DEGREE PROJECT IN COMMUNICATION SYSTEMS, SECOND LEVEL
STOCKHOLM, SWEDEN 2015

Addressing non-conformities in a ERTMS implementation

Collecting non-conformities in ERTMS simulation and analyzing their management via a database

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2015-07-10

Master's Thesis

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Abstract

The European Rail Traffic Management System (ERTMS) aims to standardize train control-command and communication systems in Europe. The main goal of its introduction is to develop trans-European railway traffic and increase competition. The two main components of ERTMS are European Train Control System (ETCS), which is an Automatic Protection System (ATP), and GSM–Railway (GSM-R).GSM-R is a radio transmission system that provides data and voice communication between the train and trackside facilities. Classical rail signaling systems are recommended to be updated to meet these standards.

This master's thesis is conducted in cooperation with Bombardier Transportation (BT), the rail equipment division of firm Bombardier Inc. It explores a part of ERTMS implementation and aims to identify its failures/non-conformities during its simulation. A non-conformity is any deviation or nonfulfillment of a requirement involving a product manufactured at BT. This thesis first collects failures/non-conformities in test sessions and stores it into databases. A failure/non-conformity is processed by many engineers from the time it is detected in a test until it is resolved. This thesis project seeks to investigate the exchange and the management of failures in both the tools and databases, together with analyzing the interaction between engineers through tools and databases. Non-conformities detected during the simulation is stored in databases. The goal is to utilize this data to highlight parts of ERTMS implementation which generate most of non-conformities during the simulation. This information indicates to engineers where to focus and act in order to improve Bombardier Transportation's products.

This thesis successfully simulated a part of ERMS implementation. Several different tests cases were conducted and seven non-conformities were detected. These non-conformities were used to investigate and analyze the process of managing failures in tools and databases. This thesis proved that the exchange and the management of information about non-conformities was inefficient and time consuming. In the worst case, non-conformities were completely lost during this process. Several corrective actions were proposed in order to improve the handling of non-conformities.

Keywords

ERTMS, GSM, ETCS, Simulation, Non-conformity, Management, database

Sammanfattning

Europeiskt styrsystem för järnvägstrafik (ERTMS) har i mål att till standardisera tågledningas- och kommunikationssystem i Europa. Den huvudsakliga målsättningen är att utveckla transeuropeiska järnvägstrafiken och öka konkurrensen. De två viktigaste komponenterna i ERTMS är European Train Control System (ETCS) och GSM-Railway (GSM-R). ECTS är Automatisk Protection System (ATP). GSM-R är en radiotransmissions system som tillhandahåller data och röstkommunikation mellan tåg och markanläggningar. Klassisk järnväg signalsystem rekommenderas att uppdatera för att uppfylla dessa standarder.

Denna magisteruppsats sker i samarbete med Bombardier Transportation (BT) som är järnvägsutrustning uppdelningen av företaget Bombardier Inc. Det skall utforskas en del av ERTMS implementering och som syftar till att identifiera sina avvikelser och misslyckanden under sin simulering. Denna avhandling samlar först med misslyckanden/icke-avvikelser i testsessioner och lagrar det i databaser. Ett icke-avvikelser är någon icke uppfyllande av ett krav som medför en produkt som tillverkas vid BT. Ett misslyckande/icke-avvikelse behandlas av många ingenjörer från den tidpunkt då den upptäcks i ett test tills det är löst. Detta examensarbete syftar till att undersöka utbytet och hanteringen av brister i både verktyg och databaser, tillsammans med att analysera samspelet mellan ingenjörer via verktyg och databaser. De upptäckta enhetligheterna under simuleringen lagras i databaser. Målet är att utnyttja dessa data för att markera delar av ERTMS implementering som genererar merparten av avvikelser under simuleringen. Denna information indikerar att ingenjörer var att fokusera och agera i syfte att förbättra Bombardier Transportations produkter.

Denna avhandling har med framgång simulerat en del av ERMS implementering. Flera olika tester fall genomfördes och sju avvikelser upptäcktes. Dessa avvikelser användes för att undersöka och analysera processen för att hantera misslyckanden inom verktyg och databaser. Avhandlingen visade att utbyte och hantering av information om avvikelser var ineffektivt och tidsödande. I värsta fall, var avvikelser helt förlorad under denna process. Flera korrigerande åtgärder föreslogs för att förbättra hanteringen av avvikelser.

Nyckelord

ERTMS, GSM, ETCS, simulering, icke-avvikelse, management, databas

Acknowledgments

Professor Gerald Q. Maguire Jr.

For all of the **valuable** feedback in my research. You always push students to surpass themselves in order to produce an excellent report.

Antonio Salvi & Per Jansson

For guiding me in my research at Bombardier Transportation and your valuable feedback

Tomas Persson

For provided lectures and introduction on tools used in simulation environment

Romain Tiennot

My office-mate for guiding me in the company.

Stockholm, July 2015
Laurier Ndikuriyo

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List of acronyms and abbreviations

ATP	Automatic Protection System
AuC	Authentication center
BSC	Base station Controller
BSS	Base Station System
BT	Bombardier Transportation
BTM	Balise Transmission Module
BTS	Base Transceiver Station
CDF	Cumulative Distribution Function
CPE	Customer-Premises Equipment
CR	Change Request
DMI	Driver-Machine Interface
EGPRS	Enhanced Data rates for GSM Evolution
EIR	Equipment Identity Register
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
EVC	European Vital Computer
GA	Generic Application
GP	Generic Product
GPRS	General Packet Radio Service
GSM	*Groupe Spécial Mobile* – later know as Global System for Mobile Communications
GSM-R	GSM – Railway
G3T	Graphical Train Track Tool
HLR	Home Location Register
IMSI	International Mobile Subscriber Identity
ILS	Interlocking
ISDN	Integrated Services for Digital Network
ITS	Interlocking Yard Simulator
JRU	Juridical Recorder Unit
KMC	Key Management Center
KMS	Key management System
KPI	Key Performance Indicator
LAN	local area network
LEU	Lineside Electronic Unit
LTM	Loop Transmission Module
LTE	Long Term Evolution
MA	Movement Authority
MSC	Mobile Switching Centre
NSS	Network and Switching Subsystem
OMC	Operation and Maintenance Center
OPNET	Optimum Network Performance
OTE	Onboard Test Environment
OSS	Operating Sub-System
PE	Project Engineer
PLMN	Public Land Mobile Network
PSTN	public switched telephone network
RBC	Radio Block Center
RIU	Radio Infill Unit

SA	Specific Application
SMS	Short Message Service
STM	Specific Transmission Module
TCC	Traffic Control Center
TIU	Train Interface Unit
UMTS	Universal Mobile Telecommunications System
VLR	Visitor Location Register
VSIM	Vehicle Simulator
WP	Work Package
WIMAX	Worldwide Interoperability for Microwave Access
XML	Extensible Markup Language

1 Introduction

This chapter briefly introduces the thesis area together with the problem definition. The goal of this thesis project and the methodology used to reach it are described. The chapter ends with a delimitation of the thesis project and the structure of this document.

1.1 Background

The European Rail Traffic Management System (ERTMS) aims to introduce a computerized train signaling and traffic management system within the European Union. In order to increase competiveness in railway traffic, the European Union introduced this standard to allow compatibility between all European railway networks [1]. At the present time, there are more than 20 different train control systems used in different EU countries and each county uses more than one control system [2]. By using a *common language*, trains can cross national borders without changing driver or locomotive as it is necessary today. ERTMS has two mains components:

European Train Control System (ETCS)	The ETCS is the core of ERTMS. This system is often called ERTMS/ETCS. It is an Automatic Train Protection (ATP) control system that allows trains to interlocking signals, points, and set routes. For example, this prevents conflicting movement at junctions or crossings.
Global System for Mobile Communications – Railway (GSM-R)	This system uses the same principle as the Global System for Mobile Communications (GSM). However, it is only used in the railway sector and has its own specific operating frequency band.

Figure 1-1 shows the ERTMS/ECTS reference architecture, with the different components of onboard and trackside equipment[1]. The details of this figure will be discussed in Sections 2.2 and 2.3.

Bombardier Transportation (BT) Company is developing and installing ERTMS. The aims of this system are to standardize the train signaling system together with management of train traffic. The installation of ERTMS follows the simulation of ERTMS implementation at the BT laboratory in Stockholm. The aim of this simulation is to verify whether the system implementation fulfills all of the requirements specified by the general requirements [3]. This simulation allows BT to identify and correct all non-conformities of an ERTMS project by reproducing the actual operating environment in a virtual environment in the laboratory.

A non-conformity is any deviation or nonfulfillment of a requirement involving a product manufactured at BT. Identified non-conformities are detected by the simulator and stored in databases. A tool is a software/computer program which provides specific functions to create and support a database. A database is a collection of data which has been defined with a given model and shares the same attributes. A multitude of databases entries can be created by one tool. This database allows engineers to manage non-conformity by handling and exchanging information through common databases.

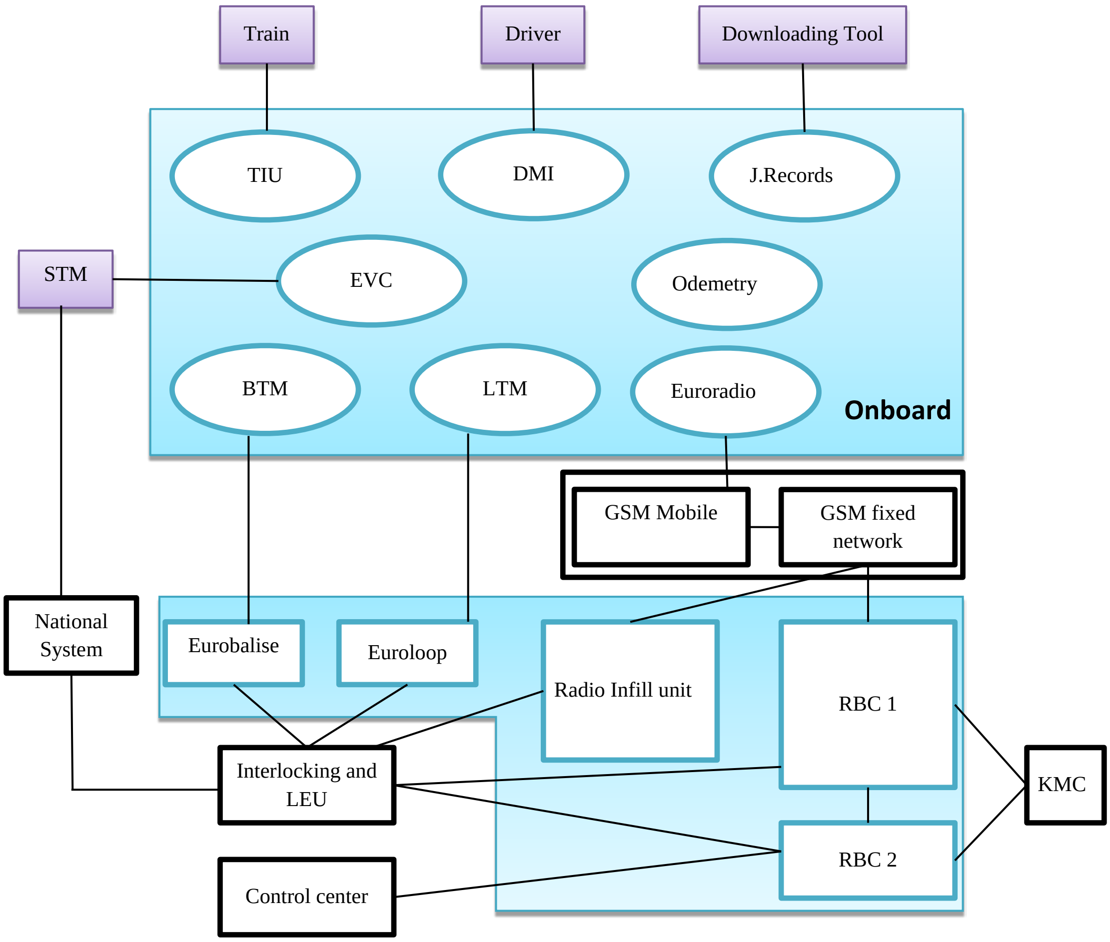

Figure 1-1: **ERTMS/ETCS Reference architecture [4]**

1.2 Problem definition

The simulation of an ERTMS implementation in laboratory is a large project. It is divided into many parts and the overall implementation takes a long time to realize. This project contributes to the simulation of part of a specific ERTMS project. The goal of this simulation is to identify non-conformities which require corrective action.

BT has defined the life cycle of a non-conformity from when a non-conformity is found until corrective action is applied. The different steps in this life cycle involve many engineers who must manage this non-conformity by handling and exchanging information through tools and databases. Today, engineers complain about the lack of exchange and management of information about non-conformities via the databases. The process needs to be investigated in order to improve the sharing of information between engineers and to ensure the traceable handling of each non-conformity. It is desirable that non-conformities are classified into categories to allow engineers to identifying where the majority of non-conformities are found. This classification provides an indication of where a focus must be put in order to improve the quality of BT's products and systems.

1.3 Purpose

The purpose of this thesis project is first to identify non-conformities detected in a simulation of a portion of a given ERTMS implementation project. Second, the project is to help BT identify where the process of handling and managing these non-conformities in database is ineffective. The objectives are to propose improvements on this process in order to simplify and harmonize it within all BT projects.

1.4 Goals

The thesis project's objectives are based on the company's needs to identify non-conformities in their product, while at the same time improving and simplifying the way these non-conformities are handled and managed in the various databases. These objectives have been divided into the following sub-goals:

- Detect non-conformities via simulation of a ERTMS implementation,
- To investigate the way non-conformities are handled and managed in the database,
- Analyze the interaction of engineers through tools and databases, and
- To define a method of classifying and presenting non-conformities.

1.5 Research Methodology

The problem definition and research direction were provided by BT. A research method was selected in order to satisfy their problem specification and requirements.

The simulation of ERTMS in the laboratory uses quantitative research. This method is appropriate since it requires verifying a hypothesis or theories by quantitative measurements, via experiments, or testing. In this case, an ERTMS implementation is simulated in a computer environment and then evaluated with respect to BT's requirements. In contrast, qualitative research develops hypotheses and theories by understanding meanings, opinions and behaviors[5]. However, the use of qualitative methods is not entirely excluded - due to the fact that such methods are in part used during the investigation of tools and databases. Indeed, in order to reach the second and third sub-goals of this thesis as stated Section 1.4, a classical literature study on tools/database was conducted with an analysis of current processes for handling and managing non-conformities. Then, discussions with tools and database users were conducted in order to identify the problems that they encounter with the current way of handling and managing non-conformities in the various tools and databases.

1.6 Delimitations

The simulation is limited to a given part of an ERTMS implementation. This limitation has been determined by BT to consist of the portions of this work that are taking place in the laboratory where the author of this thesis is working. Therefore, the investigation is limited to only the most widely used databases in Region North*.

* BT is divided into different geographical areas. Region North consists of Scandinavia and the Baltic countries

1.7 Structure of the thesis

Chapter 2 presents relevant background information about GSM-R and ETCS. In this chapter, it is also described tools and materials used in ERTMS simulation and related work. Chapter 3 presents methods and methodologies used in research. An analysis of the process of managing failures reported in databases is presented in Chapter 4. The results of the simulation and investigation are presented in Chapter 5. In addition, it describes corrective actions to be applied in order to improve the process of managing failures in databases. Chapter 6 concludes the thesis and provides suggestions for future work.

2 Background

This chapter provides general background information about ERTMS. Additionally, this chapter describes ERTMS levels. Section 2.5 provides background on the tools and tests equipment to be used in this thesis and Section 2.6 on managing non-conformities with a database. At the end of this chapter, work related to this project will be described.

2.1 Introduction

ERTMS has two mains components:

- European Train Control System (ETCS)
- Global System for Mobile Communications – Railway (GSM-R)

Each of these will be described in greater detail in the following sections.

2.2 GSM-R

The GSM-R is based on the Global System for Mobile Communications (GSM), but is only used within the railway sector.

2.2.1 Basic GSM network

The European Telecommunications Standards Institute (ETSI) developed the second generation (2G) of cellular networks called *Groupe Spécial Mobile (GSM)*. The aim of GSM was to improve cellular network beyond the first generation (1G) of cellular networks. Instead of using analog signals as in the first generation, this GSM utilizes digital signals. Due to its superior voice quality, GSM rapidly replaced the first generation networks and by 2014 had become the most popular wide area mobile communication in the world (see Table 2-1).

Table 2-1: Global Mobile Market share [6]

Standard	**GSM**	**CDMA**	**WCDMA**
Market shared 2014	81.08%	10.28%	7.90%

During the second phase of GSM, the GSM network architecture was extended to transmit user data packets. One step in this evolution was the introduction of General Packet Radio Service (GPRS). This was subsequently improved to increase the data transmission rates with the introduction of Enhanced Data rates for GSM Evolution (EGPRS). This extended system architecture is shown in Figure 2-1.

In practice, the GSM network is a set of interconnected networks within a given geographic area. Each one of these interconnected networks is called a Public Land Mobile Network (PLMN). Each of these networks is maintained and controlled by a service provider [7]. A PLMN has three main entities:

Base Station System (BSS)	The BSS is the core function of a PLMN. The BSS enables communication between a mobile terminal (called Customer-Premises Equipment - CPE) and the rest of network via a Base Transceiver Station (BTS) and Base Station Controller (BSC). The BTS connects a CPE to the BSS and handles multiplexing, speech encoding and decoding, and controls power & modulation. The BSS consists of multiple BTSs controlled by one or more BSCs. The BTS receives measurement from the CPEs and the BSC makes handover decisions between different radio channels and between different BTSs.
Network and Switching Subsystem (NSS)	The main function of NSS is to control one or more BSSs. The NSS contains three entities: the Mobile Switching Centre (MSC), Home Location Register (HLR), and Visitor Location Register (VLR). The HLR and VLR are databases which store the International Mobile Subscriber Identity (IMSI) and telephone number associated with each CPE. These databases keep track of the CPE's current location and what services it can utilize. The VLR manages only CPEs within a given area, while the HLR manages all of an operator's subscribers. The MSC handles authentication, registration, geo-localization, incoming calls, outgoing calls, transmitting/receiving SMS, etc. An important function of the gateway MSC is to interconnect this network with other networks, such as the public switched telephone network (PSTN)
Operating Sub-System (OSS)	The administration and control of network are the responsibility of the OSS. The OSS consists of several components: Equipment Identity Register (EIR), Authentication center (AuC), and Operation and Maintenance Center (OMC). The EIR has list of CPEs which it can track for specific purposes and can allow or deny them the ability to communicate. The AuC stores each CPE's identification and authentication information. The OMC is responsible for analyzing the operation of the network and manages the BCS.

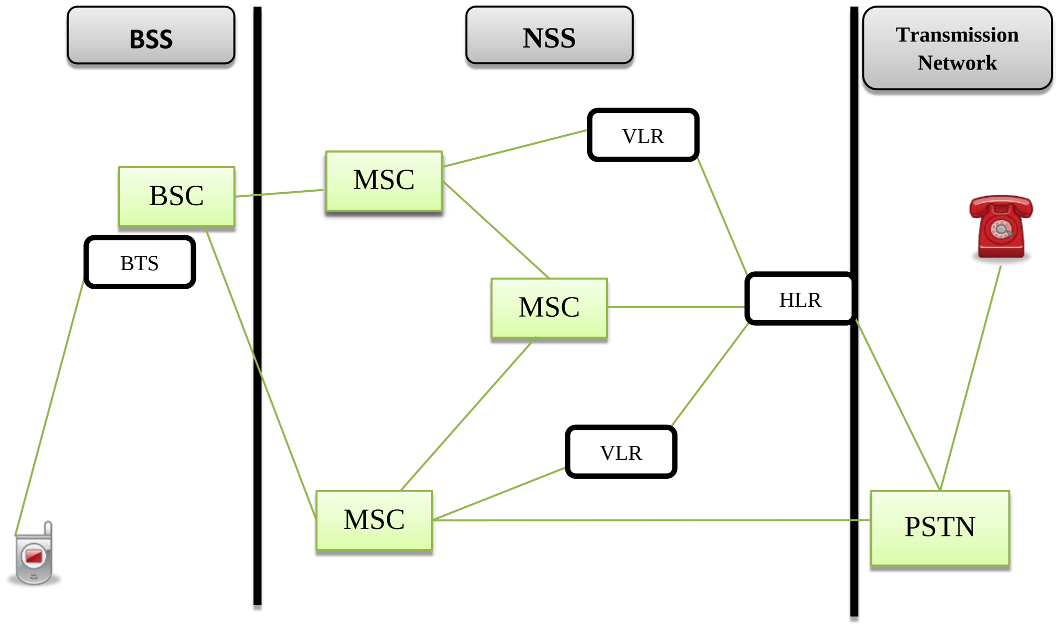

Figure 2-1: **GSM architecture Overview**

2.2.2 GSM-R differences from GSM

A specific frequency band is reserved for GSM-R. GSM-R uses 900 MHz in Europe [8]. GSM-R allows trains to be constantly connected to the trackside equipment and a control center. The railway companies have access to the GSM networks within different countries which allows interoperability of GSM-R with all GSM networks in Europe [9]. Figure 2-2 shows an overview of the GSM-R system and its interconnection via the MSC over an ISDN network to a Radio Block Center (RBC)[10]. The RBC is responsible for exchanging information with both onboard and trackside equipment in its area [11].

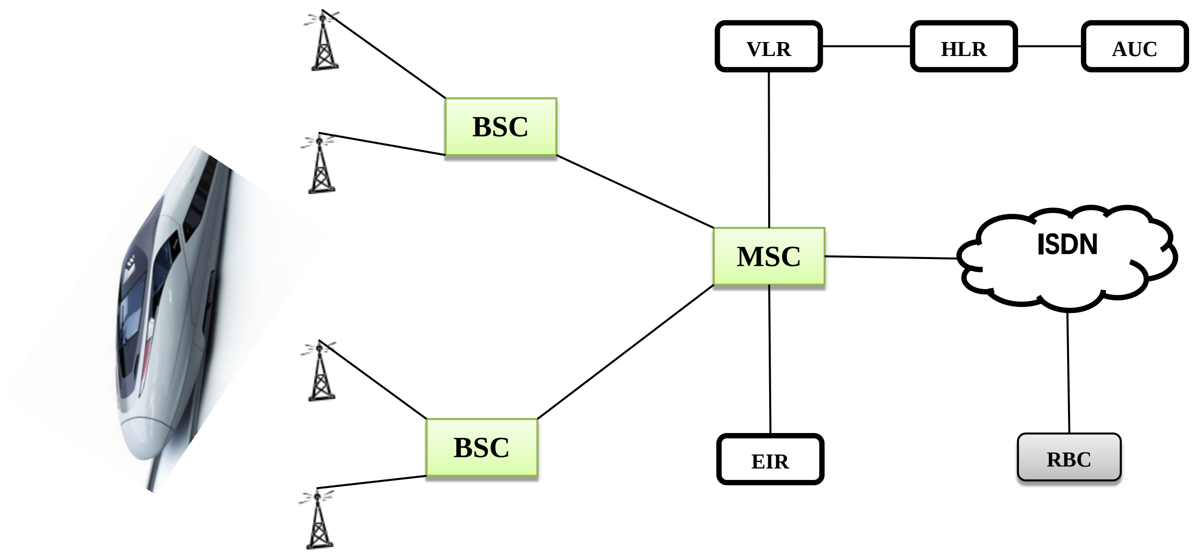

Figure 2-2: **GSM-R overview**

2.3 ETCS

ETCS consists of two main sub-systems: trackside and onboard equipment. The trackside equipment consist of those components which are installed outside of the train – typically along the railway right of way, while onboard equipment are installed inside the train[12]. Trackside and onboard equipment must communicate and interact via the GSM-R wireless links [13]. Figure 1-1 (on page 2) showed the overall ERTMS/ETCS Reference architecture. The elements of this architecture are described in the following subsections.

2.3.1 Trackside equipment

A sub-system is a combination of components that are interoperable. The trackside sub-system consists of the following components:

Balises	This component is frequently called a Eurobalise. It communicates with the onboard sub-system. The balises are organized in groups and each group and each balise has a unique identifier. The goal of these balises is to help a train to determine its direction of travel by sending telegrams. Balises are able to send a fixed message or different messages once they are connected to an electronic switching unit. By allowing the same message to be sent by more than one balise of each group, the system ensures that the message reaches its destination, even if one of the balises fails. The train's balise reader's electromagnetic field energizes balises as it passes over them. The balise responds by periodically sending a telegram to the train. The balise reader is described in the next subsection.
Euroloop	The Euroloop is based on a leaky cable and a modem which send telegrams to the train over a length of track, unlike the grouped balises which are localized at one spot. The main advantage of the Euroloop is the flexibility in location where the train can receive a message. These components are only used on Level 1. (The concept of a level is described in Section 2.4.)
Lineside Electronic Unit (LEU)	The LEU is a device that interacts between Eurobalise, Interlocking, and external trackside systems. The balise sends a telegram generated by an LEU that has received information from external trackside systems or Interlocking. In some cases, the Eurobalise is replaced by Euroloop or Radio Infill Units (RIUs) which transmit the message via the loop or via GSM-R (respectively).
Radio Block Centers (RBC)	The RBC is responsible for the safety of the trains that cross within its area. By receiving information from interlocking, block systems or level crossings, and by exchanging information with onboard sub-system, the RBC computes messages to be sent to the train. These messages describe the route and the speed limitation within the RBC's area, while ensuring that all conditions are in place for the train's movement, such as route state, occupancy, etc.

	The train's position is calculated and recorded in the RBC database and transmitted to the next RBC, once the train is on the way to enter the area supervised by this next RBC. A RBC is only used in Level 2 and 3 and messages are sent via GSM-R.
Radio Infill Unit (RIU)	RIU increases the performance of the line. Indeed, it is able to send wireless messages to onboard equipment along a predefined length of track, unlike fixed balises that only transmit messages when a train is passing over it. Messages are sent via GSM-R. The RIU logically corresponds to a balise.
Key management System (KMS)	Communication safety between train and trackside components is provided by KMC. The KMC manages the cryptographic key by generating, updating, and dispatching authentication keys via the Key Management Center (KMC) and by handling the asymmetric key material.

2.3.2 Onboard equipment

The onboard equipment is computerized system with different modules or units. Depending on which application level of ERTMS they are installed for and according to the requirements of each supplier, these modules or units can be individual parts of the system or combined together. These modules are:

European Vital Computer (EVC)	The EVC is the kernel module. It is a computer that supervises the train's movement by using the information exchanged between the trackside equipment, the train driver, and other onboard equipment.
Train Interface Unit (TIU)	The main function of the TIU is to control the interfaces between the train and onboard equipment. There are four principal interfaces. The first interface is the train braking system which is used in case of an emergency or in services brake. The service brake is not a safety critical brake, unlike the emergency brake. The second main interface is the train control that controls the change in traction, raising or lowering the pantograph, and other functions. The third interface is the engine control which is used during service or the emergency braking to cut the traction power in order to cancel the tractive effort. The last main interface is the cab status information which determines the position of the direction controller. The direction controller indicates in which direction a train is moving into.
Balise Transmission Module (BTM)	The BTM controls the interface between onboard systems and Eurobalises by managing their data communication.
Loop Transmission Module (LTM)	The LTM module controls the interface between the onboard sub-system and Euroloops installed trackside.
Euroradio	Using GSM-R, the Euroradio module secures the communication between onboard and trackside sub-system. The Euroradio encodes and decodes messages sent to and received from the RBC.

Odometer	Odometer estimates the train's speed and its displacement by using information received from a speed sensor. This information is transmitted to the EVC which uses it to calculate the train's speed and location in combination with other information received from tachometers.
Juridical Recorder Unit (JRU)	The JRU is the memory of the system. It records different information and events from the equipment, driver interactions, and some EVC commands. This record is for legal and juridical investigations in case of an accident or incident.
Driver-Machine Interface (DMI)	The DMI onboard equipment displays information on a display, which is read by the driver in order to determine the maximum allowed speed, the permitted distance to travel, and the point where the driver should start to brake. The driver interacts with the display by buttons that change their function depending on the train's situation or supplier. In general, the most important information that is displayed is: • Supervised distance information - the distance remaining before the train should change its speed. • Speed information - indicates the train's current speed and the maximum authorized speed in the area. • The planned area shows advanced information and an overview of the track (i.e., rail line) ahead. • A supplementary Driving Window is a part of the display where the symbols used change according to functions implemented in the ETCS Application level. It can also display text messages and other interesting events to the driver. • A monitoring window provides extra information to the driver, such as geographical position, time, etc. • A Main Menu Window indicates the function of each buttons on the DMI.
Balise Reader	The Balise Reader supplies power to the balises or Euroloop. In return, it receives a telegram from them and transmits this message to the EVC with the help of BTM or LTM.
Specific Transmission Module (STM)	This module permits the train to read messages from national trackside equipment when a train is not driving on an ETCS equipped rail line. Using STM, onboard equipment is able to provide the same functionality as a notional train protection system, by reading magnets or loop messages from the national trackside equipment.

2.4 ERTMS Application Levels

The rail network specification is different in many countries and regions; therefore, the ERTMS/ETCS is divided into five application levels [1]. This diversity constrains the onboard equipment to operate at different levels depending on which rail line the train is running on. In other words, onboard equipment are active and in operation depending on the installed trackside equipment.

2.4.1 Level 0

This level is used when an ETCS' train is forced to run on a rail line with trackside equipment which does not meet ERTMS requirements. This level can be also used in case of *force majeure*, when ETCS trackside equipment is not operating. There is onboard equipment which continues to be used even in this situation, such as supervising the maximum train speed and maximum authorized speed. An Eurobalise is used to announce the train it is switching to a rail line with a level 0 specification. As a result the on board equipment which handles Eurobalise transmission is also used in this level. In this level the driver is responsible for reading and interpreting the trackside signals.s

2.4.2 Level STM

The Specification Transmission Level allows the train to run on rail lines with trackside equipment that has a national protection system. The STM (described in Section 2.3.2) is the element on this level that receives information from the trackside from the national system and translates it into a format that the onboard ETCS equipment is able to understand. This level depends highly on the information supplied by each national protection system. The train transits to Specification Transmission Level if the driver activates this mode or if onboard equipment receives information from the trackside ordering the activation of this level. When this occurs, the onboard equipment verifies whether the STM is working properly, otherwise the equipment automatically brakes the train and notifies the driver.

2.4.3 Level 1

Level 1 occurs when existing trackside infrastructures are updated by the installation of trackside ECTS equipment and the fixed signal system remains in place. The "old" infrastructures (interlocking, line side signals, and track vacancy) are connected to the ETCS trackside equipment (Eurobalise and/or Euroloop and RIU). Sometimes an adaptor is used. The LEU allows communication between the balise and the lineside signal or the data link that controls the signal (as shown in Figure 2-3). In this way the lineside signal controls the concordance of the information send to the train and the current lights being displayed along the track. Unfortunately, the displayed light can change after the train has passed the balise and the information maintained by the train is incorrect in this case. For this reason a train must slow down even when the displayed light gives the priority to that train (green). In order to avoid unnecessary train braking, Euroloop can be installed and transmits in advance the next main signal in the train's current direction. Another solution is to send this information via an RIU through GSM-R.

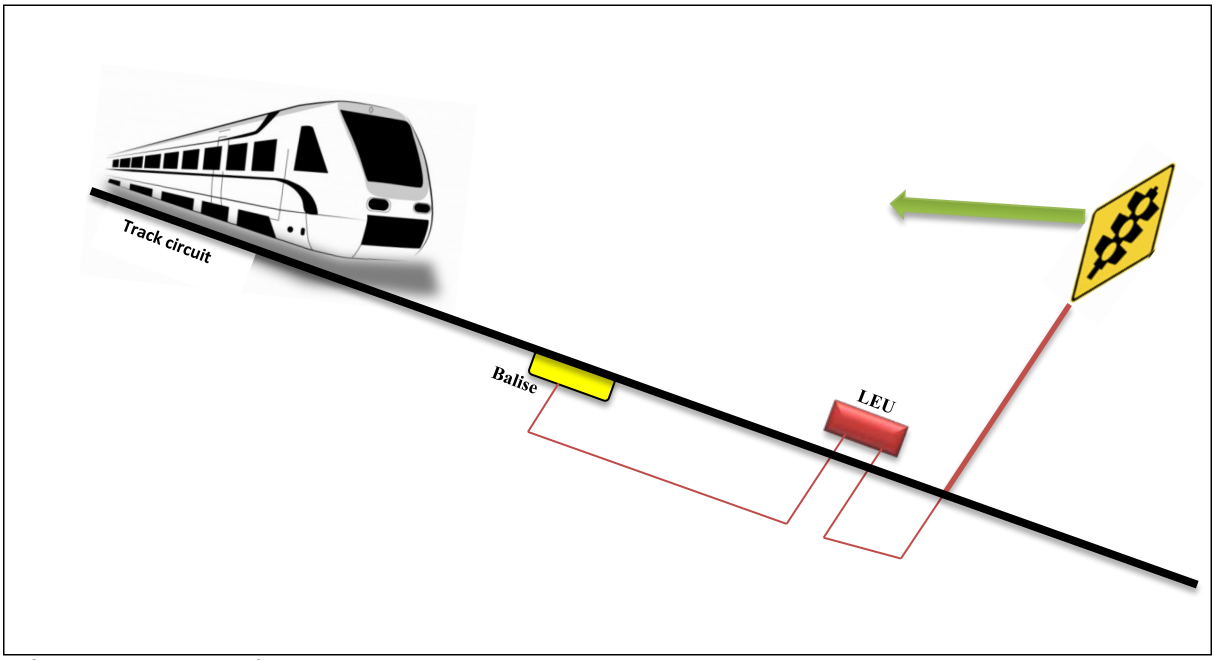

Figure 2-3: Level 1

2.4.4 Level 2

As in the previous level, this level is also designed to be inserted in the existing infrastructure. The significant difference between the two levels is that the fixed lineside signal is not required in this level. The trackside equipment is mainly based on the RBC's track clearance Detection and the Eurobalises. The lineside signal is replace by a virtual signal displayed on the DMI. The communication between onboard equipment and RBC is bidirectional and uses GSM-R (as shown in Figure 2-4). The onboard equipment automatically transmits to RBC the exact position and direction of the train which was determined by the information received from Eurobalise. The combination of this information and the information sent by interlocking allow the RBC to constantly calculate the movement of a train within its area. The RBC sends movement authority (MA), speed profiles, and route data to the train. The onboard equipment uses the information via radio received and the available information in the train to analyze the necessary speed and information to be displayed on the DMI.

The whole system allows the train to move on the track by itself, although supervision remains the responsibility of the train driver.

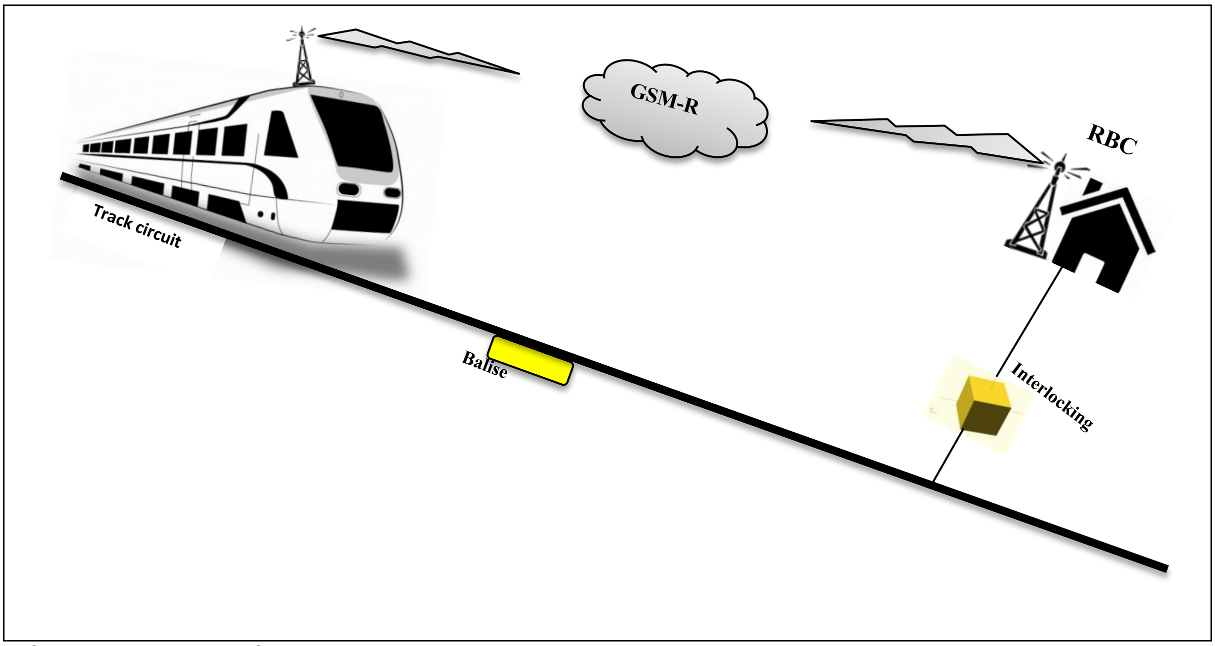

Figure 2-4: **Level 2**

2.4.5 Level 3

In this level, the trackside detection equipment is no longer required. In this case, the detection of the trains is the responsibility of the onboard equipment. The train must report its position and the train integrity information to the RBC (as shown in Figure 2-5). The presence of a given train on a track is based on this information and the uniqueness of the train is confirmed by the ETCS identity from its relevant ETCS onboard equipment. Eurobalise are mainly used as a location reference in this level. The driver receives information via the DMI which allows him or her to confirm the integrity of the train.

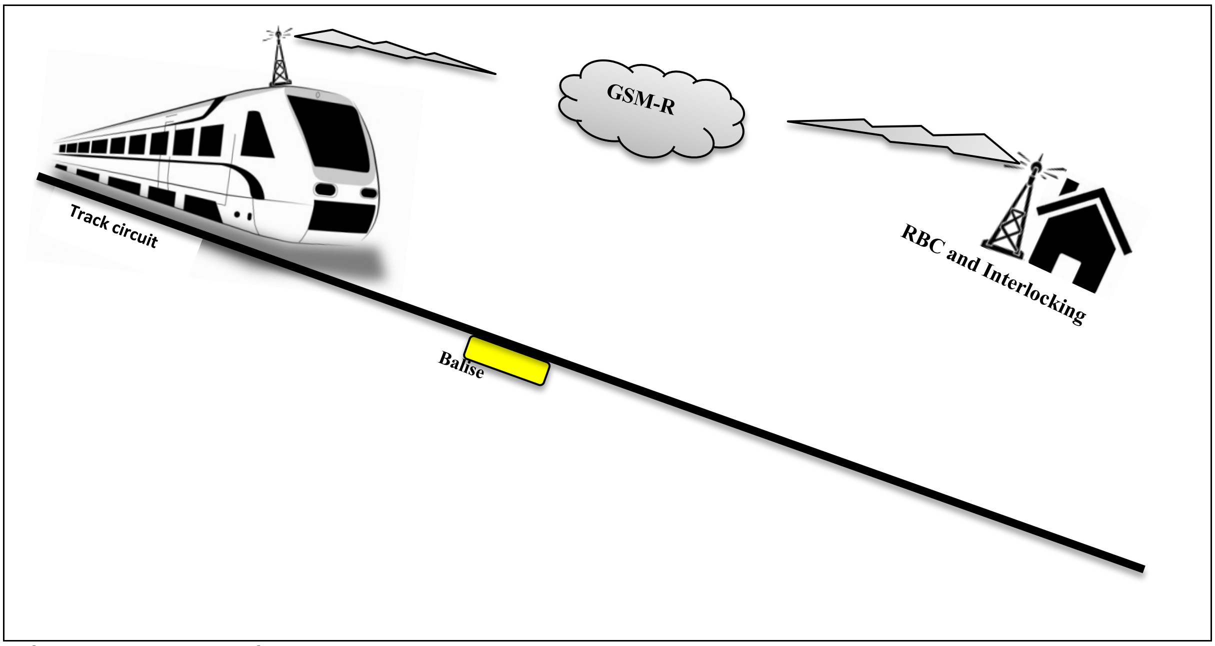

Figure 2-5: **Level 3**

2.5 ERTMS simulation environment

This section describes materials used in the simulation of ERTMS level 2 at BT laboratory in Stockholm. This laboratory is equipped with a simulated ERTMS level 2 system as shown in Figure 2-6. This simulation environment has been developed in order to test effectiveness and ensure safety of each ERMTS project. The simulated environment is often a combination of several pieces of software and hardware that must work together. The track of a given ERTMS railway line with its infrastructure is reproduced in that environment. All events which can occur during the run of an ERTMS train are predefined in this environment.

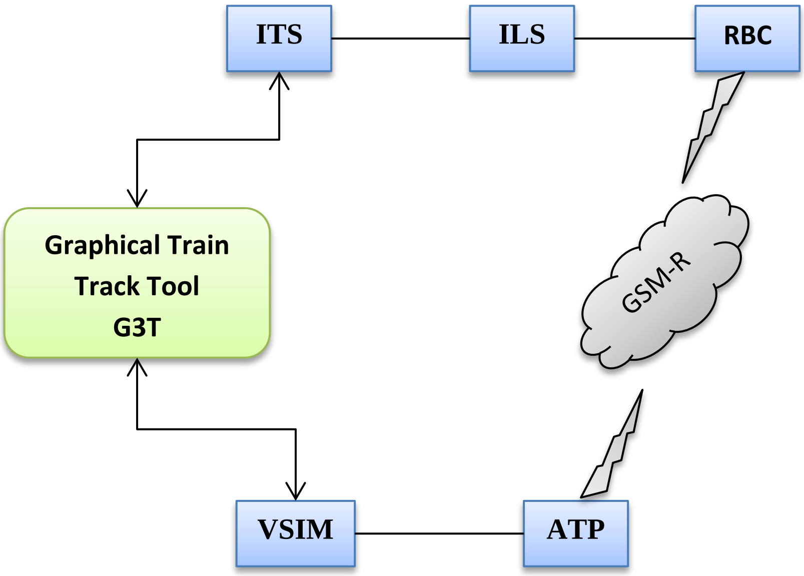

Figure 2-6: ERTMS simulator tools architecture overview

The simulation environment is made up by the following entities:

Graphical train track It allows reproducing railway line with graphs. It provides a general overview of the whole railway line with its line and stations. The graphical topology depends on railway line to be simulated. Figure 2-7 shows part of a given railway line with several "lines" and stations. This reproduction is used to indicate the general result and the progress of tests together with portions of railway lines where a focus must be putted on or retested.

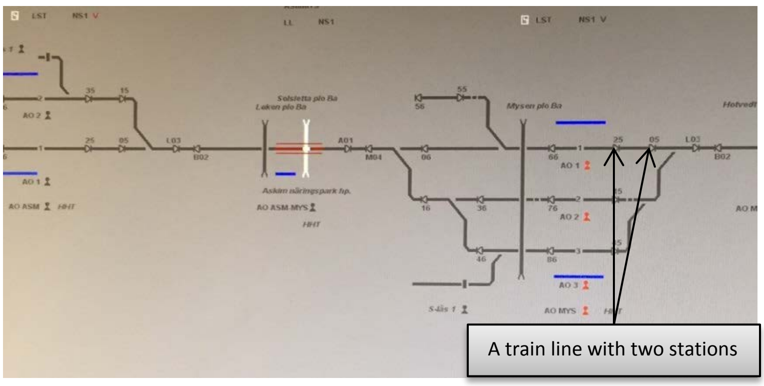

Figure 2-7: Graphical reproduction of railway line

Graphical Train Track Tool (G3T)

It is a user interface that acts as a central unit during tests in the simulator. Indeed, G3T is the software that guarantees communication and interaction between different pieces of wayside and onboard equipment as well as with other simulators entities during tests. In the same time, it provides a graphical user interface that reproduces all tracks objects of each line and indicates train movements during tests. G3T allows to control and to display train movement, to generate simulation data for the onboard equipment, to display all trackside objects on the graph and to report train movement to the trackside. In Figure 2-8, the train is represented in bleu rectangle and its position is indicated in X-axis of the graph. The trackside equipment is represented by T. The Y-axis specifies the train speed. The top part of the figure is used to control the train by setting its movement and its controllers. Further details about using this tool can be found in an internal BT document [14].

Figure 2-8: **Track Graph**

Vehicle Simulator 2000 (VSIM 2000)

It is a software system that acts as a train vehicle for onboard hardware during lab tests. VSIM 2000 interacts with a real ATP hardware through RBC for ERTMS application Level 2. G3T controls train movement by generating tests data for VSIM 2000 and by reading information from it. Figure 2-9 shows the user interface of VSIM 2000 with some windows used to “create” a wished vehicle. The usage of VSIM 2000 is more described in [15].

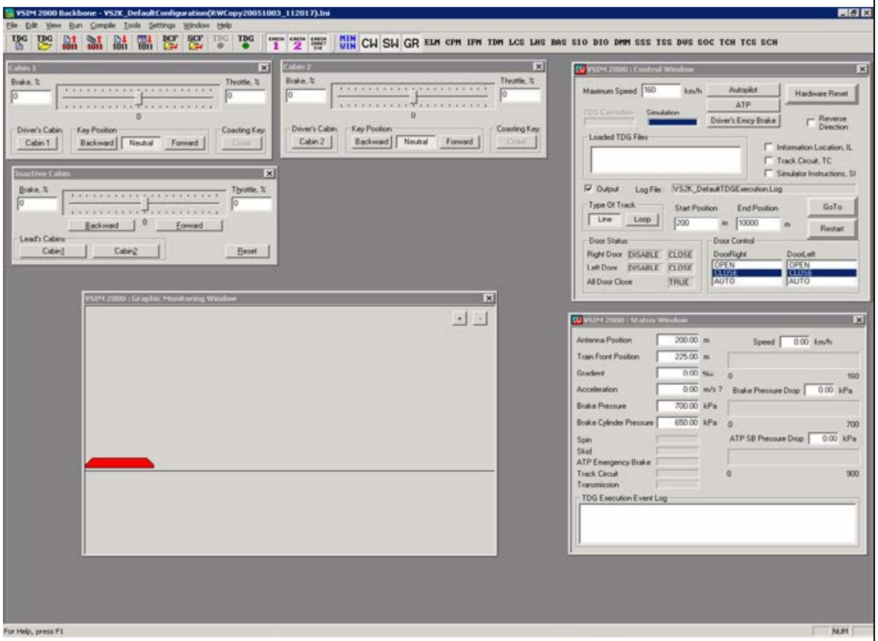

Figure 2-9: VSIM 2000 user interface

Onboard equipment and DMI

All onboard equipment is connected to the same central unity which is the brain of the whole onboard system. The simulation environment uses a real onboard central unity (Figure 2-10) with a real DMI (Figure 2-11) which are usually installed on a train[16].

Figure 2-10: Onboard central unity

Figure 2-11: DMI Display

Interlocking (ILS) and Interlocking Yard Simulator (ITS)

It is a combination of a real interlocking system (ILS) and other simulated interlocking modules (ITS). G3T interacts with ILS through ITS by sending train occupation status. At the same time, ITS simulates other trackside equipment. The ILS is used with the ITS as shown in Figure 2-12.

Figure 2-12: **ILS used in lab**

Radio Block Center (RBC)

A real RBC is used during tests. This RBC is shown in Figure 2-13. The RBC is described further in Section 2.3.

Figure 2-13: **RBC used in the lab**

2.6 Reporting ERTMS simulation failures in database

This section describes the process of reporting via tool and in databases those failures that were detected during simulation. Prior to this I will briefly describe the strategy adopted by BT to manufacture its products.

2.6.1 BT production strategy

BT has adopted automakers strategy in the development of its product. Automakers have developed an automobile platform which allows use of the same components of a car in different models of vehicles. These components often share design, engineering, and production systems [17]. The aim of this strategy is to reduce the development cost and to increase effectiveness. BT uses this strategy in the development of its hardware and software. This strategy consists of three productions levels:

Generic Product (GP)	The GP contains the core functions of a product and its basic functionality, hence one GP will be reused in all projects and sites all over the world.
Generic Application (GA)	The GA is the set of equations to implement each type of object in a product in order to adapt the GP to a given project and site: A GA is a specific product for a customer, but is reused at every site of this customer.
Specific Application (SA)	A SA is the characterization of every individual object, device, or system in accordance with the geographic description and the specific installation, hence there is one product for each site and it is unique for each site

The main disadvantage with this strategy is that if a failure in the GP or GA level is **not** identified during tests, then this will have an impact on many products. This type of systematic failures seems to happen frequently in the automobile industry. For example, since 2008 Toyota was forced to recall over 31 million vehicles around the world due to faulty airbags inflators [18].

For this reason a failure found in a product during tests must be corrected, but must also be identified to production management as to which level it belongs to, in order to identify all of the products that it will affected by this failure.

2.6.2 Submitting ERTMS simulation failures in database

At BT, a product is used in many projects and each project has a hundred or even a thousand engineers working on it. At the same time, the resolution of a failure may require the intervention of many engineers. Therefore, BT uses tools and databases to manage failures and to exchange information between different projects and engineers. This exchange of information is fundamental when it comes to handling failures. Indeed, reported failures may have an impact on the security of the system or the system may not work at all until these failures are resolved. At the same time, the consequences and implications of reported failures may impact other projects or must be resolved in another production level. For all of these reasons, the exchange of information via the databases must be both fluent and safe.

At BT, Region North is only involved in development of GA and SA projects. Therefore, it creates entries in the database used to report failures found in these productions levels. As a failure might be resolved in the GP production level, the failure is entered into the database by tools that will indicate the failure occurs at the GP level.

2.6.3 Rational Change

In Region North, IBM® Rational® Change is the tool used by BT to manage failures [19]. As mentioned earlier, a failure is any deviation or nonfulfillment of a requirement of a product and at BT is called a Non-Conformity (NC). Once a NC is discovered, a Non-conformity Report (NCR) is entered using Rational Change. This NCR consists of all analysis and documentation related to the NC. The submission of a NC in Rational Change requires that a user fills in the following mandatory information (shown in red in Figure 2-14):

Problem Type	A NC can be classified as a defect or a hazard. A defect is an error in the product, while a hazard is a defect which may have an impact on the security of the system. Thereby, a particular focus must be placed on a hazard.
RCS project name	As each project has a specific name, this field specifies which project a NC is related to.
Product name	States in which product the NC was found.
Synopsis	A short description of the problem
Description	A sufficient description of the problem to allow the reader to understand the problem
Product version	A product may have many versions, hence the specific version that the NC has been detected in is noted in this field.

In addition, the user can also define: the severity of the NC, the safety severity of the NC (i.e., if it is classified as a hazard), or the relevant work package when the project has been divided into several different packages. These fields are *not* mandatory and depend upon the experience of the person who submits the NC.

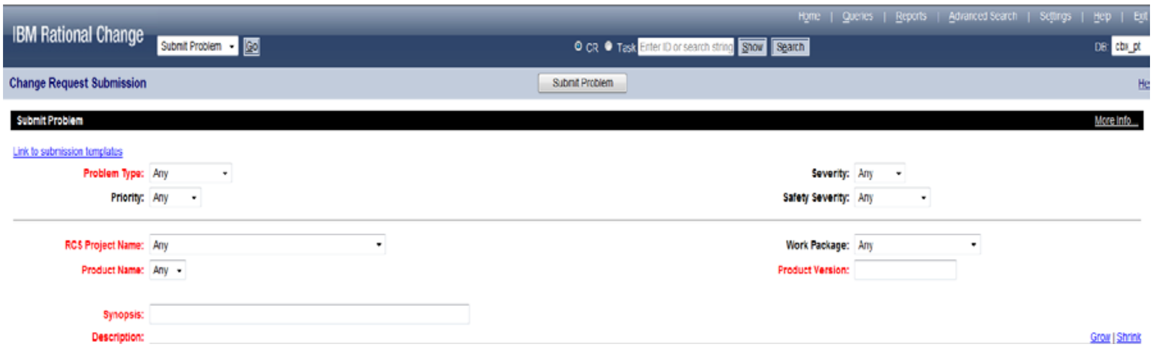

Figure 2-14: **Submission interface to the Rational Change database**

2.6.4 EAPD Helpdesk

This tool is used for communication between the GP production level with its customers who are projects in the GA and SA production levels [20]. In these two production levels, projects combine different products that were developed at the GP level. During the realization of GA and SA projects, some extra information on product may be needed or it may be found that a product has a deviation and does not fulfill all requirements. In these cases, a request is sent to GP level using EAPD Helpdesk.

The core of this tool is a website where a change request and questions from GA and SA projects are posted (Figure 2-15). The only fields to be complete during the submission of a change request or a question are the “Summary”, “Description”, and “Product Name”. In the Summary field, a short description of the change request is given. The description of the problem should be sufficient to allow the reader to understand the problem. This description is given in the “Description” field. The submitter of a change request has a list of products in “Product Name” field to choose from and the user must choose which product this submission is related to. The submitter can also specify a specific version of this product. If the user wishes to notify other users of their action, their usernames are entered in “Cc” field.

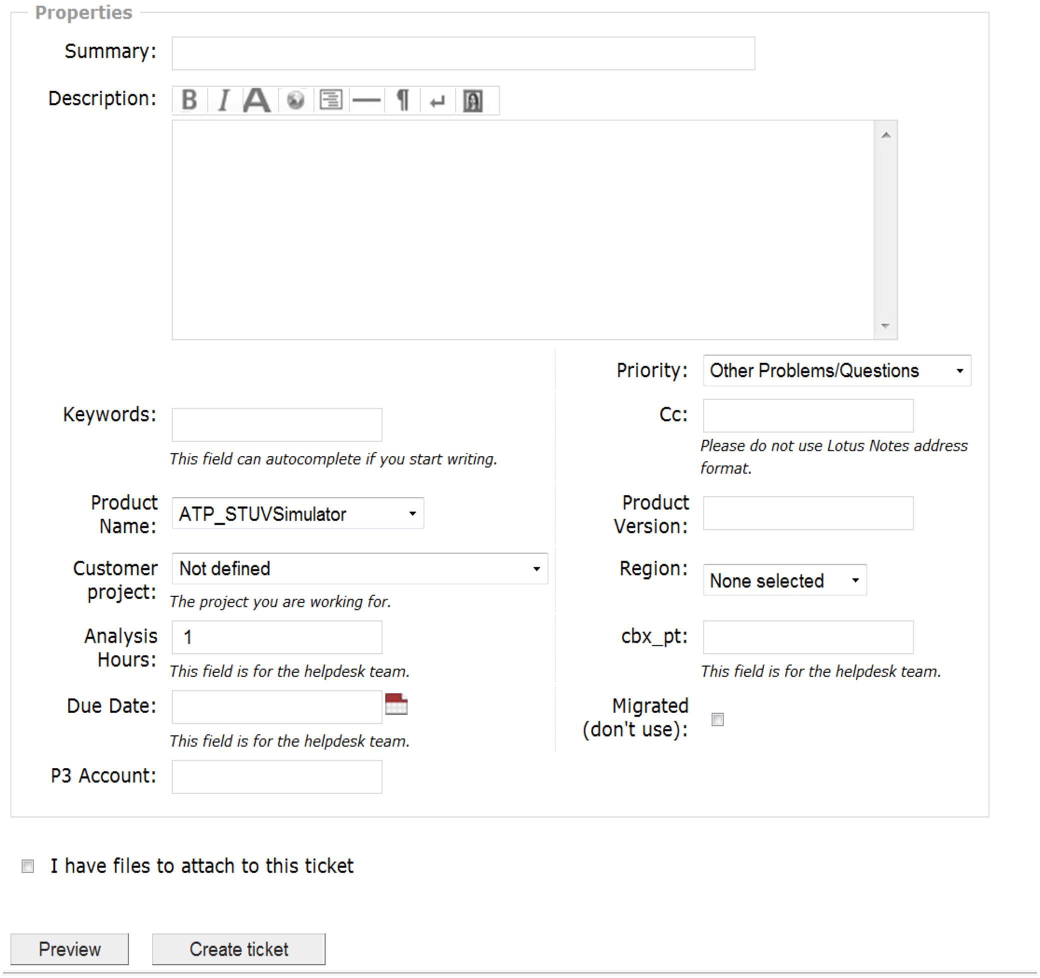

Figure 2-15: **User interface of EAPD Helpdesk**

2.7 Key Performance Indicators (KPI)

Key Performance Indicators (KPIs) aim to measure the performance of an organization in a particular area or activity [21]. Depending on the area or activity to be evaluated, KPIs can focus on the company’s gross revenue, the customer’s satisfaction, demography, system failures, etc. The measurement unit of a KPI is based on the evaluated area or the activity of the organization [22].

KPIs highlight the success, progress, or current state of the evaluated activity or area by providing a clear and visible indication about it. In order to be useful, KPIs should follow the following requirements [23]:

- **S**pecific

  Each KPI must be well defined with a clear goal to reach and must have a utility in the evaluated activity or area.

- **M**easurable

  Each KPI must be able to be obtained with concrete and measurable data. It should also define when the goal is reached.

- **A**chievable

  Each KPI should have a realistic and attainable goal.

- **R**elevant

  Each KPI requires sufficient resources and knowledge in order to have achieve a relevant goal.

- **T**ime-bounded

  Each KPI requires time in order to be calculated. This time should not be too long, otherwise the KPI could be useless when its value is finally known.

KPIs which fulfill the requirements above are commonly called SMART KPI [24].

2.8 Related work

This section describes related work on ERTMS which have taken place earlier. The objective is to familiarize the reader with this area. BT has conducted many projects on ERTMS simulation. Unfortunately, these projects are often confidential and only Bombardier employees have access to them. Bombardier's competitors have also adopted the same attitude due to trade secrets. For this reason that it is difficult to find public studies that deal with this subject in depth. Therefore, I have chosen articles that are related to ERTMS in general.

2.8.1 Is GSM-R the limiting factor for the ERTMS system capacity?

In 2012, Gustaf Lindström conducted a study on the capacity of GSM-R (one of the main ERTMS components) [25]. In this study, an in depth analysis was conducted on the interconnection between ETCS and GSM-R, from the method of transmitting data to the quality of service of GSM-R, while analyzing available frequencies and radio channels. The result of this study showed that GSM-R was in general *not* the limiting factor in ERTMS at that time, even if there were some factors limiting its capacity, such as interference with other public mobile services or limited capacity in an area with a high density of trains using GSM-R. However, with increasing usage of ERTMS in the future, GSM-R could be a limiting factor. For this reason the capacity of GSM-R should be increased together with its functionality. Mitigations proposed to improve the quality of GSM-R were to use filters in order to avoid interference with other service operators, to allocate more frequencies to GSM-R, and to combine the usage of ERTMS levels 1 and 2 in an area with high traffic.

2.8.2 Virtual lab based on co-simulation to include impairments of wireless telecommunication, such as GSM-R, on the evaluation of ERTMS

In this study, an ERTMS simulator is connected to Riverbed Technology's OPNET, a simulator for the wireless telecommunication subsystem of trackside and onboard equipment, as shown in Figure 2-16. OPNET simulates the ERTMS telecommunication subsystem by taking into account impairments, such as electromagnetic interference that can occur in the real world. This work describes the co-simulation approach of an OPNET and ERTMS functional simulator [26].

This study showed that OPNET provided models for the UMTS, WIMAX, and LTE technologies, but not for the GSM-R. Although several custom GSM models, such as GPRS have been proposed for the OPNET simulator, they are still under improvement to produce a complete GSM-R.

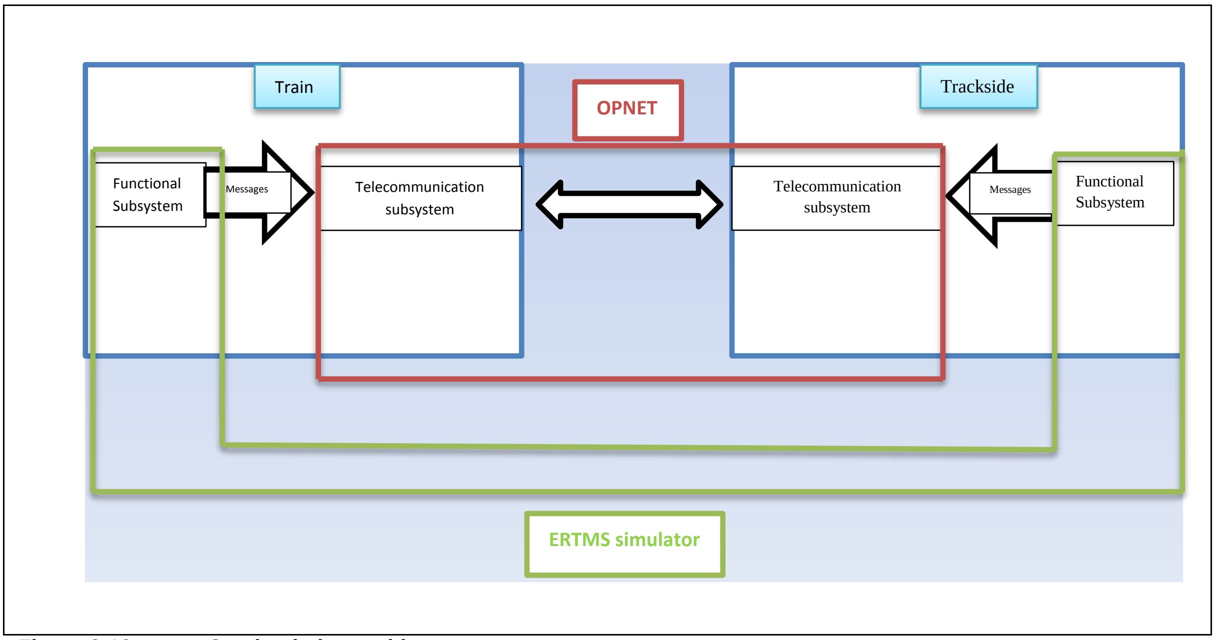

Figure 2-16: Co-simulation architecture

3 Methodology

The purpose of this chapter is to provide an overview of the research method used in this thesis. Section 3.1 describes the research process. Section 3.2 details the research paradigm. Section 3.3 focuses on the data collection techniques used for this research. Section 3.4 explains experimental design and planned measurements. Section 3.5 focuses on Pareto principle.

3.1 Research Process

The research process started with meetings with and lectures from the industrial advisers for this project. The aim of these meetings and lectures was to provide a deeper understanding of the goals of this project as well as to learn the inner working of the company. The industrial advisers also provided me with a user name and password which allowed me to login into the company's internal network and documentation database. This database contains all of the documentations needed by BT's engineers in order to accomplish their work. A combination of BT's documentation database and other sources of information allowed me to review the relevant literature and this resulted in the background that was presented in Chapter 2. The next step was to determine and simulate the specific part of an ERMTS implementation which this project should contribute to. Simultaneously, an investigation was conducted on the process of reporting and managing non-conformities in tools and databases by analyzing their working processes and discussing this with tool and database users. Then corrective actions were proposed in order to improve this management process. Finally, a method of classifying and presenting non-conformities was defined together with concluding this project. Figure 3-1 summarizes these steps conducted in order to carry out this research.

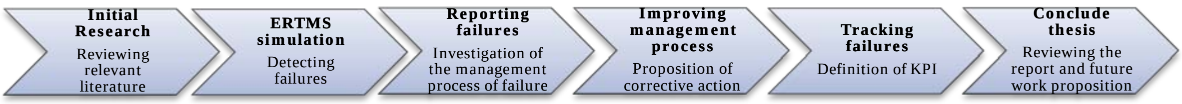

Figure 3-1: Work flow diagram

3.2 Research Paradigm

As described in Section 1.5, quantitative and qualitative research methods were used in order to reach this project's goals. When several methods are used, Anne Håkansson advises that each method should be applied one at time [5].

Scientific methodologies applied in ERTMS simulation:

Quantitative methods	This research method is appropriate since it requires verifying hypothesis or theories by quantitative measurements, via experiments, or testing [5]. ERTMS implementation is simulated in a computer environment. The collected data indicates directly the failures of ERTMS implantation. In contrast, qualitative research develops hypotheses and theories by understanding meanings, opinions and behaviors.
Deductive approach	This research approach is used to verify or falsify hypotheses [5]. The results of simulation are verified if they are in line with defined results by BT.

Experiment tools	The main tools used in simulation were G3T, VSIM 2000, onboard central unity, ILS and RBC (Section 2.5). VSIM 2000 simulates a train vehicle. The simulation uses a real Onboard central unity, ILS, and RBC. G3T interconnects all of the tools used in the simulation.

A number of scientific methodologies were applied in this investigation of managing reported failures that have been stored in a database:

Empirical qualitative methods	The empirical qualitative research method was chosen from among the variety of qualitative research methods that have been defined[27] because the investigation of the process of managing failures that have been reported in a database was conducted in a real environment, unlike the simulation of ERTMS. The empirical qualitative research method was also chosen because it is used to discover and understand the current situation by getting proofs based on observation, experimentation, and tests [5]. Indeed, the result of the investigation was based on observation and analysis of the current process of managing failures reported in a database. At the same time, some experiments were conducted by submitting reports of failures from the simulation into the database and monitoring these reports during their lifecycle.
Inductive approach	The inductive research approach is commonly used with qualitative methods. It tries to formulate theories or propositions from observation or experiences [5]. In this thesis, we tried to formulate theories in the problem area of managing reports of failures and based upon our based on observations and experiences proposing how to improve their handling.
Exploratory investigation	The investigation explored all of the possibilities that I could to identify as many areas as possible where the management process of dealing with reported failures has a problem. Observations and experiment are complement with discussions with a number of database users.

3.3 Data collection

In this study, two different sources of data were collected. There were non-conformities which were detected during the simulation of an ERTMS implementation, and the results of the investigation of the process of managing failures in database.

As stated in Section 1.4, one of the sub-goals is to detect non-conformities via simulation of an ERTMS implementation. Therefore as stated in Section 1.6, the first step was to determine the specific part of an ERMTS implementation this project should contribute to. Unfortunately, this took longer than expected due to the fact that the simulation did not start at the planned time due to construction work in the laboratory. As a result I was forced to change which part of ERTMS simulation I should contribute to. Simultaneously, an investigation was conducted on the process of reporting and managing non-conformities in tools and databases by analyzing their working processes and discussing this with tool and database users. These users were approximately ten employees that use tools and databases in their work.

When the simulation began, a test specification with specific test cases was delivered which should be performed in the lab together with their expected results [28]. If there was a difference between the simulation's result and the expected result, then a NCR was created and submitted via the database as described in Section 2.6. Each test case with unexpected results was repeated three times before submitting a NCR. As was stipulated earlier, I constantly monitored the submitted NCRs during their complete lifecycle. This contributed to my investigation of the process of reporting and managing NCR in database.

3.4 Experimental design/Planned Measurements

This section describes the structure of hardware and software used in the simulation environment (described in Section 2.5). It explains how the lab environment was configured and parameterized in order to conduct our tests. Section 3.2.3 describes the planned tests.

3.4.1 Test environment

The simulation was conducted at BT's laboratory in Stockholm, within the section of this laboratory dedicated to ERTMS simulation. The structure of this lab is illustrated in Figure 3-1. The laboratory environment was made up of a combination of real and simulated sub-systems. The ILS, RBC, and Onboard central unity (shown in the left in the figure) were real hardware. Each simulated sub-system was installed on its own computer. In this project, the simulated railway line was an ERTMS Level 2 and was made up of 130 lines and 90 stations.

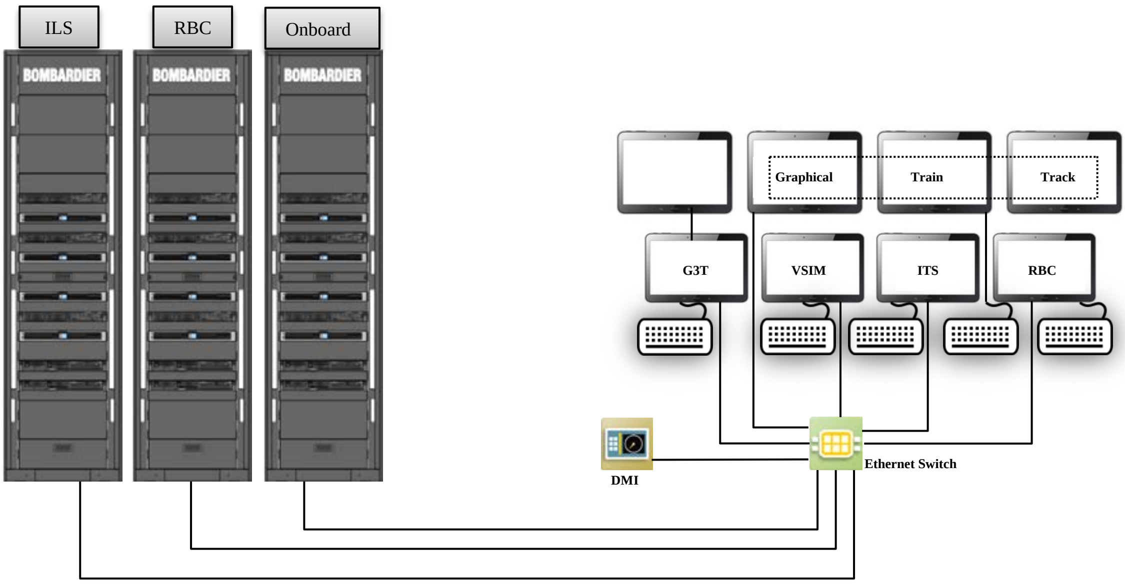

Figure 3-2: Architecture overview of lab hardware structure and user interface

3.4.2 Test environment setup

The G3T [14] is the master simulator within the lab environment because it acts as a central unit which guarantees communication and interaction between all pieces of the simulation (as was shown in Figure 2-6 on page 14). Thus, most configurations were done via this tool.

The first required step is to configure the G3T parameters. As this tool communicates with other tools through a network, all of the IP addresses and ports numbers need to be correctly configured as indicated in [29] (via the interface shown in Figure 3-3). Next, the RBC's ID and phone number are specified (using the interface shown in Figure 3-2). By using the G3TModule Test, it is possible to verify whether all of the configurations have been successfully applied. This test ensures that G3T is able to interact with all of the other tools used in simulation.

Figure 3-3: Configuration of RBC ID and phone number

Figure 3-4: G3T configuration remote access

The next step is to download the file of ERTMS railway line which should be simulated, an example is shown in Figure 3-4. This file is the type of XML 112 and contains the full topology of the railway line to be tested.

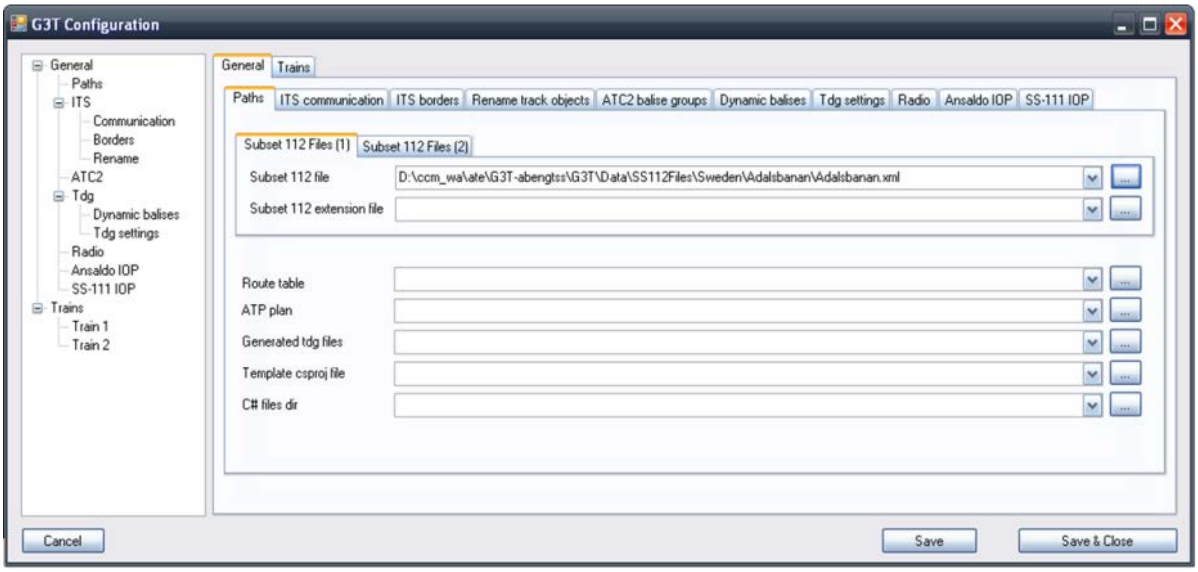

Figure 3-5: ERTMS file to be used

In order to begin the simulation, the railway line section which should be simulated, is selected. As each station of the railway line has a specific number assigned to it, each section of the line is delimited by two stations. After the selection of the section, G3T begins to automatically compose the route and all sub-routes (Figure 3-5). The tool loads also different trackside equipment which is found on that section. Information on selected route is sent to Graphical Track Train which highlights it in green (Figure 3-6).

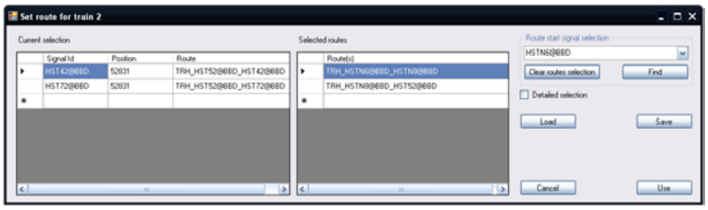

Figure 3-6: Setting a route

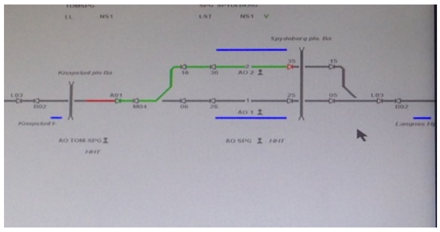

Figure 3-7: Overview of a route in Graphical Track Train

A train running on the selected route is simulated by VSIM2000. VSIM2000 allows the person running the simulation to specify the characteristic of this train, such as its maximum speed or setting up cabins. A cabin is a train car that is designed to carry passenger. The train driver sits in the cab of the locomotive and allows the driver to control the train by using different tools. The train length and the antenna position are configured in G3T (as shown in Figure 3-7) and this information is sent to VSIM2000. The antenna offset is the distance between the front of the train in meters (shown as A or B in Figure 3-8). The train length and the distance between antennas are part of a test's specification [28]. The G3T controls the train's movement by generating test data for VSIM2000 and by reading information from it. All of the user interface windows, which are used during the configuration of the train are shown in Figure 3-8 and further details can be found in [15].

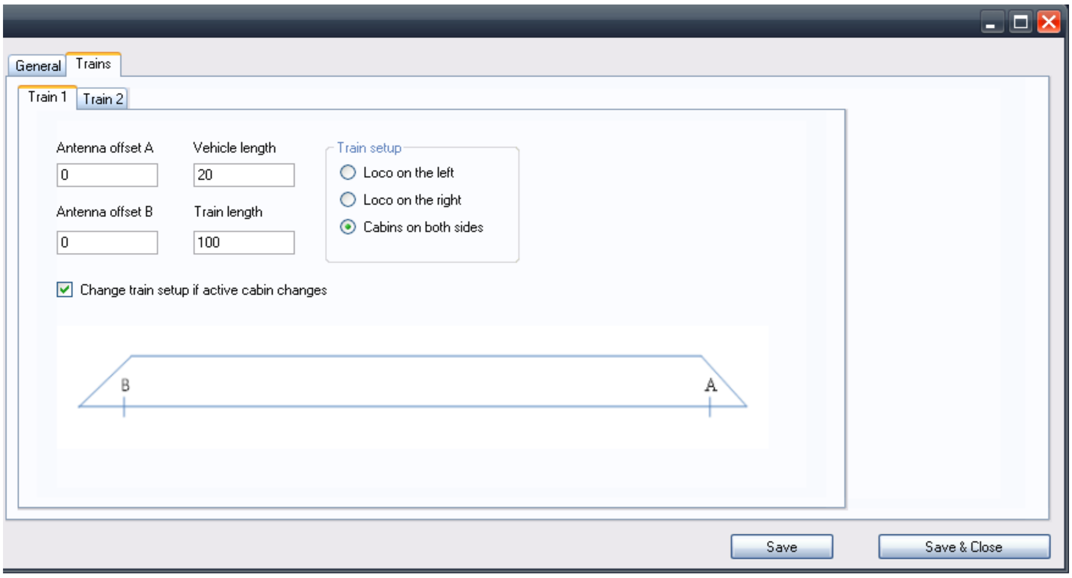

Figure 3-8: Train data configuration

The driving direction of train is selected in G3T together with the activation of one of the train cabins. As it might be expected, the activated cabin will depend on the train driving direction. After having simulated the route in one direction, the first cabin is deactivated and the second cabin is activated. And then, the train runs in reverse direction.

The interaction between users (driver) and Onboard equipment is via the DMI. The DMI displays driving information, such as the acceleration of the train or the speed of the train which it receives from G3T. The user uses the DMI top command actions, such as to start the mission and then the train moves on the track by itself.

Figure 3-9 shows G3T user interface without a route and Figure 3-10 shows the same user interface after setting a route and starting the train in Level 2. The user interface displays the name and position of signals, level crossings, and balises.

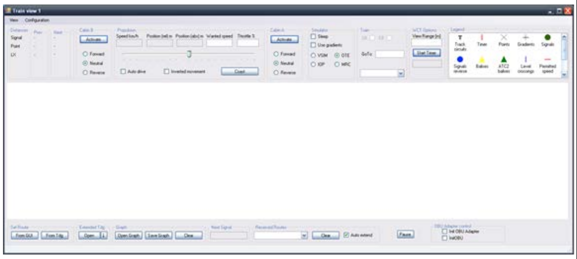

Figure 3-9: G3T interface before setting a route

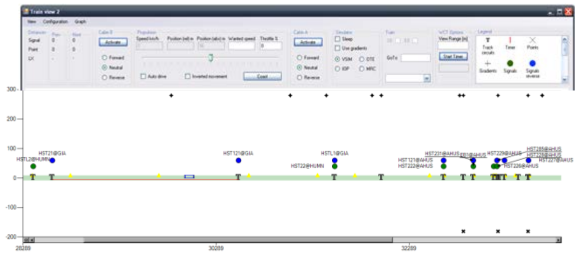

Figure 3-10: G3T user interface after setting a route and a train on the track

3.4.3 Test cases

All of tests cases to be performed were specified in BT's document "Test Specification - ERTMS L2" [28]. The expected results of each of these tests are presented in a table in this document. If the tests result of each test case was not identical to the expected results, then a non-conformity exists and a NCR was created. The following paragraphs describe the tests that were performed.

3.4.3.1 Run train over all train routes

The objective with this test is to verify if all routes are released correctly after a train's passage. The track is divided into a number of blocks which allows determining the exact position of the train. Each block is delimited by signaling equipment. The system allows a train to run on a block if at least the next block is free. The route state is saved in the system allowing other trains to use the same blocks and route. This test is performed over all routes in the system. The G3T provides the result of this test. This test is performed in the three steps shown in Table 3-1.

Table 3-1: Run train over all train routes

Step number	Action	Expected Result
1	Set a train route	Train route is set
2	Set the following train's route	Train route is set
3	Simulate a train, run it along the first train's route	First route is released after the train has passed each block of the route

3.4.3.2 Speed reduction

The system defines the normal speed for each route. This test verifies if it is possible to reduce the speed of each route. The G3T can reduce the permitted speed in a given area [14]. The train's speed and permitted speed are displayed on the DMI. This test is accomplished in the step shown in Table 3-2.

Table 3-2: Speed reduction

Step number	Action	Expected Result
1	Set a train route or several train routes	Train route(s) is/are set
2	Activate speed reduction over one route or several routes	Speed reduction is activated
3	Simulate a train and run it over the route	Train runs with the correct speed according to the defined reduction

3.4.3.3 Reversing

The objective of this test is to verify if it is possible for the train to reverse in a defined area. Reversing mode is used to change the train driving direction while the driver is using the same cab. This test consists of the four steps shown in Table 3-3.

Table 3-3: Reversing

Step number	Action	Expected Result
1	Set a route over a area where it is possible for the train to reverse.	Train route is set
2	Run the train into a reversing area and stop the train.	Reversing mode is indicated on the DMI
3	Select the Reversing mode and confirm	DMI allows driving the train in reverse.
4	Reverse the train to end of reversing area	Train stops at end of reversing area

3.4.3.4 Entrance

The simulated railway line is connected at eight points to other railway lines with national protection system (Level STM). Sections in Level STM have been simulated in the system and precede the train's entrance into Level 2 area. The objective is to verify the train's entrance into Level 2 area. This test consists of the four steps shown in Table 3-4.

Table 3-4: Entrance

Step number	Action	Expected Result
1	Set a train route out of the L2 area	Train route is set
2	Set a train route into the entrance to a Level 2 area.	Train route is set
3	Run a train in STM mode towards the entrance.	Train receives Movement Authority (MA) into L2 area and the driver changes to application L2 by pressing a button on DMI. The train moves on the track by itself
4	Stop the train at the end of the (L2) route.	Train stops at end of the route

3.5 Pareto principle

The Pareto principle was created by Joseph M. Duran when he noted that 80% of consequences stem from 20 percent of causes [30]. The Pareto principle offers the greatest potential for improvement as an improvement of only 20 percent of causes an increase by 80 percent. This principle is used to define a method of classifying and presenting failures in KPI. By using the Pareto principle and producing KPIs at fixed time intervals, it will be possible to take early actions in the development of a product or project based on the evolution of the observed failures. This principle is also used to improve the process of handling reports of failures by creating a KPI which mitigates the problems concerning the process of managing reports of failures in the database.

4 Process of managing failures reported in a database

This chapter analyzes the process of managing reported ERTMS simulation failures in a database. This analysis is based on an investigation that was conduct on the database presented in Section 2.6.

4.1 Rational Change

In Rational Change, a submitted failure report is called a Change Request (CR)**.** Anyone with access to Rational Change is able to submit a CR. Each CR is assigned a unique identifier which allows it to be tracked during its complete lifecycle. A notification of the submitted CR is sent to the Rational Change account of the relevant Project Engineer (PE). The PE is the person who is responsible for engineering of a given project. CRs assigned to each PE, are listed in the homepage of the PE's Rational Change account. It is possible to find a submitted CR by initiating a search in the database and using its unique identifier or by project name. The lifecycle of a CR consists of eight states and the status of each CR is indicated in Rational Change as one of the states shown in Table 4-1.

Table 4-1: Possible states of a CR during its lifecycle

CR Status	Action
1. **Submitted**	A CR is submitted by anyone with access to the Rational Change database
2. **Assigned for analysis**	In cooperation with other engineers, the PE decides that an analysis is necessary and an analyzer is appointed and the name of this analyzer is specified via Rational Change. Otherwise, the CR is closed.
3. **Analyzed**	An analysis of the CR has been conducted and reported in the database.
4. **Assigned for implementat ion**	The same team from step 2 evaluates whether the analysis is sufficient and determines if an implementation to address this CR shall be executed. The team appoints an implementer and specifies the name of this implementer is recorded via Rational Change.
5. **Implemented**	The planned implementation has been executed and the result is reported in database.
6. **Assigned for verification**	The same team from step 2 decides whether it is necessary to verify the implementation, if so a verifier is appointed and the name of this verifier is recorded via Rational Change. Otherwise, the CR is closed.
7. **Verified**	If the verifier finds that the implementation is correct they report their result in database via Rational Change.
8. **Closed**	This status indicates that the problem is resolved and the solution has been accepted.

The person who has been appointed to be an analyzer, implementer, or verifier, receives a notification about this task and this task will be visible on the homepage of this person's Rational Change account. Once the CR has been assigned to another person, then the CR is removed from the homepage of PE's account. As explained early, Rational Change has some mandatory fields which must be completed when a CR is submitted. One of these mandatory fields is the name of the project to which the CR is relevant. Therefore, when a project is started, the PE must choose the name of the project to be used in this database. All CRs related to this project must be posted indicating the project's name. If a CR must be transferred from one project to another, the

responsible person simply changes the name in the field “Project Name”. A CR can be transferred to another project no matter what its status is. The transferred CR will have the “submitted” status when it arrives at the other project. If an analysis of a CR reveals that it should be handled at the GP level, then the PE designates a person who should transfer the CR to the GP level database.
Figure 4-1 is an overview of a CR in Rational Change. All possible states of a CR during its lifecycle are showed in “Visual Status” in chronological order. The current status of a CR is highlighted in yellow (“Assigned For Analysis” in Figure 4-1).

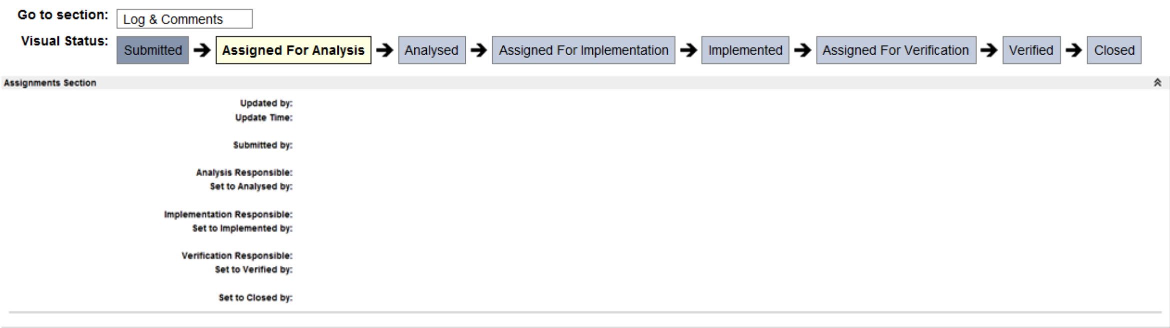

Figure 4-1: CR in Rational Change with “Assigned For Analysis” status

4.2 EAPD Helpdesk

As mentioned in Section 2.6.4, this tool is used for communication between the GP level and its customers in the GA and SA production levels.

In order to post a CR or a question (both result in an entry called a Ticket) one must have an account in EAPD helpdesk. Once a ticket is created, it is assigned a unique identifier. This identifier is used to track the ticket during its lifecycle. The identifier is also used in the GA or SA database (implemented using Rational Change) to link the CR to its ticket. In the field “Product Name”, the creator of ticket chooses from a list of products the product that this CR is related to. All products at the GP level have a designated person who is responsible for the analysis of each newly posted ticket that is related to the product which they are responsible for.

The creation of an EAPD Helpdesk account only requires an access to the EAPD Helpdesk website. The only required information is the user’s choice of a user name. Entering this user’s e-mail address is optional.

Via the EAPD Helpdesk it is possible to comment on a ticket and change its status. In either case, the creator of the ticket will receive a notification e-mail of the action regarding their ticket. The lifecycle of a ticket is explained greater detail in Table 4-2.

Table 4-2: Ticket lifecycle

CR Status	Action
1. **New**	A user created a new ticket
2. **First analysis**	In this state, the designated person responsible for the analysis of each newly posted ticket related to their product, performs a quick analysis. If the submitted CR or question is accepted, then ticket is forwarded for further processing. Otherwise the ticket is closed. The ticket's creator is notified of these actions via an e-mail.
3. **Detailed Analysis**	In this state the ticket is carefully analyzed and an initial solution is proposed or complementary information is requested from the ticket's creator. The analyzer writes their proposal in the ticket and changes the ticket's status to "Waiting for customer". A notification e-mail is sent to the ticket's creator.
4. **Waiting for customer**	Once the ticket creator accepts the proposal the ticket is closed. Otherwise, the ticket creator should provide additional information. If the creator has not responded within 3 months, the ticket is automatically closed.
5. **Closed**	This status indicates either (1) that the solution has been accepted and the ticket is closed or (2) the ticket creator did not respond within 3 months and the ticket has been in "Waiting For Customer" status all of this time, hence the ticket was automatically closed.

5 Analysis

In this chapter, we present the results from both our simulations and investigations and then discuss them. Section 5.1 presents the simulation results. Section 5.2 presents the result of the investigation of the process of managing failure reports in the database.

5.1 Simulation results

As, I did not have any previous experience with ERTMS simulation, I was personally impressed with the simulation results. Few failures were detected although each test case was executed many times. Only seven failures (see Table 5-1) were detected during ~310 tests. This means that in ~2.4% of tests the ERTMS system did *not* fulfill all of the requirements specified by BT's general requirements. The main reason for this low rate of failures is that the simulated ERTMS project was at the SA production level. As explain in Section 2.6.1, SA products are based on GA products. For example, the first installation of ERTMS Level 2 in Sweden is classified as a GA project. All the following ERTMS installations of Level 2 are based on that GA project and use almost the same systems and products. In our case, this second SA project was based on the earlier GA project. Therefore, this system benefited from the ameliorations and improvements applied to both projects. As a result, relatively few failures were detected in our simulation.

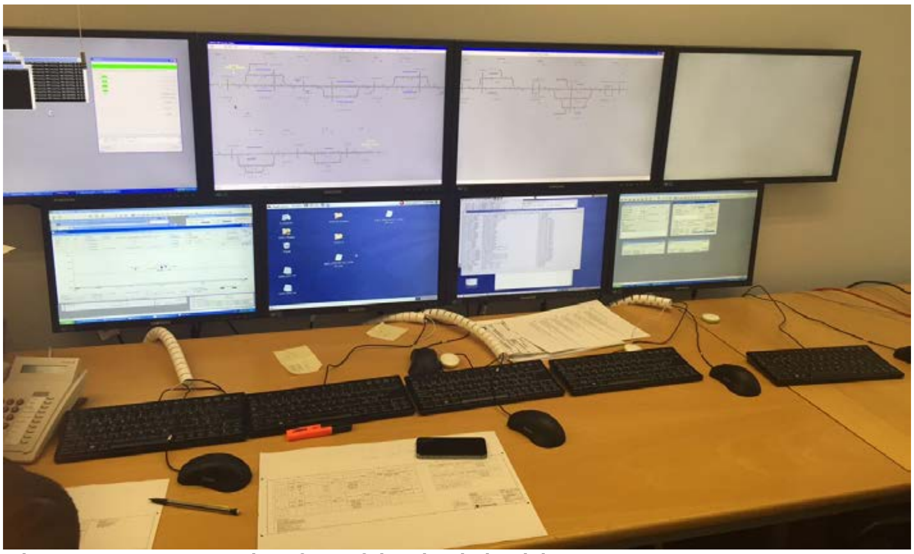

Figure 5-1: : User interface of the simulation laboratory

Table 5-1: Simulation results

Tests cases	Results
Run train over all train routes	Three train routes could not be released.
Speed reduction	Speed could not be reducing in three train routes.
Reversing	No failure was detected.
Entrance	In one entrance, the train did not receive MA in order to change into Level 2

All of these failures were reported via Rational Change and served as examples during my investigation of the process of reporting and managing failures in the database.

5.2 Problem area in the process of managing failures in databases

This section describes problem area of the process of managing failures in Region North. Section 5.2.1 focuses on Rational Change while Section 5.2.2 focuses on EAPD helpdesk.

5.2.1 Rational Change

In Section 2.6.3, the mandatory fields when reporting a failure via Rational Change were described. Unfortunately, the result of my investigation revealed that this requirement was not always followed. Indeed, some engineers do not correctly complete all mandatory and recommended fields, such as product version or work package. This situation for the product version tends to happen by mistake. During discussions with the databases users, I realized that they sometime do not perceive the utility of all this information, especially the need to specify the work package or severity of a CR which has been classified as a Defect. This is due to the fact that the instructions in the document “Change Management Instruction Change-Request handling with Rational Change-SA and GA products”[19] do not explain the goal of completing these fields.

During my investigation, I found that approximately twenty CRs were lost during their transfer from the SA to the GA production level. My analysis determined that they were transferred to an incorrect project name. This error was caused because the names of these projects in database were quite similar, as shown in Figure 5-2. Indeed, the PE responsible for choosing the name of the project that is to be used in the database usually does not take into account the names of other projects already used in database. Additionally, the database still contains many names of projects which have been closed for years, thus increasing the probability of losing CRs - especially when a closed project has a similar name as a current project. In fact this was what occurred in the case of these approximately twenty CRs, i.e., CRs from a SA project were transferred to a GA project which has been already closed. As closed projects no longer have a PE, when these CRs were transferred to the closed GA project no one was available to handle the CR. As the PE of the SA project did not notice his mistake, these CRs effectively disappeared in a virtual black hole.

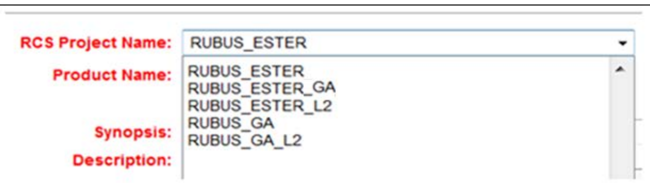

Figure 5-2: Projects with similar names in Rational Change

To a lesser extent, Product name field tends to have the same problems as Project Name field. Indeed, there are many products with similar names and, especially many products are obsolete and are not used anymore.

In the lifecycle of CR in Rational Change, the states “Assigned For Analysis”, “Assigned For Implementation”, and “Assigned For Verification” are often called intermediate status. When a CR status is changed into one of these states, the name of an analyzer, an implementer, or a verifier must be specified by a PE (as was shown in Figure 4-1 on page 32). Unfortunately, these fields are not mandatory, thus the PE can changed the CR status *without* specifying the name of analyzer, implementer, or verifier. As a result these CRs are lost as CRs in these states no longer appear in the Rational Change account of the PE and they do not appear in the account of any other person as no one has been specified to perform this task.

The other problem with intermediate states is that a deadline is generally not specified. I found during my investigation that some CRs which have been in the state “Assigned For Analysis” had been there for more than 2 years. These CRs can be also considered as effectively “lost”.

As an example, I examined CRs in intermediate status for the project on which I participated on simulation. The result is shown in Table 5-2. There were CRs which have been in intermediate status for more than half year and more than one year. The table also points out the number of CRs which have been inactive for the last three months; hence, these CRs have not received any comment or modification for more than three months. These three categories were chosen after the discussion with the engineers. They indicated that a CR is normally solved in three months, but a more complex CR might take up to six months. If a new version of a product is required in order to eliminate the failure, then this can take one year.

Table 5-2: CR in intermediate state

	Inactive > 3 Months	In state ≥ 6 Months	In state ≥ 1 Year	Total
Assigned For Analysis	12	8	5	25
Assigned For Verification	5	4	3	12
Assigned For Implementation	1	1	1	3

The critical situation was in “Assigned for Analysis”. There were roughly 12 CRs which did not receive any comment or change in the last three months, of these there were 5 CRs which have been in that state for more than 1 year.

During my investigation, I noticed that all lost or delayed CRs were in defect category. As described early, a CR can be submitted as a defect or a hazard. A defect is an error in the product, while a hazard is a defect which may have an impact on the security of the system. Thereby, PE and engineers placed a particular focus on hazards; hence none hazard was lost or delayed.

Rational Change does not have a general administrator who is responsible for it. Therefore, any engineer can update this database. The problem is that each engineer tends to update the database depending upon their own usage, such as project level or wayside/Onboard project. This occurs due to the fact that different engineers prioritize information differently, thus fundamental information for engineers in given project may be considered useless by others. At the same time, users do not have a person to contact if they have a problem or suggestion regarding Rational Change.

5.2.2 EAPD helpdesk

In EAPD helpdesk, a ticket is created in order to submit a CR or a question. If there is a change in ticket status or a comment on the ticket, then a notification should be sent to the creator of this ticket. Unfortunately, the creator often does *not* receive any notification. My investigation has revealed that there are two reasons for this. The first reason is that EAPD Helpdesk does not require an e-mail address to be entered during the creation of account, as this information is considered optional. Thus, some users do not fill-in this field. The second reason is that the notification system of EAPD Helpdesk does not work correctly. Indeed, while many users specified their e-mail addresses during the creation of their accounts - they never receive any notifications from EAPD Helpdesk. I was able to verify this behavior by creating my own account in EAPD Helpdesk. Next I created and submitted a fictional ticket, but I never received any notification on a comment or a change in the status of the fictional ticket, even though my e-mail address was registered. A consequence of this is that unless the ticket creator constantly monitors their tickets there will be a delay in handling them. For example, if EAPD Helpdesk sends a request to provide additional information in order to complete a CR, it can take a long while before there is a response – until someone manually checks the status of their previously submitted tickets. In worst case, a CR can be completely lost when a CR has been in "Waiting For Customers" status more than three months, as this ticket will automatically be closed by EAPD Helpdesk!

5.3 Tracking failures with Rational Change

Tracking a CR with Rational Change allows us to follow the evolution of CRs within Rational Change in terms of KPIs. These KPIs are designed to provide a clear and visible indication of the evolution of non-conformity based on submitted CRs. By analyzing these KPIs, it is possible to take actions *early* in process of development a product or executing a project.

As stated in Section 2.7, KPI should follow SMART requirements for to be useful. Thus, all defined KPIs in this section fulfill such requirements.

5.3.1 KPI 1: Project conformity

As stated in Section 2.6.3, some projects have been divided into Work Packages (WP). Each WP consists of a list of products which may be related. The original goal of work packages was to simplify query in Rational Change. During the investigation and analysis of the database, it was realized that the usage of both failures submitted via Rational Change and Pareto principle could produce a SMART KPI on project conformity:

- Special

  The goal of this KPI is to highlight which WP produced most of failures during the simulation and its utility is to show an engineer where to focus. In short term, this KPI highlight if the project conforms to the expectations (zero failure).

- Measurable

  The input of this KPI is the submitted CRs in Rational Change for a given project. The project must be divided in WP.

- Achievable

  The goal of this KPI is realistic and attainable as it uses submitted CRs in order to point out the parts of the project, which produce the majority of failures.

- Relevant

  KPI requires enough resource and knowledge in order to have a relevant goal.
  This KPI is simple and can be produced by any engineer.

- Time-bounded

  Time to calculate a KPI should not be too long, otherwise it could be useless when it is achieved. In our case, our KPI is based on the result of the query in Rational Change. And as simulation of a project takes months, there is enough time to produce and present this KPI.

The following example is a hypothetical scenario to illustrate the suggested procedure.

In this example, the failures per WP are shown inTable 5-2. The project is divided into 5 WP (WP1, WP2, WP3, WP4 and WP5) and has 100 CRs submitted. These numbers are randomly chosen in order to simplify our calculation. Figure 5-3 is a Cumulative Distribution Function (CDF) which indicates the number of failures in a WP while showing its proportion in project. The X-Axis indicates the Work Package (WP). The left of Y-axis indicates the number of failures in WP while the right of Y-axis indicates its proportion in the project. The figure clearly highlights that 79% of failures were generated by WP1 and WP2 in the project.

Table 5-3: Failures per work package

	WP1	WP2	WP3	WP4	WP5	Total
Failures	20	15	4	3	2	44
Proportion in projects	45%	34%	9%	7%	5%	100%

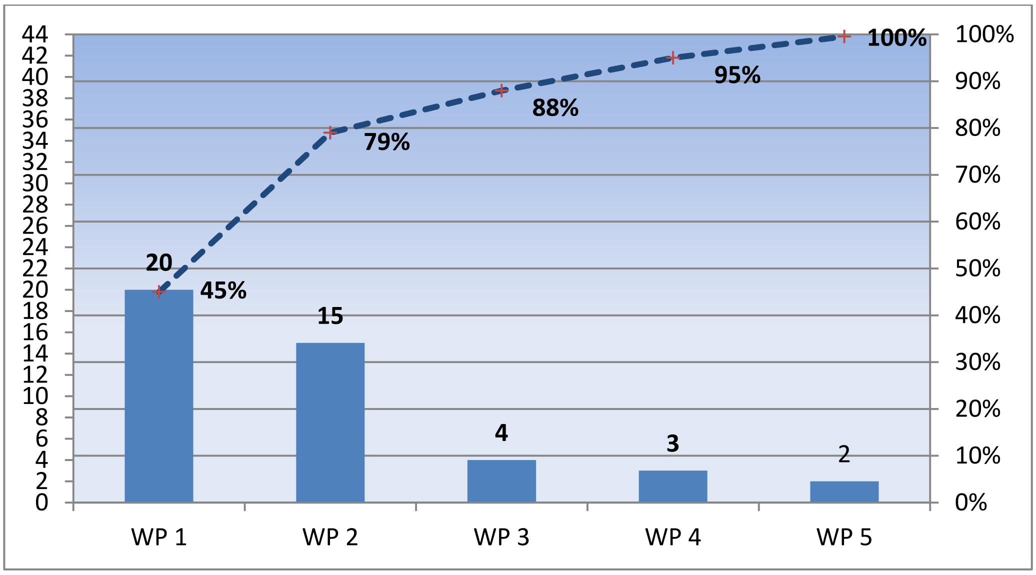

Figure 5-3: KPI on project conformity

5.3.2 KPI2: Product Conformity

As mentioned early, WP may consist of several products. Thereby, after the definition of the KPI1, it is useful to highlight the product which generates the most failures in the WP. In this analysis the KPI2 has been defined as product conformity. Its goal is to specify the product with the most failures in WP. This information indicates to engineers where to focus. The input of this KPI is the submitted CRs for a given WP (in our case WP1). The next step is to apply the Pareto Principle on the WP which generates the most failures.

In this example, we continue to use data from the example in KPI1 (Table 5-2). In this case, the Pareto principle is applied to the WP1 which is highlighted in Figure 5-3. WP1 is randomly divided into 4 products (P1, P2, P3 and P4) in order to simplify our calculation. Figure 5-4 clearly highlights that the first product (P1) generates the most failures in the WP1.

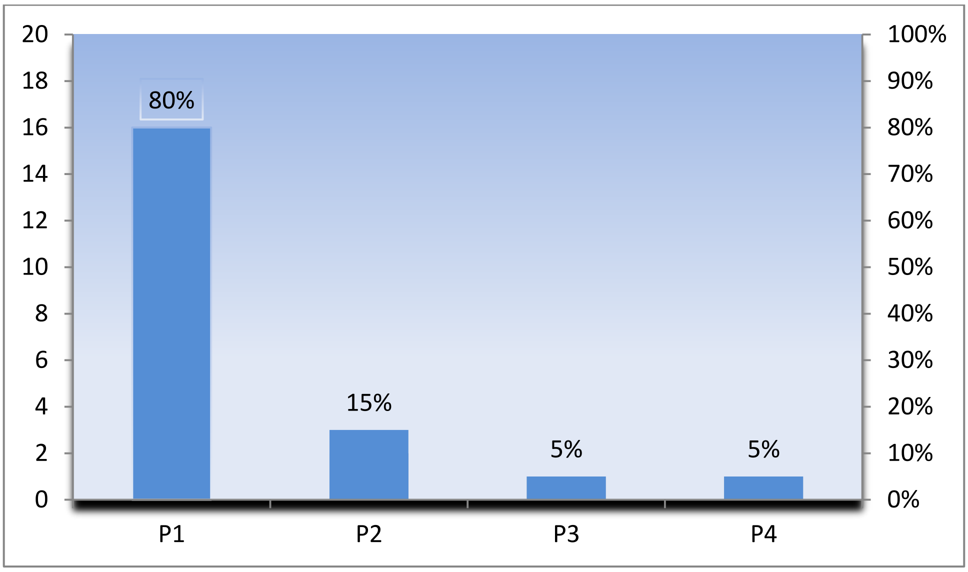

Figure 5-4: **KPI product conformity**

5.4 Improvement in the process of managing failures in Region North

This section summarizes problem area in the process of managing failures in database and presents suggestions to apply in order to improve this process. Table 5-4 lists a number of suggested actions that should be taken to correct or mitigate each of the problems that have been identified with the CRs in Rational Change. Table 5-5 lists the corrective actions that are suggested for EAPD Helpdesk.

Table 5-4: **Corrective action Rational Change**

	Problem area	Corrective/Mitigating Action
Rational Change responsible	There is no person responsible for Rational Change	1. An **Administrator** of Rational Change should be designated
CR Submission in Rational Change	Because Project or Product names can be quite similar a CR can be submitted to the wrong Project or Product name	2. **Remove** 'closed' Projects or 'obsolete' Products from the Project/Product List 3. **Projects/Products names** should be chosen carefully by the **administrator** in order to avoid any confusion. 4. Each CR should have an **owner** who is responsible for it (Ex. the submitter of the CR). The owner should monitor CR until they are closed.
CR Submission in Rational Change	The User Manual of Rational Change does not explain the goal of the completed fields.	5. **Update** Rational Change User Manual
CR Submission in Rational Change	Severity field allows classifying CR, but values have not been defined	6. **Define severity** values in 3 categories: High, Medium and Low. This information should be added to User Manual.
CR Assignment for Analysis, Implementation or Verification	Name of the person in charge of the Analysis, Implementation, or Verification is forgotten to be filled in Rational Change.	7. Modify the Rational Change in such a way the responsible of the Analysis, Implementation or Verification is a '**mandatory'** field

CR assignment for Analysis, Implementation or Verification	CRs assigned for Analysis, implementation or verification have not any specification when they must be resolved or are followed up either to see their progress. Then CR are stopped up in the same status	8. A **deadline** should be added in Rational Change and a notification should be sent to the owner if CR should stay inactive in the same status more than 3 months.

Table 5-5: Corrective action for EAPD Helpdesk

	Problem area	Corrective/Mitigating Action
CR submission in EAPD Helpdesk	It is not mandatory for the ticket creator to register its contact e-mail.	1. It should be **mandatory** for all EAPD users to register their **e-mail address** during the creation of their account 2. EAPD Helpdesk should require the **telephone number** of the user.
CR submission in EAPD Helpdesk	Submitter do not receive any notification if there is a modification to their ticket, even they have registered their e-mail address	3. EAPD should update its **notification** system.
Ticket are closed	Ticket is closed automatically after 3 months even that the owner may not receive a notification on it (See above)	4. Before to close a ticket, EAPD should **contact** by **telephone** the ticket owner who did not react to their request on ticket.

5.5 Discussion

This section describes the major challenges that have been taken-up in order to conduct this project.

Before starting test execution it was essential to conduct a literature study on ERTMS, but it was also essential to understand the principles of the operation of the simulation environment. The laboratory environment has a complex architecture with an extensive set of functions which have been developed in order to simulate ERTMS in a virtual environment. Moreover, the test specification did not describe all steps, abbreviations, terms, names, or operating principles of each test case [28], as assumed that the tester already had this knowledge. For all of these reasons, it required a great amount of time in order to be able to execute different tests cases. The strategy that was adopted was to focus on a few tests cases (see Section 3.2.3). The simulation took roughly three weeks, including an introduction to the testing tools. This simulation was conducted under the supervision of Tomas Persson (a test engineer at BT).

Section 5.2 presents the results of my investigation of the problems in the process of managing failures as recorded in a database at BT in Region North. This result is *not* a definitive list of all of the problems in this process. Instead, it is simply the result of the investigations carried out during this thesis project. I tried to identify as many relationships as possible between different problems regarding CRs in the database and their impact on the process managing the overall process. Section 5.4 summarized these problems and listed some proposed corrective actions which should be applied in order to improve this process.

The KPIs defined in Section 5.3 were proposed to be calculated after *each* test session in order to be most useful. A test session can last two days to two months depending on the number of tests cases to be conducted. The producer of these KPIs should be the test engineer and these KPIs should be presented to the PE.

6 Conclusions and Future work

This section concludes this thesis project. Section 6.1 presents general conclusion on reached goals, insights gained together with what should be done differently if I had to do this thesis project again. Section 6.2 describes some situations which limited my effort during the realization of this project. Section 6.3 presents some suggested future work. Finally, Section 6.4 presents different relevant aspects of my work.

6.1 Conclusions

In accordance with the goals defined in Section 1.4, the main objectives of this project were to detect failures in the simulation of an ERTMS implementation, then investigate the process of managing these failures as recorded in databases together with an analysis of the interaction of users through these databases, and finally defining a method of classifying and presenting non-conformities.

All of the project's goals were successfully accomplished. A part of an ERTMS implementation was simulated and seven failures were detected. The investigation revealed many weaknesses in the process of managing failures in the databases, where in the worst cases non-conformities were completely lost. The investigation's outcomes were recommendations for improving the process of managing failures reported in the database. If these recommendations are implemented, this will reduce the interaction delay between database users, while at the same time eliminating the loss of failure reports. The emphasis of this investigation was to identify all phases of management process where reports of failures were lost. At the end of this project, a method to highlight the part of the ERTMS implementation which generates most of the failures was also defined using KPIs.

Several insights were gained during the realization of this project. As this project contained both practical and theoretical work, expertise was gained in combining learning and application of knowledge. The ERTMS and its simulation environment is a rather large and complex system consisting of several sub-systems, hence a great amount of time and work were required just to understand its operating principles, before starting to execute tests in this simulation environment. The other major challenge of this project was to work in a professional environment where the result of your work is expected by other employers (e.g. simulation results) in a timely manner; while at the same time other employers have planned to use the same tools (e.g. the resources of the laboratory). An insight into the importance of finishing work on time was gained.

The simulation of ERTMS was delayed by several months which had an impact on the whole project. Initially the plan was to use failures detected during the simulation as a start in the investigation of the management process. As the simulation was delayed by nearly three months, this investigation instead began by analyzing the process of managing reports of failures which were already reported in database. The other consequence was that I was forced to change tests cases which I should simulate. So if I were to do the same work again, I should follow the original plan, first detecting and reporting failures, and then investigating the process of managing reported failures.

6.2 Limitations

The first step in this project was the adaptation of the author to his new work environment at BT. In order to better carry out this project, it was necessary to learn some of BT's unwritten rules and how to work in this environment, such as when is the best time to contact a person, where to find information on a given tool, who to ask, etc. This may seem insignificant, but my lack of this knowledge tended to slow down my work on this project.

The author was forced to change the tests cases which he should execute in the simulation environment, due to a delay in the renovation of the laboratory building. A consequence of this delay was that the author could not accomplish this project within the planned time.

6.3 Future work

The next step after this thesis is for BT to apply each of the corrective actions proposed in Section 5.4. Some of these corrective actions have been already planned, such as updating the notification system of EAPD together with a requirement of an e-mail address and telephone number for each user. BT has plans to apply these changes in September 2015. As some errors were made due to mistakes or lack of information about the purpose for a number of the different fields in the database entries, BT plans to first update the Rational Change User Manual [19] and then to train engineers about how to better use this database.

The simulation of ERTMS continued in laboratory as was planned. This simulation is planned to continue until December 2015.

6.4 Reflections

The first objective of the simulation was to detect failures. However, it also allowed me to understand the meaning of a failure together with its consequence - if it is not solved because it was lost. Indeed, the simulated implementation was an ERTMS Level 2 which allows the train to move on the track by itself, although supervision remains the responsibility of the train driver. The train must constantly be connected and able to interact with its environment. If the train should not be able to interact with one of its sub-system, such as a signal or level crossing due to an error from a lost failure, these consequences could be severe (even if I did **not** find any lost or delayed failure, which may have an impact on the security of the system during my investigation). Therefore, by identifying and proposing corrective actions to improve the process of managing failures, this project contributes to avoid dangerous situations in the future.

KPIs have been defined, but have met with apparent reticence by the PE. The experienced PE pointed out that classifying failure per WP and per product could cause some engineers to **not** report failures in the database in order to avoid their negative impact on a KPI. This situation tends to happen especially when engineers are at the same time responsible for a given product. Normally, the PE (in cooperation with other engineers) evaluates the proposed solution and decides whether it is sufficient or not. If the applied solution is incorrect and there is no one to evaluate it, then the product quality will decrease.

Proposed corrective actions will improve the process of managing failures. This will eliminate lost CRs, while at the same time reducing the time necessary to resolve a failure. This fact will have an impact on the profit of BT. Indeed, there will be a reduction in the development time of each product and it allows the company to deliver its products on time.

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