–Kerava

From Km	To Km	From Signal	To Signal
26.01	26.322		P573
26.322	26.68	P573	
26.68	27.03		
27.03	27.39		
27.39	27.745		P613
27.745	28.35	P613	
28.35	28.68		KE_T5
28.68	29.088	(E606)	KE_T5
27.745	28.35	P613	
28.35	28.68		KE_T6
28.68	29.088	(E606)	KE_T6

Kerava–Helsinki

From Km	To Km	From Signal	To Signal
29.088	28.682	KE_T5	E605
28.682	27.85	E605	
27.85	27.54		
27.54	27.24		
27.24	26.93		
26.93	26.63		
26.63	26.322		E614
29.088	28.682	KE_T6	E606
28.682	27.85	E606	
27.85	27.54		
27.54	27.24		
27.24	26.93		
26.93	26.63		
26.63	26.322		E614
26.322	26.015	E614	
26.01	25.71		
25.71	25.40		
25.40	25.093		E574
25.093	24.75	E574	
24.75	24.40		
24.40	24.06		
24.06	23.711		E464
23.711	23.36	E464	
23.36	23.01		
23.01	22.65		
22.65	22.3		E444
22.3	21.93	E444	
21.93	21.57		
21.57	21.20		
21.20	20.83		E474
20.83	20.44	E474	

Kerava–Helsinki

From Km	To Km	From Signal	To Signal
20.44	20.05		
20.05	19.665		E494
19.665	19.36	E494	
19.36	19.06		
19.06	18.76		
18.76	18.45		
18.45	18.151		E284
18.151	17.65	E284	
17.65	17.2		
17.2	16.757		E264
20	19.66	Lento2	
19.66	19.327		
19.33	18.99		
18.99	18.654		
18.65	18.32		
18.32	17.981		E286
17.981	17.65	E286	E264
16.757	16.2	E264	
16.2	15.823		E206
15.823	15.49	E206	
15.49	15.16		
15.16	14.83		
14.83	14.5		274e
14.5	14.165	274e	
14.17	13.83		
13.83	13.495		
13.50	13.16		E084
13.16	12.76	E084	
12.76	12.36		
12.36	11.961		E064
11.961	11.66	E064	
11.66	11.354		
11.35	11.05		
11.05	10.747		004e
10.747	10.41	004e	
10.41	10.07		
10.07	9.729		E074
9.729	9.35	E074	
9.35	8.97		
8.97	8.585		E584
8.585	8.26	E584	
8.26	7.93		
7.93	7.60		
7.60	7.28		
7.28	6.948		540e

Kerava–Helsinki

From Km	To Km	From Signal	To Signal
6.948	6.63	540e	
6.63	6.30		
6.30	5.98		
5.98	5.657		E500
5.657	5.35	E500	
5.35	5.04		
5.04	4.729		E480
4.729	4.42	E480	
4.42	4.10		
4.10	3.79		
3.79	3.47		
3.47	3.161		E440
3.161	2.753	E440	E486
2.753	2.328	E486	E430
2.328	1.92	E430	E410
1.92	1.443	E410	E280
1.443	1.01	E280	E220
1.01	0.349	E220	HKI_T1
1.01	0.349	E220	HKI_T2
1.01	0.349	E220	HKI_T3
1.01	0.178	E220	HKI_T4

Helsinki–Leppävaara

From Km	To Km	From Signal	To Signal
0.312	0.566	HKI_T19	P019RR
0.312	0.566	HKI_T18	P018RR
0.312	0.566	HKI_T17	P017RR
0.312	0.571	HKI_T16	P016RR
0.566	1.147	P019RR	P231RR
0.566	1.147	P018RR	P231RR
0.566	1.147	P017RR	P231RR
0.571	1.147	P016RR	P231RR
1.147	1.591	P231RR	P419RR
1.591	2.036	P419RR	P423RR
2.036	2.459	P423RR	P429RR
2.459	2.894	P429RR	P489RR
2.894	3.227	P489RR	
3.227	3.56		P449RR
3.56	3.899	P449RR	
3.899	4.237		
4.237	4.576		P274RR
4.576	4.913	P274RR	
4.913	5.249		
5.249	5.586		
5.586	5.923		

Helsinki–Leppävaara

From Km	To Km	From Signal	To Signal
5.923	6.259		
6.259	6.596		P204RR
6.596	6.89	P204RR	(E244)
6.89	7.2	(E244)	
7.2	7.5		
7.5	7.8		
7.8	8.15		P264RR
8.15	8.474	P264RR	
8.474	8.798		
8.798	9.122		
9.122	9.446		
9.446	9.77		P354RR
9.77	10.07	P354RR	
10.07	10.37		
10.37	10.68		
10.68	11.02		
11.02	11.415	(E304)	LPV_T4
9.77	10.07	P354RR	
10.07	10.37		
10.37	10.68		
10.68	11.02		
11.02	11.415	(E303)	LPV_T3
6.596	6.89	P204RR	(E244)
6.89	7.22	(E244)	
7.22	7.55		
7.55	7.9		
7.9	8.24		P152RR

Leppävaara–Helsinki

From Km	To Km	From Signal	To Signal
11.415	11	LPV_T4	E304RR
11.415	11	LPV_T3	E303RR
11	10.67	E304RR	
10.67	10.35		
10.35	10		
10	9.65		
9.65	9.3		E353RR
11	10.67	E303RR	
10.67	10.35		
10.35	10		
10	9.65		
9.65	9.3		E353RR
9.3	8.92	E353RR	
8.92	8.53		

Leppävaara–Helsinki

From Km	To Km	From Signal	To Signal
8.53	8.15		E283RR
8.15	7.823	E283RR	
7.823	7.495		
7.495	7.1675		
7.168	6.84		E243RR
6.84	6.6	E243RR	(P203)
6.6	6.3	(P203)	E203RR
6.3	5.97	E203RR	
5.97	5.64		
5.64	5.31		E213RR
5.31	4.97	E213RR	
4.97	4.62		
4.62	4.277		E273RR
4.277	3.901	E273RR	
3.90	3.525		
3.53	3.149		E448RR
3.149	2.689	E448RR	E488RR
2.689	2.266	E488RR	E428RR
2.266	1.828	E428RR	E422RR
1.828	1.393	E422RR	E418RR
1.393	1.027	E418RR	E230RR
1.027	0.312	E230RR	HKI_T16
1.027	0.312	E230RR	HKI_T17
1.027	0.312	E230RR	HKI_T18
1.027	0.312	E230RR	HKI_T19
9.06	8.76	E111RR	
8.76	8.46		
8.46	8.16		
8.16	7.86		
7.86	7.56		E151RR
7.56	7.25	E151RR	
7.25	6.9		
6.9	6.6		(P203)
6.6	6.3	(P203)	E203RR

Detailed results

Minimum line headway times in seconds:

		Section	Main line from Helsinki	Main line to Helsinki	Rantarata from Helsinki	Rantarata to Helsinki
Existing block sections	JKV	First and second train: Kerava/Leppävaara	191.2	235.0	260.3	166.8
		First train: Kerava/Leppävaara, Second train: Airport	189.31	226.6	177.684	160.689
		First train: Airport, Second train: Kerava/Leppävaara	189.252	203.54	177.684	161.72
		Avg. alternatning between a train Kerava/Leppävaara and the Airport	189.3	215.1	177.7	161.2
	Level 1	First and second train: Kerava/Leppävaara	192.932	236.703	262.034	168.467
		First train: Kerava/Leppävaara, Second train: Airport	190.952	228.3	179.384	162.389
		First train: Airport, Second train: Kerava/Leppävaara	191.01	203.24	179.384	158.179
		Avg. alternatning between a train Kerava/Leppävaara and the Airport	191.0	215.8	179.4	160.3
	Level 2	First and second train: Kerava/Leppävaara	194.882	199.911	263.984	170.417
		First train: Kerava/Leppävaara, Second train: Airport	192.902	230.3	181.334	161.513
		First train: Airport, Second train: Kerava/Leppävaara	192.96	197.77	181.334	162.545
		Avg. alternatning between a train Kerava/Leppävaara and the Airport	192.9	214.0	181.3	162.0
Improved block sections	Level 2 improved	First and second train: Kerava/Leppävaara	137.7	140.4	136.3	139.0
		First train: Kerava/Leppävaara, Second train: Airport	135.7	135.6	134.887	139.015
		First train: Airport, Second train: Kerava/Leppävaara	135.7	138.26	134.887	139.015
		Avg. alternatning between a train Kerava/Leppävaara and the Airport	135.7	136.9	134.9	139.0

		Existing block sections								Improved block sections			
		Level 1				Level 2				Level 2			
	Section	First and second train: Kerava/Leppävaara	First train: Kerava/Leppävaara, Second train: Airport	First train: Airport, Second train: Kerava/Leppävaara	Avg. alternatning between a train Kerava/Leppävaara and the Airport	First and second train: Kerava/Leppävaara	First train: Kerava/Leppävaara, Second train: Airport	First train: Airport, Second train: Kerava/Leppävaara	Avg. alternatning between a train Kerava/Leppävaara and the Airport	First and second train: Kerava/Leppävaara	First train: Kerava/Leppävaara, Second train: Airport	First train: Airport, Second train: Kerava/Leppävaara	Avg. alternatning between a train Kerava/Leppävaara and the Airport
Improvement [secs]	Main line from Helsinki	-1.7	-1.6	-1.8	-1.7	-3.7	-3.6	-3.7	-3.6	53.5	53.6	53.6	53.6
	Main line to Helsinki	-1.7	-1.7	0.3	-0.7	35.1	-3.7	5.8	1.1	94.6	91.0	65.3	78.1
	Rantarata from Helsinki	-1.7	-1.7	-1.7	-1.7	-3.6	-3.7	-3.7	-3.7	124.1	42.8	42.8	42.8
	Rantarata to Helsinki	-1.7	-1.7	3.5	0.9	-3.7	-0.8	-0.8	-0.8	27.8	21.7	22.7	22.2
Relative improvement	Section												
	Main line from Helsinki	-0.9%	-0.9%	-0.9%	-0.9%	-1.9%	-1.9%	-2.0%	-1.9%	28.0%	28.3%	28.3%	28.3%
	Main line to Helsinki	-0.7%	-0.8%	0.1%	-0.3%	14.9%	-1.6%	2.8%	0.5%	40.3%	40.2%	32.1%	36.3%
	Rantarata from Helsinki	-0.7%	-1.0%	-1.0%	-1.0%	-1.4%	-2.1%	-2.1%	-2.1%	47.7%	24.1%	24.1%	24.1%
	Rantarata to Helsinki	-1.0%	-1.1%	2.2%	0.6%	-2.2%	-0.5%	-0.5%	-0.5%	16.6%	13.5%	14.0%	13.8%

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