Reliability Study of ERTMS in Sweden

- An analysis of Swedish Signalling Systems

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Printed in Sweden
Media-Tryck
Biblioteksdirektionen
Lunds universitet
Lund 2020

Abstract

Sweden is currently undergoing a transition phase to a new signalling system on its railway network. ATC-2 is the current point information system in use on the network. The system will gradually be replaced with ERTMS, which will become the standardised signalling system in the European Union (EU). During this period, the Swedish Transport Administration (Trafikverket) has been commissioned by the Swedish government to produce reports on the quality of delivery of the ERTMS system.

This thesis presents a description of the technical structure of ETCS Level 2 and ATC-2. Further research into the signalling systems is done by conducting a reliability analysis, utilising Trafikverket's service monitoring reports as a source of data on faults were reliability is affected. To further elaborate on this data, interviews with people working with ERTMS at Trafikverket, SJ and Infranord were conducted.

Finally, the results are presented from the reliability analysis where faults with technical aspects of ETCS Level 2 that could cause problems for reliability are summarised. Previous studies on ERTMS are included in the discussion to strengthen the findings from the analysis. Since reliability studies like the one done in this thesis have not been published to a greater extend in either Sweden or other European countries, the report utilises studies on ERTMS where the findings in said studies could have an effect on reliability for ERTMS.

Keywords: ERTMS, ETCS Level 2, Sweden, Reliability Analysis, ATC-2

Sammanfattning

Sverige genomgår en övergångsfas mellan två olika signalsystem på järnvägen. ATC-2 är det nuvarande punktinformationssystemet som finns på den svenska järnvägen. Detta system ska stegvis ersättas med ERTMS, ett system som ska bli det standardiserade signalsystemet på EU:s järnvägar. Under denna period har Trafikverket i uppdrag av den svenska regeringen att ta fram rapporter som redovisar resultat och analyser om leveranskvalitén av ERTMS-systemet.

Denna rapport undersöker och presenterar tekniska strukturer inom ETCS Level 2 och ATC-2. Rapporten genomför därefter en tillförlitlighetsanalys där Trafikverkets rapporter om ERTMS implementeringen i Sverige används för att ta fram statistik om fel där tillförlitligheten drabbas. För att utveckla undersökningen av denna statistiska data intervjuades personer från Trafikverket, SJ och Infranord som arbetar inom ERTMS.

Avslutningsvist presenteras resultat från tillförlitlighetsanalysen där problem med tekniska delar av ETCS Level 2 som kan påverka tillförlitligheten negativt presenteras. Här tas även tidigare studier om ERTMS med i diskussionen för att stärka de fynd som har gjorts under analysens gång. Då tillförlitlighetsstudier som denna rapport gör inte har publicerats i en större utsträckning vare sig i Sverige eller övriga europeiska länder, har andra vetenskapliga rapporter använts som har undersökt delar av ERTMS-systemet som kan komma påverka tillförlitligheten.

Nyckelord: ERTMS, ETCS Level 2, Sverige, Tillförlitlighetsanalys, ATC-2

Foreword

This thesis was written during spring of 2020 and is the final part of the bachelor's degree in railway technology at Lunds Tekniska Högskola, Campus Helsingborg. The thesis' subject was initially selected by the authors and it was further developed with the help of Piotr Lukaszewicz at AFRY.

We would like to give our sincerest thanks to our supervisors Piotr Lukaszewicz at AFRY and Daria Ivina at Lund's University for all the help we have received from them to make this thesis possible.

A special thanks to all people at Trafikverket, SJ and Infranord who participated in our interviews and took their time to answer our questions.

Despite the current situation, we feel that we have still been able to do everything we wished to do with this thesis, and our goal of learning more about ERTMS has been obtainable.

Jacob Månsson and Kristoffer Wallenbro
Helsingborg May 2020

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List of abbreviations

ATC-1	Automatic Train Control 1
ATC-2	Automatic Train Control 2
ERTMS	European Rail Management System
TSI	Technical Specifications for Interoperability
ATP	Automatic Train Protection
EEC	European Economic Community
EU	European Union
ERA	European Union Agency for Railways
ETCS	European Train Control System
TEN-T	Trans-European Transport Network
GSM-R	Global System for Mobile Communications-Railway
E2	ETCS Level 2
BTM	Balise Transmission Module
CCS	Control Command and Signalling
Stax	Maximum Permissible Axle Load
Stvm	Maximum Permissible Weight per Metre
t/m	Tonne Per Metre
TRV	Trafikverket
OHLE	Overhead Line Equipment
USB	Universal Serial Bus
EVC	Euro Vital Computer
DMI	Driver Machine Interface
TI	Train Interface
JRU	Juridical Recording Unit
RBC	Radio Block Centre

1 Introduction

Sweden's railway network currently operates with the Swedish ATC-2 signalling system. First developed in the late 1960s and commissioned by 1980 as ATC-1, the system was later developed into ATC-2 with backwards compatibility in mind (Trafikverket 2016). The modern Swedish signalling infrastructure has a varied lifetime and is derived from signal box 59 (Trafikverket 2020a). This signal box laid the groundwork for further development of other modern signal boxes (*Ibid*). Nevertheless, older parts are still in use on the network as the systems have similar functionalities. This has led to a situation with modern and older signal boxes coexisting on the network. The need to modernise and replace old and outdated signalling boxes was not necessary when ATC was implemented, as the system was designed as an extension to the signalling infrastructure. This has subsequently created a problem of technical unity of parts and systems where older parts are still in use, hindering further development of the Swedish signalling system in it's current state.

Currently, the ATC-2 system operates with both relay-based signalling boxes such as Model 59 and 65 and with more modern computer-based signalling boxes like the model 85 and 95 (Trafikverket 2020a). However, the system is reaching its technical age limit and requires modernisation. As such, the Swedish Transport Administration (Trafikverket) has put forward a plan to renovate the current system by upgrading and replacing it with the standardised European ERTMS system. This will enable future interoperability with the European railway market and guarantee the future-proofing of the Swedish railway system.

The implementation of ERTMS in Sweden will take place over a planned period of 15 years (Trafikverket 2020b). This conversion period is divided into phases where sections of the Swedish Core Network (see Section 3) will be converted to ERTMS according to their state of operation, their need for reinvestment and opportunities for financing. According to Trafikverket, the introduction of ERTMS and subsequently the reinvestment into the infrastructure will make for easier monitoring of facilities maintenance and better traffic management. The new system will reduce the number of signalling boxes needed from 750 to approximately 160 units (Trafikverket 2019a).

As old and outdated signalling infrastructure will be replaced, a part of the system will remain as its functionality is still needed. The track circuit system (see section 2.3) used for train detection is a fundamental safety feature that will stay in use with the introduction of the new signalling system as it does not hinder interoperability.

It should be noted that since 2004, it is Swedish law that all investments and reinvestments into the Swedish railway network need to follow the European Union's Technical Specifications for Interoperability (TSI). The TSIs defines the technical and operational standards for a specific subsystem or part of a subsystem. There are 11 TSIs in total, each describing various technical standards for different subsystems that make up the European railway infrastructure where the Control Command and Signalling TSI (CCS TSI) specifies the control command, signalling on-board and trackside subsystems. It applies to both control-command subsystems and signalling on-board subsystem of vehicles intended to operate on the rail network of the European Union (ERA 2020a). By legislating the TSIs into Swedish law, ERTMS will eventually be applied to all of the Swedish railway network and building new lines with ATC-2 is no longer a possibility (Trafikverket 2019b).

1.1 Background

Traditionally, most European countries have had one governmental body who has maintained its country's railway system. This led to the development of unique solutions to traffic safety and signalling systems across Europe, making cross-country connections via rail difficult and made other modes of transportation more favourable. On the Swedish railway network, the current system is ATC-2 (Trafikverket 2016).

It became clear to the European Economic Community (EEC) that Europe's railways would greatly benefit from a singular signalling system and a study was launched in 1989 (European Commission 2020a). Throughout the 1990s, several key decisions were made by the EU regarding technical specifications of ERTMS and how ERTMS would play a role in rail interoperability, and two EU directives (96/48/EU and 1001/16/EU) were developed to regulate interoperability on the trans-European high-speed network and the member states' conventional rail systems (*Ibid*). Since 2004, the European Railway Agency (ERA) has been in charge of managing ERTMS' system specifications (*Ibid*).

Because of the historic development of nationalised signalling systems in both Europe and Sweden, the comparison between a new international system and an older national one is of interest. Since the older Swedish ATC-2 system has been shaped to solve or overcome specific problems related to Sweden's railway, the topic of looking at an international system's performance and if it creates an equal improvement to that of the previous system is of interest.

Research into ERTMS in Europe is generally focused on ERTMS performance, capacity improvement and economics. However, research into the system's reliability is limited (Kalvakunta 2017). This is largely done with case studies on existing lines both with and without ERTMS. Since each country has a different system, each with different functionality and performance, the national ERTMS performance research is therefore too individualised to be compared internationally. This has made available comparative research between E2 and national signalling systems difficult to use as a benchmark for ERTMS performance in Sweden.

As such, the scientific literature analysed for this thesis cover scopes such as the introduction of ERTMS onto the European railway system, technical and procedural challenges, concepts and methods of assessing railway capacity and the main factors that can affect it. Since these factors may affect the reliability of ERTMS, parameters and findings could be used to strengthen the results and conclusion made in this thesis. Reports utilised for the Results and

Discussion section of the thesis are “An overview of lessons learned from ERTMS implementation in European railways” (Smith P. et al 2012), a paper addressing the safe introduction of ERTMS into European railway systems, focusing on technical and procedural challenges with the implantation of a new traffic management system, and “An Assessment of Railway Capacity” (Abril et al 2008), publication reviewing the main concepts of and methods to perform capacity analysis on railway transport, as well as presenting an automated tool to perform several capacity analyses. Additional documentation, such as course literature, is also utilised for Result and Discussion.

As stated by Smith et al. (2012), better testing and evaluation of ERTMS would greatly aid in the deployment of the new signalling system. Although reviewed studies are limited to specific lines with specific setups, and as the configuration of the line (block length, speed and traffic) greatly impact the results (Abril et al 2008), it is difficult to evaluate and compare the performance data from said studies.

1.2 Objectives

The thesis investigates the operational reliability of the ERTMS signalling system in Sweden by performing comparative analysis on reliability statistics of the ATC-2 and E2 signalling systems. The aim is to compare the reliability performance of the two current systems and to gain knowledge of possible faults in the early stage of ERTMS implementation in Sweden.

1.3 Key Questions

1. How do ATC-2 and ETCS Level 2 operate on a technical level?
2. How does reliability on railway lines that operate with ETCS Level 2 compare to ones that operate with ATC-2?
3. What issues with reliability for ETCS Level 2 can be traced to technical components or aspects within the system?
4. What issues have emerged with the early implementation of ERTMS in Sweden?

1.4 Scopes and Limitations

Since the aim of the thesis is to look at and compare the reliability of the signalling systems in Sweden, the thesis will only consider ETCS Level 2 and ATC-2. As Trafikverket has also decided that ETCS Level 2 will be the new standardised signalling system in Sweden (Trafikverket 2019c), statistics from the one railway line in Sweden that operates with ETCS Level 3 (or ERTMS Regional) will be excluded, nor will other ETCS levels be elaborated on as Trafikverket has decided to move forward with ETCS level 2.

In order to perform a comparison between lines that operate with ETCS Level 2 and ATC-2, the railway lines that Trafikverket has listed as part of the Core Network are studied. These are lines that are part of the EU's Trans European Transport Network (TEN-T) corridors and lines that connect Sweden with other countries. See Section 3 for a brief explanation of the TEN-T network and a list over the Core Network railway lines. Reliability issues caused by level crossings have been excluded from this thesis, as they are a separate function of the signalling system.

2 Theory

Within the theory subchapters, each signalling system's technical functionality is described. The theory section utilised a qualitative analysis method to research the data collected and used in the chapter. The methods used for the thesis are thoroughly described in Section 4.

2.1 ATC-2

ATC-2 (Automatic Train Control 2) is the current operating signalling system in Sweden. The system's description is information that is vital for safe operation on the railway is transferred automatically between trackside equipment and rolling stock (Trafikverket 2015). Outside of Sweden, ATC is a combination of an ATP (Automatic Train Protection) and ATO (Automatic Train Operation) systems (*Ibid*). ATO systems include the possibility to automate train operation, something which the Swedish ATC-2 system lacks. Therefore, from an international perspective, the Swedish ATC-2 system is an ATP system.

ATC-2s functions can be summarised as the following (Trafikverket 2015, Trafikverksskolan 2019a):

- Information received from signals or signage balises is stored by the onboard system on trains. That information is then presented to the driver to assist him/her to remember what information was displayed by passed signals or signage.
- The system monitors the driver's actions and responses to said information.
- If the response from the driver is too slow, the system will step in and brake.

ATC-2 is a point information system, which means that the information received by the trains is transmitted through information points along the track, also known as balise groups (Trafikverket 2015). Every group has a minimum of two balises, which allows the onboard system on trains to detect which direction the information point is pointing towards. Multiple balises in one group also increase security as it helps to discover balise losses easier. Information points can be singular or multi-directional (Trafikverksskolan 2019a).

The information that can get passed between balises and the train's onboard system are (Trafikverket 2015, Trafikverksskolan 2019a):

- *Permitted Speed*, received from signals and permitted speed signage.
- *Target Speed,* received from repeater signals, combined main and repeater signals, main shunt signals and warning speed signage.
- *Target Distance,* distance from the information point to the next target.
- *Gradient* to the next target if necessary.
- *Train category information*, if necessary, sends varying speed to different train types, e.g. heavy freight trains.

Balises in the ATC-2 system can be categorised into five different types of balises (Trafikverksskolan 2019a):

- *A*-balise – Sends information about permitted speed and target speed to the onboard systems. Information about what type of object has been passed is also transferred.
- *B*-balise – Sends information about the distance to the next target.
- *C*-balise – Sends information about gradient between the current object to the next target. Usually not installed if the gradient between targets is uphill as uphill track segments do not extend braking distance.
- *P*-balise – Used for reducing speeds for special train classes (e.g. heavy freight trains) and to extend target distance. If used, it is always placed first in a balise group.
- *N*-balise – Used to give warning signage unique identities or signals a unique number on radio blocks.

A- and B-balises are always used in a balise group and the remaining three are only used if necessary. Each balise is either hard-coded or code-able depending on what the balise group needs to be able to send as information. For example, a warning signage's balise group will be hard-coded as it only ever needs to send one set speed and distance to the next speed signage, whilst a signal might need to be able to send multiple target speeds and target distances, requiring the use of code-able balises and encoders (*Ibid*).

Balises are not powered but rather activated when a train passes over it. This is useful for information points that normally do not require power (for example permissible speed signage), but importantly a security check in case of a power outage, the balises will not stop functioning (Trafikverket 2015). When activated by a passing train, a balise sends the information it is coded to send in the form of a telegram, and it does so continuously until the train has passed. The onboard system on trains requires the telegram to be accepted at least four times. The telegram consists of an 8-bit synchronisation word and at least three 4-bit information word with 4-bit redundancy, the X-, Y- and Z-words programmed into the balises (Trafikverksskolan 2019a). X-words contain information about what kind of balise type the train is currently passing over. Y- and Z-words relay track information, e.g. speed and distance. This information is analysed by the trains onboard system differently depending on the X-word and in some cases, it also depends on where in the balise group the information is taken up.

For balise groups connected to signals, ATC-2 uses encoders to program the balises. The encoder's task is to interpret information about the signalling aspect from trackside optical signals, then encode it and transfer the information to a codeable balise. The encoder is directly connected to the signal lamps circuit and can monitor the current in that circuit, enabling it to read what signal aspect is displayed on the signal. There are two types of encoders used in the Swedish ATC-2 system, parallel encoders and serial encoders. The key difference between parallel and serial encoders is that the latter can offer a more flexible solution for controlling the encoder and is also able to transfer more data (telegram) to the code-able balise (Trafikverksskolan 2019a).

2.2 ERTMS

ERTMS is composed of two different major systems (European Commission 2020b):

- ETCS – (European Train Control System), the signalling aspect of ERTMS, ETCS is the standardized ATP/ATC system used in Europe.
- GSM-R – (Global System for Mobile Communications – Railway), mobile communication system used exclusively on the railway.

The technical specifications of these systems are specified in the Baseline for ERTMS (Baseline 3). The Baseline of a project corresponds to the version of the technical specifications designed and validated for that specific project. In this instance, a baseline for ERTMS is a set of documents with a concrete version that are listed in the TSI CCS. This contains a set of specifications that constitutes a given baseline (European Commission 2020d).

ETCS Level 2 involves continuous supervision of train movement with continuous communication via GSM-R between both the train and trackside equipment (*Ibid*). ETCS Level 2 is used as an overlay on the underlying train detection, integrity supervision, interlocking and track circuits signalling system (European Railway Agency 2016).

Track circuits are used for train detection and they communicate directly with the Radio Block Centre (RBC). Trains constantly relay information about the direction at balise passage and current positions via the GSM-R network to the RBC. The key difference between ATC-2 and ETCS level 2 is that movement authority is not relayed via a balise but is instead transmitted through GSM-R directly to the train. This means that the status of upcoming blocks can be sent continuously in real-time and directly to the driver thus eliminating point to point transition. This way of data transition makes the use of trackside optical signals redundant and therefore ETCS Level 2 does not require any traditional Swedish signals (Trafikverket 2019c).

ETCS can be divided into two parts, the onboard part (ETCS On-board) and the trackside part (ETCS Trackside). ETCS On-board is the part of the system that is located onboard the vehicle. This system communicates with the train, the drive and on-board recording devices. The On-board system consists of the following components (European Commission 2020c):

- Euro Vital Computer (EVC)
- Driver Machine Interface (DMI)
- Train Interface (TI)
- Juridical Recording Unit (JRU)
- Balise Transmission Module (BTM)
- GSM-R antenna and an Odometer.

All the mentioned components communicate with the EVC, making it the core of the ETCS onboard device. The EVC is part of the Automatic Train Protection logic and interacts with all other train functions. The DMI is the interface between the ETCS and the Driver in the form of (in most cases) an LCD touch screen panel with control and indication functions, allowing the driver to communicate with the system and get visual information (*Ibid*).

The TI makes it possible for the ETCS to issue commands and exchange information to the rolling stock, thus allowing the driver to control the vehicle through the ETCS onboard system. The JRU is the train equivalent to a “black box”. This component stores important data and variables from train journeys, allowing later analysis. The BTM’s task is to process signals received from the onboard antenna and retrieve application data messages from a balise, the BTM works as an intermittent transmission between track and train. An odometer is used for calculating the distance run by the train. This system commonly consists of redundant tachometry and radar which are used to calculate distance, acceleration, and train speed (*Ibid*).

The trackside system of ETCS consists of (European Commission 2020c):

- Euro-balise
- Radio Block Centre (RBC)

The Euro-balise is an electronic transponder placed between the rails, storing data about speed limits, position, gradients etc. The data is either fixed or switchable depending on use. Euro-balises are passive devices meaning that they do not require any external electric supply to transmit data, instead the device gets energized through the BTM upon passage (European Commission 2020).

Balises on lines equipped with E2 usually function as a position maker to update the RBC on the position of the train. The balises are installed in balise groups, a balise group contains two or more balises. Each balise can transmit a telegram (data), and the combination of telegrams from multiple balises in the same group creates a message. As E2 lines are based on Euro radio for track to train communication, the Eurobalises (in general) only contains data for location referencing (European Railway Agency 2016).

The RBC functions as a centralised safety unit. The device receives train position information, sends movement authorisation and other information required by the train for its movement via GSM-R. The RBC obtains signalling-related information, route status and other information through the interaction with the interlocking. It can also manage the transmission of selected trackside data and it has the ability to communicate with adjacent RBCs (European Commission 2020c).

2.3 Track Circuits

Track circuits are used to control and check the status of track sections (i.e. if the section is occupied or not). The tracks circuit consists of a circuit that is connected to a relay. The relay is kept open as long as the circuit isn't disrupted. When in the open state the track circuit will indicate that the section is not occupied. This setup creates a failsafe system where if the power is disrupted the tracks circuit automatically indicates that the section is occupied. (Trafikverksskolan 2019b). E2 will continue to utilise this type of detection system, as it is a fundamental system that will not require to undergo any changes during the transition from ATC-2 to E2. In doing so, the existing signal blocks and associated infrastructure will remain unchanged.

The track circuit system consists of two parts, the circuit feeder and the circuit receiver. The purpose of the feeder is to supply the track circuit with power and provide the necessary resistance needed for the relay to close the circuit should it be disrupted. There are currently two types of feeder in use by Trafikverket, track circuit feeder with and without batteries. Although different, both variants use the following components: a rectifier used to feed the circuit with direct current, a variable resistor used to set the required amount of resistance for the relay to switch state, and a parallel coupled choke coil to filter out current from the overhead catenary system. Additionally, the feeder with batteries also uses a circuit breaker to protect the batteries from a current surge and is also connected to the rectifier allowing for constant charging of the batteries. To keep the two types of feeder's electrical properties as identical as possible the other type of feeder simply uses a resistor in place of the batteries to add similar resistance provided by the batteries (Trafikverksskolan 2019b).

The receiver section of track circuits has three necessary components: a JRK relay, variable resistor and a series choke coil. The resistor and choke coil protect the relay in the circuit from excess power, as they can vary the amount of resistance depending on the frequency of the electricity passing through (Trafikverket 2019d). The relay’s function is to tell if a track section is occupied by a train or not, as the relay loses power if a train is currently within a section.

The choke coil is required on electrified sections of track if the track circuit is part of a switch and said switch has electric heating and/or the track circuit is longer than 40 m (*Ibid*).

For sections of non-electric track, the requirement of having a choke coil on receivers where the circuit is longer than 40 m does not apply, and the coil is therefore only necessary in switches. However, sections of non-electrified tracks have additional components in track circuit receivers that are not required in receivers on electrified sections of track. They are excess voltage protection from lightning and external main ground bar, ground stakes or other earth electrodes (*Ibid*).

3 Description of Core Network

The Core Network in Sweden is a part of The Scan-Med corridor, one of nine corridors part of the Trans-European Transport Network (TEN-T). TEN-T addresses the implementation of a European-wide transport network to remove bottlenecks, technical barriers and close gaps whilst strengthening economic, territorial and social cohesion in the EU (European Commission 2020e). The Swedish Core Network also includes railway lines and hubs that are considered the most important in Sweden and lines connecting Sweden with other countries (Trafikverket 2020c). These lines are presented in Table 1 and Figure 1 below.

Table 1 Core Network Lines and their operating signalling system as of 2020.

Line Number - Railway Line	Signal System	Line Number - Railway Line	Signal System
01 - Västra Stambanan	ATC-2	22 - Stockholms närområde	ATC-2
02 - Södra Stambanan	ATC-2	23 - Göteborgs närområde	ATC-2
03 – Västkustbanan	ATC-2	24 - Malmö närområde	ATC-2
05 – Ostkustbanan	ATC-2	26 - Godsstråket genom Skåne	ATC-2
07 - Stambanan genom Övre Norrland	ATC-2	27 - Stockholm övrig	ATC-2
08 - Norra Stambanan	ATC-2	28 – Botniabanan	E2
09 - Godsstråket genom Bergslagen	ATC-2	29 – Haparandabanan	E2
11 - Norge/Vänernbanan med Nordlänken	ATC-2	31 - Ådalsbanan	E2
12 – Värmlandsbanan	ATC-2	49 - (Kilafors) - (Söderhamn V)	ATC-2
21 – Malmbanan	ATC-2	58 - (Södertälje hamn) - Södertälje Centrum	ATC-2

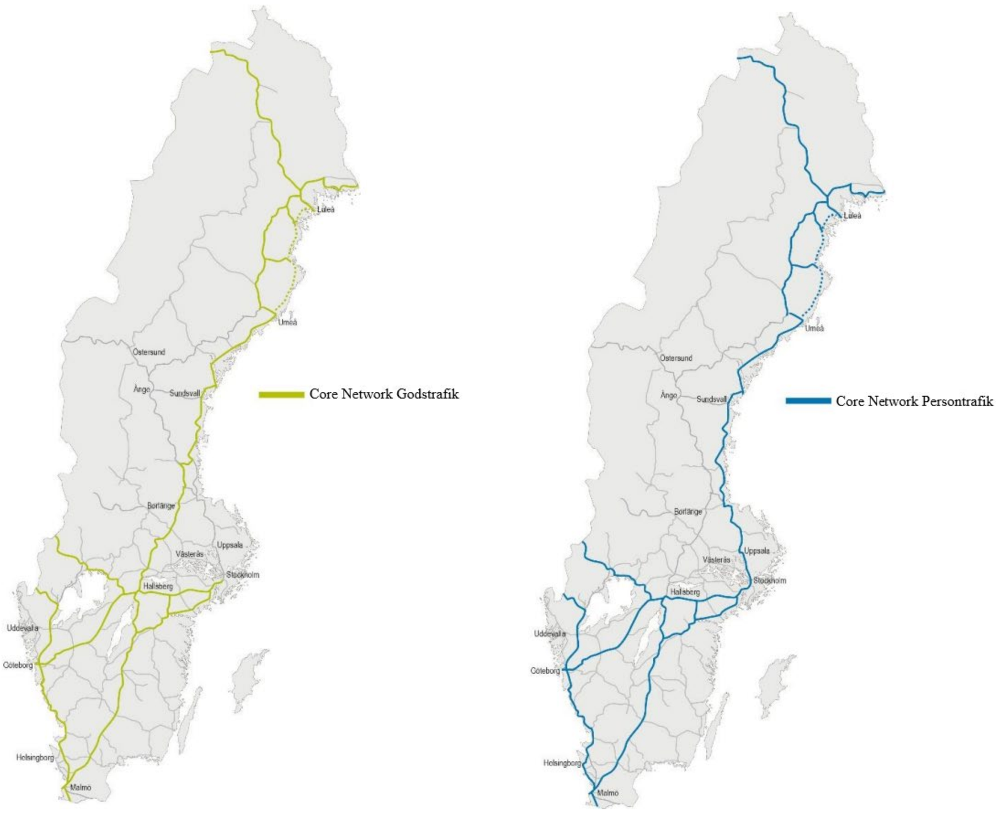

Figure 1 Core Network (Left side Freight traffic, Right side Passenger traffic) Source: Trafikverket

3.1 Lines Equipped with ERTMS

Each of the railway lines that operate today in Sweden with ETCS Level 2 has all either gone through refurbishment alongside the installation of ERTMS or have recently been built. As shown in Table 1, these are the Ådalsbanan, Botniabanan and Haparandabanan. Each railway line is however only single-tracked. Overall, the infrastructure for these lines is considerably more modern than the remaining railway network in Sweden. Technical specifications for the E2 lines can be found in Table 2 below.

Traffic on the lines follows a similar structure (except for Haparandabanan), with mixed traffic. The main operators for passenger services are Norrtåg and SJ, whilst the cargo operators on the lines are Green Cargo and Hector Rail.

However, these lines do not represent the full scope of the Core Network, as none of the lines sees dense traffic flows and they do not connect to any important hubs on the Swedish railway network.

Table 2 Technical data for the Swedish ETCS Level 2 Lines (Trafikverket 2019e, 2019f, 2020d)

Technical Data			
	Ådalsbanan	**Botniabanan**	**Haparandabanan**
Track Type	Single Track	Single Track	Single Track
Electrified	Yes	Yes	Yes
Traffic Management System	E2	E2	E2
Communication System - GSM	Yes	Yes	Yes
ETCS	Yes	Yes	Yes
Line Category	D2 Stax 22.5t Stvm 6.4 t/m	E4 Stax 25t Stvm 8t/m	E4 Stax 25t Stvm 8t/m
Type of Traffic	Mixed freight and passenger	Mixed freight and passenger	Freight
Permitted Speed	200 km/h	250 km/h	250 km/h

Figure 2 Ådalsbanan. Source: Trafikverket 2020e

Ådalsbanan, originally constructed between 1890-1925, is a 180 km long line that runs north from Sundsvall to Långsele alongside the east coast of the Gulf of Bothnia. Trafikverket refurbished the line between 2003 to 2012 south of Västeraspby and equipped the line with ETCS level 2. The newly refurbished section of the line was inaugurated in September of 2012 and has not received any major upgrades since. The northern section of the line between Långsele and Västeraspby is described by Trafikverket as being in a very poor condition. This section only sees limited freight traffic and is not equipped with any line block system (Trafikverket, 2020e).

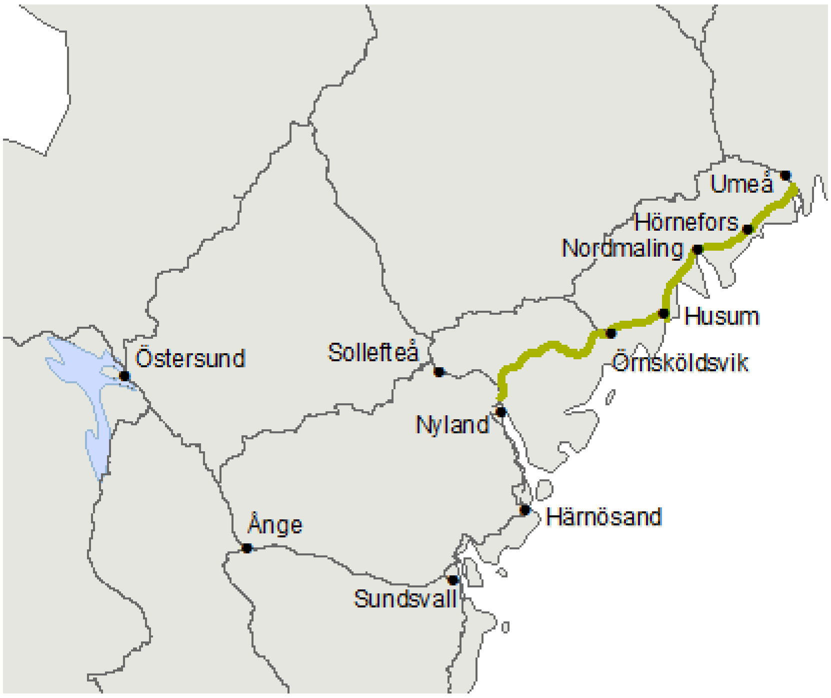

Figure 3 Botniabanan. Source: Trafikverket 2020f

Botniabanan is located on the east coast of northern Sweden. The line is 190 km long and runs north from Nyland to Umeå passing several towns along the coast. Botniabanan is so far one of the biggest railway infrastructure projects in Sweden. The line was completed in 2010 and is one of the first lines equipped with ERTMS in Sweden (Trafikverket, 2020f).

Figure 4 Haparandabanan. Soure: Trafikverket 2020g

Haparandabanan is located in the north of Sweden and runs between Boden to Haparanda and the Finnish border. The line is of significant international interest as it is the only connection by rail between Sweden, Finland and subsequently Russia. The line is an important link for freight transportation between northern and southern Sweden. Recently, a new 42 km long section of the line between Bredviken and Haparanda was refurbished (Trafikverket 2020g)

4 Method

The following sections describe the methods utilised during the different parts of the study. The overall method used was a qualitative study method, selected based on data available.

4.1 Document Study

Documentation about technical data for ERTMS was gathered online from the European Commission websites/database. For acquiring technical data on ATC-2, the documentation from Trafikverksskolan’s (a school part of Trafikverket) signalling course for engineers was used to gather information, with additional documents from Trafikverket.

To obtain data on reliability for ERTMS in Sweden, Trafikverket’s reports on service monitoring was utilised. These reports are published by Trafikverket to present analyses and results which are used to evaluate the quality of service of the ERTMS system (Trafikverket 2018). The data published within these reports come from the Core Network, and it includes data for ATC-2 and ERTMS lines. These reports are ordered by the Swedish government to be published yearly by Trafikverket (Infrastrukturdepartementet 2020). The method used for analysing the data collected from these reports is that of a meta-analysis, were the results published within the reports are compiled and valued for further analysis. Data from these reports were collected visually from the included figures (See Attachments Section 10.4), this could lead to an increase in statistical errors in the produced figures (Figure 8 to 11). All reports retrieved from Trafikverket are listed below in table 3.

Table 3 Documentation used for Reliability Study. Source: Jacob Månsson and Kristoffer Wallenbro

Researched Documentation	Document ID
Projekt ERTMS Årsrapport 2016	TRV 2017/40851
Projekt ERTMS Årsrapport 2017	TRV 2018/40275
ERTMS-tillförlitlighetsrapport	ERTMS17-234
Driftuppföljningsrapport ERTMS-projekt	ERTMS18-945
Årsrapport 2018 - Driftsuppföljningsrapport ERTMS-projektet	ERTMS19-0315
Årsrapport 2019 Driftuppföljningsrapport ERTMS-program	ERTMS2020-0129

The reports on service monitoring have been published since 2012, but data from 2016 and onwards has been utilised as the later ones include data published by the earlier reports. The reports published in 2017 and 2018 (with the IDs TRV2017/40851 and 2018/40275) contains a broad oversight of the implementation process, while the other reports focus on service monitoring and the current state of reliability on the railway network.

The following list shows what data is presented in each report. As more data becomes available over time or the time scope of certain reports are shorter than others, some data is not presented in every report. Each report that has a specific kind of data has its document ID listed next to the listed data. If all reports contain a data source, it will say All. They include data on:

- Deviations per technical aspect/causation (All) - All deviations that occurred during the time period that the graph in each report covers. The ones requiring remedial maintenance are later elaborated on more under faults per track km etc.
- Faults per track kilometre (All) - The average amount of faults based on total track length of each subdivision of the Core Network.
- Delays per train kilometre (All) - Total delay time based on train km, were train km is the total length a train travel.
- Delay minutes and number of delayed trains per fault (All)
- System faults per ten train trips. (ERTMS19-0315 and ERMTS2020-0129) - Number of faults were a train had to brake to a complete stop and then restart its onboard system. Data for the ERTMS lines are only available, as the surveillance system for ETCS and GSM-r (GSM) does not catch faults that occur on ATC-2 lines.

The reports also contain statistics on track, telecommunication, signalling, overhead equipment (OHLE) and miscellaneous faults (faults that have not been able to be categorised), as to demonstrate the other differences between lines part of the Core Network.

4.2 Interview Study

To expand the information gathered during the document study, semi-structured interviews were performed with representatives from SJ AB, Trafikverket and Infranord. The interviews were performed to get more facts on the data gathered during the document study and to get each sector's viewpoint on the transfer from ATC-2 to ERTMS.

Before each interview was conducted, a list of questions was sent to each interview participant to prepare for their interview. They were also notified that other possible questions may be brought up during the interview should any additional questions from the authors arise. Each interview began with the participants conducting a brief presentation about themselves.
Each question was then presented to the interviewed party, which was followed up by the interviewee's answer and discussion surrounding said answer. After all questions had been presented that had been emailed to the interviewed party beforehand, any other questions that had surfaced during the interview or the days before the interview were presented and discussed. Out of the three interviews, two were recorded by computer software (Trafikverket and Infranord) and one was recorded by pen and paper (SJ AB).

The individuals who were interviewed at SJ AB were a technical specialist at and a senior engineer. Both have been working with ERTMS at SJ AB since 2008. For the Infranord interview, a signal supervisor who has been working as a signal technician for 35 years and as a signal technician supervisor for the last 15 years participated. Simon Tafreshi, who is a technical specialist in the ERTMS program at Trafikverket, participated in an interview concerning questions related to the work of Trafikverket.

4.3 Analysis

General workflow and process

The general process of the analyses can be summarised with the following figure:

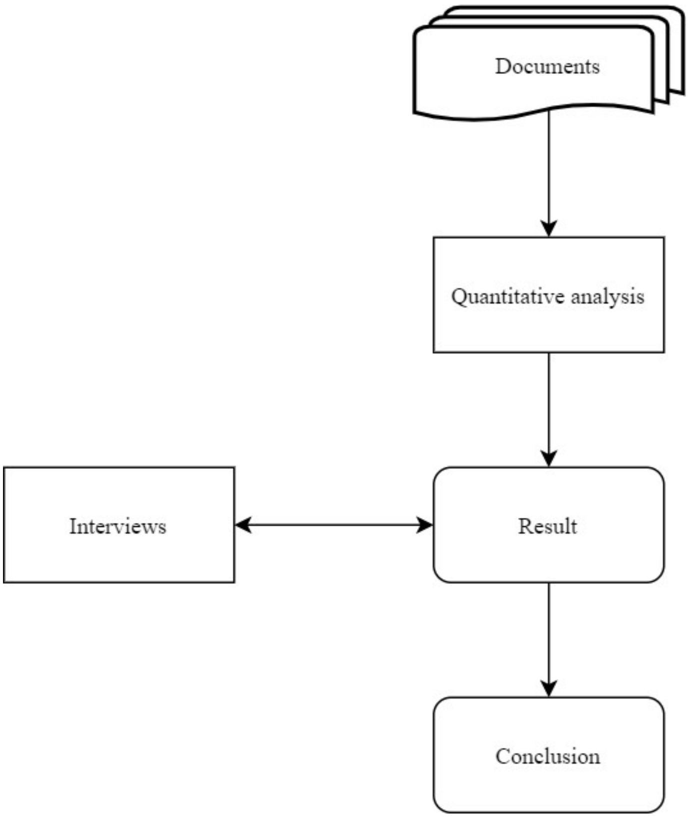

Figure 5 General Workflow. Source: Jacob Månsson and Kristoffer Wallenbro

The figure illustrates that the process was not entirely linear with a clear start and endpoint. The data from the interviews were used as a feedback loop and were compared to the data from the documents and vice versa. It was especially important to do to formulate the results but also to strengthen the conclusion.

Data Analysis Method

A qualitative analysis was conducted to process the collected data form the document study. The goal of this analysis was to answer the questions: "How does reliability on railway lines that operate with ETCS Level 2 compare to ones that operate with ATC-2?" and "What issues with reliability for ETCS Level 2 can be traced to technical components or aspects within the system?". To do this, data from all documents were summarised to get a broader perspective and time scope over the total period studied.

The documents covered a total period of 4 years with some overlapping data due to varying document content. Data from all the categories (see section 4.2) was studied over this period and any problem identified in the data was noted. The period is important to determine the scale of any problem found in the ERTMS reliability data as well as identify possible causes to said problem. When processing the data, the following aspects where considered:

- **Earlier Fault** – Have problems appeared earlier and have there been any improvements since they were initially found?
- **Corrected -** Are there reliable indications that the problem has been corrected?
- **Unique** – Are there problems with the technical aspect of the system unique or is it a common issue for both ATC-2 and ETCS L2? This is to highlight potential new problems that the previous system did not have.
- **Other Factors** - Are the problems caused by the effects of an outside source for example unusual weather or faulty installations etc.?
- **Frequent** - Is the problem continuously resurfacing or does it occur sparingly?
- **Impact on Reliability** - Does the problem cause issues for the reliability of the signalling system?

The goal of this process is to filter out data not relevant to the scope of this thesis. This is done because of the stated scopes and limitations (see Section 1.4 Scopes and Limitations) as they lay as a basis for the type of data studied.

In order to further expand the groundwork for this thesis, supplementary semi-structured interviews were conducted. To perform the semi-structured interviews, the following method (Figure 6) was used to generate relevant questions for the interviews. The process aims to further elaborate on the problems discovered in the document study done previously.

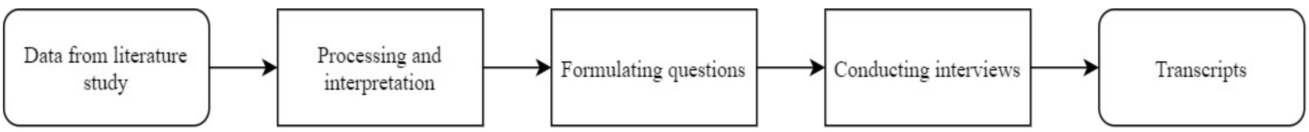

Figure 6 Description of Interview Process. Source: Jacob Månsson and Kristoffer Wallenbro

By processing the data from the document study questions where formulated to better understand the data, but also to further the research of ERTMS reliability. The data kept from the conducted interviews are presented in the form of transcripts containing both questions and answers. The questions formulated build largely on the results from the document study (see Section 5.2), intending to acquire more data for the thesis and particularly to answer the questions stated in scopes and limitations.

A thematic analysis of the transcript was performed to process the information from the conducted interviews.

Firstly, the interesting and relevant topics mentioned during the interviews were highlighted so that all-important details could be marked in the transcripts. This process aims to highlight and briefly summarised each interview and is commonly known as “coding”. (University of Auckland 2020)

Secondly, the highlights for the first step where categorised and all the highlights were organised into relevant groups or “themes”, where categories can be compared and similarities in the results can be showcased. The results from this process are then further analysed with the same process as the data from the document study described above.

5 Result

5.1 Document Study Result

The three latest published service monitoring reports by Trafikverket laid the groundwork of the document study (Trafikverket 2018, Trafikverket 2019g, Trafikverket 2020c), as these reports covered what the earlier published ones did with additional new data. Out of these reports, one presented a half-year report (Trafikverket 2018), whilst the other two presented a yearly report (Trafikverket 2019g, Trafikverket 2020c).

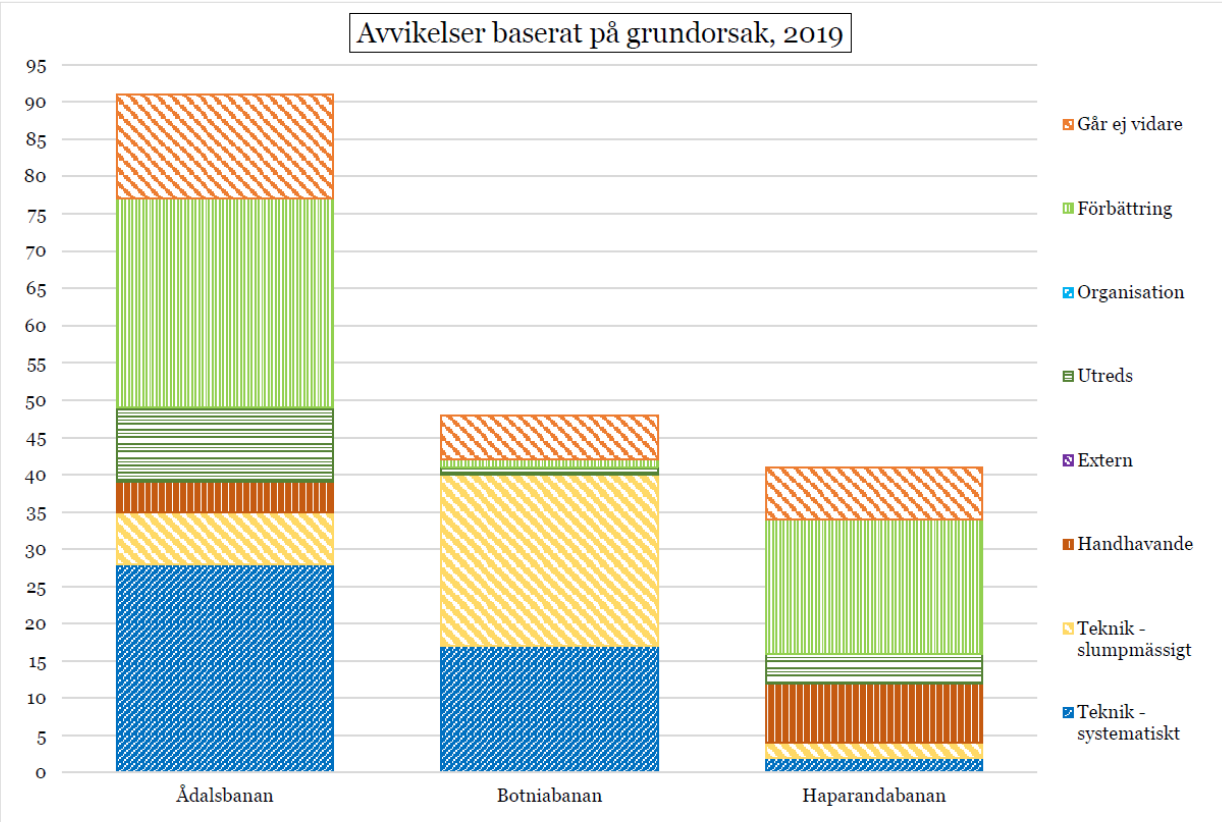

Figure 7 Deviations based on Cause (Source: Trafikverket 2020c)

Figure 7 shows how the statistics are presented in the service monitoring reports. This diagram presents the deviations based on cause during 2019 for the E2 lines. This data, along with data on faults per track kilometre, delays per train kilometre and system faults per ten train trips, laid the groundwork for the collection of data during the document study. The other diagrams from the other reports and categories can be found under attachment Section 10.4.

As mentioned earlier under Section 3.2, the faults that are further elaborated on in the reports are the ones that needed remedial maintenance, or in the case with faults that concern the onboard system on trains, requiring the train to stop completely and then restarting its system (Trafikverket 2020c).

The reports include total track length and the monthly average of total distance travelled by trains on the Core Network. These are the values that Trafikverket uses for each report to calculate the statistical data. These values help to illustrate network size and traffic flow differences between E2 and ATC-2. Data for E2 and ATC-2 lines are separately presented below in Table 4:

Table 4 Values used by Trafikverket for data calculation. Source: Jacob Månsson and Kristoffer Wallenbro (Trafikverket 2019g, Trafikverket 2020c)

Report ID	Track Length (ATC-2)	Average Train Km/Month (ATC-2)	Track Length (E2)	Average Train Km/Month (E2)
ERTMS19-0315	3382	8442765	465	272189
ERTMS2020-0129	3382	8570434	465	275814

It is important to note that all the data published within these reports are statistical, and therefore do not go into the depth of causes of the faults. Thereby justifying the need to do more in-depth research through interviews.

The deviations presented by Trafikverket were used as a data source since these are results from their internal analyses of the E2 lines during normal service (Trafikverket 2020c). Deviations help to indicate faults with the system, where the deviations are based on various causes. The causes that are presented by Trafikverket are (Trafikverket 2019g):

- Technical Systematic – A deviation caused by a failing function within the system itself.
- Technical Random – A deviation where remedial maintenance is needed to fix it. The nature of the deviation is “random” as the fault is unforeseen.
- Human Error
- External – A deviation caused by an outside source, for example lightning.
- Under Investigation – A deviation which cannot be classified when the report was published and was therefore still under investigation.
- Organisation – A deviation caused by poor communication at an organisation level.

- Improvement – A deviation which meets requirements but not it's specified functionality.
- No Information – A deviation where information about it is lacking and therefore excluded.

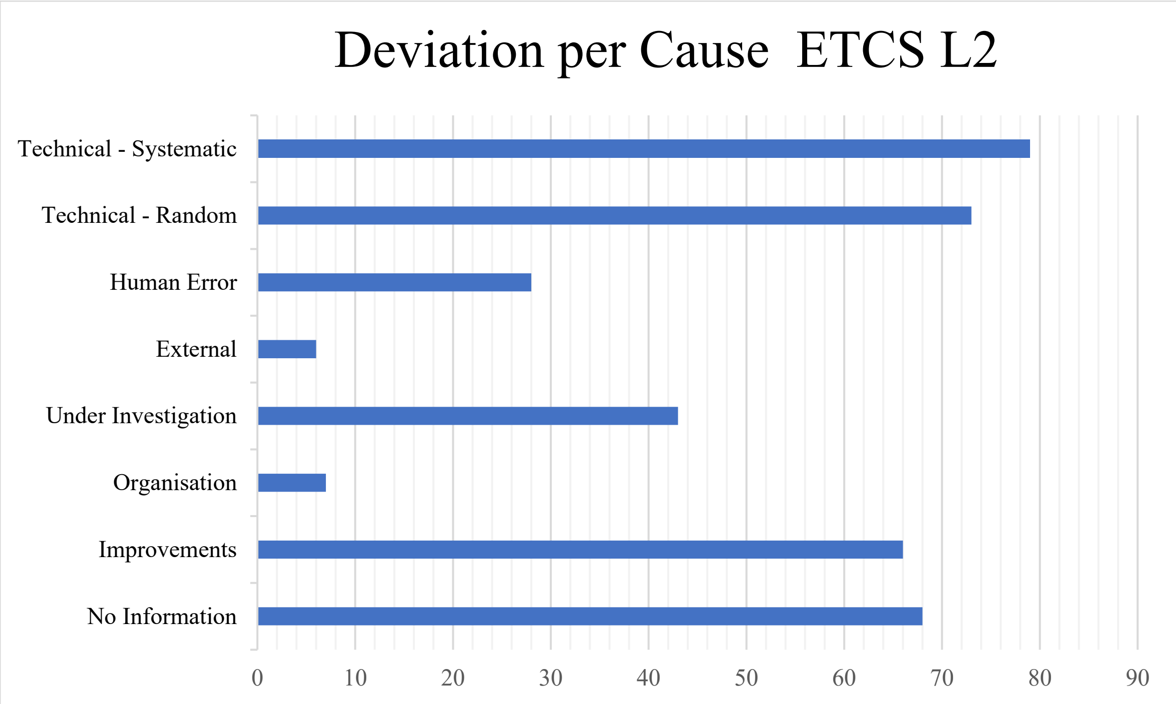

Figure 8 Summary of Deviations based on Cause. Source: Jacob Månsson and Kristoffer Wallenbro

Figure 8 presents the document study's result of collecting data on deviations presented by Trafikverket. The deviations cover a period from July 2017 to December 2019, as deviations per cause were only registered for half of 2017 in the documents studied (Trafikverket 2018). Technical – Systematic is the most common occurrence of deviation during this period, but there is not a big gap between Systematic and other common deviations. Deviations that belong in the categories of Organisation and External rarely occur. The total number of deviations during this period amounts to 370.

Figure 9 is the summarised total number of faults per 1000 track kilometres. These faults get categorised into the different technical components that fault and they are the following (Trafikverket 2020c):

- Train Dispatching
- Signage
- Signal
- Level Crossing
- Positioning System
- Balise Group
- Signalbox/RBC/Line Block Systems

To clarify, under the category Signalbox/RBC/Line Block System, RBC refers to ERTMS lines whilst Line Block System refers to ATC-2 lines. Both functionalities share a similar function and are therefore grouped. Positioning System refers to faults caused by track circuits.

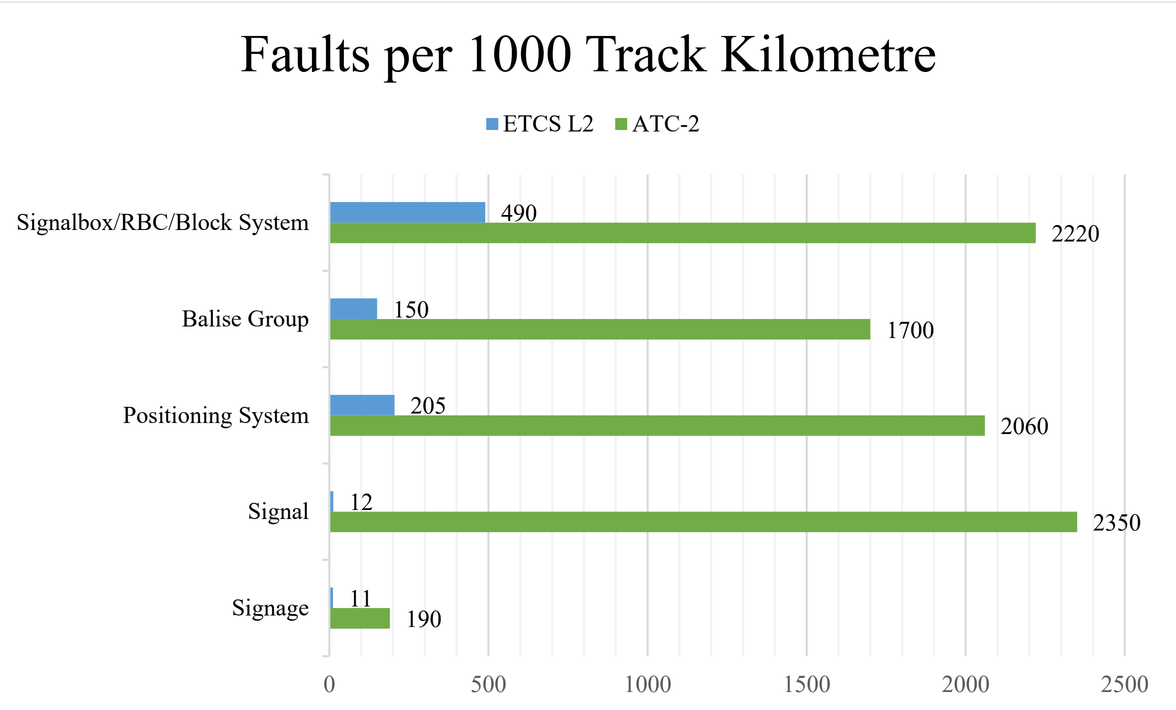

Figure 9 Summary of Faults per Track Kilometre. Source: Jacob Månsson and Kristoffer Wallenbro

Faults related to Train Dispatching and Level Crossing have been excluded as they do not fit into the scope of this thesis. The period Figure 5 covers spans from January 2017 to December 2019 (Trafikverket 2020c). During this period, the most common occurring fault for the E2 lines comes from Signalbox/RBC, whilst for ATC-2 the optical signalling system holds the biggest share, although the differences between Signal and Signalbox/Line

Block System faults are small. In total, the E2 lines have had 868 faults and the ATC-2 lines have had 8520.

In Figure 10, the Delays per 1000 Train Kilometres are presented. These are delays in minutes attributed to the same technical components as in Faults per Train Kilometre in Figure 5. They also cover the same period from January 2017 to December 2019. The delays are counted after a train is at least three minutes late.

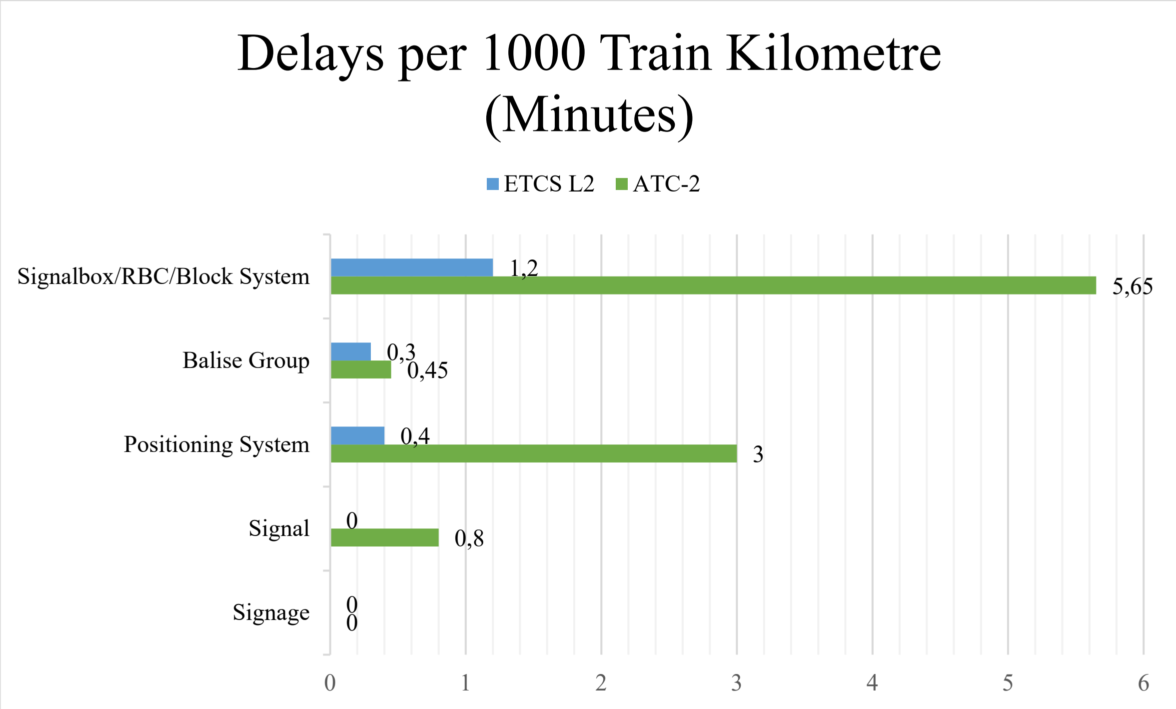

Figure 10 Summary of Delays in minutes per 1000 Train Kilometre. Source: Jacob Månsson and Kristoffer Wallenbro

This presents an odd result, as the delay time for balise groups is almost identical between the two systems, whilst the number of faults on the ATC-2 network concerning balises is much higher than that of the E2 network (see Figure 5). This is due to a fault that occurred in 2018, but further analysis of said fault done by Trafikverket concluded that it was not a balise group that had caused the error, but rather the On-Board Unit (OBU) of a train (Trafikverket 2018).

The final source of data collected during the document study was Faults per 10 Train Trips. These are faults where the train has to slow down to a stop and then restart the ETCS-onboard system. All the statistics come from E2 lines and only include trains equipped with ETCS-onboard. The trains are divided between ones that had ETCS-onboard when it was designed (green), and ones that did not (blue). See Figure 11.

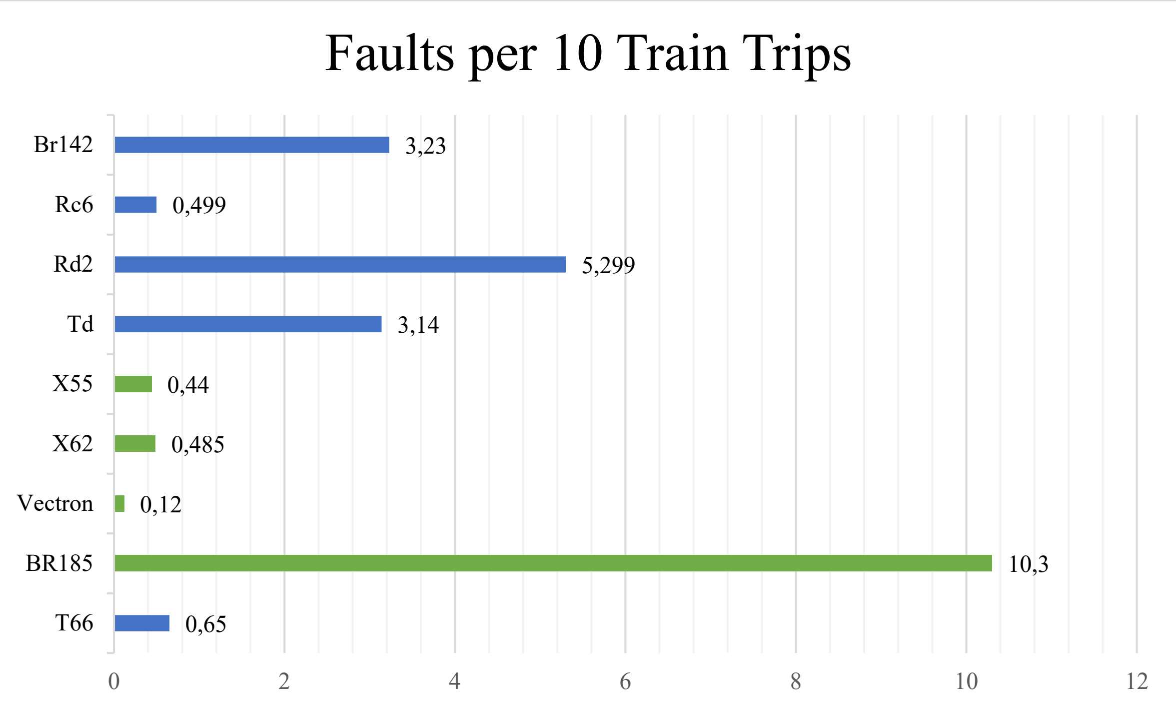

Figure 11 Summary of Faults per 10 Train Trips. Green trains were designed with ERTMS, blue trains had it installed at a later point. Source: Jacob Månsson and Kristoffer Wallenbro

It is difficult to pinpoint how accurate these values are, as the exact number of trips for each train is unknown. The trains used for passenger services are the X55 and X62 electric multiple units (EMU) operated by SJ AB and Norrtåg respectively and Rc6 locomotive operated by SJ AB. All other locomotives are operated by cargo operators on the E2 lines. BR185 stands out as having the most faults, with approximately 1,03 faults per trip. It is not clear if this anomaly is because the train travels on the lines less than the other train types or if the class has had issues with its onboard system. The period for Figure 11 spans from October 2018 to December 2019.

5.2 Interview Study Result

This section presents the results of the thematic study and short summaries of the interviews. For the full transcripts of the conducted interviews see Section 10.

The tables (Table 5 and 6) below present the results from the thematic analysis, with the negative statements in the first table and positive statements in the second table to highlight and differentiate the different opinions and statements for each interviewee. The tables also highlight opinions and statements shared between interviewees (Marked in red for table 5 and Green for table 6). The results are divided into two categories *Hardware* and

System/functionality, this is done to differentiate different types of issue and to better link and group similarities in the results. The results are gathered from interview data in the form of transcripts.

Table 5 Interview study results negative statements. Source: Jacob Månsson and Kristoffer Wallenbro

Hardware	**System/Functionality**
Trafikverket	Trafikverket
Loose balise mounts Bad contact between balis and train antenna Moisture damage for class B balise	Possible critical faults with signal box/RBC
SJ	SJ
Difficulty with space requirements for retrofitting rollingstock	Lacking an optical backup system More restrictive breaking curves Negative impact on capacity Time-consuming to install new system updates Lack of time to implement new software updates due to short notice Frequent updates are not desirable
Infranord	Infranord
Issues with loose balises	

Table 6 Interview study results positive statements. Source: Jacob Månsson and Kristoffer Wallenbro

Hardware	**System/Functionality**
Trafikverket	Trafikverket
No reconstruction needed for signal box M95	Balise groups redundancy
SJ	SJ
	Easier to report balise faults
Infranord	Infranord
Easier maintenance	Balise group redundancy
Easier balise removal	Faster remedial help

Trafikverkets describes that the main issue discovered with ERTMS is problems related to the Euro-balises. It was discovered that a specific type of the balises had problems with moisture damaged, this problem has since been addressed by Trafikverket and is now resolved. Furthermore, it was found that some balises had dislodged from their mountings or accidentally been hit by maintenance vehicles. This is however not very frequent, and the new systems overall performance is satisfactory without any major problems.

SJ AB expressed concerns about the ERTMS performance and that it might be subpar to that of ATC-2. They were concerned that ERTMS might not offer the same capacity as ATC-2 due to the way the system functions in some situations. Furthermore, the way the system updates are handled can become problematic and costly for the train operators. In conclusion, the interviewees were sceptical to the new system and its performance.

According to the interview at Infranord, the ERTMS system is, in general, easier to maintain. It is both easier and faster to perform remedial help and compared to ATC-2 the need for large stock holdings of spare parts is reduced. So far ERTMS is an improvement over ATC-2 from a maintenance perspective. The only problem discovered so far is the Euro-balise fastener, for some unknown reason, the balises can come off their mountings and in some cases dislodged entirely from the sleeper. This aside, the overall performance of ERTMS from a maintenance perspective seems to be positive.

6 Analysis

After the document study and interview study were complete, the analysis of issues discovered during these processes could take place. Through the process, results from both study processes were used to form the basis of the argumentation presented in this chapter. The issues found during the study processes that could affect reliability for ERTMS are presented below.

6.1 Lack of a Backup System

This issue became apparent in the interview study but has also been highlighted by Smith et al. (2012) where the need of a backup system was required due to the existence of many versions of ETCS with varying technical problems.

The lack of a backup system for ETCS E2 is categorised as unique (see Section 4.3) and is due to the way the systems functions in conjunction with ATC-2, which utilises optical signalling and where there exists a backup in case of balise failure. As mentioned in Section 2.2, the system uses encoders that read what signal aspect is displayed and transfers that information to the signal's balise group. Should a communication error occur, resulting in insufficient communication between the train and trackside equipment (on both E2 and ATC-2) the trains permitted speed will automatically be reduced as the driver no longer has the information required for speeds greater than 80 km/h (Transportstyrelsen 2010). This is where ATC-2 differs from E2. The driver now has the option to turn off the onboard system altogether and drive only using the optical signals. This theoretically limits the drive to a maximum speed of 80 km/h but enables the train to proceed on the train route using conventional signals. But on E2 equipped line, the train automatically reduces movement authority mode to On-Sight.

This limits the trains permitted speed to 40 km/h, thus further restricting the speed compared to ATC-2. Additionally, due to the way train routing is done on ERTMS the train only gains movement authority to the next balise group. The lack of any optical signals as a backup system separates E2 from ATC-2 in terms of back-up functionality.

E2's greater speed restriction and limited train routing can be factors that will contribute to lower reliability and capacity should a complete balise loss occur, according to the technical specialist at SJ AB (2020). This problem is not necessarily due to ERTMS and system reliability, but rather an issue for operational reliability for operators who currently drive with the restrictions provided by ATC-2. If On Sight Mode is activated, the lower speed restriction of 40 km/h may cause longer delays than necessary compared to ATC-2. Also, the time to clear a block section is subsequently increased and thus increasing the likelihood of the line becoming congested (Abril et al. 2008). Moreover, the train's movement authority may also add additional delay time as it must be manually provided for each block section until the problem is resolved. This highlights the key difference between ETCS L2 and ATC-2, were ATC-2 has significantly lower speed restrictions (permitting speed up to 80 km/h) in similar scenarios due to the presence of the optical signalling system.

The data published in the service monitoring reports indicates that this issue is currently not a problem on the E2 lines. When combining the data from Figures 9 and 10 it shows that there may be some balise faults on the E2 lines, but these do not cause long enough delays (lower than three minutes) to be registered. This questions then the need for an optical backup system, as the optical signals themselves have caused faults and delay time for the ATC-2 lines (however it is unknown if the faults are caused by an aging system and the possibility of reduced number of faults should occur if a new system is installed).

6.2 Balise Issues

The faults related to balises have been present during the entire time period studied. The characterisation of the faults, using the aspects present in Section 4.3, were Unique or caused by Other Factors. The issues are not frequent, but it is not clear if the faults could cause an impact on system reliability.

During March 2018, there was a large increase in delays per train kilometres caused by balises (Trafikverket 2018), without a clear increase in faults per track kilometres during said month when compared to the rest of 2018. The total time for the delay counted upwards of 746 minutes, however, only 35 of these minutes occurred on the Swedish ERTMS network according to

Trafikverket’s own service monitoring. The same monitoring also indicates that the deviation was caused by the OBU-system (Onboard Unit) (*Ibid*).

A majority of balise errors that occur on the ERTMS network are random errors, which often means hardware related issues. This includes errors caused by work vehicles used by maintenance entrepreneurs hitting balises, that the balises attachments are not properly attached and in cases of the locomotive’s antenna not getting a correct static contact with the balise, although the balise faults that currently occur cannot be precisely attributed to a cause (Tafreshi 2020).

What Trafikverket noticed was that Euro-balises tended to have a seasonal problem with humidity. After studying the problem, Trafikverket concluded that Euro-balise class B was more sensitive to humidity, and purchases of that balise class are no longer possible (Tafreshi 2020).

The faults caused by balises on the ERTMS network can be classified as what Trafikverket describes as a random fault. These are not “random” but is a fault which Trafikverket defines as an error requiring remedial maintenance (Trafikverket 2020c). This theory is strengthened by the interview with Trafikverket (Tafreshi 2020). Similarly, the reports published by Trafikverket also show that the majority of Euro-balise faults are random faults, but there are also occurrences where the errors are caused by human faults (Trafikverket 2018). The reports also show that over time the number of balise faults have not increased, which could also point to that the faults are not systematic as a growing number of faults could implicate issues on a technical level (Trafikverket 2020c), as was the case with balise class B that was very sensitive to humidity (Tafreshi 2020). Through the interview with Infranord there is more evidence to point to that the faults are of a random hardware-related character (Infranord 2020). Most faults that are related to balises have been hardware related.

There is evidence that the ETCS balises have better functionality than that of ATC-2 balises. Having only a fixed type of balise makes it easier for maintenance companies to maintain the system (Infranord 2020), instead of having the ATC-2 system of two types of balises, fixed or programmable, and having encoders. Eliminating the latter two items suggests a reduction of complexity within the system, thereby improving the quality of maintenance. Through the interviews with Trafikverket and Infranord, both parties concluded that the ETCS balises do not suffer from systematic errors on a scale which could impact reliability negatively (Tafreshi 2020, Infranord 2020). The only systematic issue with the balises that has surfaced during the research period for this thesis was balise Class B’s sensitivity to humidity

(Tafreshi 2020). This was solved through Trafikverket by restricting purchases and new installation of said balise class. In general, common issues such as lightning strikes affect both ETCS and ATC-2 balises equally, as this is due to the difficulty of dealing with said problem. However, the recurring problem for ETCS balises is hardware-related problems of loose balises that both Trafikverket and Infranord cannot point out a specific cause for.

6.3 Retrofitting old rolling stock

It was discovered from the interview study that when equipping rolling stock originally built with ATC-2 with the new ETCS onboard equipment can require more space than previously available with the old ATC system. This is categorised as unique (see Section 4.3) and is related to the ETCS-onboard system for E2. According to the technical specialist at SJ AB (2020), the new ETCS onboard system requires approximately a base of 600x600 mm and a height clearance of 1200 to 1500 mm. Additionally, a further 600 mm is required to install systems for train operation in other countries (*Ibid*). This is a significantly greater volume compared to the space requirements for ATC-2 which the rolling stock was originally designed to be equipped with.

The new increased space requirements are most likely going to affect passenger traffic the most as available seat space is important for profitability (Andersson et al. 2017). Locomotive-hauled trains are the least affected as they typically have large machine rooms only designated for machinery and other equipment (*Ibid*). However, the use of Locomotive-hauled passenger trains in Sweden has been in decline since the year 2000, and in 2018, 86 per cent (or 2607 of 3084) of all the transport vehicles in passage traffic were either made up of multiple units or sets of multiple units (Trafikanalys 2019).

Equipping multiple units with ETCS is preferably done with the equipment installed somewhere where it does not affect the personnel area. Since the Trafikanalys statistics (Trafikanalys 2019) shows an increase in the usage of multiple units, this available space might become an issue. Multiple units often have their traction and other technical equipment installed in the undercarriage of the car body. A typical 26-meter-long car with two bogies and a floor height of 1 meter above top of rail has about 30-35 m^3 of available volume for technical equipment (Andersson et al. 2017, p 17-5). But because the available inner space is valuable for maximising capacity and operational revenue, the trend is usually to improve the use of inner space as much as possible. Therefore, the space available in the undercarriage is usually utilised to its fullest potential. This means that new equipment might have to be installed elsewhere and thus affecting the available personnel area (*Ibid*).

One solution is to distribute the new equipment throughout the multiple units. The new equipment can be placed under passenger seats and in luggage compartments. However, this solution often only works on vehicles with simpler chair designs and not on long-distance passenger trains. For example, on long-distance trains operated by SJ AB the space under their seats is not sufficient enough to place any ETCS equipment. This might lead to the removal of one or more seats to make space for the new equipment (SJ AB 2020). The typical inner floor area of a first-class seat for mid to long-distance travel is between 1.4 to 1.6 m^2 and 1 to 1.1 m^2 for second class (Andersson et al. 2017, p 17-5). This means that train operators can lose anywhere between 1.1 to 2.8 m^2 of inner floor area depending on the number of seats removed (one-second class seat or two first-class seats).

Another potential problem according to the technical specialist at SJ AB (2020), is the placement of the GSM-R antenna for E2 on the roof of the carriage. Because of the space restrictions between multiple antennas and between antennas and other equipment, finding suitable locations might become a problem when equipping rolling stock with ETCS. It is important to note that the onboard system for ETCS E2 does not have a clear effect on the operational reliability of a vehicle when compared to vehicles where ETCS E2 was preinstalled. This is made evident by the data from Trafikverket (see Figure 11) of vehicle faults showing only slight differences between vehicles with ETCS onboard preinstalled and vehicles retrofitted with the systems.

6.4 System updates on vehicles

This issue was brought up during the interview study. Similarly, to the issue with the lack of a backup system, it is an issue of operational reliability when compared to ATC-2, as ATC-2 lacks any kind of onboard system updates. Therefore, the characterisation of this fault is unique to ERTMS.

The onboard system on trains that run with ERTMS, in contrast to ATC-2 running trains, sees frequent updates. This is done by taking the train or locomotive that needs to update its onboard system out of service. The train is then taken to a depot, where a software engineer plugs a USB into the onboard computer to update the system. The train or locomotive will then need time to test if the update was installed properly. This process normally takes between one to three days to complete (SJ AB 2020).

When compared to ATC-2, were no significant updates are requiring similar procedures (SJ AB 2020), this has raised some concerns from the technical specialists at SJ AB. Here they cite that there is comfortability with having ATC-2 as that system does not need to be updated. They also state that updates do not tend to be warned about beforehand, but rather dropped on them with short notice (SJ AB 2020). It is also not a guarantee that the process takes one to three days, this is an approximation stated during the SJ AB interview which can be delayed further should a fault have appeared during the installation process (*Ibid*). This is unique to ERTMS and is systematically different form ATC-2, where ATC-2 was not constructed with frequent software updates in mind.

Data presented in Trafikverket's report from 2020 (which can be seen in attachment Section 10.4) shows that the trains that SJ AB operates with and has ETCS installed on are not the locomotives that register a system fault per ten train trips the most (Trafikverket 2020c). Here one can see though that the RC6 locomotives have a slightly larger number of faults when compared to SJ AB's only other train types equipped with ERTMS, X55 Regina. However, it does not prove that older locomotives are more susceptible to faults with the onboard system, as other more modern train types like the BR142 has a substantially higher number of faults (*Ibid*). Trafikverket also notes that it is difficult to conclude what causes the onboard system faults with the current system that the faults get reported to, and that a deeper analysis of the onboard system needs to be done (*Ibid*). With the existing statistics at hand though, it is possible to conclude that system updates do not cause too much disruption to reliability.

7 Conclusion

The technical differences between ATC-2 and ETCS Level 2 are substantial due to the way they operate. The absence of any optical signals and signage (except for section markers) creates a new way of traffic management and railway signalling thus requiring new systems. The introductions of the RBC and radio communication directly to the trains transferring movement authority is compared to ATC-2 very different. Besides these technical differences, E2 and ATC-2 still operate with some key similarities. Both systems utilize the Swedish track circuit/train detection system which is a part of the underlying interlocking system for both ATC-2 and E2, meaning that both systems are using some form of a more traditional line block system.

Since ERTMS' implementation onto the Swedish railway network, Trafikverket has published reports on Quality of Service. In these reports, data from Trafikverket's internal analysis of the system is published and general faults that occur on the Core Network's ERTMS and ATC-2 lines. Both categories of data indicate that ERTMS performs better than ATC-2. This is possibly due to ERTMS' components being newer than that of their ATC-2 counterparts, that ERTMS lacks technical components that ATC-2 has such as signals and that lines equipped with ERTMS are more modern and see less traffic. The technical components which ERTMS shares with ATC-2, such as the signal box and positioning system, are ones which perform worse in terms of reliability when compared to the other categories (see Figure 9). This part of the system may cause problems for reliability in the future, but it is not caused by the ERTMS system itself.

Currently, there are not any major issues with technical components within ERTMS that may cause issues for the system's reliability. The issue with balises on the ERTMS network does not cause delays long enough to be registered within the Quality of Service reports, which may be artificially low due to the nature of the traffic flow on the ERTMS lines, as this might look differently on lines with much denser traffic flow were time is limited for maintenance. A problem with balises not attached properly on a line where traffic is denser, causing problems for maintenance teams to get out and fix the issue, thereby disrupting traffic flow and causing delays is possible but currently purely speculative. The issue raised concerning the lack of an optical backup system is interesting but not realistic with the data available today. There have not been any major faults were balises has stopped functioning and trains being forced to drive On-Sight in Sweden during the period analysed in this thesis.

The introduction of ERTMS in Sweden has (so far) been successful with ETCS Level 2 performing notably better than ATC-2 in terms of reliability. In general, no major flaws or faults with the new system have emerged and those discovered have been rectified and documented. The more prominent issues are mostly related to the onboard part of ETCS and factors related to a negative impact on profitability for railway operators. In general, there are no significant issues with the system that could potentially harm reliability in the futures with the expiation of ERTMS on the Swedish railway network.

8 Discussion

The consensus on the new ERTMS signalling system is split. The result of the study shows that from the maintenance entrepreneurs and Trafikverket's point of view, the new signalling system is an improvement over ATC-2, whilst from the operator's viewpoint is that it is a new expensive system with very little improvement. The results also show that different parties have different views on how a new and improved signalling system should function. We assume that there might be a lack of information and knowledge exchange between different parties as the views on the new system differs substantially. Furthermore, the interviews show that although some parties express similar statements (both positive and negative) with ERTMS, the overall results show than there are different views on whether or not ERTMS will bring any improvement compared to its predecessor ATC-2.

It is important to note that the data analysed in the reports are statistical summaries, and performing a deeper analysis with the current states of the system would be preferable due to the following reasons:

- ERTMS lines being more modernised and refurbished
- The lines have less traffic and in general, have a lower capacity than their ATC-2 Core Network counterparts.
- Relatively low heterogeneity compared to the traffic on the Core Network

This, in turn, could make the results presented by Trafikverket's reports to have a lower accuracy for ERTMS reliability, as it might not present the full reality of the actual performance of ERTMS once fully implemented on the Core Network.

Due to how the different systems operate during balise loss, the concern raised during the SJ AB interview is legitimate. If balise loss occurs on an E2 line, the permitted speed for a driver becomes only half of what ATC-2 allows. This creates a situation were E2 does what it has been created to do, but with what is currently allowed on the Swedish railway network, it creates a lowered operational reliability for train operators in Sweden.

However, looking at the data available from Trafikverket in Figures 9 and 10, the issue does not seem very realistic. Balise faults on the E2 lines occur sparingly and do not cause long enough delays to be registered into the data for Figure 10 (a minimum three minutes is required). The one year which delay time was registered to balises, the data was incorrectly registered as further analysis by Trafikverket concluded that the fault which caused the delay time was due to a train’s OBU. Therefore, it is questionable to have a backup system if the balises do not fail often, especially when taking into account the number of times the optical signals fail on the ATC-2 network (see Figure 9) and the cost of installing new equipment and maintaining it.

As mentioned, balises on E2 lines sparingly break down. Earlier issues with balises sensitive to humidity have been fixed by Trafikverket no longer purchasing the balise class that was sensitive. What remains as an issue is the problem were balises become loose. Both parties at Trafikverket and Infranord suggested similar causes to what might be causing the problem, however neither could point out a specific cause. By looking at the available data on delays in Figure 10, this issue does not cause delays long enough to be registered. This could be a product of lower density traffic on the current E2 lines and should this issue still be present after further implementation of ERTMS, the problem may grow bigger on lines were time is limited for maintenance.

Currently, these issues do not seem to cause much delay for trains when looking at the data provided by Trafikverket, but as discussed previously the data might not be correct for dense traffic and high capacity sections of the network and the true scale of this problem might not be apparent until greater implementation in the Core Network.

Additionally, as ERTMS is implemented a part of the fleet of rolling stock will have to be retrofitted with new equipment as they were not constructed with ETCS onboard in mind. In the result, the experts at SJ AB expressed concerns about the space requirements and potential passenger capacity losses from the new system. This is especially problematic with multiple units as they make up a large portion of today’s passenger traffic. Although some older multiple units might be replaced before they need to be retrofitted, this issue is still likely to be a relevant problem especially for passenger train operators with fleets consisting largely of older multiple units. This is especially troublesome for smaller train operators with limited revenue streams and high operational costs.

Finally, the issue that concerns system updates for trains. SJ AB stated here that these are dropped onto them with short notice and the process of taking a train out from service for approximately one to three days is not preferable. The updates also appear with a frequency that, at SJ AB, they consider to be too often. This, in contrast to the ATC-2 system where trains have not needed to update their systems for approximately 30 years. They would prefer instead that the system updates were less frequent and that the time between being informed and the updates needed to be implemented is long enough to plan out when each train needs to be taken out of service. This is a problem for operators in general because this might affect them economically.

9 Further Research

Based on the findings from the research that could not be further elaborated on, the authors present recommendations for further reached into the topic and subjects discussed in this thesis:

- Economic impact on railway operators for implementing and maintaining ERTMS.
- Further research into hardware problems for ETCS Euro-balises.
- ERTMS reliability on dense traffic and high capacity networks.
- If the speed restrictions for ERTMS when compared to ATC-2 restrictions harm line capacity.

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11 Attachements

Sections 10.1 to 10.3 contain the transcripts from the interviews held with Trafikverket, SJ AB and Infranord.

11.1 Trafikverket Interview

The following questions were emailed to Simon Tafreshi the 24th of March

- Ur samtliga rapporter kan man se att störst fel ligger på områderna balis, rbc/linjeblockering och utdel. Vad, på en teknisk nivå, är det som har skapat dessa problem?
- Vilka tekniska områden är det som skapat mest kritiska fel?
- Hur skiljer sig Ställverk 95 för ATC-2 mot ERTMS?
- Blir fel med spårledningarna annorlunda på banor med ERTMS mot ATC-2?
- Påverkar trafikmönstret/trafikflödet frekvensen av mängden fel

Summary of interview with Simon Tafreshi 26 mars 2020

Ur Trafikverkets rapporter om driftuppföljning för ERTMS kan man se att de tre områden där mest fel inträffar på ERTMS banor är balis, linjeblockering/RBC och utdel. På en teknisk nivå, vad är det som går fel?

Det man ser i statistiken i rapporten är att det har varit ett fel inom detta område och inte vad för typ av fel. Vad man har märkt av utifrån erfarenhet är att det flesta utav balisfelen har varit slumpmässiga fel. Det vi menar med slumpmässiga fel när det gäller baliser är att det är hårdvarurelaterade fel. De körs på av underhålls-/arbetsfordon, att fästerna sitter löst och när fordonen kör över baliserna så får antennen inte en korrekt statisk kontakt med balisen och då rapporteras fel.

Det skiljer sig lite mellan baliserna på ATC-2 banorna och ERTMS banorna. Man har olika leverantörer för ERTMS (Bombardier och Hitatchi) och konventionella ATC baliserna har Bombardier tagit fram. Även om baliserna ser väldigt lika ut är de olika produkter, där mjukvaran är annorlunda konfigurerad. Fuktskador för ERTMS baliser har varit ett säsongsbaserat problem. Här hittade man att det finns olika klasser av ERTMS baliser med varierande kvalité, där klass B var mycket mer fuktkänslig. Detta innebär att man på Trafikverket inte beställer in denna balistyp längre.

För ställverk/linjeblock/RBC är det tre separata funktionaliteter för båda signalsystemen. Däremot slås dem ihop i statistiken som tas ifrån databasen

LUPP, vilket gör att det ser ut som att det är massa fel inom dessa system, utan att veta vilket utav dem som det är mest fel på. Utdelarna är en underkategori till ställverken, vilket är varför de även inkluderas i den nämnda kategorin och det är framförallt för att de inte har någon redundans. När det blir ett fel i någon utav utdelarna, t.ex. att något kort pajar, behövs utdelen bytas ut och tills att det blir utbytt är det inte fungerande, medans ställverk/RBC på ERTMS är redundanta, vilket innebär att ifall någon utav dem slutar fungerar tar den andra över och då märker man inte att det har inträffat något fel. Men när det väl händer är det kritiskt.

Baliser i balisgrupper inom ERTMS är majoriteten redundanta dem med, då ifall en inte fungerar finns det andra som kan ge samma besked.

Vilka områden är det som skapat mest kritiska fel?

Framförallt Ställverk/RBC.

Blir fel med spårledningar annorlunda på ERTMS banorna jämfört med ATC-2?

För L2 är felen likvärdiga med ATC-2.

Hur skiljer sig Ställverk 95 för ERTMS gentemot ATC-2?

I ERTMS har vi RBC:n som inte finns för ATC-2, så det finns ett gränssnitt för ställverket att den kan kommunicera med RBC:n i ERTMS. Hårdvaran är mer eller mindre samma för båda signalsystemen, men tanken är att när Trafikverket upphandlar nya 95:or utvecklar man konventionella M95 för ATC-2 så att man kan senare enkelt byta till ERTMS och kunna behålla hårdvaran. Det gör man på Malmbanan just nu.

Påverkar trafikmönstret/trafikflödet frekvensen av mängden fel?

Absolut, i dagsläget är det så att mängden och typen av trafik på ATC banorna är betydligt större än den på ERTMS banorna. Den frågan har man brottat med på Trafikverket ett tag, med rapporterna jämför man äpplen och päron. Men man har ett mål inom Trafikverket att man ska kunna prestera minst lika bra med ERTMS som ATC-2, vilket är varför man försöker normalisera statistiken. Men man kommer inte ifrån att för ERTMS banornas del så är det nya spår och nya signalsystem.

11.2 SJ AB Interview

The following questions were e-mailed to technical specialist at SJ AB five days before the interview to give him time to prepare for the interview. A translation of the questions can be found under the summary of the interview on the next page.

1. Anses ERTMS installerat ombord på äldre lok som Rc6 att ha samma tillförlitlighet som de moderna tågen där det är tänkt från början att det ska vara utrustade med ERTMS?
2. Upplever lokförarna en förbättring med ERTMS kontra ATC-2?
3. Från ett operativt perspektiv, märks det att man får mer kapacitet med nya signalsystemet?
4. Hur fungerar det med mjukvaruuppdateringar? Är det svårt att genomföra? Blir det en tydlig skillnad gentemot äldre versioner?
5. Är kommunikationen mellan ansvariga parter bättre när felavhjälpning behövs på linjer med ERTMS kontra ATC-2?
6. Är det lättare att göra prognoser för förseningar för ERTMS än ATC-2?

Before the interview, he responded to the mail

SJ har 27 egna fordon utrustade med ETCS. Som ni säkert redan vet så finns ERTMS och persontrafik enbart på Botniabanan och Ådalsbanan. Våra fordon är X55 (SJ3000) och Rc6-E. SJ 3000 går i persontrafik över stora delar av landet och som längst i norr upp till Umeå (dvs på Botna och Ådalsbanan). Rc6-E loken går i nattågstrafiken och går från Göteborg upp till Narvik, även dessa passerar alltså Botnia och Ådalsbanan. I huvudsak går alltså fordonen på ATC-banor. Det finns inget automatiskt system på SJ som övervakar och separerar ATC trafik från trafiken på ERTMS-banor. Vid de tillfällen det uppstår problem, oftast inrapporterat av förare, så vidtar ett manuellt arbete för att ringa in felet. Inträffar felet på ERTMS banor kan vi få viss hjälp av Trafikverket, de har system som övervakar radiotrafiken mellan fordon och bana vilket är en viktig pusselbit när man felsöker.

Trafikverket gör kontinuerligt egna mätningar på tillgängligheten och jämför ATC med ERTMS. Som grund använder de interna felrapporter för att mäta felfrekvensen och vi på SJ har ingen större insikt i vilka kriterier de använder. Vi vet dock att generellt sett så är förare nöjda med tillgängligheten på ERTMS banor så länge allt fungerar som det ska. Problem på Botnia och Ådalsbanan ger mer kraftfulla restriktioner än fel på ATC bana eftersom ERTMS banor saknar backupsystem i form av ljussignaler.

Till saken hör också att Trafikverket rullar ut nästa version av ERTMS, känt som BL3. Detta innebär att ERTMS förväntas bli mer stabilt. Utrullningen planeras ske på Botnia och Ådalsbanan i höst.

Summary of interview with SJ AB 9 mars 2020. This interview was not recorded, however extensive notes were taken during the interview. This summary is based on those notes and have been translated into English. The questions are listed both in Swedish and English, with the English ones written in italics.

Anses ERTMS installerat ombord på äldre lok som Rc6 att ha samma tillförlitlighet som de moderna tågen där det är tänkt från början att det ska vara utrustade med ERTMS?
Is ERTMS considered to be as reliable in older locomotives and trains when compared to modern trains where it has always been planned for them to be equipped with ERTMS?

When the onboard system is installed in trains, the functionality is exactly the same. SJ has not noticed any differences with reliability between different locomotives and trains, and therefore no conclusion can be made that one train type functions worse than the other. Currently there are two train types at SJ equipped with ERTMS, X55 and RC6-E.

Upplever lokförarna en förbättring med ERTMS kontra ATC-2?
Do the train drivers feel an improvement with ERTMS compared to ATC-2?

The train drivers' feedback on the new signalling system is mostly positive.

Från ett operativt perspektiv, märks det att man får mer kapacitet med nya signalsystemet?
From an operator's perspective, is it noticeable that one gets more capacity with the new signalling system?

No, the opposite in fact. Due to more restrictive breaking curves for ETCS Level 2 than ATC-2, that Trafikverket plans to keep stations in operation with ATC-2 as it is seen as too experimental at this stage to rebuild larger stations with ERTMS, the fact that block lengths are kept more or less the same, the lack of a backup system in the form optical signals and when speed is restricted by the ERTMS' backup is half of what one is allowed on ATC-2 lines, we at SJ feel that capacity won't increase. This theory is strengthened by Trafikverket's own research into capacity through Korridor B.

Hur fungerar det med mjukvaruuppdateringar? Är det svårt att genomföra? Blir det en tydlig skillnad gentemot äldre versioner?
How does software updates work? Are they difficult to implement? Is there a clear difference compared to older versions?

In order to update the software on trains, the train in question that needs an update has to be taken out of service. When the train is then taken to a depot to update its software, a software engineer simply connects a USB with the software update into the onboard computer and then proceeds to update it. We haven't noticed yet that a new version would be worse than a previous one, however, there is always a risk for bugs to appear but they are often easy to deal with.
The problem with software updates is that there is a lack of time to implement them. Since it requires that a train is taken out of service these updates need to be planned ahead of time, however we are usually notified about a new update with no ahead of time warning. Taking a train out of service also costs us money, especially when you take in the fact that these updates can take up between one to three days to properly implement. This can take longer since the trains need to be tested with the new update to see if it was installed properly and functions as intended. What we at SJ would like to see is larger and less regular updates.

Är kommunikationen mellan ansvariga parter bättre när felavhjälpning behövs på linjer med ERTMS kontra ATC-2?
Does the communication between responsible parties function better when remedial repairs are needed on lines with ERTMS compared to ATC-2?

From SJ's view it might function a bit better on ERTMS lines. For example, balise errors on the ERTMS network are easier to deal with as the train driver gets a specific error code.

Är det lättare att göra prognoser för förseningar för ERTMS än ATC-2?
Is it easier to make delay predictions for ERTMS than ATC-2?

This is more Trafikverkets responsibility, but we haven't noticed that things are all that different.

11.3 Infranord Interview

The following questions were sent to the signal supervisor at Infranord three days before the interview was held.

- Upplever man att det är enklare att underhålla ERTMS än ATC-2?
- Är felavhjälpningstiden (tiden det tar från att vara på plats, identifiera felet och sedan lösa problemet) längre för ERTMS än ATC?
- Upplever man den digitalisering som medför ERTMS som något bra eller dåligt?
- Är det mycket arbete med mjukvara med ERTMS eller är det mesta hårdvaru-relaterat?

Summary of interview with Infranord 16/04/2020

Upplever man att det är enklare att underhålla ERTMS än ATC-2?

Ja tänker man bara på balishanteringen så är ERTMS mycket enklare än ATC, då vi inte har några styrbara ERTMS baliser. Finns ca 1000 Eurobaliser på Botniabanan. Det är inte heller ofta att en balis är trasig men vi får byta nån då och då. Här är det enkelt med att då behöver man endast skruva loss den trasiga balisen och sätta dit en ny, om man har en styrbar balis så kan det vara två grejer det kan var fel på, balisen och kodaren på ATC-2. Så det är betydligt enklare med balisunderhåll på ERTMS.
På ERTMS kan en balisgrupp vara borta då det inte stör tågen. Det finns en grupp som analyserar själva ERTMS systemets felkoder och där kan de se om en balis har larmat ofta eller om en balis har lossnat. Den felkoden får vi skickade till oss och så far vi till balisen. Nästan 100% av fallen är balisen borta. De problem vi har haft mest med ERTMS baliser är att de lossnar och att fastsättningssystemet inte är bra. Ingen som riktigt vet när dem lossnar heller.
Det fanns klass B i början, det var det vi monterade. Det finns två olika klasser på eurobaliserna och vi kör med Bombardiers. Med de nya klass A baliserna ska baliserna sitta 46 mm upp från slipers, till skillnad från B baliserna som monterades med 23 mm mellanrum. Sen är klass B ca 30 mm tjock medans A är 50 mm tjock. Här kan man jämföra mot ATC-2 baliser som ska monteras med 3mm mellanrum till träbaliser och 23mm till betong.

Är felavhjälpningstiden (tiden det tar från att vara på plats, identifiera felet och sedan lösa problemet) längre för ERTMS än ATC?

Nej, det går snabbare på ERTMS. Och det har mycket med att göra att oftast beror balisfel för att själva balisen är borta. Själva identifieringsprocessen tar längre tid för ATC, samt så måste vi gräva upp skarven för styrbara baliser ifall det är fel på själva balisen.

Upplever man den digitalisering som medför ERTMS som något bra eller dåligt?

Det är inte så stor skillnad, då det finns redan seriella baliser för ATC.

Är det mycket arbete med mjukvara med ERTMS eller är det mesta hårdvaru-relaterat?

Det är mest hårdvara man har haft problem med, men det blir en större hantering med mjukvara eftersom man måste ha varenda fil [för baliser]. Där kan man dock ladda in filerna i handdatorn och så har vi dem där tills att man måste uppdatera filerna. För ATC behöver man i regel inget sånt. Vi har några seriella baliser där man behöver mjukvara, annars är det pluggar till fasta baliser som gäller och ingen mjukvara behövs. Men det mesta arbete som görs är hårdvara då balisfelen är oftast beroende på att balisen är lösa och bland det flesta utav dessa baliser är det bara att sätta tillbaks dem på plats. Det är på sätt och vis inget fel med själva hårdvaran för baliserna.

Är det mer att byta ut till nya saker eller går det att laga komponenter till ERTMS?

Det är ungefär samma för ERTMS och ATC. På ERTMS gör vi inget med trasiga baliser utan vi slänger bort dem. Samma för ATC, men kodarna skickas iväg för lagning.

Har man samma storlek på lager för de olika signalsystemen?

Man har ett större lager för ATC. Då ska du ha kanske fem olika kodare, fyra olika baliser plus seriellkodare. Där är det ganska mycket grejer som man behöver för det systemet och så behöver man seriella baliser. Så det är ganska mycket mer lagerhållning för ATC då man har det seriella och parallella systemen inbyggda i signalsystemet. För ERTMS behöver vi bara en balis.

11.4 Document Study Diagrams

Presented in this section are the diagrams used during the document study. These laid the groundwork for data collection and the foundation for further analysis and the interviews.

Deviations based on Cause

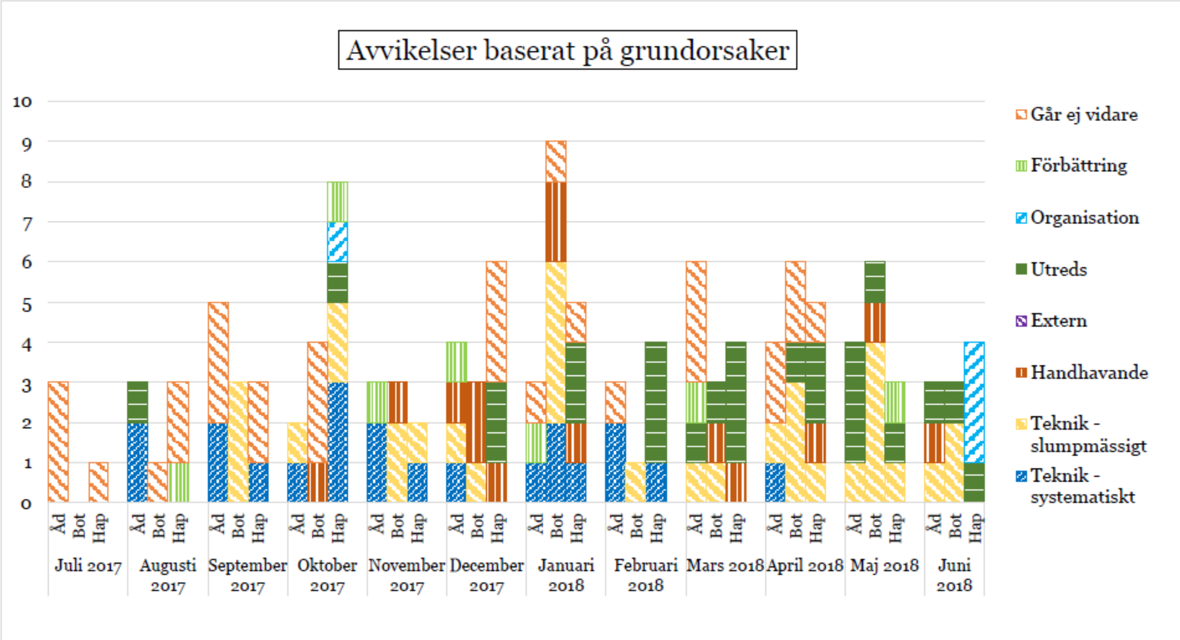

Figure 12 Deviations based on Cause (Source: Trafikverket 2018)

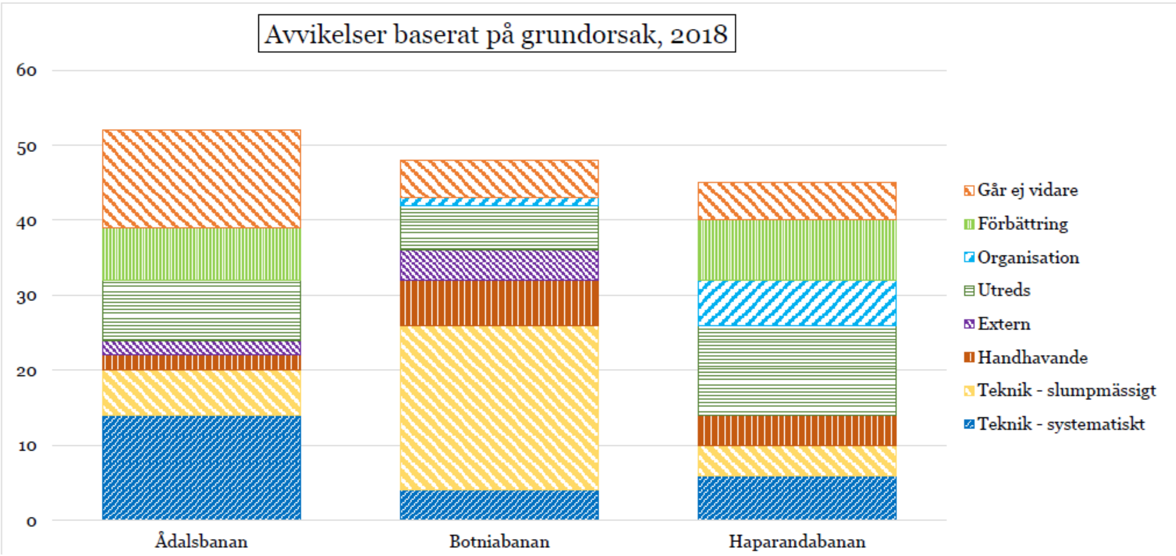

Figure 13 Deviations based on Cause (Source: Trafikverket 2019g)

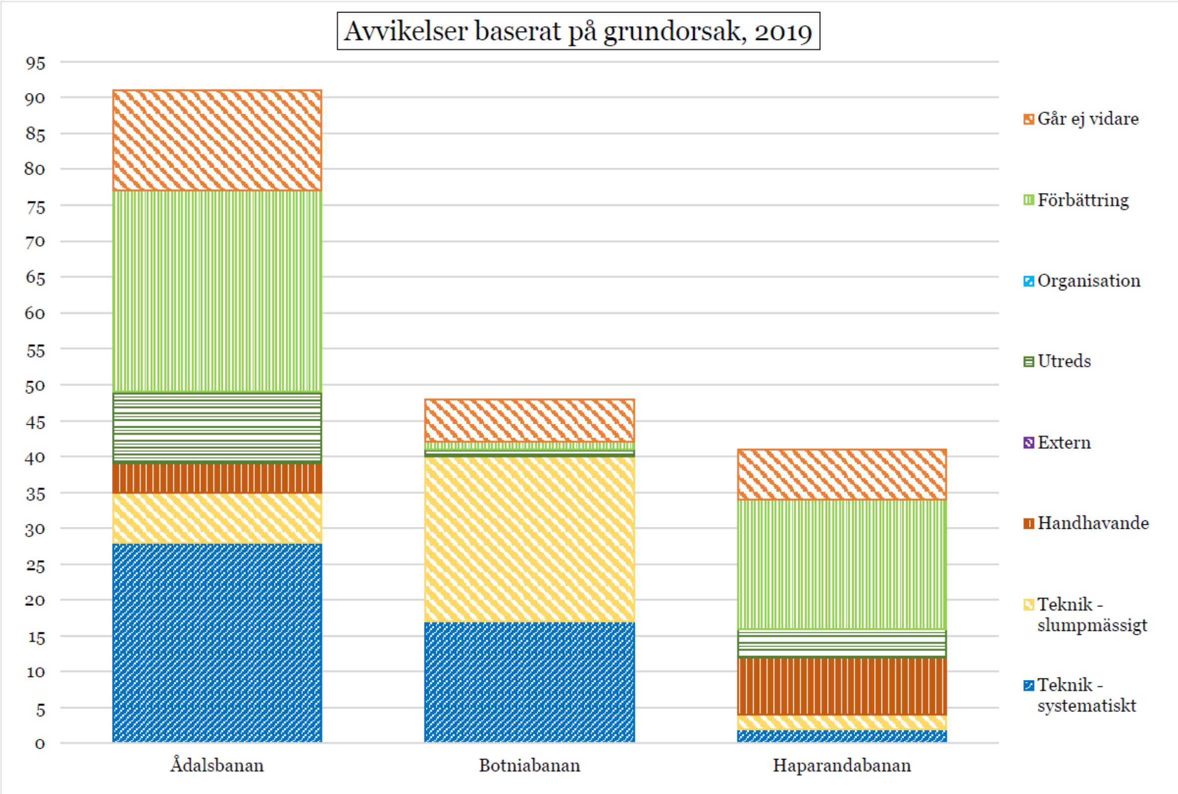

Figure 14 Deviations based on Cause (Source: Trafikverket 2020c)

These diagrams present the deviations that have occurred during their timeframe based on the causation for each deviation. Each diagram only presents the three E2 lines in Sweden. The different causations are in descending order from Figures 12, 13 and 14:

- No further investigation – Faults were information is missing or investigation into it cannot be expanded upon.
- Improvements – Faults that comply with demands but not its functions
- Organisation – Faults caused by design or communication errors etc.
- Investigation – Faults that could not be categorised when the report was published
- External – Faults caused by an external factor, e.g. lightning
- Human Error
- Random Technical – Faults were remedial help is required to fix.
- Systematic Technical – Faults which occur due to functionality.

Faults per track kilometre

The diagrams here present the faults that required remedial maintenance to fix. These faults presented here are the ones that are listed as a random technical fault in the diagrams that show deviation based on causation. For each diagram, the left columns show faults on ATC-2 lines, while the right columns show faults on E2 lines.

The different categories that are present in each diagram in Figures 15 through 17 are in descending order:

- Train dispatchment
- Signage
- Signal
- Level Crossing
- Positioning System
- Balise Group
- Signal box/RBC/Line Block System

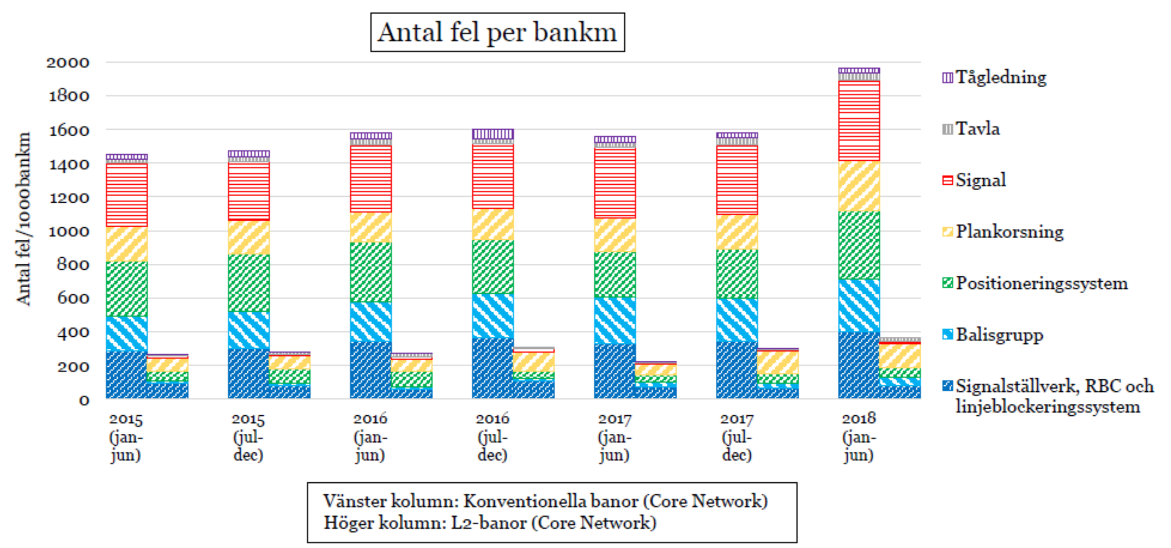

Figure 15 Faults per Track Kilometre (Source: Trafikverket 2018)

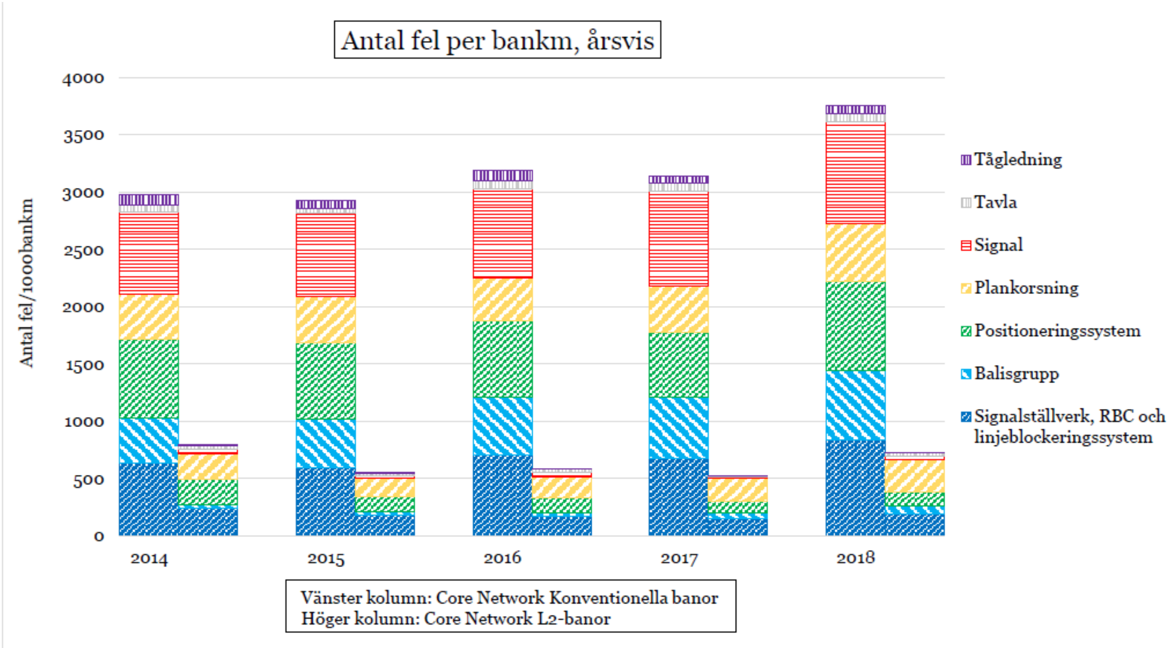

Figure 16 Faults per Track Kilometre (Source: Trafikverket 2019g)

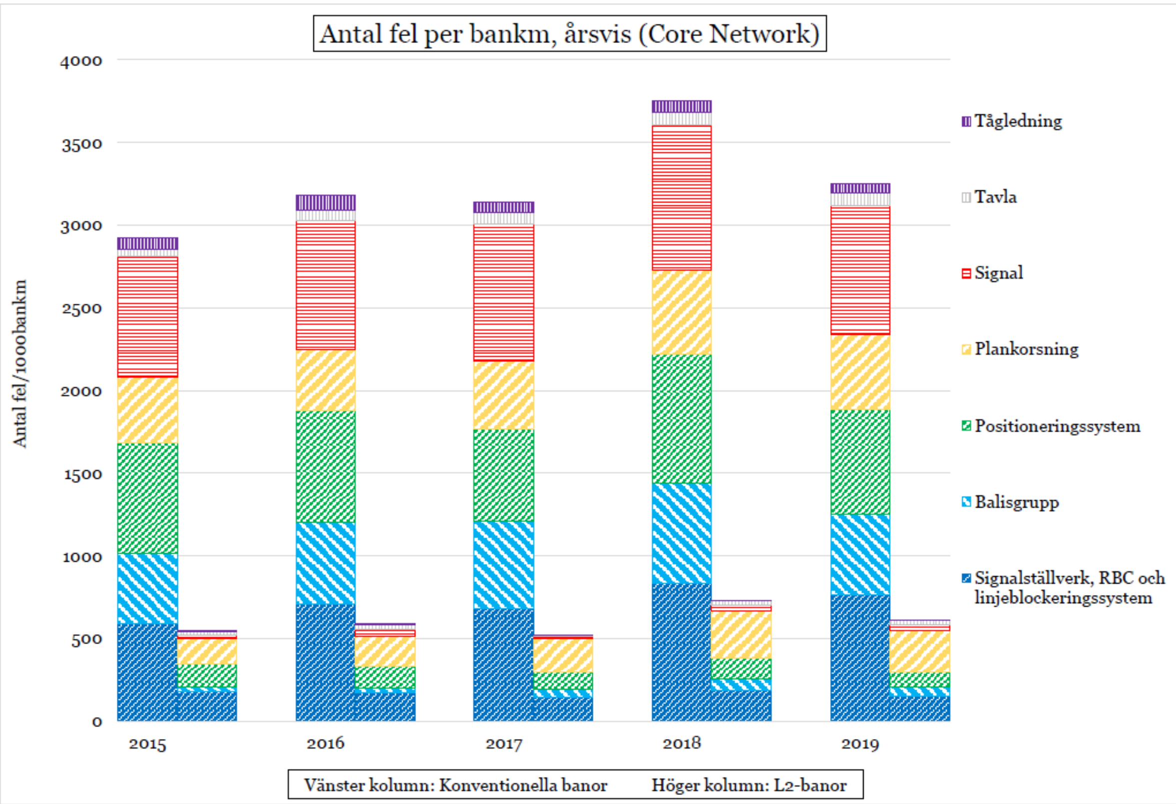

Figure 17 Faults per Track Kilometre (Source: Trafikverket 2020c)

Delays per Train Kilometre

These diagrams (Figures 18, 19 and 20) show the number of delays caused by the faults presented under the previous section. The same left and right column separation and categorisation are used here as in faults per track kilometre.

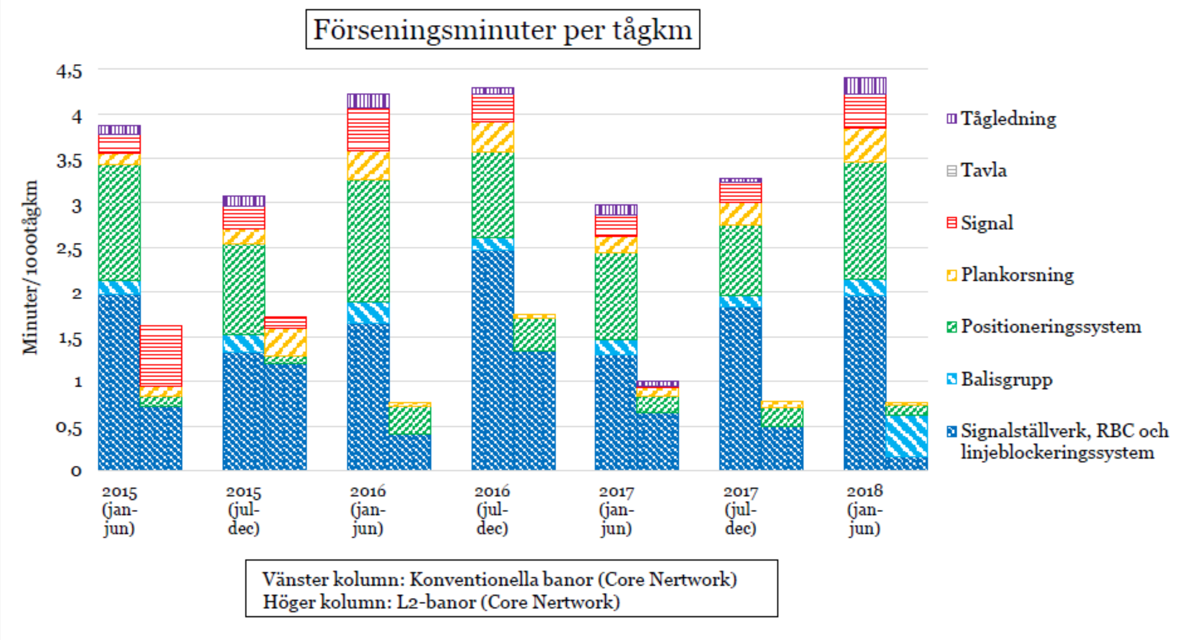

Figure 18 Delays per Train Kilometre (Source: Trafikverket 2018)

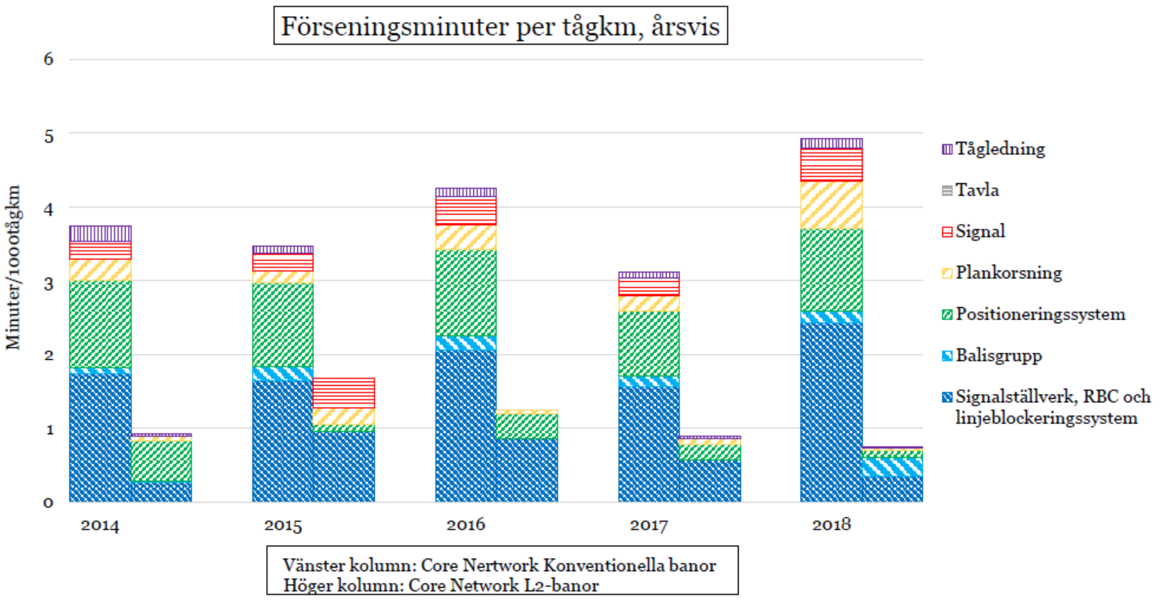

Figure 19 Delays per Train Kilometre (Source: Trafikverket 2019g)

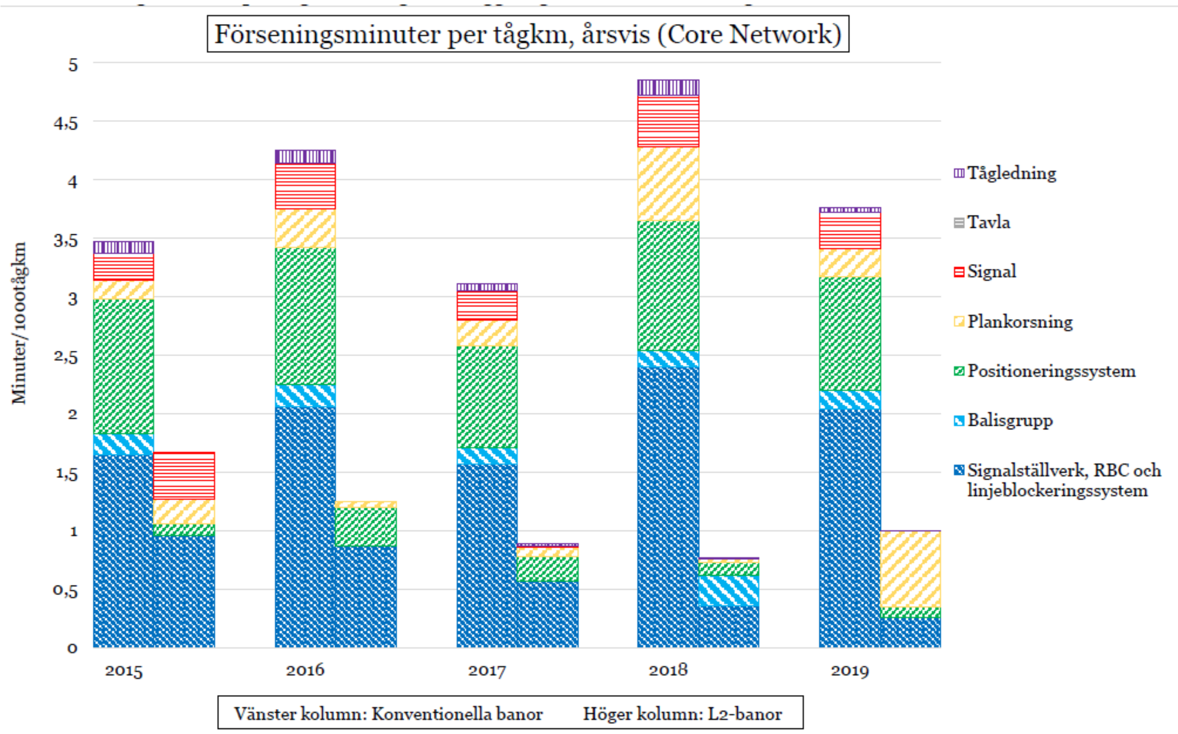

Figure 20 Delays per Train Kilometre (Source: Trafikverket 2020c)

Faults per 10 Train Trips

Figure 21 and 22 present the system faults on trains were a train required to stop completely and restart its onboard ETCS equipment. Note that all faults presented in these diagrams are all registered on the E2 lines. The different categories on these diagrams are the different locomotives and EMUs running on the E2 lines.

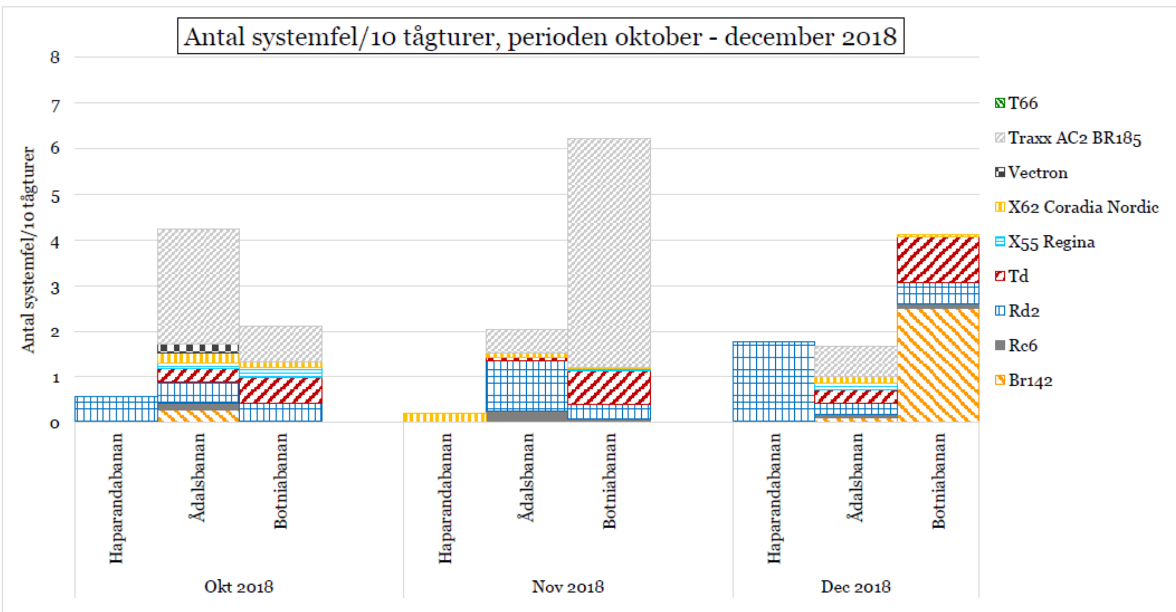

Figure 21 Faults per 10 Train Trips (Source: Trafikverket 2019g)

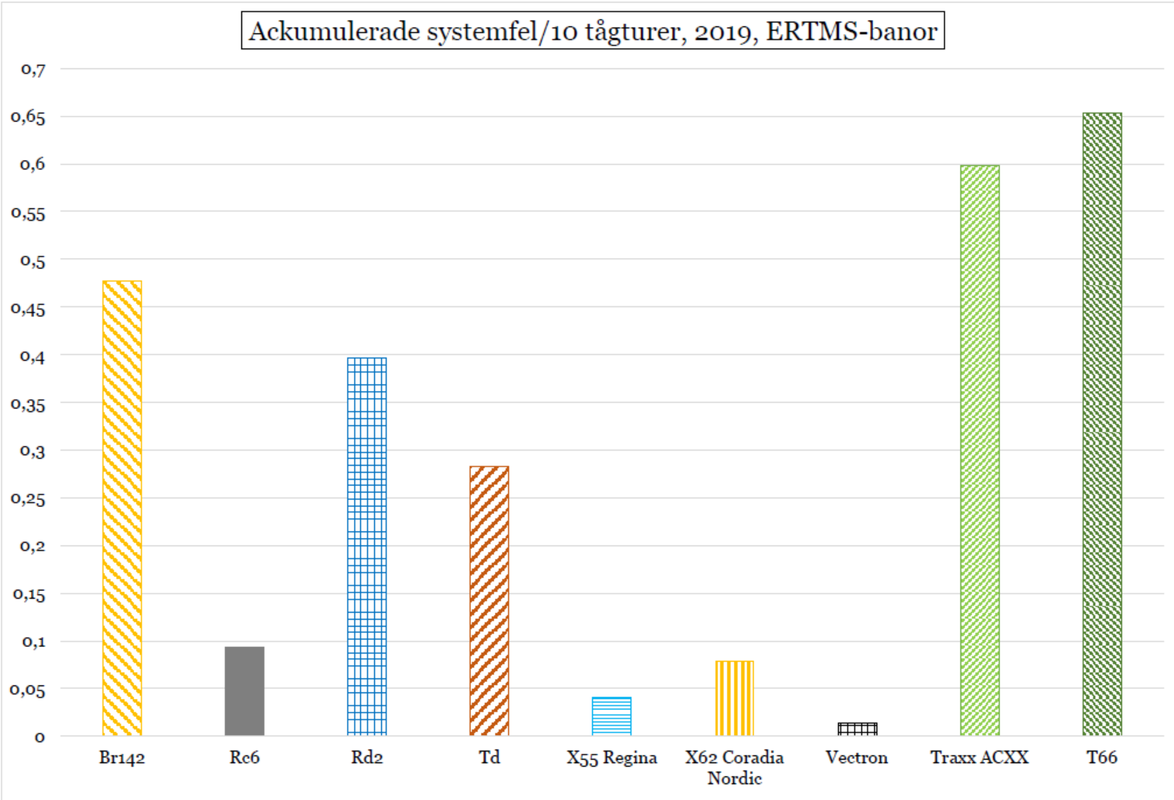

Figure 22 Faults per 10 Train Trips (Source: Trafikverket 2020c)