Safety Case for the Introduction of New Technology into an Existing Railway System

Peri Smith
M.Sc., B.Eng., DIC
20th September 2016

Imperial College London
Department of Civil and Environmental Engineering
Centre for Transport Studies

Thesis submitted for the degree of Doctor of Philosophy and the Diploma of Imperial College London
Declaration

I hereby declare that the work here within is that of the author and work of others has been appropriately referenced.

Some of the material represented in this thesis has been published in conference and journal material as referenced in this thesis.

PhD Student: Miss Peri Smith Date: September 2016

Academic Supervisor: Professor Washington Ochieng Date: September 2016

Academic Supervisor: Dr Arnab Majumdar Date: September 2016

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Dedication

I dedicate this research to my great-grandmother Metella Smith.
Abstract

This thesis addresses safety in the railway industry with a focus on safety culture, defined by the United Kingdom’s Health and Safety Executive as ‘the behavioural aspects (i.e. what people do) and the situational aspects of the company (i.e. what the organisation has)’. Current safety management systems do not appropriately incorporate safety culture. This has the potential to cause serious harm to human life.

As the definition implies, safety culture is not easily measured or quantified. It involves factors that influence human behavior in safety critical and technology dense environments such as the railway environment. Furthermore, as railways become more advanced in their operational capabilities and integrated across European countries, safety culture will become increasingly important.

Therefore, safety culture should be a key component of an organisation’s safety management system. However, research to date has shown its integration to be piecemeal. To address this problem, this thesis specifies an enhanced safety case that uses safety culture as an integral part of the process. This provides an improved approach towards safety management.

The key findings from this research show that railways are inherently safe. This is primarily due to the regulations across technical and operational disciplines. Regulations and procedures typically relate to the three possible operational states that can occur: normal, degraded and emergency. An example of a degraded operational state includes a signal failure where a train driver may be given the permission to proceed at caution. The variability between the states can affect a human’s understanding of the various technical interfaces and their emergent properties. This in turn can affect the type of behaviour exhibited by a driver, signaller, controller or maintainer. System architecture is therefore an essential tool to identify functional and physical relationships and can be used as a training tool. Training was found to be an effective measure to practically test and evaluate safety culture behaviours. Specifically, the use of a simulated environment has shown to be efficient for learning and training exercises and can be used to improve an organisation’s safety management system.

The safety case derived in this thesis is therefore, driven by the safety management system and is optimised by an understanding of the particular environment and the user interfaces. The process of integrating safety culture is shown through the improved and derived safety assessment process developed in the thesis.
Acknowledgements

I would like to thank Professor Ochieng for the opportunity to carry out research at The Lloyds Register Foundation Transport Risk Management Centre at Imperial College. Conducting research in the field of railway engineering safety has been an enjoyable and motivating experience.

I would like to give additional thanks to Professor Washington Ochieng who sponsored my research via the Civil and Environmental Engineering Department.

This opportunity has not only enabled me to carry out research in a field which I thoroughly enjoy but it has also enabled me to travel and meet a variety of people both via academic and professional industry networks in the UK and abroad.

I have been fortunate enough to have peer colleagues good in nature, willing to share knowledge and work as a team. I would like to particularly thank Samira Barzin, Felipe A.C Nascimento and Nicolo Daina.

Through my travels and conducting this research as a part time student I have had support from a number of organisations. This includes The Lloyds Register Foundation, Abellio Greater Anglia, VTI in Sweden, Transport for London and Network Rail. I would particularly like to thank staff from Abellio Greater Anglia, from the managers to the participant train drivers whose subject matter expertise and experience has been used to support data analysis.

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However, all being said, my foremost thanks is to our Holy Father Jehovah for guiding and sustaining me in everything that I do, in all situations and in everyday of my life. In closing, I thank the most important person in my life, my mother Eugenie Smith who I love very much. I thank her for her kindness, support and encouragement to be the best I can be. I also thank my mother for her positivity towards whichever avenue I have been routed in life.
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<tr>
<td>AHP</td>
<td>Analytic Hierarchy Process</td>
</tr>
<tr>
<td>ALARP</td>
<td>As Low As Reasonably Practicable</td>
</tr>
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<td>ATOC</td>
<td>Association of Train Operating Companies</td>
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<td>ATP</td>
<td>Automatic Train Protection</td>
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<td>AT</td>
<td>Auto Transformer</td>
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<td>AWS</td>
<td>Automatic Warning System</td>
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<td>BTM</td>
<td>Balise Transmission Module</td>
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<td>BTS</td>
<td>Base Transceiver Station</td>
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<td>BSC</td>
<td>Base Station Controller</td>
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<td>CAA</td>
<td>Civil Aviation Authority</td>
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<td>CADET</td>
<td>Critical Action Decisive Evaluation Technique</td>
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<tr>
<td>CCTV</td>
<td>Closed Circuit Television</td>
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<td>CENELEC</td>
<td>European Committee for Electrotechnical Standardisation</td>
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<td>CIS</td>
<td>Customer Information System</td>
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<td>CCS</td>
<td>Command Control System</td>
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<td>CPNI</td>
<td>Centre for the Protection of National Infrastructure</td>
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<td>CSAS</td>
<td>Circuit Safety Analysis System</td>
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<td>CSM</td>
<td>Common Safety Methods</td>
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<td>CSR</td>
<td>Cab Secure Radio</td>
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<td>D/A</td>
<td>Decision / Action</td>
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<td>DITLO</td>
<td>Day In The Life Of</td>
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<td>DLM</td>
<td>Data Link Module</td>
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<td>DfT</td>
<td>Department for Transport</td>
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<td>DMI</td>
<td>Driver Machine Interface</td>
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<td>DNO</td>
<td>Distribution Network Operator</td>
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<td>DOO</td>
<td>Driver Only Operation</td>
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<td>DSD</td>
<td>Driver Safety Device</td>
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<td>ECML</td>
<td>East Coast Mainline</td>
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<tr>
<td>EMU</td>
<td>Electrical Multiple Units</td>
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<td>EOA</td>
<td>End of Authority</td>
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<td>EOR</td>
<td>European Operating Rules</td>
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<td>ETCS</td>
<td>European Train Control System</td>
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<td>European Traffic Management Layer</td>
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<td>European Railway Traffic Management System</td>
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<td>EVC</td>
<td>European Vital Computer</td>
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<td>European Railway Agency</td>
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<td>F/B</td>
<td>Fall-Back</td>
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<td>Failure Mode Effect Analysis</td>
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<td>FOC</td>
<td>Freight Operating Company</td>
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<td>Functional Requirements Specification</td>
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<td>Fault Tree Analysis</td>
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<td>FTN</td>
<td>Fixed Telecom Network</td>
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<td>Fixed Terminal System</td>
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<td>Formula One</td>
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<td>GCR</td>
<td>Group Call Register</td>
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<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<td>GPRS</td>
<td>General Packet Radio Service</td>
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<td>GSM-R</td>
<td>Global System for Mobile Radio Communications</td>
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<td>GSN</td>
<td>Goal Structure Notation</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<td>HAZOP</td>
<td>Hazard and Operability Analysis</td>
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<td>HLR</td>
<td>Home Location Register</td>
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<td>HSE</td>
<td>Health and Safety Executive</td>
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<td>Health and Safety at Work Act</td>
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<td>HTA</td>
<td>Hierarchical Task Analysis</td>
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<td>HVAC</td>
<td>High Voltage Alternating Current</td>
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<td>Abbreviation</td>
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<td>IBJ</td>
<td>Insulated Block Joint</td>
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<td>IBM</td>
<td>International Business Machine</td>
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<td>ICAO</td>
<td>International Civil Aviation Organisation</td>
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<td>IDC</td>
<td>Interdisciplinary Design Check</td>
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<td>IDR</td>
<td>Interdisciplinary Design Review</td>
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<td>IM</td>
<td>Infrastructure Manager</td>
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<td>IMR</td>
<td>Interlocking Machine Room</td>
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<td>ISRD</td>
<td>Industry Shared Risk Database</td>
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<td>IT</td>
<td>Information Technology</td>
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<td>LDT</td>
<td>Long Distance Terminal</td>
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<td>LOC</td>
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<tr>
<td>MA</td>
<td>Movement Authority</td>
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<td>MAIB</td>
<td>Marine Accident Investigation Board</td>
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<td>MARS</td>
<td>Major Accident Reporting System</td>
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<td>MOD</td>
<td>Ministry of Defence</td>
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<td>MoU</td>
<td>Memorandum of Understanding</td>
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<td>MMI</td>
<td>Man Machine Interface</td>
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<td>MSC</td>
<td>Multiple Switching Centre</td>
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<tr>
<td>MTO</td>
<td>(hu)Man-Technology-Organisation</td>
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<td>NR</td>
<td>Network Rail</td>
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<td>NRN</td>
<td>National Radio Network</td>
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<td>National Rail Trends</td>
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<td>NSS</td>
<td>Network Switching Subsystem</td>
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<td>OAET</td>
<td>Operator Action Event Tree</td>
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<td>OHLE/OLE</td>
<td>Over Head Line Equipment</td>
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<td>ONR</td>
<td>Office of Nuclear Regulation</td>
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<td>ORR</td>
<td>Office of Rail and Road (Formally the Office of Rail Regulation)</td>
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<td>Definition</td>
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<td>On Train Data Recorder</td>
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<td>PA</td>
<td>Passenger Announcement</td>
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<td>PCA</td>
<td>Principal Component Analysis</td>
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<td>PDH</td>
<td>Plesiochronous Digital Hierarchy</td>
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<td>Passenger Help Points</td>
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<td>PLUM</td>
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<td>PZT</td>
<td>Point Zone Telephone</td>
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<td>QMP</td>
<td>Quality Management Plan</td>
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<td>Railway Accident Investigation Branch</td>
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<td>Risk Assessment and Information Management System</td>
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<td>RBC</td>
<td>Radio Block Centre</td>
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<td>RCM</td>
<td>Remote Condition Monitoring</td>
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<td>Rail Freight Group</td>
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<td>Railway and Other Guided Transport Systems Regulations</td>
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<td>Rolling Stock Operating Company</td>
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<td>Remote Terminal Unit</td>
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<td>Railway Undertaking</td>
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<td>Supervisory Control and Data Acquisition</td>
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<td>SCMM</td>
<td>Safety Culture Maturity model</td>
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<td>Selective Door Opening</td>
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<td>SME</td>
<td>Subject Matter Expert</td>
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<td>Safety Management Information System</td>
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<td>Station Management System</td>
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<td>Signal Passed At Danger</td>
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<td>SPSS</td>
<td>Statistical Package for Social Science</td>
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<td>Strategic Railway Authority</td>
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<td>SRP</td>
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<td>SSMS</td>
<td>Systemic Safety Management System</td>
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<td>Acronym</td>
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<td>TFM</td>
<td>Trackside Functional Module</td>
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<td>TIU</td>
<td>Train Interface Unit</td>
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<td>TOC</td>
<td>Train Operating Company</td>
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<td>TPWS</td>
<td>Train Protection Warning System</td>
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<td>TSI</td>
<td>Technical Specification for Interoperability</td>
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<td>TSLG</td>
<td>Technical Strategy Leadership Group</td>
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<td>Transport Undertaking</td>
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<td>Visitor Location Register</td>
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<td>VHME</td>
<td>Vehicle Health Monitoring Equipment</td>
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<td>WFA</td>
<td>Weighted Factor Analysis</td>
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Chapter 1  Introduction

This thesis addresses the important issue of safety in the railway industry focussing on safety culture. Safety culture is defined by the Health and Safety Executive as:

‘the product of individual and group values...that determine the commitment to an organisation’s health and safety management’ (Health and Safety Executive, 1993) in addition to technical safety issues.

This definition is used in the UK railway industry and is therefore, adopted in this thesis. In this chapter, an outline of the entire research is provided, including the research question, overall aims, objectives and concludes with a pictorial process flow which depicts the approach taken to address the research problem.

1.1 Research Background

The design of railways over the course of time has proved to be an ingenious idea. Railways, which convey passengers and freight, are a heavily utilised method of transportation as demonstrated by the Greeks in 600BC and continues to be the case today. For example, the national trend in the UK as reported by the Office of Rail Regulation (ORR) shows a 7.3% increase in passenger journeys for the first quarter of the period 2013-2014 (Office of Rail and Road, 2013) relative to the same period in the previous year with an associated record revenue increase.

However, as railway usage increases, it is necessary that railway networks expand and evolve to meet demand. Analysis of existing railways shows that heritage infrastructure and technology constitute a large part of railway design. Therefore, as railways modernise, the existing heritage infrastructure is required to absorb or be integrated with new technology. As a consequence, the economic and historical value of heritage railways still remains to be recognised and work to preserve and market their value continues to be carried out by the Heritage Railway Association, in addition to the UK government (House of Commons, 2015). As existing railways modernise, it is essential that they are able to withstand the demands placed upon them by increasing passenger growth and system modernisation. This is acknowledged in the UK’s Railway White Paper, ‘Delivering a Sustainable Railway’ (DfT, 2007) and supported by research from the other European countries who recognise the safety critical nature of railway infrastructure (Johnsen & Veen, 2011).

As technical complexity and railway automation increase as a part of railway modernisation, there is the potential for risks to be introduced. Risks include those posed to key users such as train drivers, passengers and the technical systems that control railways. Train drivers have a critical role in railway operations, especially in areas that are evolving through a transition to higher levels of automation.
such as in signalling. Signalling technology removes the need for trackside colour light indication introducing greater control from the train. In such a scenario, there are significant changes in driving practices. Therefore, it is very important that unambiguous information is displayed to the train driver. Changes to the driver machine interface are seen as macro-mental by some parties within the railway industry, this includes train drivers and train driver trainers. For example, misunderstanding of the changes within the driving environment can introduce changes to the quality of driving, proficiency and level of competency. As a result, it is necessary for safety culture to be embedded in all elements of the railway organisation from the trainers to the operation and maintenance procedures. Safety culture is a broad subject and is summarised here as it relates to behavioural aspects, ‘what people do’ and situational aspects of a company ‘what the organisation has’ (Health and Safety Executive, 2005). If implemented effectively, safety culture, which is a core part of safety management can be used to mitigate technical and human factor related risks and is a key focus of this thesis. Emphasis on safety culture in the railway industry has been identified as lacking from two aspects. There is a lack of safety culture in the core engineering disciplines which create the railway system, this includes telecommunications and software disciplines. Furthermore, there is a lack of safety culture in the operational areas of railway systems. This can be due to poor organisational culture or lack of awareness of the benefits of safety culture to overall safety. As stated by Canada’s Railway Safety Act review panel “the cornerstone of a truly functioning Safety Management System is an effective safety culture” (Government of Canada, 2010). That is, the commitment to a safe railway should be shared by all stakeholders including users. A Safety Management System (SMS) addresses how safety is managed, which includes the issues of safety culture and risk management. The safety case is used to communicate clearly without ambiguity, the safety of the system in question utilising information obtained from the SMS. Safety cases are often technically driven documents with less emphasis placed on safety culture as a means for risk mitigation. This research addresses this gap and formalises its integration.

In order to evaluate the various factors that influence safety, an initial review is undertaken of the literature on railway trends in the context of technology development and passenger usage. Trend analysis provides measurable information and the ability to project future outcomes, a feature that should improve safety.

1.2 Aims and Objectives

Based on the research background above, the aim of this thesis is to specify a safety case which utilises an innovative approach of safety culture analysis, to identify all aspects necessary to demonstrate the level of safety in a technically modernised railway system. The following objectives have been formulated to achieve this aim:

- **Objective 1**: Design and develop a system architecture that is representative of a conventional and modernised railway system.
Railway systems are complex environments which are currently undergoing significant development in a number of countries to increase capacity and to meet freight and passenger travel demands. Furthermore, this development aims to enhance safety. Literature shows that the physical and functional structure as well as the formation of an integrated railway environment is an area that still requires rigorous evaluation and derivation. This is because of the continuing impact of technology on the railway system, requiring an understanding of how systems interact. This has been addressed in this thesis through detailed observational assessment of the driving environment. Consequently, system architecture is required to understand where new systems are introduced into existing legacy railway environments, where risks and failures have the potential to occur and their impact on human behaviour in an operational environment. Utilising expertise from industry Subject Matter Experts (SMEs), the railway system architecture has been developed in this thesis to show functional and physical relationships between railway system components. This captures the changes in technical system functionality and system operation based on the integration of new technology and design changes, which represent the transition from legacy to modernised technology.

- **Objective 2:** Investigate the technical developments of railway systems including technical system functionality, operation, risk, severity and counter measures in the form of safety culture.

Awareness of safety risks and safety culture within the railway industry is increasing as shown by the various safety methods and safety awareness measures taken by railway stakeholders. However, there remains a lack in the application of a holistic approach to the integration of safety culture methods within railway organisations and via the associated Safety Management Systems. This is important to ensure that safety awareness is embedded into the railway industry at all levels. This thesis presents the railway as a system to facilitate a holistic approach to the assessment of its safety. Achievement of the first objective supports this through the specification of the physical and functional architecture. It is also essential that applicable standards are understood for a system environment which has a number of technical and non-technical subsystems interacting and operating together. The railway environment is safety critical and there are a number of hazards and risks; the majority of which are known through progression of time. However, in cases where new technologies are introduced new risks can emerge. As a result, analysis of failure modes has been undertaken with respect to methods which can mitigate failures. Mitigation measures include aspects of safety culture and technology innovations.

- **Objective 3:** Identify behavioural changes in train drivers who have experience of existing and modernised railway systems.

There are a number of key users and operators in the railway environment, including train and track maintainers, signallers, controllers and train drivers. This research focuses on the train driver because the operational driving environment has undergone significant change, specifically through adaptation of the Driver Machine Interface (DMI). The DMI is a safety critical interface for signalling, removing the need for usage of colour light trackside signals. Instead, signalling information is displayed to the train
driver via a Graphical User Interface (GUI). This introduces changes to driver procedures, such as train data entry and communication methods. Observational studies of train drivers and questionnaires have been conducted. The data is used to compare driver behaviour pre and post railway technology modernisation and implementation. The potential for driver behaviour to affect safety is reviewed and mapped to measures in safety culture. There are key processes that a train driver carries out, such as train preparation which requires data entry into the DMI. Data entry provides the characteristics for trains. Incorrect data entry could impact performance and in the worst case compromise the safety of a train and the transported load. In this case, safety culture could be used to change behaviour and reinforce safe practices. Observational studies and interviews constitute a part of safety assessment and are used to identify how risks are managed.

- **Objective 4: Specify a safety case for the railway industry**

There are many facets to ensure that a railway system is safe, this ranges from operational roles for technical system control by signallers and controllers to railway maintenance activities. Maintaining a safe system requires understanding of all risks and hazards with the overall aim of preventing accidents through risk mitigation. Standards are used by the railway industry which stipulate requirement processes and tasks to demonstrate safety. Safety assessment methods, which include observations are conducted as part of the third objective and are used to understand how risks can be reduced in relation to human behaviour. A safety case is a common approach to demonstrate and evidence how safety is managed. However, safety cases have minimal weighting towards safety culture. This research draws upon the importance of safety culture in a safety critical environment and its importance as part of safety management when developing a safety case.

### 1.3 Thesis Structure

This thesis is presented over eight key chapters, the first of which introduces the subject matter and thesis structure as detailed here. The second chapter details the relevance of system architecture in the context of a railway environment. The system architecture for a mainline railway is derived to depict the technical systems that constitute it. This is used to provide a high level indication of how systems interface and integrate and forms a considerable part of the preliminary work to support the subsequent research in this thesis. The system architecture emphasises the complexity of railway systems and also reflects the key human interfaces, which support operation of the technical systems. This provides a holistic representation of the railway environment.

The developed system architecture also presents aspects of technical change that have been driven by the need to enhance safety and integrate European railway networks. European railways have seen modernisation via the European Railway Traffic Management System (ERTMS). The development of system architecture therefore, supports understanding of the risks posed between:
(i) technical systems and
(ii) technical systems and its users, which include rail passengers, train maintainers and train operators.

Chapter 2 also discusses the benefits and disadvantages of various modelling tools used by other rail industries such as metro railways to depict the architecture and complexity of their networks. The derived system architecture is a tool to support evaluation of human interfaces and failure modes, which can impact the safety of an operational railway.

Chapter 3 utilises the architecture derived in Chapter 2 as a basis to understand the structure and operation of railway systems. This is used to facilitate the assessment of the methods and practices for safety management utilised in the railway industry. As a result, this chapter presents a detailed analysis on the safety management techniques. Comparisons are made with other safety critical industries, to identify commonalities and gaps in the methods used for safety management, with the purpose of incorporating best practice from other industries. Current safety management techniques do not effectively integrate safety culture. Safety culture is therefore explicitly explored in Chapter 3. The theories behind safety culture and the approaches taken in the railway industry and other safety critical industries to address and understand the concept are examined also. Safety culture is a significant factor in any safety critical organisation and forms a part of an effective Safety Management System (SMS). However, not all organisations place significant emphasis on it as a means to mitigate risk. Safety culture is a subset of safety management and is currently lacking. In order to carry out safety assessment it is important to know the system architecture and safety management system in place.

Chapter 4 builds upon the literature review and system architecture analysis carried out in chapters 2 and 3 and delves into the detail of safety assessment. When assessing safety, a common focal point is any process is risk evaluation. This is largely because a risk that is uncontrolled can have severe consequences on safety and there are often associated financial implications. Based on these consequences this chapter consolidates best practices from selected European railway organisations. Furthermore, non-railway industry approaches are reviewed. For example, railways are composed of a range of intelligent systems, which are increasingly susceptible to cyber attack. As a result, methods applied by the Information Technology (IT) industry are relevant to this thesis. Best practice is taken for use if it is transferable and incorporated into the safety assessment process for railways. From this review, a safety assessment process is derived for application on railways modernised by ERTMS technology. Chapter 4 specifies a derived safety assessment process and Chapter 5 improves and validates the safety assessment process by subjecting it to a number of failure scenarios.

There are a number of failure scenarios that can occur in the railway environment, which can negatively impact its operational safety. Therefore, for this thesis, a number of failure scenarios are reviewed to evaluate the derived safety assessment process in terms of hazard identification and resolution through safety culture. The primary methods to gain data for safety assessment were through observations and questionnaires as detailed in Chapters 5 and 6.
Chapter 6 employs the safety assessment process from the previous chapters to assess railway safety based on observations of the causal factors behind safety failures. Safety failures are initially analysed through review of publicly available information and supplemented by observational studies and a questionnaire survey of train drivers. As shown in Chapter 2, train drivers have a frontline operational role of particular importance to safety. This role is one of the focus points for the safety assessment work carried out due to the operational interface with modernised technology.

As discussed in chapter 3, as part of safety management, safety culture is critical to safety as it can include actions such as short cuts, work arounds or suggested work improvements. All of these can occur in the operational environment. Therefore, as a part of safety assessment in Chapter 6 the cultural aspects that impact driver actions are also evaluated and the results presented.

Chapter 7 consolidates the aspects of safety culture, safety management and safety assessment through the formulation of a safety case. The safety case as a tool is used by a number of industries to demonstrate how safety is managed and maintained through a project’s lifecycle. In this chapter, importance is placed on how such a tool can be used to ensure that safety culture is routinely considered by an organisation as an inherent process. This correlation to safety culture is a novel way to construct a safety case.

Following development of a safety case in Chapter 7 the value and practical implementations of this research are discussed and concluded in Chapter 8. This Chapter summarises the research findings, contributions and practical applications. It is noted that risks cannot be eradicated, as there will always remain social problems, individual perceptions and failures in technology. However, there is great potential to shape user behaviours and progress towards greater avoidance and eradication of major problems that have the potential to cause harm. The ability to mitigate these failures through safety culture is an important concept to adopt. Table 1-1 below presents the thesis structure and provides a brief outline of the key topics covered within each chapter.
<table>
<thead>
<tr>
<th>Chapter No.</th>
<th>Thesis Stage</th>
<th>Key Contents</th>
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| 1.         | Introduction | - Identifies the research problem  
- Outlines research aims and objectives |
| 2.         | The railway system: current and modernised | - Railway system functionality  
- Derivation of railway system architecture for conventional and mainline railways  
- Assessment of technical developments via the European Railway Traffic Management System. In particular elements of train control and communication |
| 3.         | Fundamentals of safety management | - Safety management processes  
- Incidents and accidents  
- Lessons learnt from non railway safety critical industries  
- Origins of safety culture  
- Cross industry comparative review of safety culture |
- Development of a safety assessment process |
| 5.         | Safety Assessment Associated with Safety Culture | - Literature review of publicly available information, questionnaires, observations and comparison of UK mainline railways to European developments with ERTMS signalling on Swedish railways. |
| 6.         | Results | - Results of questionnaires, observations and comparison studies. |
| 7.         | A new safety case for modernised railways | - Developed safety case |
| 8.         | Conclusions and future work | - Findings, conclusions and research novelties. |

Table 1-1 Outline of thesis structure
Chapter 2  The Railway System: Current & Modernised

Railway transportation is traditionally viewed as a means to transport passengers. It also offers an effective method for the movement of goods in a safe environment. To maintain a safe environment, railway infrastructure which includes track and other civil assets should be reliable (not prone to failure) and maintainable. In addition, a means for safe and reliable train driving and control is a principal requirement for a safe railway. This is achieved partly through the implementation of a signalling system. Hence, innovation in technology is critical to the achievement of an efficient railway system. This chapter is concerned primarily with the introduction of new technologies into the railway system. It starts with a review of the technical history of railways to evidence the substantial impact that they have on society. Maintenance statistics and trends in passenger journeys are also used as a barometer to indicate passenger confidence levels in UK mainline railways. This is followed by a discussion on key safety critical systems and is shown through high level analysis of the core technical system elements in addition to those technologies which are used to modernise railways and enhance safety practices. The discussion on safety critical technologies is then presented within the context of a comprehensive system architecture developed in this thesis. Evaluation of the system architecture in this chapter captures the development process including transitions from existing railway system design to include new technologies, complex system interfaces and potential obstacles.

The initial focus is on the UK railways, as the architecture developed in this chapter is for existing railways and is representative of the UK configuration.

2.1  Configuration of Railways

In order to understand the wider configuration of railways across Europe a high level review of the range of signalling protection systems is undertaken. Signalling protection systems are of particular importance because ‘train movement safety depends on it and the control and management of trains depends on them’ (Railway Technical Web Pages, 2016). European railways have developed over many years and utilise similar principles for traffic control and train protection.

Early signalling methods in the United Kingdom used visual indications such as flag waving in addition to whistles for audible notification. These methods were also implemented in countries such as France, which in 1885 realised the need to unify railway lines to achieve best practice (Calvert, 2008). This later progressed to the use of fixed colour light signals for safe train separation, still in use today. This type of signalling has also developed in its design, varying from two aspects to multi aspect
colour light signals. This colour light approach conveys to the train driver the status of the route ahead and is a significant development over earlier historical methods in terms of visibility, installation and lamp durability.

Further developments in technology over the years have underpinned significant upgrades in the signalling systems. Figure 2-1 graphically charts the technological development of railway systems and their enablers from 1825 through the period of early mechanical signalling to the present day solid state interlocking. Today's systems utilise digital radio technologies for train communication and Solid State Interlocking (SSI) to drive functions and send information, which is in stark contrast to earlier mechanical signalling techniques. The state-of-the-art underpinning technologies are the basis of the current upgrade of European railways through implementation of the European Railway Traffic Management System (ERTMS).

Figure 2-1 Technical progress in railway signalling (Frederick, 1995)

This section has presented the importance of engineering technology in the development of railways. Technology continues to evolve and as systems develop, their usability can be integrated into the railway environment to improve reliability, capability and performance. This is discussed further in Section 2.7, which relates to the incorporation of navigation technologies into railways.
2.2 Societal Impacts on Railways

Railway development has significantly impacted social behaviours, economies and geographical landscapes. This is shown in the statistics from the UK’s Office of Rail and Road, formally the Office of Rail Regulation (ORR) that operates a data portal detailing National Rail Trends (NRT) for Great Britain (Office of Rail and Road, 2013). The portal provides a means to analyse a variety of official statistics ranging from passenger and freight performance, to information on assets and usage. As an example and in relation to developments in technology highlighted in Section 2.1, there is evidence in the portal to support advancement in technology including the capabilities to examine railway tracks for failures, such as fractures, corrugation or breakage. This enables maintenance to be targeted, reducing the potential for safety to be compromised. Figure 2-2 provides a measure of incidents per month in relation to track failures on mainline railways (RSSB, 2014). From Figure 2-2, it can be seen that there are clear peaks and troughs in the number on instances of track failure via either buckled or broken rails. These are mitigated through maintenance measures such as rail grinding, used to extend the life of railway track. This has a positive impact of reducing the number of incidents.

![Figure 2-2 Trends in Mainline Railway Track Failures (Railway Safety and Standards Board, 2014)](image)

In addition to the information presented in Figure 2-2, Figure 2-3 presents the statistics on passenger journeys from which rail revenue can be determined for the financial years from 1965 to 2014. The plot shows that passenger journeys have steadily increased with the exception of two distinct time periods namely 2009-2010 and 1994-1995, it can be argued that this is probably due to issues associated with cost and/or safety. As seen by recent cases of flooding and storms in 2014, safety can have an impact on passenger journeys. Storms and flooding pose a risk to power lines (Kay, 2014) and other railway assets such as track ballast, which can be washed away and affect the track support system. Furthermore, trackside systems such as track circuits, which provide a means for train detection, as discussed further in Section 2.3.2 can also be affected. An example of the impact of flooding was seen in Reading, UK, where there were 35 days of lost train journeys (Network Rail, 2014).
Considering the wider railway, European organisations have had many limitations in the development and implementation of appropriate mechanisms for the management of railway safety. These limitations include failures in training, staff recruitment and staff retention, all of which can be linked to failures in an organisation's management culture. Brooke’s vision of the UK railway system as identified by (Casson, 2004) agrees with the organisational cultural defects mentioned. There is a common belief that privatisation in 1993 of UK railways introduced these cultural defects into the organisational structure of the railway. This is subject to opinion and experience at the time.

Brooke also put forward the idea that the exhibition of a safe culture would occur following radicalisation of training regimes put in place for managers. Therefore, in order to effectively manage a railway system, an appreciation of its purpose is required, that is, to (i) serve passengers (ii) transport freight which includes coal, minerals and quarry products and to (iii) transport military goods. Railways service the demands of a number of users and provide a good source of economic income. Brooke’s beliefs (Casson, 2004), highlighted that the structure of a railway organisation should be visionary rather than pragmatic. However, this trade-off (between vision and pragmatism) is undesirable since it is possible for the railway to be both visionary in terms of technology developments and realistic in terms of cost and safety management.

Historically, railways have undergone continuous development for a number of reasons. These include location and time related travel demands, technology enhancements, operational service
performance and failures in safety. The UK in the early 2000’s saw the start of significant railway development, largely attributed to a response to failures in safety practices. This has been significantly influenced by adherence to European legislation, which impacts how safety is managed along with safety policies and staff training. Railways have had a long period of evolution. However, safety practices have been brought to the forefront due to the immediacy of the impact that disasters have had on rail users. An example is shown by the Clapham Junction accident in the UK (Railways Archive, 1989), which had a significant number of fatalities. The following section presents an overview of railway functionality to aid understanding of its structure and operation. It is supplemented by an overview of the systems that have relevance to technically ensure an operationally safe environment.

2.3 Railway System Functionality

Railway systems are complex technical environments in which a number of systems interact. These complex interactions require a number of processes and procedures to maintain safe operation. To aid understanding of the structure of the railway, the key railway components are shown in Figure 2-4.

![Generalised view of a railway](Foley, 2011)

Figure 2-4 Generalised view of a railway (Foley, 2011)

Figure 2-4 depicts the key building blocks that form a railway system, capturing what is vital for operation and control. The components or sub-systems (interlocking, train detection, signals and point operating equipment and trains) enable signalling control and routing via interlocking, signals, points systems and train detection methods. An overview of the functionality of these safety critical components is provided in the following subsections. The systems explained here are reflective of what is present in both conventional signalled railway and modernised railway systems as they are
core to both railway environments. The descriptions aim to provide a background to understand how the railway changes following technical modernisation. These descriptions also aim to outline the key principles of railway signalling operation.

2.3.1 Interlocking Subsystem

As Figure 2-4 indicates, interlocking is central to railway operations. It is the means to control the movement of rail vehicles and also the means by which train routes are set, thus ensuring the prevention of conflicting train movements. The interlocking system controls point operating equipment used for route setting and utilises status inputs from track circuits and points systems for train detection which are ‘vital’ logic processes. The term ‘vital’ in the context of railway operations has been described as ‘a process or function which has the ability to change the state of a traffic signal to a less restrictive aspect, move points or permit train movements’ (Foley, 2011). If this vital functionality was not enabled, trains would derail or collide, resulting in fatal accident scenarios for railway users. The significance of the term vital is also important as it differentiates from ‘non vital’ systems which have relatively minor implications to operational safety. Railways often make use of interlocking boundaries as shown in Figure 2-5. Boundaries are useful to show segregation of design responsibility, for example, if different project contractors are involved or for purposes of signalling control. As emphasised in Figure 2-5 below, signal 101 is used to demarcate the interlocking of signalling system Y from signalling system Z.

![Figure 2-5 Railway system interlocking boundary](image)
2.3.2 Train Detection Methods

Unlike road vehicles, trains are unable to quickly change direction if an unforeseen event occurs in the path ahead. A car can swerve out of the path of danger. However, a train is restricted to a set route. For this reason the railway's signalling system requires a means for train detection. This is achieved by dividing the track into fixed areas and installing track circuits, which are used to detect the absence of a train on a section of track.

Train detection aids the efficiency and regulation of trains on a specified route. This section briefly discusses the methods that are in existence in the UK for train detection, especially those which have stood the test of time, specifically, the track circuit as it is a safety critical system.

The UK has evolved from using a man to wave a red or green flag to show whether a section of railway line was clear or occupied, termed ‘human detection’ to the use of track circuits. Track circuits, an invention by Dr Robinson, as detailed in the Third Annual Report of the Block Signal and Train Control Board to the Interstate Commerce Commission in 1910 (Knapp, 1911) was a major turning point in the evolution of railway signalling.

“The track circuit is today the only medium recognized as fundamentally safe by experts in railway signalling whereby a train or any part thereof may retain continuous and direct control of a block signal while occupying any portion of the track guarded by the signal.” (Knapp, 1911) Pg 50 & 51.

![Figure 2-6 Track circuit operation clear aspect (SCBIST, 2010)](image)
The operation of the circuit is relatively straightforward. It involves a voltage feed to a section of line and a relay via the running rails. In the absence of a train the relay is energised and picks up. The associated signal is green which enables a train to enter that section as shown in Figure 2-6. Conversely, when a train is present on the track the wheels create a short circuit causing current to bypass the relay, which then drops as shown in Figure 2-7. The usefulness of the relay status is that it can be used as a means to control elements of the signalling system, such as the track signals in addition to detection of broken rails. The track circuit also has an important failure feature of a ‘right side failure’. That is, if an element of the circuit fails, the relay appears de-energised and the track circuit appears to be occupied and a red signal aspect is shown. Technological modernisation has brought about newer computerised methods for train detection which includes the axle counter. The axle counter is often used as an overlay detection system, which is in addition to track circuits and works on the basis of positioning. The axle counter establishes the occupancy within a track section, by counting the number of train axles that are in that section or which have left that section of track. The track circuit has been superseded by the more reliable axle counter (Rail Signs and Signs of Great Britain, nd).
Ultimately, train detection can be summarised as a method of protection as it maintains safe train separation. This method, like other signalling subsystem operation has constraints, such as the length of the line and length of the block section which can have operational effects on capacity.

### 2.3.3 Signals and Point Operating Equipment

Signals and point operating equipment are discussed jointly in this section because of their operational relationship on the railway. Signals and points are interlocked, a topic discussed throughout this section.

Signals are a visual aid for safe train separation and provide protection. Signals prevent trains from colliding with each other, in particular at junction areas and are a means to maintain safe operation. Signals provide the train driver with information which indicates the status of the route ahead that is, whether it is safe to keep in transit. Following modernisation of railway systems, signalling has progressed from the concept of fixed block to moving block signalling. As explained by (Abril, Barber, Ingolotti, Salido, Tormos, & Lova, 2007) a moving block system offers the benefit of continuous train position monitoring which enables a railway to enhance train regulation and passenger services. This concept is addressed through understanding of the European Railway Traffic Management System (ERTMS) described in detail in Section 2.4.2.

In addition to signals, Point Operating Equipment (POE) are a significant part of the railway track environment. POE also referred to as point systems, enable railways to become multi-lined and allow trains to transition onto different routes. Point systems involve moving parts, which enables route changes. Therefore, there is a level of system vulnerability to failure or reduced movement, for example, because of changes in weather. Mitigations of such vulnerabilities include Remote Condition Monitoring (RCM) (Redecker, 2012). Studies employing RCM have shown that the availability of points systems are markedly improved (Redecker, 2012). Signals and points are interlocked, where interlocking is defined as:
‘A general term applied to the controlling of the setting and release of SIGNALS and POINTS to prevent unsafe conditions arising, and the equipment which performs this function. Can be applied to mechanical or electrical equipment’ (Institution of Railway Signal Engineers, 2011) Pg 18.

Therefore, and as demonstrated by the definition given by the Institute of Railway Signal Engineers (IRSE) the relationship between signals and points is a safety critical one. If there is a conflict in the set-up of signals and points an accident could ensue.

2.3.4 Train Systems

Train systems are designed to control huge forces, this includes the internal subsystem weight of the train and cargo load, in addition to dynamic forces incurred whilst travelling over uneven tracks or point systems. Trains are therefore, designed to be physically stable and flexible. The design of a train system is flexible in the respect that train wheels have the ability to accurately follow the track whilst having the ability to motor (accelerate) and brake.

Trains have a number of interfaces, with the primary external interface existing between the wheel and the rail. This is a critical interface as it has a number of risks associated with it, which range from adhesion, wheel slip slide issues to operational risks such as service delays and on-board passenger comfort.

On-board a train, there are a variety of systems which work together to achieve efficient management of traffic. This includes the trains control system, on-board computer and communication interface which includes passenger announcement systems, driver to train guard communication channels and the means for external communication to the signaller.

2.3.5 Implementation of Railway System Functionality

This Chapter has introduced the technical systems that are pivotal to railway operations. This is reflected in this subsection within the wider context of operational railway functionality. As shown in Figure 2-9 below, the operation of the systems detailed in Section 2.3.1 to Section 2.3.4 support key functions required to be processed as part of railway operations. This includes functions required for communication and power networks.

As a result, functionality analysis has been carried out at high level to support the development of a functional architecture. This architecture identifies functionality and maps it to the appropriate railway systems that currently exist. This is detailed in both Table 2-1 and Figure 2-9 to show the system functionality and links between the systems.
<table>
<thead>
<tr>
<th>Railway System</th>
<th>Subsystem</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrification</strong></td>
<td>Generation system</td>
<td>Energy provider</td>
</tr>
<tr>
<td></td>
<td>Transformers</td>
<td>Efficient use of energy, conversion of energy</td>
</tr>
<tr>
<td></td>
<td>Overhead Line</td>
<td>Provision of electric current to trains via pantograph system on train</td>
</tr>
<tr>
<td></td>
<td>SCADA</td>
<td>Alarm management for power systems / means to coordinate electrical protection</td>
</tr>
<tr>
<td><strong>Track</strong></td>
<td>Running rails</td>
<td>Provides an interface and supportive structure for train wheels to operate.</td>
</tr>
<tr>
<td></td>
<td>Ballast</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slab track</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixing mechanisms</td>
<td></td>
</tr>
<tr>
<td><strong>Trackside Equipment</strong></td>
<td>LOC Case</td>
<td>Termination point for copper cabling/telecommunications cables</td>
</tr>
<tr>
<td></td>
<td>Trackside Functional Module</td>
<td>Used to monitor functions such as signals, warning systems and track circuits (inside LOC Case)</td>
</tr>
<tr>
<td></td>
<td>Data Link Module</td>
<td>Is used to convert signals and connect interlocking (inside LOC Case)</td>
</tr>
<tr>
<td><strong>Track Mounted Equipment</strong></td>
<td>AWS</td>
<td>Permanent magnet / electromagnet arrangement linked to trackside signals. Dependent on the energised or de-energised status of the electromagnet a signal is given in cab to the train driver</td>
</tr>
<tr>
<td></td>
<td>TPWS</td>
<td>A brake is automatically applied to the train if the train is travelling too fast in relation to a stop signal as determined by the track loop arrangement.</td>
</tr>
<tr>
<td></td>
<td>Track Circuit</td>
<td>To detect the absence of a train</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To provide safe train separation</td>
</tr>
<tr>
<td></td>
<td>Points Heating</td>
<td>To prevent points locking up during cold periods or winter weather</td>
</tr>
<tr>
<td></td>
<td>Balise</td>
<td>Stores infrastructure data and transfers this to the passing train upon activation.</td>
</tr>
<tr>
<td></td>
<td>Axle counter</td>
<td>Form of train detection</td>
</tr>
<tr>
<td></td>
<td>Signals</td>
<td>Used to notify the train driver about the conditions of the railway i.e. whether to proceed or to stop.</td>
</tr>
<tr>
<td><strong>Rolling Stock</strong></td>
<td>multiple</td>
<td>Transportation of passengers and/or freight utilising a range of technologies for train control and protection.</td>
</tr>
<tr>
<td><strong>Stations</strong></td>
<td>multiple</td>
<td>User interface for passengers</td>
</tr>
<tr>
<td><strong>Control Centre</strong></td>
<td>multiple</td>
<td>Operational control, remote system monitoring</td>
</tr>
<tr>
<td><strong>Wayside IMR</strong></td>
<td>Levers for control of signals and points</td>
<td>Control of points and signals to enable a safe route for train travel</td>
</tr>
</tbody>
</table>

*Table 2-1 Functions of key railway systems*
For the systems shown in Figure 2-9 examples of functions that have been identified are indicated with the prefix ‘f’. The functions provided are not exhaustive but give an indication of the functions required by the various subsystems. For example, at depots and sidings locations within a railway network a number of functions are carried out. This includes data download from Train Interface Units (TIU), similar to black boxes in aeroplanes. The power network on the other hand varies in scale, dependent on the level of power required by a system. However, the function remains the same, to supply and distribute power. Understanding of the system functionality has been used to support the development of the railway architecture discussed in Section 2.4.
2.4 Railway Architecture

The overview of railway system functionality discussed in Section 2.3 presented the foundation on which very complex railway systems are built. The railway environment seamlessly integrates all elements of mechanical, electrical, civil, architectural and software engineering for its operation. This level of integration creates a system. A system can subsequently be defined as

‘A set of objects together with relationships between the objects and between their attributes’ (Hall & Fagan, n.d) Pg. 18

This definition places importance on individual objects (which can otherwise be seen as subsystems), the safety critical importance of the objects and the relationships between them. An alternative definition by (Braband, 2011) defines a ‘technical’ system as a ‘product developed by a supplier including its design, implementation and support documentation’ (Braband, 2011) Pg 186. Both definitions concentrate on the physical components but are void of emphasis on human the interfaces that include operators and their associated actions. The latter definition focuses on the system requirements specification up until the safety approval process. This is a good approach to defining a system as it considers the project lifecycle which involves a detailed analysis and routine validation across all phases including maintenance and decommissioning of assets.

A study of the railway in its entirety, consisting of technical and non-technical elements is a largely neglected research area. However, work by (Chandler, 1977) evidences the link between expanding technical structures and large corporations. This is a reflection of the rail industry worldwide, where the railway is viewed as a technical structure requiring a supporting organisational structure. It is recognised that the ability to increase the capacity of railways has enabled greater commercial usage; and an unprecedented output and movement of goods has been an ever-growing activity because of technology improvements.

Due to the complexity of railway systems and the various interpretations of a system, a system architecture has been developed to aid understanding of a system. Creation of an architecture has been used in this thesis to extensively analyse the railway environment through graphical depiction and use of building blocks to represent the systems that compose a railway. The benefits of system architecture include its ability to make it easier to spot differences, patterns or system integration problems early on. It can also be used to spot what is missing in a design, something that is not always apparent when reviewing design literature. For this reason, it is fundamental that Systems Engineering practices are conducted whilst developing architecture. Systems Engineering involves:

- A critique and analysis of existing systems,
- Management of the evolution of the complexity in a system,
- Identifying whether systems integrate, evolve and operate reliably, (Crawley E. , 2007),
The domain of Software Engineering often uses architecture as part of regular engineering practice. Software has been reviewed as it is a subsystem of the railway environment and is heavily utilised for control, command and information systems such as those implemented on-board the train. This includes activities such as remote monitoring or as part of signalling control. Research conducted by (Gacek, Abd-Allah, Clark, & Boehm, 1995) extensively looks at the definition of a software system architecture. The benefit of their approach is that the architecture is broken down to not only consider the physical building blocks but also to encapsulate stakeholder needs, identifying particular rationale behind any interconnections or constraints on the system interfaces. The value and financial importance of implementing a system architecture is also explained as:

‘Until one has an architecture whose rationale ensures that it will satisfy the needs of the system’s stakeholders, it is very risky to proceed into full-scale system development and evolution. Thus, the achievement of a Software System Architecture as defined here can and should be used as the precondition for transitioning from an uncommitted requirements / architecture exploration stage into a full-scale development and evolution stage based on a solid set of requirements / architecture commitments’ (Gacek et al, 1995) Pg 6.

The software industry relates architecture to project risk, as a key tool to show integration and management of stakeholder requirements. The software framework has been designed to minimise redesign and associated cost implications. It is noted by (Gacek et al, 1995) that stakeholders are of key importance in the software industry. This is also the case for the railway industry where a high percentage of stakeholder’s income comes from UK passengers as shown in Figure 2-10 below.

The figure has been incorporated to demonstrate the roles and responsibilities within the railway industry and the range of actors, which include Freight Operating Companies (FOCs) to government bodies. Furthermore, the railway industry in the UK must adhere to a number of standards and practices that come from these bodies. This includes (i) at the wider European level, European interoperability specifications (ii) Network Rail company standards and (iii) Railway Group Standards.

The use of system architecture during project development minimises the need for rework, particularly if it is used to support identification of risks early on. Early risk identification supports reduction of project lifetime costs if the risks can be engineered out. System architecture can therefore be viewed as a tool to support safety management.
Some organisations within the railway industry, namely London Underground Limited (LUL) currently utilise a framework titled TRAK Enterprise Architecture Framework to model system architecture. This framework is not used widely in the railway industry as different railway stakeholders have different approaches to system architecture development. However, the TRAK tool is used as it is a known tool for Systems architecture development and was initially built to support software engineering practices. Subsequently, the UK railway industry, through the RSSB, started the process of developing and implementing system architecture. The Technical Strategy Leadership Group (TSLG) has been commissioned by the RSSB to develop a model, which at a high level shows the technical functions which integrate to create an operational railway (Rail Safety and Standards Board, 2011). The work undertaken by TSLG had input from a range of stakeholders from across the railway industry including Train Operating Companies (TOCs). This was used to create specific views to represent the railway’s architecture. The views relate to contractual relationships, technologies and potential engineering opportunities. In addition, the architecture has the use as training material for those new to railway technology. The TSLG model looks at architecture from a number of perspectives, including: capability, operational, procurement and the solution perspective. Conversely, the architecture developed for this research focuses on the technical and human system interfaces and utilises SME expertise from relevant engineering disciplines. This supported understanding of the
change to the railway following integration of new technology. The architecture developed for this thesis aims to be concise and holistic within one architectural view. Figure 2-11 shows an example of the functional architecture for a given scenario related to calculation of a required route. The architecture captures the activity/scenario (shown in the yellow box) and the surrounding functions and systems (shown in the orange boxes) required to achieve the activity. This process is visually useful for depicting relationships and has the benefit of a clear structure for identifying relationships between systems or functions. However, the limitation of this tool lies in the construction of the model which is complex due to the layers within the models. Furthermore, it is constrained by the number of processes required to create objects which can become labour intensive. To improve the usefulness of the outputs of its application the TRAK method could incorporate a new perspective which could be titled the ‘safety’ perspective. This perspective could specifically relate to safety aspects of the activity/scenario (shown in the yellow box).

Figure 2-11 TRAK Railway functional architecture (Rail Safety and Standards Board, 2011)

The railway industry additionally utilises an international standard for architecture descriptions. ISO/IEC/IEEE/42010 standardises terminology and rules for architecture frameworks and descriptions and has been specifically developed for software intensive systems.

This standard outlines that an architecture description is the means by which system architecture is documented; and defines architecture as the:
‘Fundamental concepts or properties of a system in its environment embodied in its elements, relationships and in the principles of its design and evolution’, (Architecture Descriptions in ISO/IEC/IEEE 42010, n.d).

There are a number of approaches that can be taken to describe a system, from process flow to graphical block diagram, as shown in the previous example. An alternative representation of system architecture is shown in Figure 2-12, which represents a Chinese intelligent railway. The architecture at a high level details the key systems and the associated sub systems. It has been designed to make use of colour coding to categorise systems, specifically dispatch, train control and supervision. The system representation although simplistic, clearly shows the elements that are key for the railway to operate. It is also useful because it incorporates technical, safety and human factors in its representation. This architecture would be improved if a functional layer (as per Figure 2-9) was included to show the relationships.

![Figure 2-12 Intelligent railway system architecture (Ning et al, 2006)](image)

As Figure 2-11 and Figure 2-12 have shown, the railway can be described and represented in different ways. The railway environment is extremely complex, thus the level of detail and complexity
should be tailored. As a result, the following section presents the architecture that has been derived in this thesis from review of literature and detailed discussions with Subject Matter Experts (SMEs).

The SMEs are Engineers from Network Rail who have specialisms in the fields of Power, Signalling, Control & Communications and Track. The use of SMEs from Network Rail provides an accurate view of the technical and physical railway as NR is the Infrastructure Manager for UK mainline railways. The correctness of the developed architecture is further evidenced by system architecture schematics, which have been developed to represent an aspect of the Crossrail railway. The architectures representing the Crossrail project, a major railway engineering programme have been reviewed by the SME disciplines previously stated and authorised by a Principal engineer at Network Rail. An example of which is included in Appendix I. However, to gain an even more comprehensive view of the railway environment, structured interviews could have been carried out with other key users of the railway such as ticket hall and station staff with the aim to encompass all users of the operational railway environment. System architectures have been created in this thesis to reflect the modernisation of UK mainline railways. These schematics specifically reflect the migration in technologies. As shown in Section 2.3.5, as a starting point, functional architecture has been developed in order to understand how the various subsystem functions relate to each other.

2.4.1 Architecture Description – Conventional Signalled Railway

Railway safety is ensured through adherence to the relevant safety requirements and safety assessment methodologies. Additionally, factors including contractual, commercial and societal relationships must be accounted for. This requires, in the first instance, a detailed understanding of the architecture that comprises a railway from both a functional and physical perspective.

The architecture that has been developed as part of this research is shown in Figure 2-13. It is based on a UK mainline railway system signalled according to conventional signalling methods, specifically, employing trackside signals. As mainline railways in the UK are managed by Network Rail, information to construct the architecture was also assembled from Network Rail’s publicly available information. This is used to provide an insight into railway system operation (Parker, 2014). Therefore, specification of the system architecture has been based on information from publicly available documents, SMEs in addition to the experience of the author. This has been validated through technical discussions with engineers and SMEs from Network Rail in the fields of Telecommunications, Electrification & Power, Track and Signalling.

The approach taken in the design of the developed system architecture consists of two key stages:

1. Representation of linear systems: These have been used to represent track, overhead line equipment, network transmission methods, ethernet and internet protocol. These linear systems have been drawn separately as they all have interfaces with multiple systems. The UK railway infrastructure and electrification protection sectors identify the mainline railway as a linear electrical system with multiple sources of supply (Knight, 2011).
2. Interfacing with these linear systems are key systems which include rolling stock, stations, control rooms, trackside equipment and users. Users are representative of the human interface which includes maintainers, train drivers and passengers.

For the development of the system architecture presented in this thesis, literature discussed earlier on in this section was used to determine the level of detail required to create an architecture. The literature review demonstrates various system interactions in addition to differences in the level of system granularity. That is, whether to present architecture at component, sub-system or system level.

The architecture captures a number of key features required for a safe railway. Firstly, the backbone systems of power and telecommunications which support the entire railway network as described by Dalton (Dalton, 2009). Telecommunication networks increasingly facilitate many existing and new customer services, thereby creating a strong relationship between the telecommunications industry and railway industry. There are also interfaces between safety critical and non-safety critical systems. For example, the safety critical interlocking system is a vital and core system for safe route locking. Interlocking is a signalling method, which prevents the manipulation of levers that could otherwise endanger a train whilst it occupies a route section. The architecture also highlights the level of integration and in general is a visual aid used to identify issues to address. This includes the use of ageing assets and the integration of new equipment into existing railway environments. The architecture can be used to yield scope gaps within a design.

The architecture derived in Figure 2-13 directly relates to the functional architecture depicted in Section 2.3.5, which presented the functional interrelations between systems. Figure 2-13 identifies and depicts a number of safety critical interfaces, examples of which are detailed below.

- **Telecommunications**: Communication assets are necessary for operational tasks, networks and station systems. The latter includes the surveillance aspect of station communications (Darlington, McManus, & Hailes, 2009). As shown in the architecture (Figure 2-13), bearer systems are required for signalling control and electrification. Furthermore, telephone communication plays a large role within a railway system. A number of telephone communication points are present in the railway system. This includes the operational control room, the electrification control room, trackside locations, station and mobile radio communication points on-board the trains. Where there are level crossings present on a route, there are associated telephone systems.

- **Power Systems**: This varies based on the power required by the system in question. For example, significant power is required by the electrification system (which includes OLE, Transformer stations and conductor wires). This can range from 25kV for an AC system and 750V for a DC system (Network Rail, 2010).
• Rolling stock: These vary between passenger, engineering and freight types of rolling stock. Each stock type is composed of numerous subsystems with some variation in the design and configuration. Rolling stock interfaces with operational control, signalling and trackside systems in addition to the train operator. The intelligence of the interfacing on-board / trackside sub systems provide the ability for selective door opening, enabling of the correct door side and over-speed warnings for example.

• Third party system influences: This includes lightning and radio frequencies.

• Third party power suppliers: This includes regional electricity suppliers, Distributed Network Operators.

• Electrification Feeder Stations: Alternating and Direct Current distribution networks and track section cabins.

• Station environment: This includes the user service environment such as shops, offices and information display points.

It is important to note that the integration of these systems requires emissions, magnetic fields and harmonics to be in line with European standards such as the EN50121 series (BSI, 2015).

The next section of this Chapter modifies the conventional railway architecture to account for the new interfaces that have been introduced to meet the functionality and requirements of a modernised railway system.
Figure 2-13 System depicting a conventional railway system (adapted from Smith et al., 2013)
2.4.2 Architecture Description – European Railway Traffic Management System

Section 2.4.1 derived a system architecture representative of the existing mainline railway as depicted in Figure 2-13. This section uses this architecture and develops it further to align with modernisations in technology that are occurring on European railways.

The demand for safety enhancing technologies, greater efficiency and capacity in railway systems has spurred on the development and implementation of the European Railway Traffic Management System (ERTMS). The ERTMS system is a prime example of a technology that uses a high degree of automation. Other industries such as road transportation are also progressing in the field of automation. Intelligent cars have features such as automatic parking and emergency braking. However, the limitations and challenges differ to that of railways. The road industry is notably limited by its environment. For example, a vehicle may not work as efficiently in rural environments compared to highly congested environments. This is because highly congested environments have more intelligent infrastructure and regulation for traffic and incident management. An intelligent car can communicate and decipher intelligent infrastructure such as cameras and road markings. As there is greater variability in a rural environment (terrain and infrastructure) it would be less suitable for intelligent vehicles. Railways aim to operate in all environments and conditions.

Modernisation of any safety critical transport system requires additional consideration of the key interfaces which include the following:

- **Human factors** - specifically the relationship between machine and human, whether there is increased workload, a productive amount of work load or otherwise;
- **Operations** - how traffic management changes;
- **The environment** – How the system design / redesign impacts energy consumption and
- **Integration** – Impact of upgrading an existing system with legacy components;

The interfaces can be developed further based on an understanding of the evolution of the system architecture due to modernisation.

There has been European wide recognition in the railway industry of the concept of a single integrated railway. This is in compliance with the Technical Specifications for Interoperability (TSIs). The TSIs include specifications for the rail vehicles, fixed installations (infrastructure and energy), control and command signalling to safety in railway tunnels (European Railway Agency, n.d). The term interoperability can be categorised into four distinct areas, which focus on Energy, Infrastructure, Rolling stock and Signalling. The realisation of a single system has the potential for many benefits. This includes maintenance facilities, which could enable train stock to be maintained anywhere in Europe with any country affiliated through ERTMS being able to access maintenance equipment.
The ERTMS architecture consists of four layers, namely (i) European Operating Rules (EOR), (ii) European Traffic Management Layer (ETML), (iii) Euro-radio (GSM-R) and the (iv) European Train Control System (ETCS). EOR and the ETML are operational layers whilst the latter GSM-R and ETCS layers are technical (Smith, Majumdar, & Ochieng, 2012). The ETCS, located on-board rolling stock, is a computer based system that compares the maximum permitted speed with the trains’ actual speed. The ETCS, which is implemented across Europe is in line with EU directives and is the signalling system for cross border train operation and is the most complex layer (Dalton, 2009). The ETCS interfaces with track and radio systems for speed optimisation and control and has three distinct levels of technical operation. ETCS Levels include Level 1 (L1), 2 (L2) and 3 (L3), with the signalling system design moving from trackside to on-board the train respectively. This technology is a significant development and change to railway systems throughout Europe as shown in Figure 2-14 below which specifically draws focus to the on-board train systems and the key trackside interfaces which include interfaces to legacy systems such as interlocking.

Figure 2-14 ERTMS ETCS levels of functionality adapted from (Network Rail)

As ETCS technology is an Automatic Train Protection (ATP) control system designed for operation across European railway networks, the functionality enables a train to adhere to interlocking (signals,
points and set routes) decisions (Kanso, Moller, & Setzer, 2009) and stop at the correct locations. Therefore, as a form of ATP it prevents train collisions through translation of the route into a Movement Authority (MA). Conventional signalled railways across Europe make use of a range of train protection systems which utilise different technologies as shown in Figure 2-15. Consequently different systems are required on-board the various passenger and freight trains (Parsons Brinckerhoff, 2011).

Figure 2-15 European map depicting existing train protection systems (Media Rail, n.d)

The architecture that has been derived in Figure 2-16 to represent a railway signalled according to ERTMS technology highlights the core ERTMS ETCS subsystems. The architecture specifically identifies the key systems necessary for train control with respect to the three distinct ETCS levels. As discussed above, Level 1 ETCS involves track to train communication, via track located euro-balisés, otherwise termed balises. The balises interface with existing signalling and line side signals are retained. Level 2 involves track-to-train and train-to-track communication. There is continuous radio communication from the track to train and interlocking confers the train route to a Radio Block Centre (RBC). The RBC calculates correct movement authority, giving authorisation to proceed. In this case, the balises are used as an odometry reference. Level 2 is an enhancement to level 1 ETCS as movement authority is via digital radio, the Global System for Mobile Communications – Railway (GSM-R) and enables elimination of trackside signals. Level 3 ETCS improves the ability of level 2 by introducing a train integrity function, which replaces conventional train detection. At this level the RBC uses GSM-R for transmission between track and train. Level 3 also allows moving block technology, where the train is regarded as a moving block and the track receives the train location and train...
integrity from the train. This is shown in detail in Figure 2-14 and within the wider context of the system architecture shown in Figure 2-16 with further definitions provided below of key systems.

- **Balise Transmission Module (BTM):** Mounted on the train this unit reads the track mounted balises.
- **European Vital Computer (EVC):** A central hub of computer equipment for the on-board train systems.
- **Driver Machine Interface (DMI):** Operational interface for the driver requires data input onto a screen.
Figure 2-16 System architecture depicting a modernised railway system (Smith, 2013)
Figure 2-16 has been developed using the method explained for Figure 2-13 which presents the conventionally signalled railway. That is, key linear systems are depicted with interfacing systems connected to reflect that there is both a functional and a physical interface.

2.5 Global System for Mobile Communications – Railways

The previous subsections have developed legacy and modernised railway system architectures. A key element of both railways is the telecommunications network which supports a number of functions.

The modernised railway utilises the communication sub-system, the Global System for Mobile Communications – Railways (GSM-R). This system is presented in this section because it replaces both the National Radio Network (NRN) and Cab Secure Radio (CSR) communication systems. As a result, users will also have to adapt to the system. The systems that are being replaced have been in place for a time span nearing 30 years (Office of Rail and Road, 2014) and have had a physical design with the benefit of fitting most train cabs. GSM-R is now utilised in conventional railways largely for communication between the driver and signaller in addition to its uses for both voice and data communication in modernised railways. For this reason a more in depth review of its architecture and subsystem is discussed in this section.

GSM-R is a telecommunications system specifically designed for railway transmissions. This communication technology is endorsed by the International Union of Railways (UIC) and is specified through functional and system requirement specifications (International Union of Railways, 2012). The technology, mandated in 1997 as a standard for European railways by the European Commission (GSM-R Technology at a Glance, 2012) is unlike commercial telecommunications systems, it is less vulnerable to market variations as it focuses on passenger usage, safety and reliability.

In accordance with the goals for an interoperable European railway network, GSM-R replaces a number of incompatible analogue communication systems that have been used for railway transmission. The move away from analogue systems is deemed inevitable, as use of legacy components often restrict design and are often difficult to resource and replace due to significant changes in technology. However, during physical installation of GSM-R systems on-board trains a number of integration issues as well as logistical problems were encountered. The GSM-R train borne equipment did not satisfy the space envelope that was in place for CSR. For example, the suppliers of GSM-R had designed their GSM-R systems to fit the more generous train cab capacities as found on European trains and as explained by (Kessell, 2014) this could be quite challenging.

GSM-R technology is used as a means for information transmission for a number of railway users and systems. This is seen from a physical system perspective through use of system architecture. The system architecture identifies key interfaces and points of integration and is drawn in the context of
the railway environment akin to Figure 2-13 and 2-16. The system architecture is used as a basis to identify the key GSM-R interfaces. These interfaces include the train system, control centre and human interfaces, which have been identified and specified with the assistance of Subject Matter Expert knowledge. Figure 2-17 includes the following interfaces:

1. GSM-R NSS to the Radio Block Centre
2. GSM-R Voice (Driver) to the Route Control Centre
3. GSM-R data modem (onboard) to the European Vital Computer
4. GSM-R Trackside to GSM-R data modem (onboard)
5. GSM-R data modem (onboard) to the Maintainer

As shown in Figure 2-17 a generalised view of the GSM-R interfaces are presented. The systems which interface via GSM-R include on-board rolling stock and trackside systems. Where there is a human interface this is also indicated. From a human machine interface perspective the key GSM-R
interfaces are operational, in the control room and on board the train. The GSM-R platform puts in communication the on-board European Vital Computer (EVC) with the trackside located Radio Block Centre (RBC) which carries out control command functions.

Looking in more detail at the GSM-R subsystems, Figure 2-18 provides an overview of subsystems that compose GSM-R. GSM-R technology at ETCS level 2 enables movement authority to be continuously transmitted to the train. This occurs via the Radio Block Centre (RBC) and is made visible to the driver through the train cab display. The train’s position and direction of travel is automatically reported at regular intervals to the trackside RBC (Ngai, 2010). Thus it can be said that the RBC is a vital interface in the ETCS as it provides an interface for the signaller to observe and influence operational aspects (Rail Safety and standards Board, 2010).

The GSM-R communication process for the ETCS implements a connection means for ETCS information transmission, whereby information on movement authority, train speed and train position requires connections to be established, maintained and released. The established connection between a train and RBC is sustained for a whole trip (Ruesche, Steuer, & Jobmann, 2008). Figure 2-18 captures the GSM-R based on research by RSSB (Rail Safety and Standards Board, 2012) and the architecture used for the GSM-R implementation on the Deutsche Bahn (Germany) (DB Netze, 2012). The GSM-R architecture can be broken down into four building blocks: Mobile Station (MS), Base Station Subsystem (BSS), the Mobile Switching Centre (MSC) and Operations. The MSC manages and switches calls to and from the mobile terminals of drivers and other railway users through the Fixed Telecoms System (FTS) and is the control equipment for the whole network. The Base Station Controller (BSC) on the other hand manages the resources of the Base Transceiver Stations; such as handover where the BTS additionally provides the channels by which communication is carried out between the mobile stations (Senesi, 2008).

![Figure 2-18 GSM-R system architecture (DB Netze, 2012) and (Rail Safety and Standards Board, 2012)](image-url)
The difference in functionality between GSM-R, which is specific to railways, and GSM is the frequency range in which it operates as shown in Figure 2-19. This frequency range has some variation across the European member states. The functions that these frequency bands support include on-board signalling, voice group call services and broadcasting services.

![Figure 2-19 GSM-R vs GSM frequencies (adapted from (GSM-R Operators Group, 2014))](image)

Railway stakeholders, who endeavor to ensure best practices are upheld, via the Radio Spectrum Committee raised concerns about interference of the GSM-R frequency spectrum (European Commission, 2011). This concern was raised following liberalisation of the GSM-R operational bandwidth. Currently, interference emissions from public base stations and cumulated interference signal levels from public transmitters have the potential to cause severe disruptions of the GSM-R network (UIC, 2011). This infers that the quality of the GSM-R service could be degraded. As a result, stakeholders believe that protection of the GSM-R frequency band is paramount. Figure 2-20 and Figure 2-21 respectively show why interference is possible, as shown in Figure 2-20, along many railway routes there are often numerous public network sites, these could be providers such as 02 or Orange networks, for example. The interference scenario in Figure 2-21 shows unwanted interference can occur between base stations and between base stations and mobile stations.
The issues raised via the Radio Spectrum Committee are proven to be justified. However, emphasis should also be on the reliability of GSM-R and how it affects GSM-R human related interfaces. Greater emphasis is required because the subsystems that comprise the GSM-R network do not have 100% reliability. The consequences posed to a railway suffering from communication interference, can potentially be severe.
A number of European cases highlight the issues that have occurred following interference. In 2001, German deployment of GSM-R experienced no interference. However, from 2006, due to increased usage of the neighbouring GSM band, interference problems have arisen with cases of loss of connection with passing trains. In addition to Germany, the Swedish regulator has carried out a study to identify public mobile installations that create interference to GSM-R and the requirement for public operators to install rejection filters. Similarly, the UK is discussing the protection of GSM-R sites, following liberalisation of the 900 band which has led to uncoordinated and unadvised deployment by UK operators (UIC, 2011). The French on the other hand from 2006 have carried out detailed analysis of GSM-R disturbances, which include analysis of the severity and impact posed to the railway from interference. Table 2-2 shows examples of disturbances and the associated severity. The cases specific to ETCS have identified a high level of severity on urban routes, which are routes usually with high passenger demand.

<table>
<thead>
<tr>
<th>Quarter of disturbance detection</th>
<th>Disturbance position rural/urban</th>
<th>Voice service impacted</th>
<th>Severity of voice impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006 Q2</td>
<td>Urban</td>
<td>Voice (operation critical)</td>
<td>Critical</td>
</tr>
<tr>
<td>2008 Q4</td>
<td>Rural</td>
<td>Minor voice impact</td>
<td>Minor</td>
</tr>
<tr>
<td>2009 Q2</td>
<td>Rural</td>
<td>No impact on voice quality</td>
<td>Minor</td>
</tr>
<tr>
<td>2009 Q4</td>
<td>Rural</td>
<td>Voice (operation critical)</td>
<td>Major</td>
</tr>
<tr>
<td>2010 Q4</td>
<td>Urban</td>
<td>Data (ETCS)</td>
<td>Major</td>
</tr>
<tr>
<td>2010 Q4</td>
<td>Urban</td>
<td>Data (ETCS)</td>
<td>Major</td>
</tr>
<tr>
<td>2011 Q1</td>
<td>Urban</td>
<td>Voice (operation critical)</td>
<td>Critical</td>
</tr>
<tr>
<td>2011 Q1</td>
<td>Urban</td>
<td>Voice (operation critical)</td>
<td>Major</td>
</tr>
</tbody>
</table>

Table 2-2 Radio Interferences in France (UIC, 2011)
2.6 The Role of Humans in a Railway System

This chapter has discussed both the functional and technical aspects of railway systems. Nonetheless, railway systems would not be able to operate without human interaction. The role of humans in the railway environment is therefore, an important one and can be classed as human factors. The subject of human factors is very broad and includes aspects such as ergonomics, behaviour, training and procedures (Health and Safety Executive, 2007). Where applicable, some of these topics are dealt with in Chapter 4 and 5 of this thesis.

Furthermore,

‘Good Human Factors in practice is about optimising the relationships between demands and capacities in considering human and system performance i.e. understanding human capabilities and fallibilities’ (Health and Safety Executive, 2007) Pg V.

In addition,

‘Human factors refer to environmental, organisational and job factors, and human and individual characteristics, which influence behaviour at work in a way which can affect health and safety’ (Health and Safety Executive, 2007) Pg 15.

The definition of human factors aligns to the importance of humans in the railway environment. The railway is a safety critical environment in which it is essential that human behaviour is in line with procedures that aim to ensure safety of the railway. To support this, effective training is required, therefore factors of the job also have an influence.

Key roles within the railway environment include the following:

- Engineers: Of all disciplines (Electrical, Mechanical, Civil, Power, Communications, Quality, Assurance and Systems) who create and ensure the railway is designed and constructed in accordance with standards and safe practices.
- Planners: Arrange and plan engineering activities in the operational railway environment, which require possessions.
- Signallers: Regulate train movement and ensure that all manoeuvres are safe.
- Train operators (train drivers): Operate different types of train stock, this includes passenger, engineering and freight stock.
- Control Room Operators: Ensure that the railway is operating in conjunction with prescribed operating rules and procedures.
- Maintainers: Maintain the railway which includes fault finding and fault rectification activities.
- Passengers: Users of railways for transportation.
- Protection Staff: Ensure that before engineering activities are being carried out and during engineering activities that the working environment is safe to be worked on.
- Station Staff: Liaise with passengers and operational control to ensure that the station environment is safe and operational.
- Cleaners: Maintain the cleanliness of the railway environment, particularly at stations, sidings and depot environments.
This list although not exhaustive, provides examples of key roles that are required within the railway environment. Not all of the roles presented are operational but range based on skill, expertise and training. The architecture in Figure 2-17 includes examples of some of the human interfaces listed above.

2.7 Navigation Technologies

From the perspective of a railway system, use of modern navigation technologies will change the system architecture. Navigation is a field which is gaining pace within the railway industry as shown through Italy’s test demonstration, partly funded by the European Space Agency (European Space Agency, 2014). Early integration of satellite technologies into railway systems has proven challenging for a number of reasons, this includes:

(i) Railway safety standards and processes - which need to be complied with for railway signalling;
(ii) Signal availability - which can be affected by railway topologies such as cuttings (slopes) and tunnels;
(iii) Multipath propagation - which means signals can reach receiving antennas by two or more paths with the potential for correlation errors; (Sunderhauf, Obst, Wanielik, & Protzel, 2012)

The use of satellite technology is an exciting progression for railways as there is potential for viability to be improved. Satellite navigation, in particular the Global Navigation Satellite System (GNSS) has a number of applications which include train guidance, track inspection and determination of train integrity. The state of the art in GNSS application is specifically shown by localisation in railways (Technische Universitat Braunschweig, n.d). The advantages of satellite localisation include increased capacity and precise positioning of the end car of a train.

As shown in the system architectures, the trackside element of the railway uses balises to transmit location information and ground data to trains. This information is also fed to service control centres for driver information. However, use of navigation technologies would remove all the balise equipment related costs because virtual balises would be employed based on a digital architecture. Other challenges and proposals include the integration of satellite assets at level crossings to help improve safety, this would require significant emphasis on integration, as satellite navigation assets will have to integrate with existing terrestrial assets. Nonetheless, the railway industry is already ensuring that investment is available for further innovation and research of methods to ensure a safe and secure railway (European Commission, 2016) and this is inclusive of navigational aids.
2.8 **Summary**

This chapter has shown how railways evolve through systematic analysis of railway systems, specifically through creation of architectural representations. The principal usefulness of a system architecture is as a means to identify where there are potential technical scope gaps in relation to system integration or to identify areas for development, for example failure modes and priorities for intervention. The rail industry has a number of issues, which are important when developing and modernising a railway system. These include cost and safety. Development of the railway’s functional and physical architecture enables an understanding of various processes, information flow, interactions and of how the processes are supported by technologies, procedures and people. It is also useful to understand where there is scope for reuse or repeatability of subsystems that may not be impacted significantly by railway development.

Railways have been shown to be vital for both the economy and users. Therefore, as railways modernise to improve services, it is important that failures are minimised through effective system integration. The changes in the implementation of the railway system functions that enable transition from conventional methods of signalling to ERTMS signalling (ETCS level 2) have been presented. The differences that modernisation introduces can be summarised in three key areas shown in Table 2-3 which demonstrates there is impact to both technology and human interfaces. This is crucial for safety management, which includes failure mode analysis and development of mitigations.

<table>
<thead>
<tr>
<th>No.</th>
<th>Function / System Design</th>
<th>Conventional railway</th>
<th>ETCS Level 2 railway</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Movement authority – authority for a driver to move</td>
<td>Indicated to the train driver by trackside signals</td>
<td>Indicated to the driver by the GSM-R and balise transmission to the train</td>
</tr>
<tr>
<td>2.</td>
<td>Train Detection, position and integrity</td>
<td>Track circuits</td>
<td>Balises – send train position information</td>
</tr>
<tr>
<td>3.</td>
<td>Driver Interface</td>
<td>Speedometer interface</td>
<td>ETCS Driver Machine Interface</td>
</tr>
</tbody>
</table>

*Table 2-3 Railway function comparison*

The process taken to develop system architecture has highlighted that there is a scope gap in the application and development of system architecture from review of research literature. As a
consequence, an understanding of the benefits of its application has not been fully realised in railway research to date. For this reason, the potential benefits and uses of system architecture have been demonstrated throughout this chapter. It is also important to note that system architecture is in place as a means to anticipate all failure modes and is therefore used to support safety. Converse to academia, the use of system architecture is often a starting point for safety analysis of railway system functionality. Industry stakeholders such as RSSB have progressed the use of the TRAK tool to demonstrate the benefits and uses of system architecture. It has been demonstrated that the railway can be constructed from a functional and physical building block perspective, which can be translated into formal documentation thus creating a system architecture description. In order to fully conceptualise the railways operational environment, system architecture is one of the best methods for demonstration for design development.

Aside from defining a system architecture description using standard ISO/IEC/IEEE/42010 the use and application of systematic processes is outlined in a number of standards. In particular, IEC 61508, CELENEC EN 50129 and EN50128.

EN50128 relates to procedures and requirements for electronic systems that are widely used in the railway environment. EN50129 on the other hand, relates to lifecycle activities, which are of particular applicability when a system is entering into operation. All these standards are in the context of a safe environment. As observed by (Faulkner & Storey, 2001) system architecture should be viewed as an early design requirement as it is beneficial for system safety analysis, specific methods include Hazard and Operability analysis, Fault Tree Analysis (FTA) or Failure Mode Effect Analysis (FMEA).

As shown in section 2.4.2 the railway has undergone modernisation in the form of integrated technology and new processes. As a result, modernisation brings with it a number of factors which can impact the social usage of railways. This ranges from the fear of the unknown, to environmental change. Public feelings and opinions on topics such as these are justifiable as there is a change from conventional signalling methods and the implications of modernisation via new technology are not fully understood. The change in technology will also impact other key users of railways namely train drivers who have an operational interface. This is described in more detail as part of this research’s safety assessment analysis presented in Chapter 5. Many countries outside of Europe are also modernising their railways with technology that has similar functionality to the European Railway Traffic Management System. A case in point is demonstrated by China (Ning B. , 2010) and New Zealand. It could be beneficial for such organisations who have implemented this technology to engage in lesson learned dialogue with Europe.

The next chapter builds upon the architecture developed and interrogates the fundamentals that drive the management of safety and the consequences to the railway industry.
Chapter 3  Fundamentals of Safety Management

3.1 Introduction

This chapter discusses the approaches taken to manage safety within the railway industry. These methods are compared to other industries based on the criteria that they are high risk and safety critical. Comparisons are made to ascertain whether there are useful or effective processes that can be mapped and tailored to the railway industry to enhance safety. This chapter also examines safety management processes and the potential for improvement (summarised in section 3.3). The requirement for and methods taken by various industries to utilise Safety Management Systems (SMS) is examined. Understanding of the key factors and processes required for an optimal SMS, and identifying priority areas for further research is gained. At the core of any SMS should be a progressive safety culture, an area still in its infancy in a number of safety critical sectors. In order to develop an effective SMS it is important to understand the impact of risks to the railway. This is discussed by analysing trends in accidents, incidents and near miss statistics.

Accidents, incidents, near misses and environmental damage can occur in a range of surroundings. However, the risk is amplified if any such event occurs in a safety critical environment such as railways, which have a range of technologies and users interfacing. Risk can be attributed to a number of factors, ranging from intentional erroneous acts, lack of training or failure by management to adequately assess safety risks and hazards. A SMS is vital in mitigating such risks, it is composed of procedures and processes designed to provide effective safety management and maintain residual risk to levels which are As Low As Reasonably Practicable (ALARP). That is, weighing risk against time and money. In usual circumstances, good practice is employed via use of standards and it is important for duty holders to be able to demonstrate risk control and reduction.

Safety can be viewed from the context of accidents, incidents and near miss occurrences. Each constitute a vital part of any organisations SMS and are defined using definitions from the (International Association of Oil and Gas producers, 1999) in addition to definitions from the UK Health and Safety Executive (HSE) for comparison.

**Definition 1: Accident** ‘Any event which results in injury, and/or damage and/or loss. (IAGC Consensus 1993).’ (International Association of Oil and Gas producers, 1999) Pg 8.

**Definition 2: Incident** ‘An event or chain of events which has caused or which could have caused injury, illness and/or damage (loss) to assets, the environment or third parties. (OGP report 6.36/210, 1994 ‘Guidelines for the development and application of health, safety and environmental management systems’).’ (International Association of Oil and Gas producers, 1999) Pg 6.
**Definition 3: Near Miss/Near Accident** ‘Any event which had the potential to cause injury and/or damage and/or loss, but which was avoided by circumstances (IAGC Consensus 1993).’ (International Association of Oil and Gas producers, 1999) Pg 8.

The HSE on the other hand define accidents and incidents as follows, particularly relating to reporting of these events:

‘An accident is a separate, identifiable, unintended incident, which causes physical injury. This specifically includes acts of non-consensual violence to people at work. Injuries themselves, e.g. ‘feeling a sharp twinge’, are not accidents. There must be an identifiable external event that causes the injury, e.g. a falling object striking someone. Cumulative exposures to hazards, which eventually cause injury (e.g. repetitive lifting), are not classed as ‘accidents’ under RIDDOR’. (Health and Safety Executive, n.d.)

Both the Oil & Gas industry and the HSE make a distinction between accidents and incidents. This is because of the resulting consequence of the particular event.

The responsibilities of the HSE extended until April 2006, after which the responsibility for regulating health and safety on railways in Britain was transferred (by the Railways Act 2005) to the Office of Rail and Road (ORR) (Butcher, 2010). This is clarified below by an excerpt from the Memorandum of Understanding (MoU) between the HSE and the ORR (Office of Rail and Road, 2015).

3. HSE considers, in accordance with Section 11 (6) of the Health and Safety at Work Act 1974 (HSWA), that this MoU facilitates the performance of its functions under part 1 of HSWA. The Office of Rail Regulation considers, in accordance with paragraph 2(a) of Schedule 3 to the Railways Act 2005 (RA 2005), that this MoU contributes to the provision of appropriate arrangements for fulfilling its duties in relation to the railway safety purposes.

4. HSE and ORR undertake to cooperate to enable each other to carry out their responsibilities and functions, and to maintain effective working arrangements for that purpose.’ (Office of Rail and Road, 2015)

The definitions are therefore, reflective of what is used for safety analysis of accident and incident statistics on Britain’s railways pre 2006. From 2006, the ORR makes use of Railways and Other Guided Transport Systems (Safety) Regulations, 2006 (ROGS). This is the UK’s implementation of the Railway Safety Directive (RSD) (Office of Rail and Road, 2015).

Definitions 1 and 2 for accidents and incidents respectively, are shown to relate to events that arise as a consequence of safety failures. Definition 3 differs, as it is an unrealised event where there is no resultant injury or damage to assets, the environment or third parties. However, it is recorded due to the possibility of being a precursor to events of greater severity. The importance of definition 3 - near misses is emphasised by (Jones, Kirchsteiger, & Bjerke, 1999), in addition to the impact of accidents and incidents as part of a SMS. They observe that any near miss that arises should be treated as a
significant event and a forewarning to potential accidents. It has been interpreted from their analysis that near miss identification and examination should be used as a means for accident and incident prevention, with stronger emphasis on the reporting element. This implies that in order for safety analysis to be effective, near misses which induce safety failures need to be understood in the first instance. Therefore, they must be reported exhaustively and accurately. From an economic perspective, near misses do not produce high financial outlays when compared to events such as a derailment or user fatality and as a result, near misses receive less attention.

In addition to the definitions used by railway safety regulators in Britain, those used by the Swedish Transport Agency are also included in this thesis. This has specific applicability because the data analysis carried out as part of this research is on Swedish railways that have implemented ERTMS technology. These definitions are based upon the Railway Safety Directive (RSD), which has also been implemented by the UK from the year 2006. The definitions for accidents and incidents as described by the Railway Safety Directive (European Union, 2004) are as follows:

**Definition 1: Accident** 'accident' means an unwanted or unintended sudden event or a specific chain of such events which have harmful consequences; accidents are divided into the following categories: collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others; (European Union, 2004) Pg 5.

**Definition 2: Serious Accident** 'serious accident' means any train collision or derailment of trains, resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment, and any other similar accident with an obvious impact on railway safety regulation or the management of safety; 'extensive damage' means damage that can immediately be assessed by the investigating body to cost at least EUR 2 million in total; (European Union, 2004) Pg 6.

**Definition 3: Incident** 'incident' means any occurrence, other than accident or serious accident, associated with the operation of trains and affecting the safety of operation; (European Union, 2004) Pg 6.

The Railway Safety Directive provides no specific definition of a near miss. However, this term was specifically defined by the HSE. The term ‘near miss’ is referred to within the context that there are procedures in place for reporting them. The process of reporting is carried out throughout the railway industry in the UK.

The Swedish Transport Agency has demonstrated safety improvements as a result of trends in accidents and incidents (Swedish Transport Agency, 2012). This is shown in Table 3-1 and Table 3-2 below. Table 3-1 shows that in order to maintain risk to ALARP levels, financial allocations need to be proportional to the risk.
<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Description of Event</th>
<th>Safety Improvements Made</th>
</tr>
</thead>
<tbody>
<tr>
<td>07/04/2011</td>
<td>Malmö</td>
<td>Uncertainty concerning DSB Sverige AB’s financial capacity</td>
<td>An inspection has been conducted in which the Transport Agency reviewed whether DSB Sverige AB met the financial capacity requirement.</td>
</tr>
</tbody>
</table>

Table 3-1 Examples of Safety Improvements made by the Swedish Transport Agency which were triggered by an accident or incident (Swedish Transport Agency, 2012)

<table>
<thead>
<tr>
<th>Item</th>
<th>Safety Improvement</th>
<th>Description of Trigger</th>
<th>Description of the Problem Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Inspection of the Swedish Transport Administration regarding the implementation and enforcement of regulatory framework relating to work in the track environment, such as emergency planning and reduced speed past worksites.</td>
<td>Inspection discovered that information and new regulations on this were not being followed within the Transport Administration.</td>
<td>Contractors are exposed to considerable risk during work in the track environment.</td>
</tr>
<tr>
<td>2.</td>
<td>Inspections have been conducted in which the transport Agency reviewed whether DSB Sverige AB met the financial capacity requirement.</td>
<td>Inspections discovered shortcomings in DSB Sverige AB’s finances. The company was required to develop an action plan to address these shortcomings.</td>
<td>The company should be capable of meeting its financial obligations during the following 12 months.</td>
</tr>
<tr>
<td>3.</td>
<td>Brake test performed by the driver. Check procedures of relevant Railway Undertakings. Activity in progress.</td>
<td>In response to recommendations from the Swedish Accident and investigation Board.</td>
<td>A number of trains have been operating with greatly diminished braking effect.</td>
</tr>
<tr>
<td>4.</td>
<td>Management of drawings</td>
<td>In response to recommendations from the Swedish Accident and investigation Board.</td>
<td>If there are drawings in circulation that do no correspond to reality, serious safety faults may result, especially during switching.</td>
</tr>
<tr>
<td>5.</td>
<td>Inspection notes</td>
<td>The media</td>
<td>Operational track systems that are impaired by acute and weekly faults.</td>
</tr>
</tbody>
</table>

Table 3-2 Examples of Swedish Transport Agency Safety improvements with triggers other than one specific event (Swedish Transport Agency, 2012).

Reviewing examples in Table 3-2 for comparison to UK railway practices. Item (3) relates to performing a brake test. As standard training and practice on UK railways a brake test is one of the first actions performed by a train driver embarking on a new train journey as a safety precaution. Item (4) refers to drawings, final ‘As Built’ drawings should always be provided to maintainers to reflect the actual build configuration of the railway. These areas which the Swedish Transport Agency identify as areas for safety improvement are already inherent safety practices in the UK.

Tables 3-1 and 3-2 show that inspections of the organisation identified safety failures due to non-practice of regulations. This could be partially attributed to the further issue that there was a finance shortfall. Furthermore, the Swedish Transport Agency made use of recommendations from the
Accident and Investigation Board to improve their safety practices and to reduce the potential for failures in safety.

The definitions of accident and incident scenarios that are of particular relevance to this thesis are those provided by the RSD. Common principles for railway safety are defined by the RSD, this is discussed further in Chapter 4 with respect to Common Safety Methods which has been used to develop the safety assessment process.

3.1.1 Safety Management in the Railway Industry

Emphasis on safety in the railway industry stems from the requirement to transport humans and goods in a safe manner in all environmental conditions. This can be surmised as both a moral and legal obligation. As with all major industries, cost and reputation are significant factors that influence management of safety issues. Poor safety practices often equate to bad business. The railway industry has been greatly influenced by events that have had a detrimental impact on railway users, either through injury or fatality. For this reason safety practices and management techniques employed by the railway industry are discussed here and compared in the subsequent sections to other safety critical industries. Safety management, is more often discussed in relation to a Safety Management System (SMS) which is ‘a comprehensive set of procedures for managing risk’ (Rail Safety and Standards Board, 2007) Pg 17. Guidance for heritage railways based upon the Railway and Other Guided Transport (Safety) Regulations, 2006 define safety management as:

‘the systematic management of the risks associated with railway operations and related engineering and maintenance activities to achieve a high level of safety performance. (Heritage Railway Association, 2007) Pg 3.

The Office of Rail and Road (ORR) (Office of Rail and Road, 2013) have evaluated techniques for the evaluation of management systems. Key measures of safety management have been identified as relating to (i) safety culture, (ii) performance/asset management, (iii) customer service and (iv) finance/efficiency. Findings from the ORR indicate that safety management should account for the organizational culture and that an accident, near miss or unsafe condition for example, could relate to a failed SMS. The cultural and operational performance elements are evaluated further as part of safety assessment in this thesis.
3.1.1.1 Review of Failures in Railway Safety

Failures in railway safety have occurred over many decades. These include the Quintinshill disaster in 1915 and the Harrow & Wealdstone crash in 1952 as reported by the UK Ministry of Transport. Table 3-3 substantiates this through incident statistics, which show the impact of errors in the railway environment for cases in the United Kingdom from 1892 to 1999. The cases have been selected as they all occurred on UK railways using existing signalling technology. In addition, the incident causes relate to the human interface, which is of importance in addition to the technology within a railway system. The complexity of the railway environment is evidenced in Chapter 2, which presents the system architecture for the railway environment. The system architecture demonstrates the level of integration between operational control and command, trackside signalling, rolling stock and supporting disciplines such as communication networks. All of these systems require a human interface; this could be a maintainer, operator, controller or train driver. Table 3-3 shows that the incidents are primarily attributed to the human interface.

<table>
<thead>
<tr>
<th>Incidents</th>
<th>Date</th>
<th>Cause</th>
<th>No. of trains</th>
<th>No. of deaths</th>
<th>No. of injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thirsk Rail Crash, Yorkshire</td>
<td>1892</td>
<td>Signalling error due to the signal man suffering ill health</td>
<td>2</td>
<td>10</td>
<td>43</td>
</tr>
<tr>
<td>Quintinshill Rail Crash Scotland</td>
<td>1915</td>
<td>Signalman forgets about train on line</td>
<td>5</td>
<td>230</td>
<td>246</td>
</tr>
<tr>
<td>Winwick Junction London Midland &amp;Scottish Railway</td>
<td>1934</td>
<td>Signalman and booking boy forget about train on mainline</td>
<td>2</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>Southall Rail Crash</td>
<td>1997</td>
<td>Signal Passed At Danger(SPAD)</td>
<td>2</td>
<td>7</td>
<td>139</td>
</tr>
<tr>
<td>Ladbroke Grove Rail Crash</td>
<td>1999</td>
<td>Signal Passed At Danger (SPAD) (Problems with signal visibility)</td>
<td>2</td>
<td>31</td>
<td>520</td>
</tr>
</tbody>
</table>

Table 3-3 Examples of fatal rail accidents from 1892 to 1999

The example cases presented in Table 3-3 show signalman error is the predominant cause for incidents followed by Signals Passed at Danger (SPAD). This table does not include failures in the railway environment that were triggered by or attributed to equipment malfunction. The examples have been selected to illustrate the significance of the human's operational role in the railway environment, a factor that is not usually emphasised. The three examples are shown to be attributed to signalman error and involve duties which require the individual's physical and cognitive awareness. These are classified as elements of human factors by the International Ergonomics Society. Similarly, SPADs are specifically driver related errors and can also be attributed to human factors. An example that demonstrates this is the 1999 Ladbroke Grove Rail crash which highlighted lack of visibility as a major contributory factor to failures in railway safety (Uff & Cullen, 2001). Therefore, human error...
which has been the cause of these incident scenarios is classified as the top event that leads to the incident. Such cases have shaped the future of safety practices as demonstrated by the Train Operating Company Abellio Greater Anglia who include applicable failure scenarios as part of their training regime.

Abellio provide a clear example of how lessons have been learnt from crashes such as Ladbroke Grove. During simulator based driver training, signals are purposely obscured to determine what action a train driver would take. This is largely because as was seen from the outcome from the Ladbroke Grove crash, the driver could not clearly see the signal. The expected action by a driver would be to report the number of the obscured signal and the nature and the obstruction, for example, foliage or a structural obstruction to the signalman or line controller. However, it was observed that obstructions are not necessarily reported but instead ‘managed’ as part of the driving task by some train drivers. Example cases include a driver cautiously adjusting their distance until the signal was no longer obscured and shifting in the seating position to see the signal. There is still an amount of variability between train drivers in how potential failure scenarios are dealt with. Therefore, human factor analysis has the potential benefit to clarify changes in equilibrium of humans in the environment in which they work.

The statistics in Table 3-3 also show that there are rarely more than two trains involved in a train collision. However, the severity is significant in terms of the injuries and fatalities. In the case of the railway crash that occurred in 1892, it is questionable as to whether the injuries suffered were measured as accurately as those in 1999. It is possible that due to the time period and lack of sophistication in search and find technology, and data recording equipment, that a number of injured railway users may have been omitted from the incident statistics. In some cases the injuries may not have been realised or felt immediately by the affected passengers.

Apart from human factor related issues there are technical issues that impact safe railway operations as demonstrated by the Shipton-on-Cherwell accident (Court of Inquiry, 1875). The case of Shipton-on-Cherwell in 1874 involved a train overloaded with passengers being adjusted in length through addition of another car. The railway inspectorate surmised that the train had multiple failures, which included a poor braking system design. This design did not incorporate braking circuitry for each carriage, instead only having engine braking. In addition to this, the train had wheels which were made from cast iron which fractured. These technical and design issues led to fundamental changes, specifically redesign of the train wheels through to the braking systems on passenger trains (Court of Inquiry, 1875).

This section has presented the importance of understanding the causes of an accident to enable changes to be made to safety practices by all levels of an organisation.

Following the review of the major cases in railway history (Table 3-3) and the trends of fatal accidents shown in Figure 3-1, there has been an overall decrease in fatal accidents with fluctuations in the
number of fatalities and injuries. This can be attributed to a number of factors which include (i) the political change which resulted in privatised railways (ii) the subsequent drive to change stakeholder attitudes towards safety and (iii) aims to minimise spend on penalties. Recent public information from the RSSB provides examples of safety failures that have resulted in serious injury to railway workers in the UK. As a result, associated penalties that have been imposed are often publicised. Such publications can negatively impact an organisation’s reputation.

Figure 3-1 Trend of fatal accidents on railways under British Rail (BBC, 2007)

Following high profile railway crashes in the late nineties, public awareness of failures in safety increased through media coverage. The railway industry subsequently received more societal interest (including through the media) due to the severity of injuries and user fatalities. The railway industry also has a significant number of near misses to which less attention is paid. As discussed in section 3.1, near misses are a vital constituent of a Safety Management System (SMS) and should be viewed as a precursor to accidents. Railway industry regulations, namely Railway and Other Guided Transport Systems Regulations (ROGS) also stipulate that a SMS is maintained via a common approach across European member states. This is outlined in the European Railway Safety Directive (2004/49/EC) where railway industries across Europe aim to be interoperable in their approach to safety management.

(Davey, Ibrahim, & Wallace, 2005) have carried out research into near misses employing the method of focus groups to investigate the experiences of train drivers at level crossings with emphasis on reporting of near misses. The findings from their research draws attention to the fact that the majority of the drivers interviewed had experienced an incident and/or fatality, with all the drivers experiencing
a near miss. A key finding was the train drivers’ understanding of the terms ‘near miss’ and ‘incident’, where their categorisation and comprehension of the two terms had no clear distinction in the case of some train drivers.

‘Comments were made that, “what might be a near miss for me, may not be a near miss for Joe”, and “everybody’s made differently…what could upset Harold, might not upset me” (Davey et al., 2005, Pg 4).

Also:

‘Most participants revealed that ‘near misses’ are not always reported. Some of the themes that were revealed from the discussion on reporting ‘near misses’ included difficulties from the lack of clear definition, issues of non-reporting which included personal feelings, work culture surrounding reporting and lack of perceived outcomes’ (Davey et al., 2005, Pg 4).

The above extracts from the response of train drivers show that the concept of a near miss can be construed to be particular to an individual and their emotional perception of a particular event. Hence, across safety critical industries such as the railway industry it would be of great benefit if employees and organisations were mandated to report near miss events. This should be made an inherent process of their working practices. This is currently the practice for accidents and incidents in the United Kingdom. This would remove any issues of personal feelings towards reporting and potentially reduce any perceived ideas of a blame culture.

Another practical approach to manage safety in the railway industry has been developed by Alstom Transport, a major rail business actor. Of particular interest is their work in the supply field of ERTMS. They identified the importance of developing an innovative SMS due to changes in European railways which required them to have open competition and free movement (Durand & Romei, 2007). Alstom’s SMS specifies the importance of integration, worker experience and external scrutiny. They identified the statutory nature of safety management in addition to the significance of safety culture for its employees. This is an example of a proactive approach by a company which falls under the categorisation of a supply industry. That is, one that is not obliged to carry out safety management activities as it is neither an Infrastructure Manager, Railway Undertaking or Train Operating Company.

The SMS developed by Alstom consists of a number of key elements, namely (i) policy documents (ii) manuals – detailing organisation structure, competence, training and gate reviews (iii) the safety organisation and a (iv) core competence network which looks at day to day operational roles and potential safety issues. This approach to proactively manage safety is of great benefit to the relevant companies. This is demonstrated in the European market as this type of working practice feeds into the common approach to manage safety. Detailed research into safety management systems has also been conducted by (Koursi & Duquenne, 2006) which also encompassed the associated matters of common safety methods, safety indicators and safety targets. Their research was conducted under the themes of interoperability, which has the added complication of the involvement of multiple safety
authorities for the various European railway networks. For example, in the UK this is the Office of Rail Regulation. Spain on the other hand, with extensively developed ERTMS railway networks have the Ministerio de Formento Dirección General de Infraestructuras Ferroviarias as their safety authority. As presented in Spain’s Annual Report, Article 18 of Directive 2004/49 (Government of Spain Ministry of Infrastructure and Transport, 2014) operational objectives were specifically set to redress the Safety Management System, in particular how Common Safety Methods are implemented as part of risk management in the SMS. Of particular relevance to this thesis is their work to harmonise safety management systems.

Harmonisation requires significant and complex systems integration. This is similar to this research in the respect that in order to provide a baseline for the safety management framework, comparison was made to other non-rail related safety critical industries. Koursi et al (Koursi & Duquenne, 2006) specifically created a baseline for their railway SMS based on safety critical sectors which include civil aviation, maritime, nuclear and chemical industries.

The Deming Cycle is used by (Koursi & Duquenne, 2006) since it has the benefit of targeting process and quality improvement and presents a different way to manage improvements as devised by Deming a pioneer in the field of Quality and Safety Engineering. The cycle as shown in Figure 3-2 below goes through four key stages, specifically, P-Plan, D-Do, C-Check and A-Act which (Koursi & Duquenne, 2006) have used and developed so that the SMS addresses learning from accident and incidents. Their main findings were that effective collaboration is necessary between infrastructure managers and railway undertakings. Communication between industry stakeholders is an issue which has also been validated though this research and is further detailed in the Safety Assessment section of this thesis. Collaboration issues across Europe with deployment of ERTMS was a common finding. Collaboration between railway stakeholders and suppliers is therefore essential to support risk management in particular, where risk is shared, rather than the converse of internal risk, which is integral to an organisation.
The proposed SMS shown in Figure 3-3 complies with the requirements detailed in the Railway Safety Directive. This is particularly in regard to compliance with relevant safety standards and rules. The following sections compare other safety critical industries to railway industry practices on safety management. This is to identify whether any aspects can be used to support development of safety management for railways. Therefore, the SMS in Figure 3-3 is used as a baseline for comparison.
3.2 Safety Management in Other Safety Critical Industries

The construction industry has been reviewed as a starting point, as the railway has a large civil engineering element. Therefore, issues that have arisen in the construction industry may be relevant to the railway industry. The chemical industry is addressed next due to the high risk and associated severe effects of a safety failure which is also relevant to the railway industry. The railway environment utilises a number of chemical substances and can contribute to railway pollution and contamination if not controlled. Chemicals are often used and include antifreeze glycol, detergents and sewage effluent. Finally, the aviation industry is addressed as the operational organisational structure (control and transportation) in terms of human interfaces is similar to the rail industry. The review seeks to identify beneficial aspects for transfer to the railway industry.

3.2.1 Construction Industry

Infrastructure developments within the railway industry continue to grow in Europe for a number of reasons, ranging from capacity enhancement to increased passenger journeys. UK examples include High Speed Rail Projects which are expanding UK railway infrastructure and in wider Europe the implementation of ERTMS.

Aside from railways and the civil infrastructure needed for transportation networks, the private and residential building element of the construction industry is also a high risk sector which faces high profile safety issues. The UK has a large amount of heritage residential infrastructure some of which are gradually modernised. This differs from cities such as Hong Kong in China which is expanding in new infrastructure developments at a much more rapid rate than European counterparts (HKTDC Research, 2015). Hong Kong has demonstrated the ability to produce construction developments in timescales of as little as 5 to 6 days for residential buildings. This has had an associated consequence of exceptionally high accident rates (Lingard & Rowlinson, 1993) not experienced in Europe. Table 3-4 presents construction accident and fatality figures for Hong Kong in the period 1998 to 2002. It draws attention to inadequacies in safety practices in Hong Kong, which were significantly high in 1998 and 1999. The year 1998 shows that the number of accidents and fatalities were at their greatest for workers of all industries not only construction, this reduced significantly by year 2002. It is noticed that the economy of a country can also have an impact on industry practices;

“The bursting of a property and stock market bubble in late 1997 and early 1998 has had a major and prolonged impact on consumer sentiment. Prices (measured by the Composite Consumer Price Index) have dropped for more than three years and are forecast to drop a further 2.8% for 2002 as a whole”. (The Economy)

In 1998 Hong Kong was in financial crisis and reached its lowest GDP growth for the equivalent yearly period 1998 to 2002 as shown in Figure 3-4. Improved GDP as shown in the year 2000 also aligns to improvements in the accident figures. This suggests that there was a financial driver behind the lack
of emphasis in an effective Safety Management System and safety culture for the period 1998 to 1999. The initial significant changes in these figures between the years 1998 to 1999 can also be attributed to Hong Kong’s legislative intervention which stipulated the introduction of a Safety Management System (SMS) in 1999 (Sing, n.d)

**Gross Domestic Product**

![GDP Graph](image)

**Figure 3-4** Gross Domestic Product (GDP) in Hong Kong (*Hong Kong Government, 2010*)

<table>
<thead>
<tr>
<th>Year of Accident / Death</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Labour Accidents</td>
<td>19,588</td>
<td>14,078</td>
<td>11,925</td>
<td>9,202</td>
<td>6,239</td>
</tr>
<tr>
<td>No. of deaths</td>
<td>56</td>
<td>47</td>
<td>29</td>
<td>28</td>
<td>24</td>
</tr>
<tr>
<td>No. of workers on sites (10,000)</td>
<td>7.9</td>
<td>7.09</td>
<td>7.96</td>
<td>8.03</td>
<td>7.32</td>
</tr>
<tr>
<td>No. of accidents per 1,000 construction workers</td>
<td>247.9</td>
<td>198.4</td>
<td>149.8</td>
<td>114.6</td>
<td>85.2</td>
</tr>
<tr>
<td>No. of accidents per 1,000 workers of all industries</td>
<td>64.7</td>
<td>55.1</td>
<td>51.7</td>
<td>44.6</td>
<td>37.4</td>
</tr>
<tr>
<td>No. of deaths per 10,000 construction workers</td>
<td>7.1</td>
<td>6.6</td>
<td>3.6</td>
<td>3.5</td>
<td>3.3</td>
</tr>
<tr>
<td>No. of deaths per 10,000 workers of all industries</td>
<td>1.02</td>
<td>0.8</td>
<td>0.66</td>
<td>0.53</td>
<td>0.42</td>
</tr>
</tbody>
</table>

**Table 3-4** Hong Kong construction accidents and deaths (*Poon, 2009*)
The legislation which falls under CAP59 Section 7 – Factories and Industrial Undertakings (Safety Management) Regulation, mandated safety audits. Where an audit can be viewed as an overarching umbrella process which includes a SMS. In the case of construction activities in Hong Kong, a safety management plan is introduced at the project tender stage, it is then submitted again upon allocation of a project to a contractor. This is because the safety management plan impacts a number of areas as demonstrated by the 14 elements that compose a SMS:

<table>
<thead>
<tr>
<th>Element no.</th>
<th>Element of SMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Health and safety policies</td>
</tr>
<tr>
<td>2</td>
<td>Safety organisation</td>
</tr>
<tr>
<td>3</td>
<td>Safety training</td>
</tr>
<tr>
<td>4</td>
<td>In house safety rules and regulations</td>
</tr>
<tr>
<td>5</td>
<td>Safety committee</td>
</tr>
<tr>
<td>6</td>
<td>Programme for Inspection of Hazardous Substances</td>
</tr>
<tr>
<td>7</td>
<td>Job hazard analysis</td>
</tr>
<tr>
<td>8</td>
<td>Personal Protective Programme</td>
</tr>
<tr>
<td>9</td>
<td>Accident and Incident Investigation</td>
</tr>
<tr>
<td>10</td>
<td>Emergency preparedness</td>
</tr>
<tr>
<td>11</td>
<td>Safety promotion</td>
</tr>
<tr>
<td>12</td>
<td>Health Assurance Programme</td>
</tr>
<tr>
<td>13</td>
<td>Evaluation, Selection and Control of Subcontractor</td>
</tr>
<tr>
<td>14</td>
<td>Process Control Programme</td>
</tr>
</tbody>
</table>

Table 3-5 Key elements of the SMS

From the review of each element of the SMS applied to the construction industry, all of the elements (1-14), equate to either the culture of an organisation or personal responsibilities. This has largely been drawn from British practices and standards such as BS8800, OSHA, ISO14001 and OHSAS 18001 (Bamber, 2006). BS8800 is shown to be of particular benefit to an organisation as it offers guidance on how a SMS should be made effective.
Table 3-6 shows the difference between worker and employee fatality rates for the UK and Asian countries. The UK had the lowest number of fatalities from 1999 to 2006. However, more importantly the influence of British practices on the Hong Kong construction industry can be seen in the period between 1999 and 2000 when there was a significant drop in the number of fatalities. From 2000 the number of fatalities have remained lower than 1998 when there was the highest number of deaths per 10,000 workers. The figures for Hong Kong up to the year 2006 show greater similarity to the other Asian countries, in particular South Korea.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>1.5</td>
<td>1.3</td>
<td>1.5</td>
<td>1.8</td>
<td>1.9</td>
<td>1.8</td>
<td>1.5</td>
<td>1.3</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>S. Korea</td>
<td>3.1</td>
<td>3.6</td>
<td>3.2</td>
<td>2.8</td>
<td>2.7</td>
<td>2.4</td>
<td>2.9</td>
<td>3.9</td>
<td>2.9</td>
<td>n/a</td>
</tr>
<tr>
<td>Singapore</td>
<td>3.4</td>
<td>3.4</td>
<td>2.6</td>
<td>2.6</td>
<td>1.5</td>
<td>2.3</td>
<td>2.1</td>
<td>2</td>
<td>1.3</td>
<td>0.9</td>
</tr>
<tr>
<td>Taiwan</td>
<td>2.6</td>
<td>2.5</td>
<td>2</td>
<td>2.2</td>
<td>2.1</td>
<td>1.9</td>
<td>1.8</td>
<td>1.3</td>
<td>1.7</td>
<td>n/a</td>
</tr>
<tr>
<td>Hong Kong - China</td>
<td>5</td>
<td>7.1</td>
<td>6.6</td>
<td>3.6</td>
<td>3.5</td>
<td>3.3</td>
<td>3.9</td>
<td>2.7</td>
<td>4.2</td>
<td>3</td>
</tr>
<tr>
<td>UK</td>
<td>0.57</td>
<td>0.44</td>
<td>0.55</td>
<td>0.65</td>
<td>0.53</td>
<td>0.49</td>
<td>0.43</td>
<td>0.48</td>
<td>0.36</td>
<td>0.4</td>
</tr>
</tbody>
</table>

n/a – indicates unavailable data

Table 3-6 Number of deaths per 10,000 workers (employees for the UK) (Poon, 2009)

Chan et al. (Chan, Kwok, & Duffy, 2004) observe that it is difficult to put into practice all of the 14 elements of the SMS shown in Table 3-5. This is due to a number of factors, such as the use of multiple subcontractors in a project who do not have integrated methods of work. Other factors include employees with a low level of education and general unawareness of safety management. Therefore, they propose that elements are ranked in terms of their importance, through utilisation of the Analytic Hierarchy Process (AHP) tool. This tool developed in 1970 by Saaty (Alexander, 2012) is based on a combination of both psychology and mathematics. (Soderholm & Nystrom, 2009) also explore the application of the AHP tool to identify preferences for rail criteria such as safety. They found that it has the benefit of providing organisations with a means to incorporate scientific data alongside professional judgement. The application of the AHP process enables priorities to be ascertained. From this, health and safety policy, safety organisation and safety committee were identified by (Chan, Kwok, & Duffy, 2004) as the most important in terms of impact on a SMS. A safety committee offers independence and guidance, with policy as the driver in terms of rules and regulations. These three elements contribute to a safe culture.

In summary, and drawing from developments in the construction industry, a strong safety management system has a positive correlation with a strong safety culture within an organisation at all levels. As Figure 3-5 shows, following a period of technical improvement a period of system
improvement followed. It is assumed that the technical improvement enabled systems to be understood and managed more easily which had an overall impact on safety culture with accidents at their lowest rate during the safety culture enhancement stage. A SMS will only be effective if it is practically carried out and followed, that is, it needs to be supported by employees at every level. This in turn means that the importance of safety culture can be reinforced via a SMS. In the case of Hong Kong, the main barriers that contributed to the poor accident statistics have been reduced; risk taking and adherence to rules and regulations were no longer disregarded. This implies that such industries are more perceptive of safety issues in their environment.

Comparing the construction industry’s SMS to the railway industry’s SMS as presented by the ORR (Office of Rail and Road, 2013), a strong positive correlation is shown between the two. The ORR has a top-level management structure that has the role of enforcing the safety management system throughout an organisation. Risk is then managed by planning, organising, auditing, monitoring and review processes. To enable the SMS to be effective, the railway industry ensures that there is adequate resourcing, information products and services available. Therefore the correlation between the construction and railway industry is largely in terms of the key elements required for the SMS. There will however be cultural differences. The SMS for the construction industry additionally places emphasis on aspects requiring individual responsibility, such as job hazard analysis. However, areas such as health assurance should be all encompassing and include safety assurance. The railway

Figure 3-5  Accident statistics for the construction industry in Hong Kong (Kuen, 2007) Pg 5
industry’s approach beneficially makes use of lessons learnt which would also be practical for the construction industry.

3.2.2 Safety Management in the Chemical Industry

In contrast to the railway and construction industries, other safety critical industries such as those which involve dangerous substances have realised the benefits of mandatory safety failure reporting processes. In Europe, schemes such as the Major Accident Reporting System (MARS) have been implemented as a means for European member states to report industrial accidents. Renamed eMARS it provides a means for lessons learnt to be shared on accidents and near misses (European Commission, 2012). Notably countries outside of the European Union such as Norway as observed by (Jones, Kirchsteiger, & Bjerke, 1999) have shown initiative and identified with the importance of such a reporting structure. Although not mandatory in Norway, they populate MARS with accident information.

Some of the issues experienced in the railway industry have also been demonstrated by the chemical industry. For example, it has been shown that there has been less emphasis placed on the value of data on near misses in the chemical industry. Research conducted by Van Der Schaaf (Van der Schaaf, Lucas, & Hale, 1991) has been noted by (Phimister, Oktem, Kleindorfer, & Kunreuther, 2003) as it classifies near misses. Additionally, (Wright & Van der Schaaf, 2005) identify the value of near miss analysis in three areas:

- Near misses are greater in number compared to accidents and provide a good range in data from which prevention measures can be based;
- Near misses enable prevention measures to be put in place;
- Recovery behaviour can be developed from recovery actions that prevented a near miss;

However, based on the three areas above, if a near miss differs significantly from an accident in their causal patterns then the relationship between them is difficult to determine. This will therefore, be of little benefit to safety. Conversely, if near miss evaluation positively identifies correlation with accidents this could prove beneficial. Particularly in regard to the reduction of monetary outgoings that are imposed on companies as penalties for accidents and incidents.

3.2.3 Safety Management in Aviation

The International Civil Aviation Organisation (ICAO) state that:

‘Effective safety management requires a systems approach to the development of safety policies, procedures and practices to allow the organisation to achieve its safety objectives (....) and that there is no single model that “fits all”’ (International Civil Aviation Organization, 2005) Ch12-Pg 3
This differs from the Railway industry's approach to unified safety management methods across Europe, which tie in with the objectives of the European Railway Traffic Management System (ERTMS). The Federal Aviation Administration (FAA) on the other hand, characterises a SMS as a means by which acceptable levels of safety risk is achieved. The FAA divides a SMS into the categories of safety policy, safety assurance, safety promotion and risk management. This includes managerial commitment to safety, risk control strategies, training, effective communication and methods of risk control.

Comparing this to the UK’s Civil Aviation Authority (UK CAA) who take a proactive approach to safety management and who view safety management as:

‘a systematic approach to managing safety where potential safety risks are identified and managed to a tolerable level as the industry develops and evolves’ (Civil Aviation Authority, 2010) Pg 3.

This definition is in line with the Australian Civil Aviation industry which adheres to SMS guidelines outlined in the International Safety Management Manual (International Civil Aviation Organization, 2005). However, due to the complex nature of safety management in the civil aviation industry, (Gill & Shergill, 2004) developed a questionnaire to assess safety management, safety culture and Safety Management Systems in New Zealand’s civil aviation industry. Their questionnaire aimed to target the perceptions of employees towards safety and observe how these perceptions relate to organisational practices. Some of their findings can be said to be apparent or obvious approaches to safety management. For example, the finding that ‘safety education is essential in ensuring safety’ or that it is an ‘individual’s safety responsibility’ or ‘Implementation of safety policies and procedures as a method of ensuring safety’ (Gill & Shergill, 2004) Pg 235.

However, it is a good tool to confirm what is thought to be intuitive. More significantly, (Gill & Shergill, 2004) categorised their findings into factors using an assessment scale. This drew a main conclusion that organisations place higher importance on employees to be accountable and manage safety. This is rather than it being the sole responsibility of the organisation to instil positive safety practices through various organisational means. This conclusion differs from what is promoted not only in aviation but also in the railway industry, which is that employees and organisations must work cohesively to achieve safety. Such findings are important to organisations in understanding the perception of employees towards safety management and can be used as a tool to improve management of safety risk.
### 3.3 Summary – Railway and Other Industry Comparison

Section 3.2 and Table 3-7 present evidence that the application of a SMS can be used to promote safety within an organisation and can foster the idea of a safe culture in any high risk industry. It is found that the railway industry is generally ahead of industries such as the construction industry. In particular, construction organisations in Hong Kong have been shown to get up to speed with safety practices through incorporation of British standards into their methods of work. The Aviation industry, discussed in 3.2.3 is significantly developed and use a systems engineering approach to implement safety within an organisation as it tackles each phase of a project's life cycle. Table 3-7 below summarises the key safety management factors that have been identified across the review of selected industries.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Key Safety Management Factors</th>
</tr>
</thead>
</table>
| Railway  | • Significance of human actions in addition to technical factors with respect to errors is evident;  
          | • Cost in the form of penalties is a noteworthy factor for driving safety management improvements;  
          | • Greater attention should be paid to near misses as this is a common occurrence, specifically mandating reporting of near misses;  
          | • Regulations such as The Railways and Other Guided Transport System Regulations have a key objective of ensuring that the railway industry enforce a System Management System for protection against unacceptable risks; |
| Construction | • Asian (Hong Kong) construction industry have incorporated British practices and standards to mitigate against the high proportion of fatalities;  
               | • Prioritisation was found to be key to understand what impacts safety management of which safety organisation and safety committee were identified; |
| Chemical  | • Use of near miss data for prediction analysis - particularly of benefit if there is a significant amount of near miss data as near misses have higher rates of occurrences; |
| Aviation  | • Building relationships with employees such that safety is an individual’s responsibility in addition to an organisation; |

### Summary

A cross comparison of safety management approaches across the industries outlined above shows that British Standards have proven to enhance safety and reduce risk outside of the UK. However, the railway industry from a UK or European perspective can learn from other industries, in particular by placing greater emphasis on the domain of Systems Engineering which incorporates all facets both technical and human to manage engineering deliverables. It is noted that safety management is not solely regulation driven but requires internal organisational management commitment in addition to regulations, risk management, assurance and safety promotion for successful implementation.

**Table 3-7 Summary of industry comparison**

The implementation of a SMS in the case of Hong Kong, based on British standards, has shown to improve safety performance with significant changes in accident and fatality statistics. In the construction industry the implementation of regulatory and process aspects of a SMS significantly
improved safety culture. Findings from (Santos-Reyes & Beard, 2008) see this approach as only a partial solution to safety management.

For effective management of safety, (Santos-Reyes & Beard, 2008) propose that a systemic approach is taken as an alternative method to systematic safety management. The term systemic, implies that safety management is via a holistic and engrained approach rather than a systematic approach which is process driven and structured. However, the idea of a systematic SMS is not totally discounted by Santos-Reyes and Beard. It is believed that the real benefits for safety management are drawn from a systemic approach. This approach includes the following characteristics: maintaining risk, a recursive structure, inclusion of features for effective communication and human factors in a structured environment. These elements culminate in a Systemic Safety Management System (SSMS). Comparing the systemic method proposed by Santos – Reyes et al to the common systematic approach to safety management, it is agreed by the author that a SMS is largely process and regulation driven. Human factors are currently encompassed in a systematic SMS, although it may not appear explicit this often takes the form of competency and training. The difference between the SMS approaches is that the SSMS places greater emphasis on those other areas, identified as, maintaining risk, a recursive structure, inclusion of features for effective communication and human factors and how they integrate to make them systemic. Another key difference that the SSMS introduces is that of a ‘recursive organisational structure’, that is, focus is also on what level within an organisation the SMS aims to target, an area that is not always clearly indicated in a SMS.

Many elements and processes are required to create an effective SMS. However, viewing it as a systemic process rather than a systematic process may add benefits which will enable each process to integrate and be viewed holistically.

Industries from aviation to railways continually strive to improve safety through focus on technical reliability. This has had the benefit of reducing system safety risks. However human reliability and perceptions also need to be addressed with the same rigour. Promotion of safety culture has attempted to do this and is a means to progress the idea of safety management for both employees and organisations. (Liou, Yen, & Tzeng, 2008) on the other hand have also demonstrated how to create an effective SMS based on research of the airline industry. Their research recognises the inputs into human factors such as a safe culture and training alongside the inputs into strategies and policies such as rules and regulations.

Review of cross industry literature into safety management has identified safety culture as a critical component of a SMS. Incorporation of safety culture is required for a SMS to be effective, but it is an area that is still developing in its application across many safety critical industries. This is a factor, which will play a key role in European railway development. The fundamentals of safety culture are addressed in the next sub section in greater detail to ascertain its origins, development and implementation in the railway industry, this is then compared to other safety critical industries.
3.4 Safety Culture

The previous sub sections have discussed the application and detail of safety management systems across a number of industries. A good safety management system should outline how to achieve a positive safety culture and can be used as a tool to promote safety culture practices.

Railway organisations in the past have tended to place emphasis on the causal factors of failures in safety as predominantly technical. Recently, organisations have moved towards gaining understanding of the systemic aspect of failures in safety. This requires an understanding of the safety issues within an organisation, hence an organisation’s ‘safety culture’. Safety culture is defined as:

‘the product of individual and group values...that determine the commitment to an organisation’s health and safety management’ (Health and Safety Executive, 1993) in addition to technical safety issues.

The following section discusses the safety culture in the railway industry and draws comparison to that of related safety critical industries.

3.4.1 Safety Culture Origins, Theories and Applications in the Railway Industry

Safety culture as a research area has increased in importance across a number of industries. This is because it aims to investigate contributory causes to failures in safety beyond standard organisational practices, which usually involve analysis of technical error. The development and comprehension of safety culture in engineering industries and academic research fields links to work carried out by Reason (Reason, 1998) in the majority of cases reviewed.

Outside the domain of railways, research into the failures which led to the nuclear power plant disaster in Chernobyl, in the Ukraine, identify that safety culture in an organisation is tightly linked to the ability to successfully or otherwise manage aspects related to safety (Glendon & Stanton, 2000).

Safety culture has also been formally defined in a number of other ways and by a range of industries. For example, the International Nuclear Safety Advisory Group’s (1991) initial definition of safety culture followed extensive review of the Chernobyl disaster and proposed the concept of safety culture to be:

“that assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance” (International Nuclear Safety Advisory Group, 1991).

This definition has been clearly specified for the nuclear industry and was the result of the analysis of all facets of safety culture including aspects of motivation, commitment and individual awareness. (Guldenmund, 2000) on the other hand, has carried out an in depth and thorough review of safety
culture literature. This approach acknowledges that there are many dimensions to safety culture outside the widely used industry method of questionnaire-based survey and that the theory behind safety culture is also important. As a consequence, the approach taken by (Guldenmund, 2000) was to also review social psychological elements of safety culture. However, whilst acknowledging questionnaires as a useful tool to identify attitudes, (Guldenmund, 2000) cautions that care should be taken to collate sufficient data to make statistically sound conclusions on safety culture. From the review, the mains attributes of an organisation’s safety culture were identified as beliefs, perceptions, attitudes, the work environment, actions and the policies or procedures.

It is interesting to compare industry’s comprehension of safety culture to the state-of-the-art in research. The Confederation of British Industry defines safety culture as documented by the Health and Safety Executive. As explained by (Fleming & Lardner, 1999), to effectively manage and reduce accident rates in the industry setting, social and organisational influencing factors need to be understood.

The HSE’s definition of safety culture is also used by the International Union of Railways (UIC). This is a definition which is seen as an avenue by which safety can be improved as it deals with aspects such as competency and behaviours. The UIC also place significance on safety culture at interfaces, this includes railway infrastructure, organisation, routines, the environment, the individual or team. This holistic view of safety culture which addresses safety from the perspective of interfaces allows illustration of where the key events occur in addition to the key actors that determine the level of safety (International Union of Railways , 2004). This research makes use of the HSE’s definition of safety culture as described in section 3.4.

Questionnaire based methods have been used to measure safety culture and it is seen as a way to correlate attitudes and perceptions of actors at all levels of the railway industry. A number of stakeholders in the railway industry measure safety culture through questioning of users be they front line or office based. Recent developments in the railway industry have been to publicise safety through posters, leaflets and safety bulletins. This method attempts to share the responsibilities for safety with employees, emphasising the impact of individual actions, this is separate to the safety culture exhibited by an organisation as a whole.

In addition to the methods mentioned to promote and monitor safety, the railway industry such as UK Infrastructure Manager Network Rail make use of Reason’s ‘Swiss Cheese Model’ to train staff on aspects on safety prevention. This model places emphasis on safeguards, barriers and the quality of the barriers as a defence to hazards.
The concept of the ‘Swiss Cheese model’ depicts a slice of cheese as a defence; the holes in the cheese are created by errors or violations which stem from human interactions. These can be latent or active, ‘the holes due to active failures are likely to be relatively short-lived, whilst those arising from latent conditions may lie dormant for many years until revealed by accidents’ (Reason, 1998). The benefits of the model lie in the identification of a number of preconditions for hazardous acts. The holes in the cheese range from failed methods of organisational management to psychological factors. In essence, it identifies the elements of safety culture which can be described as a sub component of corporate culture. It does not operate in a vacuum; it affects, and in turn is affected by, other operational processes and organisational systems (Cooper P., 2002).

Comparison of industry and research shows that safety critical industries are heavily influenced by theoretical analysis carried out in the research field. Organisations now more readily develop training to provide staff with competency on the subject of safety culture practices and expectations.

The following sections address safety culture in a number of safety critical industries. Comparisons in safety culture are firstly drawn from the transportation sector, followed by other related sectors. This enables an understanding of the similarities and differences in safety culture across sectors and industries.
3.5 Safety Culture in Other Safety Critical Industries

Approaches to assess and incorporate safety culture practices in a range of safety critical industries ranging from aviation to the nuclear industry are addressed in this section. Similarities and differences in understanding of safety culture between the various industries are established. This is to determine whether there are any findings that are transferable and can be applied to the railway industry.

Safety culture is important across a range of industries as a means to prevent failures in safety. (Wiegmann, Zhang, von Thaden, Sharma, & Gibbons, 2004) identify four stages to categorise the theory behind safety as follows:

Stage 1 = technical period, Stage 2 = the period of human error, stage 3 = the sociotechnical period and stage 4 = the safety culture period.

This is based on research carried out by (Coquelle, Cura, & Fourest, 1995), (Perrow, 1984) and (Rochlin & Meier, 1994). The latter two stages are relevant to this research due to the history and environment of the railway, which has both developed technologically and required a change in human skill. Stage 3 refers to a socio-technical period of human interaction with technical factors, as conducted by (Hendrick, 1991) and (Rasmussen, 1986). Whilst stage 4, the final stage, relates to the organisational safety culture period, this stage assesses the performance of tasks by operators and their interaction with technology as conducted by (Gordon, Flin, Mearns, & Fleming, 1996) and (Wilpert, 2000).

3.5.1 Marine Industry Safety Culture

The marine industry like the railway industry, transports significant numbers of passengers, largely for the purposes of leisure. Marine industry trends show a newer generation of ships which are capable of transporting increased numbers of passengers through utilisation of more sophisticated automated technology and monitoring systems. A practical example of safety culture development in the marine industry is shown via the Marine Accident Investigation Board (MAIB, 2010). The MAIB in their efforts to encourage the promotion of near misses have identified a number of potential challenges to safety culture. These include unsafe acts, behaviour and conditions, which have been highlighted due to the probable impact of failures in safety to all crew members onboard a ship.

Furthermore, deficiencies in safety culture have been documented by the MAIB as,

‘a result of bad leadership, lack of training and education, lack of experience, poor technical solutions, assumptions, habits, attitudes, culture, silent acceptance, shortcuts etc”. (MAIB, 2010) Annex K

This analysis of deficiencies in safety practices follows 3 marine fatalities due to breaches in regulation, lack of inspection and maintenance (Longshore Shipping, 2011). These fatalities increased the precautionary safety measures put in place. This was through reassessment and review of risk.
assessments, safe working procedures, safety circulars and inspection. Zero tolerance policies for marine crew members and the implementation of specialised training centres were introduced following the high profile fatalities.

The marine industry acknowledged that all necessary precautions that could have prevented fatalities were not taken. The risk assessment methods in place were insufficient as hazards were not identified and leadership was ineffective. The actions taken by the marine industry align with those of the railway industry, which focus on behaviour and training needs of staff as experienced by the author whilst working for Network rail.

The case presented above from the MAIB although proactive is not the first time that safety culture has been addressed as an area lacking in development. In the year 2000, Det Norske Veritas (DNV) who conduct ship classification in addition to advisory services made a number of recommendations relating to the safety of cruise vessels (Mathiesen, 2000). A key recommendation was that employee confidence stems from knowledge and understanding of safety and that sharing best practices is of benefit to an organisation. Future expectations for the maritime industry were to increase motivation. This would be achieved through incentives, pragmatic training methods and continual reporting of incidents and near misses. These recommendations are still valid to date, as purported by MAIB analysis of safety deficiencies which show that in ten years there has been little advancement in the understanding of safety culture.

3.5.2 Safety Culture in the Aviation Industry

The behaviours displayed by pilots in the cockpit environment were observed by (Sexton & Klinect, 2001) to be a result of their perception of safety culture and attitude towards the job. General opinions associate negative attitudes towards a job as a detriment to safety. Nonetheless, Helmreich et al. (Helmreich & Merritt, 1998) identify that there has been little empirical evidence found to support the hypothesis that safety is affected by a negative organisational culture. There have been cases which prove contrary to this statement; for example, as shown by the Challenger shuttle disaster.

The idea of negative organisational culture is shown through the task of risk reclassification that occurred prior to the Challenger disaster. This has been analysed by (Vaughan, 1996) to show the failure in actions by the organisation. The process carried out by the engineers is depicted in Figure 3-7 below and has been adapted from Vaughan.
The process flow in Figure 3-7 shows that although a risk to safety was acknowledged in step 1 (potential danger identified) by the organisation. The technical analysis of the risk was re-evaluated and labelled as an acceptable risk. This is shown in step 4 where the risk is reclassified as an acceptable condition. This illustration shows that although a danger to safety was identified, the severity of the risk became diminished within the organisation and collectively accepted by the team to progress the project. This demonstrates that safety can be affected by the negative behaviours of an organisation. The negative behaviours are specifically in relation to the reclassification of the risk, as a consequence there were fatalities.

3.5.3 Safety Culture in the Medical Industry

The medical industry like the railway industry’s application of the ETCS has moved towards greater implementation of software for safety procedures. A high profile case of safety failure in the medical industry is shown by the Therac-25 case. Therac, a medical linear accelerator, underwent software development from Therac-6 and Therac-20 systems to Therac-25 (Leveson & Turner, 1993). This upgrade culminated in one of the most severe medical disasters.

In this case, organisational aspects of safety were found to be lacking, insufficient employee training and deficiency in understanding of the system resulted in severe safety critical operator error. The operators of Therac-25 lacked training, ignored error messages that they found to be cryptic and tedium was found in data entry tasks. This type of culture had multiple avenues of failure, from employee behaviour to organisational training. As identified by (Degani & Wiener, 1997) high risk endeavours such as this require a flawless organisational structure. In this case the organisation did not provide sufficient support to employees as operational procedures were inadequate and unable to prevent failure caused by human malpractice. (Pronovost, et al., 2003) on the other hand believe that the medical industry requires significant efforts to improve measures of safety culture and that culture will be improved if there is closer involvement with front line workers.
### 3.5.4 Safety Culture in Formula One Racing

The world of Formula One (F1) racing is an exciting and high adrenaline field for sport and engineering. It is also more advanced in its safety developments than a number of other industries. This is largely based on the profile of the sport, financial sponsors involved and large consumer/fan base. This ensures that an emphasis on safety is a necessary factor for the industry. The road transport industry has benefitted from methods utilised in motor sport, some of which can also be utilised in the railway industry.

The areas of focus for this industry are the vehicles in addition to the track layout as the two cannot operate independently. This is similar to the wheel / rail interface in the railway environment. Additionally, the motor sport industry has changed drastically from the early 1950’s. Figure 3-8 presents the numbers of deaths per year from the 1950’s, which saw the greatest number of fatalities in 1958.

![Figure 3-8 Formula 1 fatalities from 1950 (Snyder, 2011)](image)

In 1972 F1 made seatbelts mandatory, other mandatory introductions included protective overalls (F1 Scarlet Pit Crew). This demonstrates the variability in the factors considered to affect safety and more importantly followed through by the racing industry. Also like the railway industry, the Formula One industry has made increasing usage of Information Technology (IT) to enhance safety. Incorporation of a Circuit Safety Analysis System (CSAS) has been applied to analyse the safety of track barriers and run off areas. This removes the need to carry out practical crash testing. This technology is also prediction orientated, that is, collected data is used to predict the potential severity of an accident in a given scenario.
The railway industry also make use of intelligent engineering techniques including predictions based on track conditions to target maintenance activities. However, the recent crash involving Jules Bianchi in 2014 has raised a number of questions regarding safety, essentially whether there is a gap in safety culture. In this accident scenario, a racing car collided with an emergency vehicle, which was attending to a previous accident during the same race. In this case, the Formula One industry already have procedures in place to manage scenarios, for example, using a safety car whilst recovery is being carried out. The question here is why the procedures already in existence were not completely followed through in the case of the Jules Bianchi crash. Is it because it could have impacted the race? or the position of the race leader? Although a supposition, a conclusion can be drawn which relates to the relationship between safety culture and operational performance. The Formula One industry although well developed in elements of safety will need to redress safety culture practices to avoid collisions such as this which are avoidable due to existing procedures.

From the perspective of accidents and incidents, difficulty has been found with identification of injuries. In addition, the injuries and disorders that have been identified are not widely understood (Minoyama & Tsuchida, 2004). In a number of cases injuries have been realised after completion of a race. In the racing industry, there are a number of contributing factors to the type of incident that can arise. In particular, the design of the car, the design of the track and the duration of time driving (Minoyama & Tsuchida, 2004). All of these are factors that have a direct relevance to train drivers on railway infrastructure who interface with the train, in particular in cab train systems.

### 3.6 Summary

Sections 3-1 and 3-2 have discussed safety management systems in a number of safety critical domains. Section 3-3 identifies the key constituents that make a safety management system effective and has found that all industries have benefitted from the use of standards for purposes of governance. Section 3-5 on the other hand has reviewed safety culture literature across various transportation industries. This review has shown that there is a dependency on organisations and individuals to maintain a safe environment. Based on this, and comparing the importance of safety culture to the SMS’s used by various industries it is seen that little emphasis is placed on safety culture as part of the Safety Management System process. It is therefore, assumed that safety culture is managed via training and competence measures or via safety committees.

Safety culture includes adherence to existing rules such as which may have prevented the car crash as discussed in section 3.5.4. Therefore, although a system may be technically safe, if it is not operated in the correct environment, by trained, experienced and valued staff then safety culture can be compromised.
Furthermore, as shown in the case of the Challenger shuttle disaster in section 3.5.2, although significant risk was clearly identified via risk analysis, to achieve the schedule of works the risk was reclassified by the organisation to be acceptable.

It has been seen in the case of Therac that the task of risk evaluation throughout the process of upgrading software had not been carried out sufficiently. The safeguards that were previously in force through hardware systems had been removed with the cheaper alternative of software. The Therac case could have been prevented if the tasks were heavily procedure driven. This requires tasks to be devoid of ambiguity, with a clear sequential flow that outlines specific expected actions.

(Helmreich & Merritt, 1998) identified that safety culture can be built into an organisation through emphasis on human error. This requires a culture without blame, but also that intentional actions are not tolerated. From the review of the various safety issues that have occurred across the industries, it is seen that the culture of an organisation determines what will work for that particular organisation (Roughton & Mercurio, 2002). Roughton et al also provide various views on what defines the safety culture practiced, this includes the following:

- Safety must be integrated into every aspect of the business just like quality;
- All employees in the organisation must understand and believe that they have the right to work safely;
- All employees must accept responsibility for making sure that they protect themselves and their co workers;
- Safety is considered a value in the organisation not a priority; (Roughton & Mercurio, 2002) (Table 2.1 p22)

The last point by (Roughton & Mercurio, 2002) ‘Safety is considered a value in the organisation not a priority’ does not align with recent safety culture developments within the railway industry. The railway industry based on the authors experience view safety as a priority in an organisation not just a value. The various definitions of safety culture have also placed emphasis on employee actions rather than placing sole responsibility on the employer.

Reviewing safety culture across the various industries has drawn positive correlations with respect to responsibilities of employees and the employer. It is concluded that safety is the joint responsibility of an organisation and its workers. The transportation industries and the medical industry have shown crossovers in ideas; that is, the human element transcends all industries, this also aligns with the system architecture shown in Chapter 2.

An interesting difference also observed on the topic of safety culture is in regard to ‘national’ culture and perceptions of humans and behaviours. An example of this is shown by the organisational culture displayed by the West Japan Railway Company. This organisation implemented techniques such as harsh discipline and isolation, to humiliate employees. This presents an unclear boundary between correction and punishment and can have negative outcomes, such as inherent self-blaming by employees. Such issues were evidenced by members of the Japanese work force and aligns with
Foucault's 1977 findings that isolation is a means of classification and used as a means of punishment. The Japanese also had the ‘assumption of human errors as delinquencies or crimes’ (Chikudate, 2009). The blame culture displayed is an unhelpful approach and is of no benefit to any employee or company and is a poor approach to promote safety.

This chapter has identified the different approaches for understanding and implementing safety culture, ranging from theoretical to questionnaire based analysis both of which produce valuable results. Industries are increasingly trying to understand the theory behind safety behaviour rather than solely implementing training methods. However, safety culture needs to be effectively incorporated into the safety assessment process as it has shown to be lacking in this area. The review of safety culture as defined and specified in this chapter is used in the next chapter, Chapter 4 to develop a comprehensive safety assessment process.

Chapter 4 reviews safety assessment in the railway and other safety critical industries that have an impact on the railway environment. The review is used to facilitate the development of a safety assessment process. This process is specifically for railways and incorporates procedures and practices, which ensure that safety culture is embedded within an organisation. To test the usability of the safety assessment process developed, it is subjected to specific test cases that can occur in the railway environment. This is used to revise and optimise the developed safety assessment procedure.
Chapter 4  Safety Assessment Process

This chapter draws upon the findings in Chapter 3, which identified the factors behind the need for a structured approach to safety management. The findings from Chapter 3 indicate that for safety assessment of mainline railways, there is the need for adequate safety management systems to be in place. The SMS details aspects such as the means for risk management. As demonstrated by incident and accidents statistics, risks occur for a number of reasons and in some cases can be deemed to be of an acceptable level if mitigation is not possible. The domain of safety is still a challenging discipline in terms of trying to achieve a risk free operational environment. As shown in Chapter 3, organisational and cultural shifts in safety practices are largely shaped by experiences, such as fatalities and high records of accidents and incidents. Consequentially, this chapter develops a safety assessment process based on a detailed literature review of the best practice employed in a number of safety critical industries. The review has been amalgamated and tailored to safety for European mainline railways.

The development of a safety assessment process in any domain is used to satisfy and prove that there is a methodology for effective management of safety. Employing such a method, enables an organisation to determine what, when and how safety can fail in addition to the consequences. A review of safety assessment methodologies or what is otherwise termed safety assessment frameworks is also included in this chapter. The following subsections have been written to include lessons that have been learnt, from which best practice is mapped to the railway industry’s approach. Safety assessment is often viewed as a preventative tool and as such, its scope encompasses the roles of people, procedures and technical systems. As explained in detail in section 4.1, for the railway, topics such as interoperability are covered, this accounts for the signalling, command, control, infrastructure and other functional subsystems. Section 4.2 on the other hand addresses other safety critical industries for a holistic comparison.

4.1  Review of Railway Safety and Risk Assessment

This section compares the approaches to safety assessment in a number of countries that operate safety critical railway networks. The comparison is carried out to identify the methods to assess risk and safety. Risk is defined as:

‘the likelihood that a hazard will actually cause its adverse effects, together with a measure of the effect. It is a two-part concept and you have to have both parts to make sense of it. Likelihoods
can be expressed as probabilities (e.g. “one in a thousand”), frequencies (e.g. “1000 cases per year”) or in a qualitative way (e.g. “negligible”, “significant”, etc.). The effect can be described in many different ways’. (Health and safety Executive, n.d)

Therefore, based on the definition above, a safe environment is one that is free from risk. As a starting point, a comparison of the practices in Korean organisations to those in Europe have shown that inherent cultural differences and practices are mitigated through adherence to standards as discussed in Chapter 3. For example, the Korean railway industry has made use of standards such as ISO/IEC Guide 51:2004 (International Organisation for Standardisation and the International Electrotechnical Commission, 2014). This enables attainment of a baseline to provide guidance in relation to risk reduction and risk assessment and also supports development of a risk management process. This shows that developments in the East have been facilitated significantly by standards maintained and which originate from the West.

The standard (ISO/IEC Guide 51:2004) has been developed to provide guidance and specifically focuses on products and systems ranging from technologies to processes with the aim of addressing risks such that they are limited to a tolerable level (International Organisation for Standardisation and the International Electrotechnical Commission, 2014). The assertion made by Korean railway organisations is that understanding of a system lifecycle is of key importance, thus associated risk management must occur from the design stage. In practical engineering terms and as conducted by a number of UK railway organisations, design is broken down into specific key stages such as: (i) concept design, (ii) detailed design and (iii) final design. Each design stage is usually subject to Interdisciplinary Design Review and Checking (IDR/IDC). In UK railway organisations, risk identification starts prior to the detailed design stage. This is because, risk analysis often occurs as part of the system integration process when the system interfaces are defined at the concept. This aims to eradicate risk as the design progresses through the detailed design stage. It is important to note that risks can be introduced along the design process. This is often as the result of works being increasingly subcontracted out to various engineering third parties and or suppliers to manage project timescales and better manage works. For Korean railways, both a (i) National Railway Risk Management System Architecture and a (ii) Railway Risk Assessment Procedure were developed and put into use for railway construction. The former is shown in Figure 4-1.

Figure 4-1 shows how key system activities are managed throughout a project lifecycle, which is shown as starting at concept design. System safety management involves adherence to key documentation as shown in the orange column, which have specific deliverables across a project lifecycle. However, Figure 4-1 does not demonstrate what would have been expected for a fully effective safety risk process. This is because the process at concept design commences with hazard analysis rather than a demonstration of a system definition based on system architecture. The system definition should be used to identify the system interfaces upon which hazard analysis is performed. The process does incorporate training and supply of SMEs, which is essential for effective risk management.
The research reflective of Korean railway safety carried out by the Korea Rail Road Institute (Kwak et al., 2007) made use of cyclical data from railway accidents such as Daegu, Gupo and Kyongsan. These all had a significant number of fatalities as shown in the graphs below (Figures 4-2 and 4-3 respectively). The Daegu accident for example, demonstrated severe failures in the organisational safety process. In this scenario, a passenger set fire to a train, however the train driver failed to immediately notify the system controllers of the event. Once the controllers were notified, the following train was told to proceed at caution into the same area as the train that was on fire. The driver of the following train locked the passengers in the train and fled the scene. Furthermore, the station was not fitted with necessary fire prevention systems. This accident resulted in 79 trapped train passenger
deaths, with a total number 192 deaths and 148 injured. The organisation attempted to cover up the accident severity, with eventual jail sentences imposed on the train drivers involved (University of Manchester, n.d). Following the Daegu accident which occurred in 2003, the Railway Safety Act in 2004 was introduced in Korea, which details the principles of railway safety and focuses on risk and hazard analysis. Figure 4-2 shows that following the introduction of the Railway Safety Act in 2004, the number of fatalities stabilised to levels similar to the number of fatalities before the crash, which is between the years 1996 and 2002. This difference could possibly be due to adaptations required to processes that were previously working well for metros. The National railway on the other hand have benefited from the introduction of the Act.

**Figure 4-2** Number of fatalities on Korean Rail *(Kwak, Wang, Cho, & Yoon, 2007)*

**Figure 4-3** Number of accidents on Korean rail *(Kwak et al, 2007)*

Figure 4-3 depicts the accident numbers and replicates the pattern shown in Figure 4-2. Specifically, accidents and incidents have decreased for national railways following the introduction of the Railway Safety Act. However, accident levels for metro networks have worsened slightly. The datasets used
by the Korea Railroad Research Institute (KRRI) included incident data recorded in the railway industry database. However, where data was unattainable due to confidentiality agreements other resources were incorporated such as human error assessment, use of in house SMEs and statistical analysis to diversify the data. Figure 4-4 below shows a significant change in the number of railway fatalities. Employing a risk management structure has enabled levels of safety to approach levels attained in Europe and Australia.

![Figure 4-4](image)

**Figure 4-4** Railway fatalities (excluding suicides) per million train-kilometres in 2003-2012 for the EU-28, USA, Canada, South Korea and Australia ([European Railway Agency, 2014](https://example.com/paper)) Pg 11

At every stage, commencing with the concept design stage the Koreans have ensured that there is a method in place to evaluate hazards, the design and methods for certification of system operation and evaluation of safety performance. However, these methodologies were not successfully integrated throughout the various Korean rail organisations. This is largely because they were optional prior to 2008 when they were mandated. This aligns to statistics for the year 2006, where there were 460 accidents with an associated 190 fatalities (Kwak, Wang, Cho, & Yoon, 2007).

For example, following the railway safety act in 2004:

- Safety planning was carried out annually from 2006;
- From 2006 biennially a SMS and safety case approval process was constructed;
- From 2008 biennially risk management was carried out;
- From 2006 biennially safety inspection was carried out; (Kwak et al, 2007)

The examples above show that the emphasis on safety improved, however, as the railway is a complex environment the frequency of aspects such as safety inspection is unacceptable. For example, the railway requires inspections for (i) track systems, (ii) hazardous materials, (iii) signals and train control systems, (iv) motive power and associated equipment in addition to (v) inspections of
operating practices. These examples are demonstrative of the inspections that were mandated and carried out for federal railroads in the United States of America in the year 1975 (Princeton Education, 1978). Additionally, the frequency of inspections carried out at that time differs in frequency as shown in Table 4-1 specifically for the track railway subsystems. Indicators such as this, show that the Korean approach to safety is still decades behind what was attained by Western countries in the late 1970s.

<table>
<thead>
<tr>
<th>Class of Track</th>
<th>Type of Track</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3</td>
<td>Main track and sidings</td>
<td>Weekly with at least three calendar days between inspections or before use of track, if used less than once a week or twice weekly with at least 1 calendar day between inspections if the track carried passenger trains or more than 10 million gross tons of traffic during the preceding year.</td>
</tr>
<tr>
<td>1,2,3</td>
<td>Other than main track and sidings</td>
<td>Monthly with at least 30 calendar days between inspections.</td>
</tr>
<tr>
<td>4,5,6</td>
<td>Other than main track and sidings</td>
<td>Twice weekly with at least 1 calendar day between inspections.</td>
</tr>
</tbody>
</table>

Table 4-1 Example of track inspections based on Federal Railroad Authority regulations (Princeton Education, 1978)

Given the improved safety awareness attained by the Koreans in addition to the mandated enforcement of safety practices, Korail, the Korean national railroad operator (KORAIL, 2013) faced a high profile and public safety issue with the supplier of their trains. The use of System Engineering practices in addition to the application of assessments on the operational safety of rolling stock and train protection could have benefitted Korail. Specifically, the 63 out of 64 defect accidents which included brake failure that occurred on their trains supplied between the years 2010 and 2013 by Hyundai Rotem (Yeon Jin, 2014) could have been avoided.

Following cases such as Hyundai Rotem, Korea, via the Korea Railroad Research Institute now focus on risk and employ a Risk Assessment and Information Management System (RAIMS). This forms a key part of safety assessment. However, based on their experiences, it has been learnt that safety cannot be improved with a process alone. Safety has to be adequately enforced by management and incorporated by the relevant organisations.

The comparative analysis of European railways below shows some variability in progress on safety matters, although at a lesser scale to what was experienced in Korea. This may be for different reasons, such as poor systems integration. Across Europe there is a necessity for a safe integrated railway. For this reason a Regulatory Monitoring Matrix pilot study was led by the European Railway Agency (ERA) (European Railway Agency, 2014) and included volunteers from a number of European member states, specifically:
(a) Belgium, (b) Sweden, (c) Denmark, (d) Ireland, (e) The Netherlands and (f) Great Britain.

The ERA pilot study developed a matrix structured to assess the regulatory framework for safety assessment and methods of best practice. The categories used to measure safety were based on the Railway Safety Directive, which was broken down into its constituent key elements and sub elements. The matrix enables visibility on how key constituents were being met to address safety with focus directed towards the governmental organisations including the National Safety Authorities and Investigation Bodies. Such bodies specify the frameworks within which Infrastructure Managers such as Network Rail operate. These government level organisations were chosen to draw focus to the operational environment. However, it is noted that responsibility for safe transportation remains with the transport undertakings that are defined as:

‘Any person or organisation that operates a vehicle in relation to any infrastructure. People or organisations that only carry out work in ‘engineering possessions’ are not included’ (Crown copyright, 2006) Pg 11.

and relevant Infrastructure Managers, defined as:

‘Any person or organisation responsible for developing and maintaining infrastructure or for managing and operating a station and manages or uses that infrastructure or station or allows it to be used for the operation of a vehicle’ (Crown copyright, 2006) Pg7.

This is explained by the Railways and Other Guided Transport Systems (Safety) Regulations (ROGS) 2006 (Office of Rail Regulation, 2014). ROGS require most railway operators to maintain a Safety Management System (SMS) and hold a safety certificate (Office of Rail Regulation, 2014). For this case, the railway undertaking is an organisation that operates on infrastructure.

The aim of the Railway Safety Directive (RSD) is to develop a Europe wide approach to manage safety on railways. The detail of this directive includes procedures on how certification is given and it specifies what is required in order to achieve safety authorisation. The structure of the RSD is broken down and shown pictorially in Figure 4-5. Figure 4-5 shows 4 connected columns; the first column is the top level RSD. This is broken down in the second column into 5 ‘main’ elements that are used to define the RSD. Each of the ‘main’ elements are then further broken down in column 3 into ‘elements’, which provide greater detail and finally the detail of the ‘sub-elements’ of the RSD are shown in column 4. The sub elements shown in Figure 4-5 are 26 in total and include factors such as leadership, accountability and target setting as shown in Table 4-2 and Figure 4-6. For this thesis, information was collated which relates to selected sub elements. This was attained by conducting interviews, questionnaires and observational studies.
The approach taken by the ERA pilot study to collate information that relates to the safety sub elements was attained via on site interviews. The overall output was to provide a status overview of the risk regulation regimes across the participant countries. The framework for the matrix marked the basic elements against the government’s position i.e. where they were on a 1-5 point scale, which was coded as follows:

1=ad-hoc, 2=initialising, 3=implementing, 4=managing or 5=improving (equivalent to reaching excellence).

This thesis specifically focuses on Sweden and Great Britain for comparison with respect to the strengths and weaknesses of these nations’ safety systems. This is primarily because these countries are analysed further in the development of a safety assessment process in Chapter 5.

From Table 4-2, it can be seen that Sweden is in the initialising stage of the selected sub elements except for ‘communication’, which is at the implementation phase. In general, improvement is needed in all areas. Great Britain on the other hand, is at the initialising stage in interface management. This is a surprising result as integration is an activity that should start at the conceptual stage of any project and then progressively throughout the lifecycle. Interface management is an area that Great Britain’s railway industry has a lot of experience in, as demonstrated by major complex railway
projects. Therefore, its categorisation as being in the initialising stage does not appear to be correctly identified.

Safety culture, an important aspect of safety management is also currently in the implementation stage in Great Britain. However, developments have been seen in the way this topic is now being acknowledged through employee training and awareness days, in addition to communication and promotion of the safety regulatory framework. Great Britain describes itself as ‘improving’ (equivalent to reaching excellence) in regard to record keeping. An area which is essential for auditing purposes, to learn lessons from and to predict safety behaviours. This good level of attainment may partially be due to stakeholders such as the RSSB who analyse accident and incident statistics for the benefit of UK railway organisations.

<table>
<thead>
<tr>
<th>Country</th>
<th>Learning from failure</th>
<th>Safety culture management</th>
<th>Record keeping</th>
<th>Risk based approach</th>
<th>Promoting safety regulatory framework</th>
<th>Goal setting and management</th>
<th>Interface management</th>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Sweden</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Denmark</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Ireland</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Great Britain</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4-2 Selected Railway Safety Directive sub elements
Ireland as shown in Figure 4-6 is consistent in the management of safety related to the sub elements, whilst Denmark is similar to Great Britain in the fluctuation between excellence and initialisation.

Figure 4-6 shows that through the breakdown of the Railway Safety Directive, various facets that compose safety are identified. It also shows that safety cannot be measured or managed as a single standalone element. Employment of this matrix approach, which maps the sub elements against the level of progress (i.e. 1 to 5) has provided a high level analysis of safety and enables gap analysis to be performed. That is, areas where improvement is needed has been identified by the respective countries. This method does not provide enough detail on how these issues will be rectified, only that the countries that have completed the research have attained different levels in their satisfaction of the RSD. Furthermore, it would be beneficial to devise an integrated working group to address the gaps which leads back to ‘lessons learnt’ activities. Prior to using this matrix, the ERA ensured that other risk regulation regimes were also reviewed, totalling 117 academic and administrative studies (European Railway Agency, 2013). However, they concluded that the matrix approach was the way forward because it supports consistency between different cultures. The other methods that were analysed on behalf of the ERA by Det Norske Veritas (DNV) included research from other safety
related industries such as Medicine, Food and Aerospace across the continents of Europe, America and Asia. The primary finding was that safety benefits from a regulatory regime that is designed in terms of achieving good performance whilst not incurring cost.

From the ERA study on risk regulatory regimes the following conclusions were made by the ERA: (i) the methodology employed for safety analysis on railways is not lacking in coverage and is thus complete; (ii) the requirements for a Europe-wide approach to safety management has been met; and that (iii) there are obvious challenges as identified in Chapter 3 due to cultural differences. The organisational scale of the volunteer European organisations may impact the rating on the 1 (ad-hoc) to 5 (improving) scale. Larger more complex organisations compared to smaller organisations may have differing development needs with respect to the 5 main elements shown in Figure 4-5. Safety culture is also addressed in more detail in Chapter 6 as part of data analysis for the safety assessment activities that have been conducted.

A comparative review of ERA findings to methods employed by Korea rail shows that Korea rail have a well mapped out process, which has drawn upon best practice from the UK. Procedures and processes are clearly outlined in the risk management system architecture in line with the project life cycle. Implementation of the methodology has improved safety as is reflected by the reduction in the number of fatalities. However, the Korean rail organisation needs to review safety from the aspect of the supplier interface to ensure that supplied sub systems conform to safety regulations and requirements. It was shown that tighter control is needed from a safety assurance perspective to ensure that the correct certifications and qualified engineering personnel are in place. Issues with third party suppliers in the UK have shown to delay work development and eventual safety verification sign off from railway operators. For the UK market, the role of discipline experts for sign off of safety critical documentation is an essential part of maintaining a safe railway.
4.2 Cyber Security Risk Assessment – Impact on Railways

The subject of cyber security is a complex one and addresses the safety of computer and communication based mechanisms, which often drive a number of international infrastructures. These infrastructures include the railway, flight systems and banking systems. The topic of cyber security was neither considered relevant in the ERA study discussed in section 4.1 based on their criteria nor selected as a part of the review of safety critical industries from which lessons can be learnt.

However, due to consequences of a failure in any part of a railway’s communication system, the significance of cyber security is discussed here. A cyber attack is rated in the league of importance alongside pandemic diseases, war and terrorism by the UK government (HM Government, 2010). The President of the United States of America has also stated that ‘cyber threat to critical infrastructure continues to grow and represents one of the most serious national security challenges we must confront’ (Obama, 2013). Thus the issue of cyber security does not only affect critical infrastructure in Europe but also the rest of the world and should be addressed. Because of its relevance and importance to the railway industry, the safety framework employed in the cyber security sector is addressed here. For example, in a worst-case scenario, railways could be a target for malicious activities, which will increase in criticality as railway networks across Europe become integrated. As an example, the introduction of malware software can be used to alter a train’s response. An operational scenario could arise where the train driver is given a notification to reduce speed when in fact the train would erroneously respond with an increase in speed. A secondary factor to consider is also why an attack could happen. Therefore, the organisational culture would also need to be addressed; as such an attack could also originate from within an organisation by disgruntled staff. This scenario is less likely with existing railway technology, as there is still a large proportion of the railway that is operated by legacy and ageing signalling assets. As a result, there is potential for significant lessons to be learnt from the safety management frameworks that industries such as cyber security and air traffic management have in place.

The cyber security processes reviewed and the resultant framework developed for this research is based on the analysis of these safety critical industries. The framework endeavours to be cost effective and hence available for practical implementation.

As shown in Figure 4-7, similar to the Korean railway industry, the cyber security industry makes use of metrics to support a methodology for risk evaluation. Roles and responsibilities are identified early on within the planning stage of the assessment process. Stage 2 (assessment stage) in Figure 4-7 shows that ‘vulnerability identification’ is at the core, which can be equated to the management of risk. This enables risks to be mitigated via qualitative or quantitative risk assessment methods. This is commonly carried out in the railway industry. The cyber security safety assessment framework could be developed to look at the ‘why’ factors behind risk such as lack of regulation enforcement, fatigue and misunderstanding which would encompass elements of human factors. The cyber security
The framework shown above in Figure 4-7 used by the cyber security industry has been mapped to the ORR’s Common Safety Method (CSM) framework used by UK railway stakeholders as shown in Table 4-3. The CSM framework offers a common approach to reduce cultural barriers across Europe.
Enforcement of Common Safety Methods via the Railway Safety Directive guarantees that a common process is available for railway operators. As part of the safety management system process the UK’s IM Network Rail and other EU IMs who compose the European member states must ensure that the CSMs are adhered to. The CSM approach in Figure 4-8 for Risk Evaluation and Assessment has been compared to the cyber security framework shown in Figure 4-7. This compares two safety critical domains with process attributes that may benefit organisations outside of the transportation industry.

CSMs specifically apply,

‘when any technical, operational or organisational change is being proposed to the railway system. A person making the change (known as ‘the proposer’) needs to firstly consider if a change has an impact on safety. If there is no impact on safety, the risk management process in the CSM RA need not be applied and the proposer must keep a record of how it arrived at its decision’. (Office of Rail and Road, 2015) Pg 4

This approach is thus applicable to mainline railways in the UK, such as those utilising new communication based train control technology.

The CSM process shown in Figure 4-8 can be viewed as comprising 5 distinct stages, described as follows:

(i) Stage 1 (orange boundary) – defines the system, if the system is identified to introduce significant change to the railway, for example through novelty then the CSM process must be carried out. This will result in a finalised system definition with all interfaces and stakeholders identified. If there is deemed to be no significant change to the railway, then the engineering organisation can carry out standard engineering safety management processes which does not require independent assessment bodies.

(ii) Stage 2 (green boundary) – identifies and categorises the hazards associated with the system. The hazards are then classified based on their criticality.

(iii) Stage 3 (blue boundary) – Risk analysis and categorisation can be carried out by one or more of the risk acceptance principles shown. That is, (i) by good practice, (ii) use of a similar reference system or by (iii) explicit risk estimation which is a combination of qualitative and quantitative analysis.

(iv) Stage 4 (Pink boundary) – Following the risk process (stage 3) new safety requirements may be identified based on operation and integration of the various systems. This stage provides a check of the adequacy and correctness of the safety requirements.

(v) Stage 5 (brown boundary) - There is also the input of independent safety assessors who provide independent guidance on the various safety methods and associated documentation at key stages throughout the project lifecycle. This includes when endorsements are required from stakeholders such as the Infrastructure Manager.
Figure 4-8 CSM – Risk Assessment and Evaluation process (Office of Rail and Road, 2015).
Table 4-3 Safety Assessment Comparison

<table>
<thead>
<tr>
<th>Safety Assessment framework factors</th>
<th>Railway Industry (CSM)</th>
<th>Cyber Security Industry</th>
<th>Process incorporated for ERTMS safety assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicability of safety assessment process based on significant change to a system or procedure</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Pre planning state for risk assessment including SME discussion or test group</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>(unless this can be equated to the change proposer)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System architecture defined including definition of scope</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Identification of key players required to conduct safety assessment</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Risk analysis according to codes of practice (good practice), qualitative or quantitative analysis</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Risk evaluation and reporting</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Risk remediation</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Validate mitigation strategy equivalent to mapping to safety requirements</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 4-3 presents the results of the high level comparison of the two safety assessment processes. It can be seen that there is a high degree of similarity, i.e. a system is defined followed by risk assessment, and verification and validation against safety requirements occurs. The process/framework employed by the cyber security industry differs from the railway industry. The CSM process used by the railway industry starts by ascertaining whether there is a ‘significant’ change to a system before the CSM process is employed. The criteria for being significant include the following: (i) failure consequence, (ii) novelty, (iii) complexity of the change, (iv) monitoring and (v) reversibility. Further guidance on the specifics of the criteria is provided in more detail by the ORR.
The cyber security process also shows that there is early stage engagement and testing with SMEs. This is a preventative measure to limit the potential for error and rework. For the railway industry, SME engagement via independent assessment occurs throughout the safety assessment process, however experience has shown that SME input is particularly of benefit during evaluation of risk acceptance. Both processes indicate the necessity to perform testing and validation as part of the safety assessment process. These are vital steps to prove safety and to demonstrate assurance has been carried out.

4.3 Implementation of Safety Assessment Methods and New Features

The framework developed in this thesis is based on the review of the methods employed in Europe by railway organisations as part of Common Safety Methods. The framework also considers the factors outlined in section 4.1 which relate to selected key sub elements that comprise the Railway Safety Directive such as interface management and staff interviews. In addition, aspects of the methodology employed by the cyber security industry have been incorporated as presented in section 4.2.

The pitfalls of risk acceptance have been identified as far back as the Wright brothers in 1901. They were aware of the risks presented by the unknown environment but believed that in order to progress and achieve many avenues had to be tried (Wright & Wright, n.d). At the Western Society of Engineers in Chicago in 1901, a quote from Wilbur indicated that safety cannot be achieved without first understanding the risk:

"If you are looking for perfect safety, you will do well to sit on a fence and watch the birds; but if you really wish to learn, you must mount a machine and become acquainted with its tricks by actual trial." (Stimson, 2001)

Nowadays, the majority of organisations do not take such a nonchalant approach, largely because of the risk to life and reputation and also because the majority of systems in place are not Greenfield by design. However, assessing safety and structuring an approach for safety management supports clearer decision making. Safety assessment in the railway and cyber security industries makes use of process flows, with key tasks identified. In industries where it is necessary to have a high degree of reliability, good performance and availability, emphasis on hazards and risks is always a priority for regulatory bodies. However, there are always cases that show multiple sources of error in relation to safety assessment and adherence to safety standards.

The oil industry is known to be a financially high grossing industry under the energy and fuel banner. However, in the case of the Texas City refinery explosion a retrospective look at their failure to assess risks and safety show that the environment was effectively an accident waiting to happen (Rigot, 2007). This explosion killed 15 people and injured 180 imposing a financial loss of $1.5 Billion (Baker,
et al., 2007). Aside from cultural issues, considerable areas lacked in their risk assessment and safety processes. The Oil refinery industry learnt important lessons with the aid of an independent panel for safety and hazard investigation. The feedback included aspects such as (i) inherent non-compliance in the work environment, (ii) use of faulty and or mal functioning equipment and (iii) poor execution of risk assessment processes. These are factors that were discussed earlier and found when discussing the Korean railway industry’s implementation of a risk management system. The oil refinery industry learnt to proactively analyse risks and hazards in addition to use of processes, this resembles the actions taken by the Korean rail industry.

The safety assessment framework implemented in this research targets a number of areas. These have been drawn primarily from the comparison between the railway and cyber security industry approaches to safety assessment. The first element considered when developing the safety assessment process is the system definition and its lifecycle. It is important, whatever the organisation or industry that the system is clearly defined. This includes definition of the system’s operation through to its maintenance regimes; this constitutes the system lifecycle. The safety assessment process should include a means to assess the hazards. Hazard analysis is both from a physical and functional perspective. The hazards can then be further verified via stages of safety assessment commencing with a preliminary safety assessment. Finally, the role of Subject Matter Experts should be integrated into the safety assessment process from the system definition stage. This will ensure that the level of safety required is understood and agreed, it will identify whether the risks presented are tolerable and whether the system design configuration captures that level of tolerability.
Figure 4-9 Derived Safety Assessment Process

1. **System Definition**
   - System architecture
   - Operational concept
   - Design

2. **Review and evaluation**
   - Documented assumptions, agreements and records

3. **Hazard Analysis**
   - Analysis of accident and incident scenarios;
   - Severity/probability analysis (risk analysis);
   - Risk classification based on risk analysis to determine risk tolerability

4. **Review and evaluation**
   - Documented assumptions, agreements and records

5. **System Validation**
   - Validate the safety of the system;
   - Satisfaction of safety targets and requirements;

6. **Reporting**
   - Feeds into a safety assessment report or culminates in a safety case:
     - Risks analysis/hazards
     - Assurance processes
     - Quality management

---

- **System Definition**
  - System architecture
  - Operational concept
  - Design

- **Review and evaluation**
  - Documented assumptions, agreements and records

- **Hazard Analysis**
  - Analysis of accident and incident scenarios;
  - Severity/probability analysis (risk analysis);
  - Risk classification based on risk analysis to determine risk tolerability

- **Review and evaluation**
  - Documented assumptions, agreements and records

- **System Validation**
  - Validate the safety of the system;
  - Satisfaction of safety targets and requirements;

- **Reporting**
  - Feeds into a safety assessment report or culminates in a safety case:
    - Risks analysis/hazards
    - Assurance processes
    - Quality management

---

- **System Definition**
  - System architecture
  - Operational concept
  - Design

- **Review and evaluation**
  - Documented assumptions, agreements and records

- **Hazard Analysis**
  - Analysis of accident and incident scenarios;
  - Severity/probability analysis (risk analysis);
  - Risk classification based on risk analysis to determine risk tolerability

- **Review and evaluation**
  - Documented assumptions, agreements and records

- **System Validation**
  - Validate the safety of the system;
  - Satisfaction of safety targets and requirements;

- **Reporting**
  - Feeds into a safety assessment report or culminates in a safety case:
    - Risks analysis/hazards
    - Assurance processes
    - Quality management
The safety assessment process derived in Figure 4-9 has been formulated to have a central flow, which involves the system lifecycle. The lifecycle starts from the system definition and concludes with a validated system, which can be formally argued in terms of safety via a safety case. The intermediate stages of the process include hazard analysis activities which can range from qualitative analysis to complex quantitative analysis where required. Throughout the process, the integration of SME input has been explicitly incorporated in addition to emphasis on safety culture. Due to the novel changes to the railway design and operation it is important to check that safety culture is embedded. Review and evaluation activities in addition to working groups proactively support this. Hazard analysis is a particularly important step in the derived safety assessment process. From this stage, new safety requirements may emerge or there may be a change to the original requirements set. If the original requirements are re-used in relation to a revised system and not sufficiently re-evaluated as part of hazard analysis severe consequences could ensue. This is shown in the case of the 1996 Ariane 5 launcher used in the commercial space transport sector (Sandom, 2013). Ariane 5 reused requirements from the Ariane 4 launcher; this was inadequate because the host hardware was changed. Furthermore, there were specification and design errors in the software of the inertial system. Instead of reviewing this as part of the specification development and hazard analysis it was decided to retain commonality between the systems. This caused the self-destruct to be triggered (Sandom, 2013). This example proves the need to effectively understand the system requirements, hazards and the impact on safety.

In the following chapter and in the examples presented in the next subsection, failure mode scenarios for safety assessment heavily rely on understanding of the system and the system interfaces.

A number of assumptions are made based on areas that are not easily quantifiable such as the interface between humans and technology. The safety assessment process derived in this chapter shown in Figure 4-9 consolidates features of the cyber security industry that will significantly revolutionise railways.

4.4 Application of Failure Scenarios

The previous sections of this chapter have presented the key elements required for safety assessment. This has largely been based on the Railway Safety Directive, Common Safety Methods and the cyber security industry. Subsequently, a safety assessment process has been developed and captured in Figure 4-9. To demonstrate the effectiveness of the derived safety assessment process, it is subjected to selected failure scenarios. Application of the failure scenarios gives an early indication of how robust and usable the process is and identifies if any amendments are required.
4.4.1 Failure Scenarios

In subjecting the derived safety assessment process in Figure 4-9 to the failure scenarios, Figure 4-10 presents the details of the four approaches used which include structured interviews, questionnaires, observations and comparative analysis. This section makes use of observed failure scenarios, shown in green in Figure 4-10. Three of the observational failure scenario examples have been used for preliminary testing of the derived safety assessment process. The selected observational failure scenarios are detailed in section 4.4.2. A literature review applicable to each scenario used to test the assessment process is presented to support understanding of the failure. The remaining scenarios are presented in Section 5.3 of this thesis.

![Figure 4-10 Application of observational scenario failure modes](image)

4.4.2 Observational Failure Scenario 1: Data Entry

Train drivers are required to enter data at the start of a driving mission (National ERTMS Programme, 2014) as shown in Figure 4-11. Entering data in particular for ETCS signalled trains can have a number of impacts on a train’s operation. For example, incorrect indications could be presented to the driver such as indications to brake the train. On the other hand, for trains that are driven to line-side signals, data entry is commonly related to the Automatic Train Protection (ATP) systems on-board the train. Incorrect data entry, whether for existing or modernised trains can affect safety. The data entry process for a ‘start of mission’ for an ETCS signalled train is shown in Figure 4-11. Prompts for data confirmation and correction are integrated as part of the safety checking process. The importance of data entry has increased following modernisation of signalling systems which are increasingly data
driven. A study carried out by SNCF reviewed goods (cargo) trains and identified that 30% of entered data contained minor errors. Of these errors, there were a very small percentage that were significant, with the majority of errors having no significant consequence (Working Group Report, 2013). The entered data is used to inform the on-board train system of the performance capabilities. This scenario observes the train driver during train preparation which is prior to the mission start to see the events and impact of incorrect data entry into the Driver Machine Interface.
Figure 4-11 Start of mission (ERA UNISIG EEIG USERS GROUP, 2008) Pg. 19
The Driver Machine Interface has been reviewed from an error perspective as shown in Figure 4-12. The associated task of data entry into the DMI and the significance and outcome of an incorrect data value are shown. The European Railway Agency (European Railway Agency, 2010) as part of their functional safety analysis concur that data entry via the DMI is a critical interface. The ETCS DMI operates in real time and the data entered is of critical importance as it supports performance characteristics such as braking and speed profiles. Data entry is thus of relevance to trains which transport both freight and passengers. A practical case is shown by Lloyd's Register Rail who conduct independent safety assessment on behalf of rail organisations. Lloyd's Register Rail have looked at the implications of ERTMS on the design of rolling stock. They state:

‘the root problem is to match the train data to the actual train performance as accurately as possible, without giving the driver a very difficult data entry task during train preparation. The train data directly affects the integrity of the otherwise SIL 4 train protection system’ (Lloyd's Register, 2015). SIL 4 systems are complex, safety critical and costly and include vital signalling systems.

For ETCS trains the DMI is the interface between the train driver and the vehicles computer i.e. the European Vital Computer (EVC). The EVC is a core train system as it supervises the train’s movement also feeding a range of information to the driver via the DMI’s graphical user interface. For trains running on conventionally signalled railways this interface is not as complex. Information relayed to the train driver includes events relating to loss of network coverage, general event indications or alerts for group calls. As shown previously in the system architecture Figure 2-17, the driver directly interfaces with the on-board signalling component via the DMI for data input and receipt of information.

Requirements relating to the entire ERTMS/ETCS system are detailed in the Functional Requirements Specification (FRS) authored by the European Railway Agency (European Railway Agency, 2007). In addition to the stipulated requirements, railway networks can expand on the detail of these requirements. This allows complementary documentation to be produced, such as the...
National Onboard Subsystem Requirements Specification. For example, this has been drawn up specifically for the GB rail network via the National ERTMS programme. However, where there are deemed to be conflicts with the complementary requirements the ERA FRS takes precedence.

Functional requirements provide an overview of how the system is expected to function and is essentially the ‘do’s and don’ts for a technical safety critical system. When specifics are required, technical subsystems have their own suite of documentation, such as modules which relate to the (i) ETCS Driver Machine Interface, (ii) Functional Interface Specifications –Train and (iii) Performance requirements for interoperability. However, as a starting point, looking at the parent ERTMS/ETCS FRS, the requirements relevant to this research and the task of data entry have been extracted as shown below in Table 4-4. These requirements provide instructions on how the driver can interact with the system.

<table>
<thead>
<tr>
<th>Reference ID</th>
<th>Requirement (ERTMS/ETCS Functional Requirements Specification ERA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.2.1a</td>
<td>Train data shall be entered before the on-board ETCS equipment allows train movement.</td>
</tr>
<tr>
<td>4.1.2.11</td>
<td>Stored train data shall be offered to the driver to be confirmed when Data Entry starts.</td>
</tr>
<tr>
<td>4.1.2.13</td>
<td>The system for Train Data Entry shall provide for the input of other data required by STMs connected to ETCS. This may require additional items, not required for ETCS, to be entered.</td>
</tr>
<tr>
<td>4.1.2.14a</td>
<td>The entry of driver identification and the selection of the language shall be possible.</td>
</tr>
<tr>
<td>4.1.2.15</td>
<td>Following successful completion of Train Data Entry, the driver shall be able to perform shunting movements or train movements.</td>
</tr>
<tr>
<td>4.1.2.16</td>
<td>The following data may be entered manually by the driver or from train memory, or provided by external sources: Driver identification; Train identification (train number); STM ready for use; Data required for brake calculation; Maximum train speed; Train length; Status of air tight system; Type of electric power accepted; Data additional required for STM (if any); International train category; Train gauge; Maximum axle load of the train with a resolution of 0.5 t.</td>
</tr>
<tr>
<td>4.1.2.17</td>
<td>If the on-board fails to contact the RBC when awakening, the driver shall be asked to enter the RBC contact details.</td>
</tr>
</tbody>
</table>

Table 4-4 Extract of Data Entry Requirements (European Railway Agency, 2007) Page 21-22

To gain further understanding of the operational activities carried out by the train driver, the ERA unit on the Driver Machine Interface has been reviewed. This unit explicitly identifies and defines the dialogue sequences, data layout, data checks and validation processes as shown in Figure 4-13. This provides the driver with clarity over the driver tasks that are required for ETCS system operation. An interesting process is that of data entry checking. This process aims to eradicate any propensity towards a mistake. The process details the range of checks that are available and are categorised into one of two groups, that is, either driven by an operational rule or a technical rule. The difference between the two relates to the level of control held by the driver, that is:
(i) An operational rule enables the driver to overrule and override the data; whereas the
(ii) Technical rule makes no allowance for an overrule to be carried out by the driver but instead requires the train driver to modify a data value(s).

Figure 4-13 Data entry checking process (European Railway Agency, 2010) Pg 129
Examination of the physical ERTMS DMI graphical user interface that the train driver operates shows that all data indicated is modifiable by the driver.

As shown in Figure 4-14 a number of input fields already exist, that is, a train can be preloaded with default information relating to the trains characteristics to be validated by the driver. The preloaded data is as listed in Figure 4-14 and includes categories such as train length and axle load. Data is only entered or confirmed in the leading train cab, where the driver is situated for operational use.

A further issue with data entry has been identified (Ligier, 2014) from the perspective of interoperability. For European railways, interoperability is the key. However, for trains of variable composition such as freight trains, if a change of ETCS data is required the train would have to stop
at the boundary which separates two countries. A number of impacts have been identified with this practice of stopping trains at a frontier, such as human factors where there is the potential for greater error because of miscommunication due to a change in language for example.

4.4.2.1 Application of Observational Failure Scenario 1 to the Safety Assessment Process

For this failure scenario the DMI is the key functional system under review. This system has a clear architecture from a functional perspective and clear operational guidelines for the user interface. The user is either the train operator or the train maintainer. In the first step of the derived safety assessment process, the system definition requires clear requirements and SME expertise as inputs for its creation. This supports the outputs of the architecture namely understanding of design and identifying where there are weakness in safety culture for example.

From a practical point of view, safety culture for the DMI interface would primarily be addressed through training. Training would include aspects such as procedures, regulations and responsibilities. The important point at this stage is how the training and understanding of the architecture influences the behaviour of the train driver. As shown in Chapter 6, driver training has seen significant development through use of simulator training facilities. This interaction itself could be broadened to enable the drivers to gain experience of the DMI using software available on a handheld device.

The DMI architecture for ERTMS trains has had numerous stages of engagement with SMEs. This includes organisations such as UNISIG an industrial consortium (UNIFE, 2014) that has the role to develop technical specifications for ERTMS.

In particular, SME engagement has been achieved for hazard analysis activities for the DMI. This includes the safety requirements for hazard analysis, risk analysis and quantification of failures with respect to train driver actions. However, the quantification of failures that could be expected to be carried out by drivers could not be certified to a high level of accuracy (UNISIG, 2014).

From review of the derived safety assessment process in Figure 4-9 the inputs for hazard analysis should be amended. The revised process should now include user competency which can be explained as knowledge, experience and understanding. This is in addition to SME guidance, which is already included in the process. As explained by UNISIG who conducted the functional safety analysis of ETCS DMI (UNISIG, 2014) for the quantification of driver actions shown in Table 4-5. The driver needs a level of competency to realise when a system is not performing as per requirements as in this case it is an operational hazard.
The driver recognises that ETCS is behaving in a way that is contrary to their expectations. The contradiction is not obvious as in category B, but still clear to a driver who is paying normal attention.

OR

The driver manages to operate the train safely, although a certain degree of ETCS support which is normally present, has failed. To fall into this category, the reliance on the failed ETCS support is higher than in category B.

<table>
<thead>
<tr>
<th>p</th>
<th>Probability of Failure in Driver Actions (UNISIG, 2014) Pg. 28</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>p=0.1</td>
</tr>
<tr>
<td>OR</td>
<td>The driver manages to operate the train safely, although a certain degree of ETCS support which is normally present, has failed. To fall into this category, the reliance on the failed ETCS support is higher than in category B.</td>
</tr>
<tr>
<td>D</td>
<td>p=0.2 – 0.9</td>
</tr>
</tbody>
</table>

Using the derived safety assessment process, validation of the system’s safety can be determined in a number of ways. This includes, assessing train performance based on inputs into the DMI and review of the system by SMEs. The task of validation requires there to be clear traceability to the system requirements, which is one of the first steps and used to create the system definition.

The final step of the assessment process relates to reporting. In regard to data entry into the DMI, reporting would be one of the first steps as indicated by Figure 4-13. This is because a range of performance checks are carried out. Furthermore, the DMI is an active interface between the driver for signalling information. Therefore, any issues would be picked up directly by the driver.

From the results above showing that there are no gaps in the assessment, it is concluded that this observational scenario is fully addressed by the safety assessment process in Figure 4-9.

4.4.3 **Observational Failure Scenario 2: GSM-R Communication Failure**

An efficient GSM-R communication system enables the train driver to speak to the correct party (signalman or control centre) without interference. In the event of a GSM-R failure, the driver may feel that safety has been compromised. This observation looks at the effect on the train driver of loss of communication and hence contact to key personnel.

Train Operating Company Abellio has an interest in the impact of GSM-R application following the disconnection of the NRN and the CSR signal. Prior to the use of the GSM-R network the train driver had the ability to interchange between the NRN and CSR in the event of unavailability of either one. The function of GSM-R is twofold; it is a means of communication between the Radio Block Centre and the European Train Control System. Secondly, it is a medium for the driver and signaller to communicate or where communication is required between trackside staff and on-board staff also depicted in Chapter 2.
Establishment of a GSM-R connection is one of the primary requirements for a train system, as this is needed for the on-board train equipment to communicate. The GSM-R coverage should also be of sufficient quality thus ensuring that the train can successfully register on the network. For example, sufficient GSM-R coverage is required for entry of the train into level 2 ERTMS. In this case, a sequence of data exchange events occur between the train control system and the RBC which cannot occur if the GSM-R network is unavailable. An example of this process and the level of sequences is shown in Figure 4-15 below.

![Figure 4-15 Message sequence for entry into Level 2 ERTMS (ERTMS Users Group, 2005) Pg. 34.](image)

The train driver needs to be able to communicate with the signaller and obtain additional information that is not available via the DMI. There have been practical examples of where this has been the case. Paddington train station in London is one of the most demanding railway environments transporting commuters on mainline, underground and subsurface rail routes. However, on platforms nine and ten for mainline trains, drivers faced the issue of not being able to register onto the GSM-R network (Rule Book Module TW5, 2013). In this particular case, train drivers were unable to obtain a network signal until the train had actually departed from the platform. The uncertainty for the driver arose because there were no specific guidelines indicating exactly how far into their departure a signal would be obtained. A concern also remained that the radio could be defective and the driver would already be out of the platform area. A defective radio would be a concerning issue, as it would
affect the ability to engage in emergency calls. This real life example had an operational impact on service, as it was not unusual for trains to be cancelled or run without passengers due to this issue. This is a scenario where there is an obvious impact on both operational and safety practices. The Rulebook explicitly states that:

‘You must not allow a train or traction unit to enter service if you are aware that the OTDR that records activity in the leading cab is defective. This applies unless a working OTDR is provided elsewhere on the train’ (Rule Book Module TW5, 2013) Pg 49.

Following an investigation of this GSM-R issue by Network Rail, it was found that the cause of this failure was due to signal interference from a public network mast owned by telephone service provider 02. This issue was resolved and the risk mitigated through reduction of power on the 02 site. In addition to this, it was found that there was a failure within the GSM-R feeder and antenna system. As a result of this failure, and the impact it had to the service of various TOCs this information was disseminated to relevant stakeholders. This provided awareness of the issue and the methods of resolution. This is good practice and shows how effective management prevents risk. In summary, this failure observation reviews issues relating to GSM-R coverage and the impact of loss of communication.

4.4.3.1 Application of Observational Failure Scenario 2 to the Safety Assessment Process

The literature review in Chapter 2 has presented the system architecture for the GSM-R communication sub system. Furthermore, the risk and relevance of a communication failure has been documented above. As shown by the derived safety assessment process, hazard analysis and associated risk analysis is a key part of the process and is used to determine the impact on safety. Practical deployment and installation of GSM-R has undergone rigorous safety assessment on UK mainline railways by Network Rail (Network Rail, 2012). For this system to be validated as safe, SME review was carried out by the Infrastructure System Review Panel (Network Rail, 2012). This is in line with the process in Figure 4-9. Which states that SME review is required in addition to evaluation of the system to independently provide review on the safety of the system. From the results of the application of this scenario, it is shown that there are no gaps in the assessment process. This is because SME review is incorporated into the process in Figure 4-9.

4.4.4 Observational Failure Scenario 8: Railway Adhesion

Incident reporting from train drivers is fairly common in relation to low rail adhesion. Rail adhesion refers to the interface between the train wheel and the rail track. This problem is of significance to both passenger and freight trains. However, freight trains are larger units with a heavier tonnage capability than their counterpart passenger trains. Freight trains have to deal with the greater propensity for the braking distance to be misjudged; this is of particular importance as the train comes to a standstill at a danger signal. The Rail Accident and investigation Branch (Rail Accident
Investigation Branch, 2007) found traits with certain trains failing to stop without striking the buffer stops because of poor adhesion. This resulted in recommendations from the RAIB to implement (i) automatic sand dispersion upon detection of wheel slip slide and (ii) to amend operating instructions and standards which relate to sanding (Rail Accident Investigation Branch, 2014). Rail adhesion problems can be caused by a range of factors, such as icy rails or leaf contamination (Network Rail, 2015). Additionally, depending on the track inclination in the event of brake failure the train may roll and derail. This scenario looks at the actions taken by the driver in the scenario where there is either low rail adhesion or brake failure. The ERTMS on-board system allows the train driver to enter or validate the adhesion on the DMI, the adhesion status for the rail can also be selected as shown in Figure 4-16.

![Adhesion window](Figure 4-16 Adhesion window (European Railway Agency, 2010) Pg. 171)

### 4.4.4.1 Application of Observational Failure Scenario 8 to the Safety Assessment Process

In order to develop a system architecture for rail adhesion, understanding of the train braking system in addition to the physical interface between the train and track is required. Both can be derived from the system requirements with validation by SMEs.
In terms of risk, hazards and the impact to safety, there is always the potential for severe consequences to occur as a result of adhesion issues. This has been demonstrated by cases of near misses at Esher and Lewes (Rail Accident Investigation Branch, 2007). Cases such as this require efficient management by train operators. This could be management of the risk by following rulebook procedures or through contact with the signaller to seek operational guidance. In the case of hazard analysis it should be clear how any outputs of the hazards will be managed. If they cannot be managed this may result in change to the system requirements. The ultimate aim from a safety perspective is to keep risks from low adhesion As Low As Reasonably Practicable. Present Infrastructure Manager obligations to meet this include the following items shown below which have been extracted from Railway Group Standards (Railway Safety and Standards Board, 2009):

‘2.2.2.1 Infrastructure managers shall lead an assessment to determine the risks involved where a site of low adhesion is identified.

2.2.3.1 Infrastructure managers shall immediately advise the railway undertakings concerned when low or exceptionally poor rail-head conditions have been reported or become evident.

2.2.3.2 Infrastructure managers shall advise railway undertakings:

a) What remedial action has been taken at the sites where low or exceptionally poor rail-head conditions have been reported

b) The effectiveness of the remedial action taken.

2.2.3.3 Infrastructure managers shall review the results of the site assessment and the remedial action taken to determine if a site specific action plan needs to be developed.’ (Railway Safety and Standards Board, 2009) Pg. 6.

The outputs from working in accordance with Railway Group Standard GE/RT8040 cover two areas of the derived safety assessment process shown in Figure 4-9. Specifically, hazard analysis and system validation. Non-compliance against these standards can be used as a marker from which lessons learned can be obtained.

Lessons learned are key outputs that can be used to determine whether there is the need for requirements to be amended. Or to determine whether design scope should be changed for areas of the railway where there are on-going works for example. Lessons learned will be added as an output of the hazard analysis stage and the system validation and shall be included in the revised process. Application of information from lessons learnt activities is a key factor that can be used to improve safety culture.

Safety Culture has been defined within this thesis in Chapter 3. Section 3.4.1 is in relation to the railway industry. The term safety culture, has many subsets, which include, behaviour, management systems, organisations and individual responsibility. The relevance of utilising outputs from lessons
learned activities in relation to safety culture has been demonstrated in the Chemical Engineering industry. For example, analysis of one company found the following (Crawley F. K., 2008):

1. Flaws within design reviews – design reviews are conducted by SMEs and engineering discipline leads;
2. Route cause of failure had not been designed out – Risk and hazard analysis is a key part of any safety assessment process, therefore it is essential to use the findings of both qualitative and quantitative hazard analysis rather than assessments being solely carried out as a tick box activity.
3. Management culture – The approach to change within an organisation, be it through analysis of incidents or processes it needs to be driven from management.

The achievement of good safety culture needs to be jointly addressed by an organisation and its employees. Review of lessons learned will support this and in turn support the entire safety assessment process.

This section has presented three failure scenarios, which correspond to randomly selected observational scenarios the remainder of which are detailed in their entirety within Chapter 5. These failure scenarios have been examined against the safety assessment process derived in Figure 4-9.

In summary, based on this preliminary application of the safety assessment process the following has been identified and will be used to modify the derived safety assessment process shown in Figure 4-9:

1. User/operational competency – this is added as an input into hazard analysis;
2. Lessons learned – is an output following safety validation and hazard analysis interdisciplinary review;
3. SME reporting

It would be preferable from a design point of view that the review and evaluation carried out through the safety assessment process is by the same set of experts. This enables continuity throughout a project. However, based on review of the selected observational failure scenarios it has been identified that this may not always be feasible during the lifecycle of a project which can often last a number of years. Therefore, at each stage where SME review is required clear reporting shall be provided on outcomes, reasoning and expectations to enable continuation by any other SME. The SME should also maintain a level of independence from those designing and performing the engineering activities so that the conclusions drawn remain impartial and solely safety focused.
This chapter has considered the factors key to safety management and safety culture in an operational environment. Following literature review, in particular, making use of the Railway Safety System Definition

- System architecture
- Operational concept
- Design

Review and evaluation

- Documented assumptions, agreements and records

Hazard Analysis

- Analysis of accident and incident scenarios;
- Severity/probability analysis (risk analysis);
- Risk classification based on risk analysis to determine risk tolerability

System Validation

- Validate the safety of the system;
- Satisfaction of safety targets and requirements;

Reporting

- Feeds into a safety assessment report or culminates in a safety case:
  - Risks analysis/hazards
  - Assurance processes
  - Quality management

Figure 4-17 Improved Safety Assessment Process
Directive dataset. An indication of where selected European rail organisations feel they are in terms of their safety adherence and development has been attained. This is used to support the findings detailed as part of the safety assessment in Chapter 6. Chapter 6 particularly relates to aspects of communication, safety culture and promotion of safety regulation as per the Railway Safety Directive. Chapter 5 now delves into the detail of the remaining failure scenarios that have been used to perform the safety assessment.
Chapter 5  Safety Assessment: Impact of Safety Culture

The review of safety management in Chapter 3 focused on approaches to manage safety across a number of industries with a similar safety risk profile to the railway industry. It was found that a lack of safety culture in an organisation could lead to risks and hazards, which can self-perpetuate if not controlled. Chapter 4 built upon this by reviewing methodologies to assess safety, and specified a safety assessment process. Safety culture and safety assessment discussed in Chapter 3 and 4 respectively can both be used to determine the state of safety within an organisation. However, less emphasis is usually placed on the former. Therefore, this chapter argues the need for safety culture to be inherently integrated into a Safety Management System. This is shown through identification of failure modes as presented in section 5.1.2 followed by an assessment of how safety culture can be used to enhance safety practices. This enables the improved safety assessment process derived and shown in Figure 4-17 to be further improved if new aspects that can enhance the process are identified.

The safety assessment used in this thesis shown in Figure 4-10 is carried out in four parts and is also used in this Chapter to investigate safety culture. Namely via (i) use of publicly available information (ii) questionnaires (iii) observations and (iv) comparative studies. These methods have been used to provide a thorough examination of the factors that impact safety in both an existing and modernised railway environment.

As an introduction, a further review of risk is carried out, this is to provide a background to reaffirm why risks need to be managed and to highlight the impact on safety. This risk review is followed by a comparison of railways in Europe. This is to understand European developments with respect to those railways modernised by ERTMS, summarised as:

(i) the impact of new technology on safety from technical and procedural perspectives and,
(ii) to understand how cultural differences present themselves.

In addition to identifying the effect of technical issues partially addressed in Chapter 4, the impact of human behaviour and procedural changes are also considered. This is to determine whether safety culture can be used to mitigate safety risks. Failure modes are discussed and reviewed in section 5.1 based on the understanding of system architecture derived in Chapter 2. The latter sections of this chapter discuss safety culture related to the driving environment.
5.1 Risk: Failure Mode Scenarios

This section reviews the risks that are posed to the railway environment and measures for mitigation. As discussed in Chapter 3, the impact of risk to railway systems and users are accidents, incidents and fatalities. A risk as defined by the Health and Safety Executive:

‘the likelihood that a hazard will actually cause its adverse effects, together with a measure of the effect. It is a two-part concept and you have to have both parts to make sense of it. Likelihoods can be expressed as probabilities (e.g. “one in a thousand”), frequencies (e.g. “1000 cases per year”) or in a qualitative way (e.g. “negligible”, “significant”, etc.). The effect can be described in many different ways’. (Health and safety Executive , n.d)

Additionally, risk management is defined as:

‘the eradication or minimisation of the adverse affects of risk to which an organisation is exposed’ (Health and Safety Executive Presentation, n.d.)

This definition of risk is twofold and incorporates the concept of ‘probability’ with the concept of ‘effect’. Therefore, for a safe environment the potential for unacceptable risk needs to be managed. Legislative changes that bring about modernisation and increased automation to railways have the associated likelihood that additional risks may be introduced, which will require new mitigations.

Common Safety Methods (CSMs) indicate the importance of novelty with respect to risk. As explained in Chapter 2 ERTMS introduces novelty into European railway systems. As a result of change there is a level of uncertainty due to the integration of this new signalling system. Guidance from the UK Office of Rail Regulation on risk assessment combines this uncertainty with the consequence of failure as shown in Figure 5-1 (Office of Rail and Road , 2015). The consequence of a failure is in the context of a system not performing according to either its correct behaviour or operational state following a change. For example, this could constitute a change to a signalling system.
Therefore:

The Scale of change with respect to safety = \((\text{Uncertainty of outcome} \times \text{consequence of failure})\);

Legend: [Green = Non significant change; Yellow = Apply additional criteria; Red = significant change]

Figure 5-1 Uncertainty and Consequence Matrix (Office of Rail and Road, 2015)

This form of colour code categorisation is used to evaluate at a high level, the significance of a change to the railway and or if further intervention is required depending on the category of the uncertainty.

5.1.1 Risks and Mitigation Strategies

In order to comprehend the risks posed to the safety of operational railways, the approach taken in this research is to find an association between railway system hazards and possible consequences. Utilising a risk-based approach for system analysis, risk classification based on the likelihood of that risk occurring is required. In addition to this, methods by which these risks can be mitigated have been reviewed and can be aligned to the consequence and uncertainty matrix. However, risk categorisation is subject to verification by Subject Matter Experts. Mitigations are required to control risks to the railway and range from procedures and technical design to environmental awareness. The risks identified have differing levels of severity in their consequence as described and illustrated in Table 5-1.

Research into risk mitigation within the National Airspace System has been carried out by (Weibel & Hansman, 2005) who show that evaluation of risk mitigation has the benefit of determining whether
target levels of safety can be met. This is in addition to enabling identification of the hazards that relate to a particular system. (Weibel & Hansman, 2005) also identify that any form of measures for mitigation have an associated cost. Consequently, applying this concept to railway organisations, it is shown that mitigation measures carried out by railway organisations are often cost constrained based on the required levels of staff training and development. Following a study at the request of rail trade unions it was found that:

‘As a consequence of budgetary reductions multiple roles were now expected of many staff. Participants suggested that this impacted on the ability of staff to deliver an efficient safe service’ (McKay Sonia & Clark, 2014) Pg. 4.

Consequentially, it is shown that cost is a constraining factor and can influence the safety culture practiced by an organisation.

Railway systems as shown in Chapter 2 contain a high percentage of electrical, electronic and programmable systems. As explained by (Hills, 2007) sub systems must conform to Standard IEC61508. This standard specifies the requirements that ensure systems function within appropriate Safety Integrity Levels (SIL). The SIL is dependent on the risk posed by a failure in system safety. The following subsection details a method to analyse and mitigate risks, specifically, Failure Modes and Effects Analysis (FMEA).

5.1.2 Failure Modes and Effects Analysis

FMEA is a method by which risk analysis can be carried out on the systems that comprise the railway. Failure mode standards such as Electro-technical Commission (IEC) 812 illustrate and define methods by which failure mode analysis can be carried out. This standard shows that FMEA analysis has the benefit of being a flexible tool that is not specific in its application to a particular industry.

Analysis of the generic railway system architecture and high level system functionalities as depicted in Chapter 2 has enabled a number of failure modes to be identified and categorised in terms of their impact on safety. It is also noted that if a system fails without inducing a hazard the requirement to carry out a detailed FMEA is reduced. Safe performance of a railway system is dependent on its seamless integration and function from both a technical and human perspective. Consequently, failure mode analysis has been carried out to identify the susceptibility of systems to failures. In safety related industries this is used to optimise system design and safety processes. FMEA can be summarised as a method that:

- Allows failures to be classified – aiding maintenance and diagnosis;
- Enables evaluation of the events that lead to a failure; (Kirrmann & Eschermann, 2012).

However, it is also important to note that this method only provides qualitative solutions. If a quantitative approach is required to provide a more thorough solution a Failure Mode Effect and Criticality Analysis approach (FMECA) should be taken. An example of a FMECA approach to review
risk has been carried out by the Rail Safety and Standards Board (RSSB) as detailed in their research into failure management of the rail traffic control system (Rail Safety and Standards Board, 2007). Applicable elements from their FMECA analysis have been extracted to demonstrate the quantitative categorisation of various failure modes some of which have initially been qualitatively identified via the FMEA process. The FMEA process is presented in terms of a process flow as shown in Figures 5-2 and 5-3 below. This process categorises the stages required to identify failures and importantly highlights questions that should be asked or considered at each stage. The approach taken in Figure 5-2 is to firstly consider the railway system and users (targets) that would be affected by a failure, and then to identify the associated risk and scope. Step 4 onwards identifies the failure modes and concludes with an assessment of the impact of the risk posed and methods to counter said risks.

Figure 5-2 FMEA Process Adapted from (Morris, 2011)
The risks identified are from technical analysis and understanding of system functionality and expected operational performance for both conventionally signalled railways and modernised railways as shown in Tables 5-1 and 5-2 respectively.
<table>
<thead>
<tr>
<th>System</th>
<th>Risk</th>
<th>Consequence</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication System -</td>
<td>Loss of radio coverage; Loss of communication between driver and</td>
<td>No information to driver which could lead to a train accident</td>
<td>Driver training of procedures for communication failure scenarios.</td>
</tr>
<tr>
<td>Cab Secure Radio; National</td>
<td>signaller this would have notable impact in an emergency situation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radio Network;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication System (Physical)</td>
<td>Handset or speaker malfunction</td>
<td>Driver unable to hear speech commands or tones</td>
<td>Handset or speaker maintenance or replacement</td>
</tr>
<tr>
<td>Communication system</td>
<td>Perpetual unnecessary communication by the signaller or controller to</td>
<td>Distracted driver – impacts operational tasks conducted</td>
<td>Communication only when required for e.g. announcing safety critical</td>
</tr>
<tr>
<td></td>
<td>the driver</td>
<td></td>
<td>information</td>
</tr>
<tr>
<td>Rolling stock to rail interface</td>
<td>Adrift pigtails causing train earth faults</td>
<td>Arcing</td>
<td>Rolling stock arc protection / inspection and maintenance</td>
</tr>
<tr>
<td>Rolling stock to rail</td>
<td>The train not braking within the limits of the safe braking distance</td>
<td>Train collision SPAD</td>
<td>Adequate sanding system</td>
</tr>
<tr>
<td>interface</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Train driver to trackside</td>
<td>Train passes signal at danger</td>
<td>Minor: train overshoots signal. Major: Acts as a precursor event to a</td>
<td>Train Protection Warning System used to alert drivers enabling caution</td>
</tr>
<tr>
<td>signal interface</td>
<td></td>
<td>collision or train derailment</td>
<td>to be taken when on the approach to a red signal.</td>
</tr>
<tr>
<td>Railway track</td>
<td>Railway track degradation; Broken rail; Poor track alignment;</td>
<td>Train derailment</td>
<td>Track inspection; Ultrasonic inspection cars</td>
</tr>
<tr>
<td></td>
<td>Infrastructure failure</td>
<td>Collision Unexpected train movement</td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td>Exposed conductor wires; Wire degradation;</td>
<td>Halt in train service</td>
<td>Safety signs to warn of voltages; Training; Isolator switch; Assess</td>
</tr>
<tr>
<td>Civil structures</td>
<td></td>
<td></td>
<td>condition of wires;</td>
</tr>
<tr>
<td></td>
<td>Old / degraded structures</td>
<td>Structure collapse</td>
<td>Structural investigations; Where feasible replace with plastic which has</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>reduced maintenance costs;</td>
</tr>
<tr>
<td></td>
<td>Structural failure (fragmentation or collapse)</td>
<td>Derailment – affecting customers/train crew/tracks side staff</td>
<td>Inspection/maintenance/speed restrictions</td>
</tr>
<tr>
<td>Signalling - Legacy Track</td>
<td>Train detection system is not immunised against electrification</td>
<td>Shows the presence of a train</td>
<td>Replace with new technology such as Axle Counters: Renew track circuits</td>
</tr>
<tr>
<td>Circuits</td>
<td></td>
<td></td>
<td>to newer model</td>
</tr>
<tr>
<td>Signalling – Points</td>
<td>Points failure</td>
<td>Points cannot be set normal or reverse</td>
<td>No mitigation; Inspection;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Train delays</td>
<td></td>
</tr>
<tr>
<td>Signalling – Control</td>
<td>Work station failure</td>
<td>Inability to set routes for train journeys</td>
<td>Communicate with drivers over radio and carry out emergency procedures</td>
</tr>
<tr>
<td>Centre</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5-1 illustrates examples of typical failures and the associated risks that can occur on conventionally signalled railways. The failure modes can be attributed to technical system failures or failures of operation roles such as the train driver, signaller or controller. Table 5-2 comparatively incorporates failures associated with ERTMS related equipment. For example, the GSM-R has been presented in Table 5-2 in relation to communication failures and because it constitutes a significant part of the ERTMS system configuration.
<table>
<thead>
<tr>
<th>System</th>
<th>Risk</th>
<th>Consequence</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global System for Mobile Communications – Railway (GSM-R)</td>
<td>GSM-R system unavailability</td>
<td>Loss of means for vital communications</td>
<td>Analysis of how to maintain GSM-R reliability and availability</td>
</tr>
<tr>
<td>Global System for Mobile Communications – Railway (GSM-R)</td>
<td>GSM-R may not have required bandwidth for a particular route</td>
<td>Loss of means for vital communications</td>
<td>Installation of additional FTN nodes.</td>
</tr>
<tr>
<td>Global System for Mobile Communications – Railway (GSM-R)</td>
<td>Single point failure</td>
<td>Loss of means for vital communications</td>
<td>Recovery site; Back up equipment;</td>
</tr>
<tr>
<td>Communication system</td>
<td>Handset or speaker malfunction</td>
<td>Driver unable to hear speech commands or tones</td>
<td>Handset or speaker maintenance or replacement</td>
</tr>
<tr>
<td>Radio Block Centre (RBC)</td>
<td>RBC failure</td>
<td>All trains in area come to a halt</td>
<td>Increase dependability of RBC or provide fallback track based detection system and interlocking</td>
</tr>
<tr>
<td>European Vital Computer (EVC)</td>
<td>European Vital Computer (EVC) failure</td>
<td>Reported train location lost for affected train</td>
<td>Fallback track based detection system to support workaround.</td>
</tr>
<tr>
<td>Balise Reader</td>
<td>Balise Reader failure</td>
<td>MA and position reporting lost for single train</td>
<td>Duplicate balise reader or fallback track based detection system to support workaround.</td>
</tr>
<tr>
<td>Eurobalise</td>
<td>Derailment</td>
<td>Incorrect fitment of the balise on the track causes the balise to act as a physical obstacle to the train.</td>
<td>Track maintenance</td>
</tr>
<tr>
<td>Eurobalise</td>
<td>Interference between transmitting and receiving balises</td>
<td>Interference with other balises in the vicinity</td>
<td>Verification tests to confirm balise message accuracy.</td>
</tr>
<tr>
<td>Eurocab</td>
<td>Errors on DMI display</td>
<td>Driver caused to exceed allowed speeds in an ETCS mode which does not have speed supervision</td>
<td>This is applicable for degraded modes only. Normal operations will have ETCS supervision</td>
</tr>
<tr>
<td>Odometry</td>
<td>Odometry failure</td>
<td>MA and position reporting lost for single train</td>
<td>Increase internal diversity to allow operation with increased effective train length</td>
</tr>
<tr>
<td>Odometry</td>
<td>Odometry failure</td>
<td>Transmittal of incorrect or obsolete data</td>
<td>Reset of odometer</td>
</tr>
<tr>
<td>ETCS System</td>
<td>ETCS System performance failed; Incorrect data entry into the Driver Machine Interface;</td>
<td>Performance is altered from correct operation</td>
<td>Data entry process on-board via the DMI should be in accordance with appropriate safety practices</td>
</tr>
<tr>
<td>Railway track</td>
<td>Points and crossing switch incorrectly traversed</td>
<td>Train derailment</td>
<td>Automatic control and command of points and crossings</td>
</tr>
</tbody>
</table>

Table 5-2 Failure modes for a modernised railway (Rail Safety and Standards Board, 2012) and (UNISIG, 2014)
As with FMEA, for FMECA the functional architecture is used to gain understanding of the inter system relationships. Use of FMECA provides a clear way to demonstrate the advantages and disadvantages of system relationships as the criticality of failures can be measured. As a consequence, this supports the identification and management priority of failures. For an operational environment, what an organisation wants to ascertain is how the various failures impact performance. Performance ties in with cost, which includes implications, which can lead to penalties, as is the case for severe operational service delays. Table 5-3 below shows how risk ranking was used in the research by RSSB to categorise the level of risk into Low, Medium and High rating levels with an associated score. Table 5-4 is also an extract of the FMECA risk findings and outputs, providing further detail as it combines the qualitative elements of a FMEA to the quantitative risk scoring.

<table>
<thead>
<tr>
<th>Ratings</th>
<th>Scores</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>0</td>
<td>Cannot happen</td>
</tr>
<tr>
<td>N</td>
<td>0</td>
<td>Negligible</td>
</tr>
<tr>
<td>N/L</td>
<td>0.5</td>
<td>Negligible/Low</td>
</tr>
<tr>
<td>L</td>
<td>1</td>
<td>Low</td>
</tr>
<tr>
<td>L/M</td>
<td>1.5</td>
<td>Low/Medium</td>
</tr>
<tr>
<td>M</td>
<td>2</td>
<td>Medium</td>
</tr>
<tr>
<td>M/H</td>
<td>2.5</td>
<td>Medium/High</td>
</tr>
<tr>
<td>H</td>
<td>3</td>
<td>High</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>Certain or near certain</td>
</tr>
</tbody>
</table>

Table 5-3 FMECA risk ranking (Rail Safety and Standards Board, 2007)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Context Diagram</th>
<th>Element/Function</th>
<th>Failure/ Error</th>
<th>Safety Risk (total)</th>
<th>Performance Risk (total)</th>
<th>Safety Rank</th>
<th>Performance Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Signalling communications</td>
<td>Use a public bearer network</td>
<td>Misrouting Control room unavailability e.g. power failure, fire alarm, terrorism</td>
<td>7 9 1 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Control room</td>
<td>Signal centre size</td>
<td>Failure detection: failure prediction - existing data available from interlocking Use GSM-R/ERTMS to provide moving block radio based signalling (ERTMS L3)</td>
<td>5 9 8 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Failure management</td>
<td>Misinterpretation of data (carry out fault investigation unnecessarily)</td>
<td></td>
<td>4 3 24 43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>Signalling communications</td>
<td>Not provided as unclear how it would be used.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5-4 FMECA risk findings (Rail Safety and Standards Board, 2007)
5.1.3 Summary

Failure Mode Effect Analysis (FMEA) is shown to be a clear method to qualitatively analyse the core systems of the railway both in its existing state and following modernisation. This method also provides an insight into how newly introduced systems can introduce risks. A derivation of the system architecture into a block diagram representation provided a starting point to understand the key system interrelationships and boundaries between the various subsystems. To further analyse the risks posed to an entire operational railway and to the individual subsystems a quantitative approach should be taken. However, this requires detailed analysis such as knowledge of the technical specifications for each subsystem. A further add-on to FMEA/FMECA studies would be to map staffing competencies to the risks and ensure that there is sufficient expertise and competency within an organisation to meet demands in all scenarios that have an impact on safety. This would provide an indication of gaps in safety practices.

This section has carried out a literature review of failure modes of which the following are specifically related to the driver.

1. Communication – via the radio interface to the signaller or controller;
2. Signals Passed At Danger; and
3. Incorrect data entry into the DMI.

The next section confirms these failure mode scenarios through presentation of a design of the structured questionnaires and observations.

5.2 Understanding the Driving Environment

Understanding of socio-technical risks is of particular importance when modernising a railway. From a European standpoint, there are a range of influencing factors that shape the operation and functionality of the numerous railway networks. This includes different national practices to innovations in technology design and integration. As these factors impact safety, this thesis incorporates human factors analysis.

Of particular interest to this research is the concept of hu (Man)-Technology-Organisation (MTO) risks as discussed by (Lundberg, Rollenhagen, & Hollnagel, 2009). Their research reviews and makes reference to the underlying consequences of accidents through comparison of eight accident investigation manuals. The accidents investigated were from the railway, maritime, civil aviation and nuclear industries. Comparison of two of the eight manuals has been chosen for literature review based on lessons learned that are of specific applicability to railways.

Comparison highlights commonalities to MTO risks between road and the railway. The Vägverket manual which belongs to the road transportation domain focuses on a number of elements which can
be deemed as risks to safety in general. The identified risks can be mapped to the railway domain and they include the risk of intentional rule break, which can be categorised as a hu(Man) factor. Research conducted by the RSSB into driver error demonstrates this. The RSSB specifically carried out analysis on operator aids such as the Driver Reminder Appliance (DRA), which is designed to ensure that the driver has checked the state of platform end signals before leaving a station and noted cases of rule break (Rail Safety and Standards Board, 2004). RSSB’s observational studies showed instances of drivers failing to follow rules, in particular in safety critical roles where it was important that specified rules were followed.

Additionally, ‘over a third of drivers questioned, stated that they have set the DRA on the move. This may have arisen from the best of intentions, but it still represents a widespread violation of current procedures’ (Rail Safety and Standards Board, 2004) Pg. 16.

This example, observed by the RSSB is of particular interest, especially for the railway. In this case, rule break led to a change in operational procedures. This provides an example of where purposeful incorrect actions carried out by train drivers influenced organisational procedures and thus addresses all elements of the MTO concept.

The second manual reviewed was the Landstinget manual, covering the domain of Local Authority and Regions. The manual emphasises improvement in safety culture, whilst drawing attention to the economic impact of remedial actions. Such actions are a form of corrective behaviour, and they usually incur cost as additional resources are required to rectify a particular problem. Therefore, it can be seen as an example of an ‘Organisational’ factor that would benefit from management review to achieve ‘right first time’ behaviours in the operational environment. A comparison of these two manuals from non-railway industries to the railway industry manual, produced by the Swedish Rail administration shows that this organisation places significant emphasis on technology in regard to accident modelling. The Swedish railway administration focus on data collection, data preservation and coordination of all activities, which relate to accidents. It is obvious from a railway engineering perspective why data is of particular importance. For example, correct data input via the DMI can ensure that a train is operationally sound and has the ability to perform within its safety boundaries. In the case of failure events it is important to understand where data has been adapted or transformed either erroneously or by accident. This is an important topic in the context of modernisation of trains and is discussed in more detail in the following sections of this chapter.

Comparison of industry-wide manuals has demonstrated that there are a number of factors beyond technical issues that pose a risk to railway operation. It is interesting to note the emphasis placed on data by the railway domain. However, it has also been shown that the human element has a significant impact and possibly the most impact on safety culture. It is therefore essential that analysis of human behaviour is incorporated into a Safety Management System.

For the reasons detailed above, significant research has been conducted to gain an early indicator of the impact on safety that modernisation to European railways has had. The study detailed in section
5.2.1 Table 5-5 evaluates the safety experiences in European countries that have implemented ERTMS based on developments at the time of writing. Table 5-5 correlates to the identified relationship between hu(MAN)- Technology-Organisation (MTO) as discussed following review of the accident and incident manuals. A number of contributory factors have been identified that influence safety, including operating procedures, planning rules and cooperation with authorities. These are examples of organisational issues that influence the safety culture demonstrated by an organisation.

5.2.1 European Comparison Study: hu(MAN)-Technology - Organisation

Research by (Smith, Kyriakidis, Majumdar, & Ochieng, 2013) presents an overview of lessons learnt through implementation of technology that modernises European railways. The research specifically addresses the issues relevant to the introduction of ERTMS technology. Particularly, the ETCS component into European railway networks and accounts for any procedural challenges that have been encountered moving away from conventional signalling technology. Country variations have been compared and used to determine areas of significance that need to be addressed at a systematic level.

In order to understand the issues experienced through deployment of ETCS technology a number of experts have been interviewed. Structured questionnaires have also been conducted with responses augmented through review of publicly available information. The various forms of data have improved the quality and variety of information on the subject; enabling more thorough analysis of the complexities surrounding modernisation.

Structured questionnaires were conducted to understand issues that occurred in Spain as a starting point. Spain was the first country to implement ERTMS on its commuter lines and has an extensive operational network (Unife, 2014). Spain has since seen significant improvements in its reliability and punctuality statistics on the Madrid-Barcelona high speed line with both level 1 (L1) and level 2 (L2) of ERTMS technology. Further improvements have been seen with the implementation of ERTMS level 2 technology. However, these benefits have come at a high cost, specifically in relation to testing and deployment on operational track in addition to the long processes. Figures 5-4 and 5-5 below indicate that both the reliability and punctuality of the trains on the ERTMS railway particularly at L2 is positive. It is shown that the distance between incidences is greater with L2 and has continued to improve from the date of implementation. This reliability has been significantly aided by the use of testing laboratories which have been used to test the various subsystems that are integrated onto the trains. L1 ERTMS has seen variability in the number of incidences, however, year 2014 saw an improvement in the distance between incident occurrence. L2 on the other hand, has seen consistent positive improvement in its system reliability since 2011.
Figure 5-4 ERTMS reliability in Spain (CEDEX, 2014)

Figure 5-5 ERTMS Punctuality in Spain (CEDEX, 2014)
Figure 5-5 depicts the punctuality records for L1 and L2 ERTMS. The performance of L1 has enabled greater than 98% punctuality. Level 2 further improved on those results with punctuality nearing 100% in 2014.

In addition to Spain, interviews were carried out in the Netherlands and Switzerland, this provided an insight into the key areas of design, infrastructure and processes that impact the deployment of ERTMS onto European railways.

Significant knowledge was shared by Lloyd’s Register safety experts in the Netherlands who have front line experience of the ERTMS trials. The SME’s identified that in addition to technical complexities a key issue that halted progress was the limited knowledge sharing between stakeholders and interfacing countries. However, such issues were lessened through adherence to the European standard EN50126 as presented by Lloyd’s Register (Hajonides, 2011). Standard EN50126 facilitates projects on areas such as the roles within complex projects and associated project goals, it additionally provides a clear process by which Reliability, Availability, Maintainability and Safety (RAMS) can be established.

Parallels are drawn between implementation in the Netherlands to that in Spain. In the Netherlands, on the Amsterdam – Utrecht Line, the use of laboratories was seen as a viable option to facilitate deployment of ETCS technology (Zweers, Bronsema, & Wulfse, 2011). The benefit of this lies in areas that have a high traffic density and require timely implementation of testing activities to avoid disruption to passenger journeys.

In contrast to the testing activities, the Netherlands faced issues with cross acceptance. However through application of European standards EN50126 and EN50129 the safety approval process was attained. The aforementioned standards respectively relate to systematic processes for specification of RAMS and evidence which is used for acceptance of safety related systems.

Experience from safety experts in Switzerland, working for Swiss Federal Railways’ (SBB) aligns with that experienced by experts in the Netherlands. A number of key factors have been deduced as being essential for successful deployment of ERTMS, these include:

- A requirement for a cohesive working relationship between Train Operating Companies and the Infrastructure Manager who is responsible for the track;
- Informal working groups for knowledge sharing activities and ‘lessons learnt’ activities between the various stakeholders;
- Placement of equal focus on the operational rules as is currently given to technology;

A general overview of issues faced has been presented above for Spain, Switzerland and the Netherlands. A detailed analysis and summary is presented in Table 5-5 below, which expands on the issues faced with deployment of new technology across a number of European countries. This has largely been obtained from publicly available information and augmented with information from structured interviews with SMEs.
<table>
<thead>
<tr>
<th>Country</th>
<th>Route</th>
<th>Length</th>
<th>ETCS Level</th>
<th>Implementation Schedule</th>
<th>Capacity Influences and Technology</th>
<th>Safety/ Interoperability Issues Experienced</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>Fehmarnbelt Link [Connects lines Bandedanmark and DB Netx]</td>
<td>~ 20km</td>
<td>L2 Baseline</td>
<td>Start date: 2011 Commercial service: 2018</td>
<td>Passenger: 160km/h Freight: 120km/h Gauge: 1,435mm 15kV and 25kV AC</td>
<td>» The Danish strategy for the Bandedanmark is to implement simpler and safer operating rules; » Programme management focus should also be on avoiding the cost of disputes; » Use of Joint Test Laboratory which enables suppliers to carry out comparative testing against other supplier systems in addition to existing systems; » Aim to employ a GPRS solution to remove any communication capacity issues at areas such as at stations;</td>
<td>» Forecast general rises in traffic levels; increased capacity; shorter transit times; Reduced journey times;</td>
</tr>
<tr>
<td>France</td>
<td>European HSL Paris/Vaires-Baudrecourt</td>
<td>300km</td>
<td>L2-version 2.3.0d with TVM 430 overlay</td>
<td>Equipped, in operation end 2013; Three lines under construction: Le Mans / Rennes : in operation in 2017; SEA: Tours / Bordeaux : in operation in 2017; East European HSL Phase 2 : Baudrecourt / Vendenheim (Strasbourg) : in operation in 2017;</td>
<td>320 -350 km/h</td>
<td>» Issues with operating rules for level 2 when shutting down line side signalling and related cost; » Potential line capacity increases will not offset the extra economic cost; » Operational rules on corridor fitted with both legacy and ETCS systems; » Harmonisation of braking curves to avoid barriers at borders; » Costs and benefits of migration are not evenly shared; » Dual fitment of the high speed line with TVM 430 because no agreed deployment plan in France at the time; » Long tendering process; » Delays caused by misunderstanding between Alstom and Reseau Ferre de France (RFF); » Knowledge transfer needed for SNCF staff (maintainers &amp; installers); » A range of signalling technologies found on the French network required adaptation to ERTMS; » Public statutes can act as blockers when it comes to reuse of subsystems that have already been developed;</td>
<td>» For validation: railway test centre ‘Centre d’ Essais Ferroviaire’ (CEF) in Valenciennes: ERTMS laboratory and loop track fully equipped for functional and system validation before putting in service. Open to multi customers uses and cross validation.</td>
</tr>
</tbody>
</table>
Great Britain

<table>
<thead>
<tr>
<th>Route</th>
<th>Length</th>
<th>System</th>
<th>Start Date</th>
<th>Commissioned</th>
<th>Key Challenges Faced by Ansaldo:</th>
</tr>
</thead>
</table>
| Cambrian Line - Shrewsbury - Aberystwyth/ Pwllheli | 215km  | L2     | 2005       | 26th March 2011 | » Limited testing time - 4 hour slots;  
» Retro fitment of 20 year old trains with restricted space;  
» Confirming integration and performance with GSM-R; |

<table>
<thead>
<tr>
<th>Route</th>
<th>Length</th>
<th>System</th>
<th>Start Date</th>
<th>Commissioned</th>
<th>Key Challenges Faced by Ansaldo:</th>
</tr>
</thead>
</table>
| Berlin-Halle/Leipzig         | 1.145km| L2 F/B | 1999       | 2005         | » Obstacles to overcome are organisational and technical;  
» Different approaches to trackside and train authorisation processes;  
» Clarification is required of the EU process for putting into service;  
» At national level, development of customer requirements specifications by IM in order to promote interoperability;  
» For an interoperable ERTMS network it is essential: »Reduction of variability within the installation of ETCS;  
» Closure of open points in TSI CCS;  
» EU-wide solution for Key-Management-System;  
» Definition of operational rules, engineering rules;  
» Development of Test specifications;  
» Clarification of EU-process for putting into service (DV 29);  
» National/ Corridor Level: Development of Customer Requirement Specifications by IM; |
| POS Nord                     | 2.128km| L2 L1&2 F/B | 2005 | 2006 | » ERTMS level 2 does work as proven by German pilot project;  
» Expected benefits: promotion of interoperability, reduction in equipment costs due to standardisation of ETCS, simplification of the authorisation for putting into service; |
| Nurnberg - Munchen           | 3.159km| L2 PZB L2 | 2005 | 2008 | |
| Aachen - Belgian Border      | 4.8km  | L2 F/B | 2008 | 2015 | |
| Emmerich - Basel             | 8.680km| L2 F/B | 2008 | 2020 | |
| Aachen - Frankfurt (O) / Horka | 1.45km | L2 F/B | 2008 | 2020 | |
| German part of Corridor A plus link to Belgium | 8.680km | L2 F/B | 2008 | 2020 | |

Ansaldo took a holistic approach to system design and rules.
### Netherlands

<table>
<thead>
<tr>
<th>Line Description</th>
<th>Length</th>
<th>Stage</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSL South</td>
<td>4.30km</td>
<td></td>
<td>2. Commercial service June 2007, 3. Maximum line speed 300km/h, 4/5. Maximum line speed 200km/h</td>
</tr>
<tr>
<td>Amsterdam - Utrecht 5. Hanzelijn</td>
<td>5.70km</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Hanzelijn** (Lelystad - Zwolle) - 2.110km
- **Betuwe line**: Complexity arose because of working with five stakeholders including train operating, lease companies and infrastructure managers.
- **Fitment of ETCS** required interoperability with German, Belgian and Dutch national systems.
- **Lessons learnt**:
  1. To aid the speed of getting approvals, it is advisable to know the right people in the relevant country.
  2. It is recommended that changes in requirements should not be readily accepted.

Working to EN50126/-129 has the benefit of:
- Using the same language for all parties,
- Application of known and accepted process for project set up,
- Re-use of previous documents, templates and processes.

### Spain

<table>
<thead>
<tr>
<th>Line Description</th>
<th>Length</th>
<th>Stage</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madrid - Barcelona HSL</td>
<td>1.650km</td>
<td>L1</td>
<td>Earliest commercial service implementations in Madrid - Lerida L1 2006</td>
</tr>
<tr>
<td>Cordoba - Malaga HSL</td>
<td>2.155km</td>
<td>L1/L2</td>
<td>Max speed 200km/h - Max speed 350km/h</td>
</tr>
<tr>
<td>Madrid - Valladolid HSL</td>
<td>3.197km</td>
<td>L1/L2</td>
<td></td>
</tr>
<tr>
<td>Madrid - Toledo HSL 5. Toledo Access (La Sagra - Toledo)</td>
<td>4.21km</td>
<td>L1</td>
<td></td>
</tr>
<tr>
<td>Zaragoza - Huesca</td>
<td>5.25km</td>
<td>L1/L2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.79,5km</td>
<td>L1</td>
<td></td>
</tr>
</tbody>
</table>

- **ERTMS** was a new system with non consolidated specifications.
- **Increased complexity** due to number of suppliers involved with respect to trackside/trackside and trackside/train integration.
- **Specification evolution** while developing, integrating and validating projects.
- **Evolution of new entities, different roles and modifications in authorisation process and procedure.**
- **The trains supplied by any of the 5 unit suppliers in Spain are able to run on trackside equipment built by any of the others.**

Passenger growth:
- [Madrid-Malaga 88%]
- [Madrid - Valladolid 109%] year 2008 figures.
- Collaboration and communication between entities involved in the consolidation process of the specifications.
<table>
<thead>
<tr>
<th>Switzerland</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 45km L2 2. 65km 3. 3000km (95% of SBB network) 6. 35km</td>
<td>1. 1.190km L2 2. 2.180km L2 3. 3.156km L2 L1/L2</td>
</tr>
<tr>
<td>» Short block distances » 15kV » Short distances of MA points » high capacity RBC and interlocking high capacity GSM-R cell » Values of braking curves will become national values » Maximum speed 250km/h</td>
<td>Max speed: 250km/h</td>
</tr>
<tr>
<td>» SBB made a decision to remove the conventional line side signalling, i.e. no backup system which required cooperation between SBB and Bombardier to carry out systematic analysis of all operational problems. » For cross border traffic, transition processes were not clearly identified and complications arose with the different official regulations and languages of railway networks.</td>
<td>Key challenges faced by Ansaldo on the Haparandaban Line: » Adaptability and quick reaction to unforeseen situations. » Project planning - commissioning phases and solutions.</td>
</tr>
<tr>
<td>» Mixed traffic to optimise the traffic flow » Passenger and freight running on the same line.</td>
<td>» Early joint system design » Clear specifications » Mutual understanding of needs and possibilities » Training of signalmen, drivers and site maintainers</td>
</tr>
<tr>
<td>Country</td>
<td>Route</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>Hungary</td>
<td>Hegyeshalom – Budapest</td>
</tr>
<tr>
<td></td>
<td>Hodos - Zaaegerszeg – Kormend</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roma - Napoli</td>
</tr>
<tr>
<td></td>
<td>HSL Torino - Novara HSL</td>
</tr>
<tr>
<td></td>
<td>Milan – Bologna HSL</td>
</tr>
<tr>
<td></td>
<td>Novara</td>
</tr>
<tr>
<td></td>
<td>Milan</td>
</tr>
<tr>
<td></td>
<td>– Milan HSL</td>
</tr>
<tr>
<td></td>
<td>Bologna- Firenze HSL</td>
</tr>
<tr>
<td></td>
<td>Padova – Mestre HSL</td>
</tr>
</tbody>
</table>

Table 5-5  Comparison of Technology developments in European Railways (Smith, Majumdar, & Ochieng, 2013)
5.2.2 Conclusion

Section 5.1 has identified that there are a number of failure modes relevant to the driving environment; this includes data entry into the DMI in addition to GSM-R operational functionality. Review of the failure modes show that there are also a number of cases where serious failure consequences can occur. Section 5.2 presented the failure modes and developmental issues across Europe, which are related to technical and organisational developments. Section 5.3 presents the design of a scheme implemented in Chapter 6. However, for a credible design of a scheme, section 5.2 delved into the detail of understanding the environment in particular in relation to developments across Europe. This information is useful for the design of the scheme in section 5.3.

5.3 Structured Questionnaires and Observation Design

This section uses the methodology derived in Chapter 4 for safety assessments to practically examine the changes to railways via application of structured observational analysis, questionnaires and where possible interviews. This is required to facilitate the determination of the technical and human factors that are present in the operational railway environment which relate to safety. This thesis concentrates on two scenarios for both observations and questionnaires. The first relates to a conventional signalled railway and the latter scenario relates to railways modernised through implementation of ERTMS ETCS signalling technology. Both scenarios are tied to the role and actions of the train driver under various conditions and situations within the operational driving environment.

The driving environment for a conventionally signalled railway has been researched by (Mcleod, Walker, Moray, & Mills, 2005) from both a psychological and mathematical context. Building upon this existing research, this thesis compares the modernised operational driving environment specifically in relation to safety culture manifestations and emergent properties brought about through harmonisation of sub systems.

5.3.1 The Driving Environment

Focus on railway safety in the driving environment requires all system elements to be considered, this includes the role of humans. The human is a key system element and exhibited human behaviour plays a significant role to the safety of a railway system. The railway is a safety critical environment with the driving environment in particular on-board the train subject to significant physical change following the introduction of new technology and adaptations to physical layouts. The new onboard systems interface and integrate with a number of legacy systems in addition to new and old trackside
systems. As a result, the actions carried out by the train driver in addition to the impact of change to the driving environment are discussed in this section.

This section addresses the aims that have set in motion the modernisation and consequently design change of the in-cab environment. These are to:

- support the driving task through displaying information in a clear and consistent manner and
- align with requirements for interoperability;

Both of these aims intend to reduce the risk of a driver carrying out incorrect actions. Although the aims intend to reduce risk, modernisation not only brings about a change in ergonomic design but also causes a change in operational procedure. As a result, there are changes to the actions carried out by a train driver. All drivers will require a period of adjustment, especially for those drivers who are not supportive of organisational change driven by EU regulations. Also for those who are not technologically savvy or for those who do not easily adapt to change. Train drivers often become used to routine procedures and it is noted that driver experience varies. It is not uncommon for a driver to have professional train driving experience spanning over ten years, a period over which habits can form.

5.3.1.1 Processes within the Driving Environment

The driving environment assimilates a number of processes and functions, including alarms, warnings and images, all of which need to be managed and understood by the driver. The complexity of the driver’s cab is shown in Figure 5-6 below.

![Figure 5-6 Alstom West Coast Main Line Train Cab (Alstom, 2010)](image)

During the process of modernisation there is the potential for underlying dangers to arise that influence safety practices. Bainbridge (Bainbridge, 1983) draws attention to the idea that operator task simplification can have the converse and contradictory effect of making the task more difficult. For a modernised railway system, it is expected that the tasks which are now made redundant to the driver, because of different operational processes are those which do not add any value. However, it
has been found that tasks which have been added, such as messages or information are added with the intention to aid and optimise performance rather than introduce any distraction. It would be ideal for train drivers to be confident that the automated system is resilient and reliable. This may not be the case and this is an example of why a whole system approach should be taken. That is, to integrate and visualise the train driver as an element or a key ‘sub system’ of the railway.

European specifications such as the CENELEC technical specification CLC/TS 50459 (2005) (IHS Engineering 360, 2015) stipulate from an ergonomic perspective how information should be displayed to the driver. Information includes facets such as the structure of dialogue, colours, symbols and audibility. The other factors that have the potential to influence the driving ability of the train driver include external environmental conditions such as landslides and other categories such as trespassers and uncontrollable scenarios.

5.3.1.2 Signalling Interface to the Driver

The majority of European railways in their present configurations utilise conventional signalling techniques for the safe movement of passengers. However, due to the complexity of railway systems, a failure in any one of its sub systems, that is, the train, track, power, communications or signalling can impact the driver’s behaviour. As technology progresses and trains have greater dependency on the ETCS DMI to provide signalling information more attention needs to be paid to the potential risks.

Train drivers have varying levels of experience and often come from diverse industry backgrounds. Extensive route knowledge is often gained through driving the same route for a lengthy time period, this gives train drivers the ability to anticipate signals. Driving traits and behaviour also vary depending on the train driver. Drivers may be (i) proactive, reactive and highly efficient (ii) conversely drivers may be ineffective. These behaviours vary depending on the scenario. In either the former or latter case, both scenarios are important in determining how safety culture is considered and applied by an organisation and its employees.

Specific changes to the driving environment have seen the signalling system move from trackside to on-board the train. This transfers the driver’s attention from outside of the train cab to a signalling focus which is predominantly inside the train cab. This is demonstrated through implementation of the European Railway Traffic Management System (ERTMS), which at ETCS Level 2, trackside signals are no longer required. With the ETCS, via the DMI interface, in cab movement authorities are presented to the driver. This is a result of braking distance calculations that are computed on board the train, thus the driver now places more focus on the DMI. In a conventionally signalled railway, the colour aspect of a trackside signal indicates the route status to the driver. A green signal indicates that the route ahead is clear; a double yellow signal is a warning signal and an indication that the following signal is a single yellow which is followed by a red signal otherwise known as a signal at danger. This colour sequence is akin to what is used by car drivers on UK roads. Trackside signals therefore provide an indication of movement authority to the driver as shown in Figure 5-7. When
driving to signals, a number of techniques are utilised by train drivers to maintain safe operations, such as:

(i) self announcements: for example, announcing a yellow aspect to oneself to signify the importance of the next signal. This is a good tool and method employed by some drivers and also demonstrates a proactive approach to management of operational areas of the railway that have a higher impact on safety.

(ii) Noting down key information communicated by the signaller to prevent confusion and errors.

Figure 5-7 Trackside signal sequence (Adlington, 2014)

Modernising the driving environment via ERTMS technology has a number of potential benefits from a theoretical perspective. This includes route flexibility, increased route capacity and faster recovery from operational perturbations. These benefits are being realised as demonstrated by deployment of the system in European countries such as Switzerland and Spain as shown previously in the country comparison within Section 5.2.1 of this chapter. This is largely because the railway is neither constrained by track sections associated with the trackside signals nor signal sighting (that is, the time taken for the driver to sight a signal at danger). Progression of the railway to provide such benefits requires the train driver to adapt to the new and or modified operational environment. The change to the driving environment has the potential to introduce significant change in a driver’s behaviour and working methods. The driver’s tasks, prior to implementation of ERTMS are dependent on a number of factors, including route knowledge and anticipation of signal aspect sequencing. This is largely acquired through repetitive driving on a particular route. The ERTMS removes the need for certain behaviours that have been developed by drivers driving according to conventional signalling methodologies.

This change in technology can positively or negatively impact the driver, in areas such as concentration. A variety of information, both audio and visual is fed to the driver whilst in transit. Depending on the drivers capability and reactions, for example in an unsafe scenario this could induce information overload thus increase workload for the driver. This can have an associated
domino effect which may result in stress related behaviour. However, converse to this idea of work overload, research by (Jansson, Olsson, & Kecklund, 2005) indicates that the change in the driver’s environment does not particularly relate to work overload but instead to reception of uninformative information or information deemed irrelevant to the driver. The conclusion drawn upon by (Jansson, Olsson, & Kecklund, 2005) may have been the majority outcome for those drivers researched; however, different drivers have differing behavioural attributes. Further literature review into behavioural differences show that they can be attributed to cognitive issues.

5.3.1.3 Train Driver Cognition

Research focusing on cognitive issues relating to accidents and incidents in the railway environment has been carried out by the Norwegian Centre for Transport Research (Phillips & Sagberg, 2010). Their research utilises and develops upon work by Erik Hollnagel (Hollnagel, 1998) into the Cognitive Reliability Error Analysis Method (CREAM). The approach taken by the Norwegian Centre for Transport Research was to understand cognition in the context of a system. That includes vital elements of environmental, technical, human and organisational factors. This is the same approach taken throughout this research, that is, a holistic approach to evaluate safety in the railway environment.

Research by the Norwegian Centre for Transport Research is based on a conventionally signalled railway environment. The key findings below indicate a number of factors that influence driver behaviour and are also deemed of relevance to this research, specifically:

(i) Routine driving on a specific route produces driving by feeling;
(ii) Perception of risk by the driver can be influenced by the driver’s mood; and
(iii) A challenge to railway drivers is the level of monotony in the driving task;

Addressing the items above, in the conventional railway system the driver has adapted to anticipate signals. How methods such as this will change following the removal of signals is evaluated through analysis of publicly available research carried out on Swedish railways signalled with ERTMS technology. The mood of the driver on the other hand can also be influenced by a number of factors such as drowsiness and anxiety. In either the conventional or modernised railway environment this can be of detriment to users of the railway, having obvious safety implications. The mood of the driver is not considered in detail in this thesis but it is noted as a contributory factor to the safety culture exhibited by members that comprise operational staff. Automation is used by a number of industries to enhance safety and reduce human error. However, reducing the scope of the driving task due to automation may also introduce a level of monotony which can negatively influence driver behaviour.

The issues identified are not technically related to the railway system but relate more specifically to human and organisational issues. These can be deemed as precursors to actions carried out by train drivers. Examples of the identified issues above can be resolved through changes to processes and
procedures. For example, diversity in driving patterns may be introduced to stimulate driver activity, decrease the dependency on route experience and thus decrease the monotony brought about through routine. Analysis by the Norwegian Centre for Transport Research concludes that the greater topic of organisational culture is a precursor to driver actions. This includes demands by an organisation placed on the driver.

In addition to work carried out by the Norwegian Centre for Transport Research, the RSSB also identify the importance of train driver cognition, specifically in regard to SPADs. In this case, focus on SPADs stems from catastrophic events that have occurred. Beneficially, the RSSB have researched outside the sphere of railways and utilised research from other safety critical industries which have employed navigation technologies. Research from (McKenna & Crick, 1994) and (Young & Stanton, 1997) show that it should not be assumed that the primary task of driving does not require use of cognitive resource at a higher level. As a consequence, the RSSB have used cognition to redress approaches taken towards safety management.

The subject of cognition is a complex one, it is not the basis of this thesis but where it is relevant such as in the driving environment it is highlighted. Cognition, defined as:

‘the processes of knowing, including attending, remembering, and reasoning; also the content of the processes, such as concepts and memories.’ (Barr, 2015) Pg 136

Cognition is applicable to the driving environment, for example, the driver has to be able to reason in an emergency scenario, prioritise tasks and perform procedural operations based on either training, operational guidance from a signaller or controller or based on driving experience. As trains move towards modernised technology the cognitive processes of the train driver will change and adapt to the new environment. It is important to understand what issues are likely to occur; this is an area that will be reviewed as part of this thesis in relation to safety culture. The following subsections address this through analysis of observational scenarios and questionnaire data augmented through publicly available information related to ERTMS technology. As an initial start point, the tasks carried out by a train driver are examined; this was used to develop a methodology for the questionnaire design and safety critical driving scenarios to be observed.

5.3.2 Train Driver Task Analysis

This section evaluates the train tasks that a driver conducts and aims to be exhaustive in relation to each stage of the driving task. Task analysis can be conducted in a number of ways, to various degrees of detail. This includes Cognitive Task Analysis, Decision Flow Diagrams, Influence Modelling and Assessment Systems to Hierarchical Task Analysis. Whichever method is selected, the usefulness of task analysis lies in its methodological approach to break down complex system
operation. However, task analysis requires sufficient understanding of operational procedures and terminology by the developer of the analysis depiction.

The tasks that a train driver conducts vary according to a number of factors such as, train location; this could be at a depot or platform area. Alternatively, a driver may be inhibited from normal driving actions due to demanding situations such as adverse weather or poor visibility. Practically, the driver has to make a number of decisions and interpret the various information streams made available. This includes alarms, voice calls or signals. Consequently, a task can be defined as follows:

‘as a reference to human behaviour, the system goals for which some people are employed, how context constrains the attainment of goals, or some interaction between these and other factors’ (Shepherd, 1998) Pg 1538.

A task analysis technique employed to comprehend behaviour and used commonly in the domain of Human Factors within the railway industry is that of Hierarchical Task Analysis (HTA). HTA is a structured and systematic process and a number of benefits of this method have been identified by SMEs in the field of Human Reliability. (Embrey, 2000) draws attention to a number of pro and cons of this method alongside other methods some of which have been mentioned above. Points of interest and which are deemed applicable have been extracted and modified to help clarify the suitability of the various task analysis methods in addition to how a particular method can be used. For example, HTA may be an excellent method to design operating procedures or to understand training needs. However, it may not necessarily be the best method to fully evaluate work load analysis. As a result, Table 5-6 below depicts and compares a number of task analysis methods, specifically Hierarchical Task Analysis (HTA), Operator Action Event Trees (OAET), Decision/Action Flow Charts (DA), Critical Action Decisive Evaluation Technique (CADET) and Influence Modelling and Assessment Systems (IMAS). The applicability of the above methods in terms of usage to analyse driver tasks within this research is also discussed in Table 5-6.
<table>
<thead>
<tr>
<th>Method Evaluation</th>
<th>Task Analysis Method</th>
<th>Research Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Is this method suitable to identify training needs of train drivers?</strong></td>
<td>HTA: Y, OAET: N, DA: Y, CADE: Y, IMAS: Y</td>
<td>Majority of the methods can be used to evaluate training needs.</td>
</tr>
<tr>
<td><strong>Is this method useful for team organisation?</strong></td>
<td>HTA: Y, OAET: N, DA: N, CADE: P, IMAS: N</td>
<td>Application – HTA useful method to understand existing organisational issues in addition to potential implications of integration of new technology.</td>
</tr>
<tr>
<td><strong>Does this method explain the interface between people and control systems?</strong></td>
<td>HTA: Y, OAET: P, DA: N, CADE: P, IMAS: P</td>
<td>This is a key point for this research in particular relation to the driving environment as more control is imposed on the driver by the signalling system and the HTA method meets this.</td>
</tr>
<tr>
<td><strong>Does this method identify the interactions between task steps and possible side effects?</strong></td>
<td>HTA: Y, OAET: N, DA: Y, CADE: Y, IMAS: Y</td>
<td>Potential applicability of a number of methods.</td>
</tr>
<tr>
<td><strong>Does this method identify communications requirements between a team?</strong></td>
<td>HTA: Y, OAET: N, DA: N, CADE: N, IMAS: N</td>
<td>The driving task is a solitary task, however there is a lot of communication and is a necessary safety factor.</td>
</tr>
</tbody>
</table>

Key: Y=YES, N=NO, P=Partially fulfilled criteria

Table 5-6 Comparison of task analysis methods and applications
(Embrey, 2000) highlights that use of HTA for safety analysis covers the majority of factors of relevance to the driving environment. This method is most suited to this research for the reasons indicated in Table 5-6. Other assessment methods that look at task behaviour range from Barrier Analysis to use of computer modelling and simulation methods. A range of methods have been widely reviewed by (Kirwan & Ainsworth, 1992) who deem task analysis as a fundamental approach to achieve greater levels of safety and additionally confirm the applicability of task analysis for safety management, that is:

- ‘Where safety is important (e.g. accidents or near misses have occurred; the technology is vulnerable to human error; or operator safety actions are claimed as part of (the safety case))’;
- ‘When operational feedback raises concerns over a particular human machine interface’;
- ‘Where a significantly different technology is being used’; (Kirwan & Ainsworth, 1992)

The points raised concur with the idea that task analysis is an important milestone in determining the impact of actions on safety.

Looking in more detail at a number of the other methods, for example, Barrier Analysis, this is a method which can be equated to the Swiss Cheese Model. This is because it looks at all barriers be they physical or otherwise to prevent accidents, furthermore it looks at the failure of a particular barrier. All these methods are useful, however, it is important to relate ordered tasks or sub tasks to the system and operational requirements. HTA follows this approach and enables information to be easily organised or simplified which is necessary to understand operator tasks, as a result this analysis method has been applied in this research.

The term ‘task’ cumulatively looks at the characteristics of the systems technical behaviour in addition to human behaviour. Task analysis reflective of operations carried out by train drivers aids understanding of the complexity of the driving environment. This includes situational tasks that may be encountered.

Comparing driver tasks for conventional signalled railways to railways that in the future will be deployed with ETCS technology it is vital to understand how changes in driving practice impact safety. Tasks carried out by the train driver are viewed in the domain of the railway system environment. That is, it is inclusive of the controller and signaller as these are critical human interfaces for the driver.

As a starting point, documented details of tasks carried out by train drivers have been reviewed and collated from publicly available information. This information has been augmented by the author where understanding of tasks has previously been attained from experience on UK rail projects. Specifically through leading operational scenario workshops based on metro system automatic train control at London Underground.

The process of task analysis involves (i) identification of tasks, (ii) understanding the principles of the tasks, (iii) the equipment that is required to be utilised in addition to (iv) identification of any sub
activities that are required. Task analysis also enables investigation of where there is potential for error, a process comparable to Failure Mode Effect Analysis discussed earlier on in this chapter.

The tasks that a train driver carries out in a ‘Day In The Life Of’ (DITLO) normal train running is summarised below in Table 5-7. Specific tasks within a driving state have been shown in more detail via HTA. An exhaustive DITLO would also include operation in emergency and degraded states of the railway.

<table>
<thead>
<tr>
<th>Task ID</th>
<th>Driving State</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Pre Operational</strong></td>
<td>Train driver booking on procedures</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Pre-operational driving sub-activities</td>
<td>Sign in for duty</td>
</tr>
<tr>
<td>2</td>
<td>Pre-operational driving sub-activities</td>
<td>Acquire train information and route information</td>
</tr>
<tr>
<td>3</td>
<td>Pre-operational driving sub-activities</td>
<td>Identify train stabling location (depot/platform/sidings)</td>
</tr>
<tr>
<td>• <strong>Train preparation</strong></td>
<td>Preparation of the train for service</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Train preparation sub-activities</td>
<td>Driver checks the train exterior</td>
</tr>
<tr>
<td>6</td>
<td>Train preparation sub-activities</td>
<td>Preparation and checking of the rear cab environment</td>
</tr>
<tr>
<td>7</td>
<td>Train preparation sub-activities</td>
<td>Driver performs walkthrough vehicle check</td>
</tr>
<tr>
<td>8</td>
<td>Train preparation sub-activities</td>
<td>Preparation and checking of the leading cab environment</td>
</tr>
<tr>
<td>9</td>
<td>Train preparation sub-activities</td>
<td>Enter data using alpha-numeric pad into train management system</td>
</tr>
<tr>
<td>10</td>
<td>Train preparation sub-activities</td>
<td>Identify faulty onboard equipment</td>
</tr>
<tr>
<td>• <strong>Execution</strong></td>
<td>Start up train and execute specified scheduled route</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Execution sub-activities</td>
<td>Train driven in correct operational mode from stabled location</td>
</tr>
<tr>
<td>12</td>
<td>Execution sub-activities</td>
<td>Awareness of track conditions, obstructions, trespassers or trackside workers</td>
</tr>
<tr>
<td>13</td>
<td>Execution sub-activities</td>
<td>Perform brake test</td>
</tr>
<tr>
<td>14</td>
<td>Execution sub-activities</td>
<td>Control train speed under normal conditions with a green signal</td>
</tr>
<tr>
<td>15</td>
<td>Execution sub-activities</td>
<td>Control train speed under normal conditions with a yellow signal</td>
</tr>
<tr>
<td>16</td>
<td>Execution sub-activities</td>
<td>Drive according to speed limits</td>
</tr>
<tr>
<td>17</td>
<td>Execution sub-activities</td>
<td>Interpret route indications (speed restrictions)</td>
</tr>
<tr>
<td>18</td>
<td>Execution sub-activities</td>
<td>Adjust speed on approach to or departure from station area</td>
</tr>
<tr>
<td>19</td>
<td>Execution sub-activities</td>
<td>Monitor passenger boarding and alighting from the train</td>
</tr>
<tr>
<td>20</td>
<td>Execution sub-activities</td>
<td>Communicate with the passengers via PA system or utilise pre-recorded PA messages</td>
</tr>
<tr>
<td>21</td>
<td>Execution sub-activities</td>
<td>Identify if a SPAD has occurred</td>
</tr>
<tr>
<td>22</td>
<td>Execution sub-activities</td>
<td>Communicate with the signaller for routing past a signal at danger.</td>
</tr>
<tr>
<td>23</td>
<td>Execution sub-activities</td>
<td>Adjust train position if train has undershot (move train forward)</td>
</tr>
<tr>
<td></td>
<td>Execution sub-activities</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>--------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>24</td>
<td>Adjust train if it is has overshot stopping position following contact with control centre</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Respond to in cab warnings</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Respond correctly to commands from the automated system</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Respond to in cab call via hand set</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Identify stopping position</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Carry out procedures during abnormal conditions of trespass/ person strike/ animal strike</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Respond to emergency situations</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Communicate via on-board phone handset</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Detrain at termination stop</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Conclusion</td>
<td>Conclusion of train journey for passenger service</td>
</tr>
<tr>
<td>34</td>
<td>Conclusion</td>
<td>Check train individually or with assistance from station staff</td>
</tr>
<tr>
<td>35</td>
<td>Conclusion</td>
<td>Train is brought out of service</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Train is transferred to stabling position / train is shunted</td>
</tr>
</tbody>
</table>

**Table 5-7 Operational Task Analysis**

The tasks detailed above have been listed to show the typical states of operation which a driver transitions through. However, hierarchical tasks are more commonly represented in a diagrammatic format. This diagrammatic method is useful to visualise the task processes, interrelationships between the tasks and the ordering of tasks. The concept of this method is shown below in the examples presented in Figures 5-8, 5-9 and 5-10. The cases represent the methodology behind HTA followed by specific cases for train preparation and an emergency scenario. The cases have been drawn to relate to the tasks outlined in Table 5-7. The design format of this method places the goal at the top of the tree. This goal is akin to a driving state, under which tasks and sub task activities fall. This approach also indicates the order the task activities should be carried out providing a highly thorough approach for detailed analysis.
**Figure 5-8** Hierarchical Task Analysis process

*Do tasks 1-2-3-4 in this order*

1. TASK 1
2. TASK 2
3. TASK 3
4. TASK 4

*Do tasks 1-2-3 in this order*

- SUB-TASK 2,1
- SUB-TASK 2,2
- SUB-TASK 2,3

- This could be a new task required for ETCS operation
- This could be an altered task
Figure 5-9 HTA for Train preparation

Figure 5-10 HTA for Emergency conditions

Key

- EB – Emergency Brake
- DMI – Driver Machine Interface
- GSM-R – Global System for Mobile Communications Railways
5.3.3 Questionnaire Design and Implementation Methods

Questionnaire design has been structured around the train driver as respondents as they are the primary and end user of the railway technology inside the train cab. The questionnaire consists of 36 items with the option for participants to add supplementary information to support their answers to the available answer options. Where the occasion arose that a train driver was available after completion of their questionnaire, a structured interview was carried out. Structured interviews are used to ascertain further detail and specifics about their attitudes and perceptions of train cab design, technology and training.

The questions were formulated using non-complex phraseology to enable the perceptions and attitudes of train drivers to be expressed and understood, also to avoid ambiguity. Data gathering via questionnaires was deemed the best approach to obtain first-hand information from train drivers. Train driver instructors also completed the questionnaire material. However, their job role differs because in addition to extensive operational experience they also have the responsibility to train and instruct train drivers.

The sample size of driver participants was dependent on the availability of the train drivers in addition to their agreement to support this research. A greater number of participants enable attainment of a more diverse data set for statistical analysis. Distribution of the questionnaire material was a simple process aided by Abellio Greater Anglia, who held the questionnaire material at their training facility. The train drivers completed the questionnaires after completion of either their training and / or examination sessions on the train simulators.

The drivers who completed the questionnaires are classified according to a range of demographics which has been used to draw out correlations with driver behaviour. It is assumed that the sampled train drivers have sufficient levels of literacy and numeracy proficiency outside of the proficiencies required to be a skilled train driver.

The questionnaire has been designed to factor in the driver as an end user. Additionally, it relates to applicable objectives of the thesis, restated below:

- **Objective 2:** To investigate the technical developments of railway systems including functionality, operation, risk, severity and counter measures in the form of safety culture and methods of human interaction with new technology.
- **Objective 3:** Identify behavioural changes that have occurred to users of modernised railway systems.
Following review of the research objectives, those specific to the questionnaire were developed. From this, a set of operationalised objectives were produced, that is, specific hypotheses which can be directly linked to a list of variables (Oppenheim A. , 1966;1992). Applying Oppenheim’s approach for the first steps in questionnaire design it has been identified that breaking down objects enables questions to be produced in a structured format. This enables an insight to be provided into the unique challenges faced by the human operator.

Consideration has therefore been given to the formulation of the questions that compose the questionnaire. Specifically, questions have been designed so that they provide enough information to meet the research objectives. (Williams, 2003) emphasises that wording of questions has an influence on the participant response. Specifically, (Williams, 2003) recommends that a single question should contain less than 20 words to aid simplicity and succinctness. If on the other hand a question is wordy, there is the potential for either misinterpretation or inaccurate response to be provided due to a lack of understanding.

The process by which the questionnaire used in this thesis has been developed and conducted has been adapted in part from the transport questionnaire process as detailed by (Richardson et al., 1995). The process carried out by Richardson et al is greater in detail than the derived process applied in this thesis. As shown in Figure 5-12 the focus is primarily on the quality of the resources that enable the questionnaires to be completed. This research has a certain level of confidence in the respondent resource and capability. This is largely because the data was obtained in a controlled environment. The steps outlined in Figure 5-11 are now discussed in more detail.
Figure 5-11 Questionnaire development process

- Step 1 of the questionnaire design was to review the questionnaire methods that exist and the potential benefits and disadvantages of respective methods. There are a number of ways to design a questionnaire. A well-known method is that of Likert. The Likert scale used in this research classes attitudinal and character responses in categories which range from (i) strongly approve (ii) approve (iii) undecided (iv) disapprove to (v) strongly disapprove (Likert, 1932-1933) and is deemed to provide sufficient option coverage for driver response. This scale has been adapted by a number of researchers and includes use of 4 point, 6 point or 7 point scale variations with some researchers such as (Preston & Colman, 2000) finding favour in the adapted 7 point scale. Other viable methods to conduct and review questionnaire responses include continuous rating, staple and semantic differential scales. Each scale has its own advantages such as versatility, benefits in ease of distribution to simplicity of construction. Alternatively, the questionnaire could have been designed to be entirely open ended. This however, would complicate the analysis process. For this reason and as stated above, supplementary questions were included to provide respondents with the opportunity to add more detail.

Whichever method is taken to survey the respondents there are potential sources of error which can invalidate data. This may arise because of mal administration of questionnaire material or there may be situational factors affecting true response to questions. Furthermore, deciphering the questionnaire responses may be affected if handwriting is illegible. Also the respondents may
not be interested in completing the questionnaire, this can lead to a number of unanswered questions.

- Step 2, creating the sample questionnaire required the questions to be traceable to the thesis objectives. The questionnaire has thus been developed in two parts to reflect the respective railway environments. The first part concentrates on the conventionally signalled railway and has been issued to train drivers having experience of driving according to colour light signals. The second part of the questionnaire has been developed for train drivers with experience of driving on new railways or on railways modernised by ERTMS signalling. The questions in the latter case were developed to focus on the change to the driving environment, operations and procedures carried out in the new environment.

The questionnaires for train drivers of both conventionally and modernised railways followed the same overall structure detailed here. The first section of the questionnaire details the particulars of the staff; this includes demographics such as their length of service, gender and age. It was made explicitly clear that the information in this section will remain confidential but shall be used for statistical purposes only. Prior to issuing the questionnaire material, consultation was attained by Abellio Greater Anglia (TOC). Abellio Greater Anglia engaged with the train driver Trade Unions, who were content for the train drivers to participate in this research. The relevance of this research in the long term to UK railways, which will transform via new technology was of interest to the unions and train operator.

The second section of the questionnaire relates to training methods. This section is important as it identifies the driver’s experience of training. The penultimate section, section 3 focuses on the cab environment which is where the driver spends the majority of time and which undergoes significant physical change. An understanding of ergonomic issues will be ascertained from this section. The final section relates to safety culture, this includes questions on organisational approaches to safety. Each section has a supplementary information area where the participant driver can add any additional information deemed relevant to their feedback.
Prior to administering the questionnaire to drivers of conventionally signalled railways (Step 5) a preliminary and pilot questionnaire (Step 3) was issued to a sample of experts. The sampled experts included an academic in the field of helicopter safety management, a Lead Human Factors specialist at London Underground and a Lead Safety Engineer with a London Underground and Royal Air Force engineering background. This was complemented by a review from TOC Abellio Greater Anglia Head of Driver Training & Simulators, Head of Safety & the Environment and Head of Operations Standards & Training. All of these reviewers have extensive expertise in the mainline railway domain. Review by parties with rail experience in addition to those with non-rail expertise was carried out to ensure clarity of questionnaires and consistency in readability. Piloting the questionnaire was also a useful means to identify those questions which were either non-engaging or could be deemed sensitive/politically charged to the train driver respondents. Issues such as these could affect their response. Constructive feedback was given from all reviewers of the questionnaire material. Comments ranged from terminology, specifically referring to the clarity of questions to expansion of question detail to include coverage on areas of interest to railway organisations such as the GSM-R system. Further detail is shown in Table 5-8 below.
<table>
<thead>
<tr>
<th>SME Comment</th>
<th>Response to SME Comment</th>
<th>Area of SME expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questions that relate to workload in the driving environment are useful to understand the relationship between the human and the driving environment.</td>
<td>This has been included in the questionnaire.</td>
<td>Lead Human Factors Engineer London Underground</td>
</tr>
<tr>
<td>Simplify terminology, as those drivers with a non-railway background may not fully understand all terminology.</td>
<td>This comment is not applicable. This is because all train drivers have undergone training in order to drive a train and use the equipment that is abbreviated in the questionnaire.</td>
<td>Lead Safety Engineer London Underground and the Royal Air Force</td>
</tr>
<tr>
<td>The questionnaire places emphasis on safety culture. Safety culture is one aspect of why things can go wrong. The psychologies of safety or behavioural analysis are also relevant areas that would be interesting to capture. Therefore I would like to bring your attention to situational awareness which includes aspects such as data overload, stress, fatigue, complexity and functional creep.</td>
<td>The theme of the questionnaire relates to safety culture, which aims to extract information that includes aspects of behaviour. However, the observational scenarios have been developed to specifically capture the wider factors that influence safety culture and behaviour such as those factors which constitute situational awareness.</td>
<td>Lead Safety Engineer London Underground and the Royal Air Force</td>
</tr>
<tr>
<td>The starting age of a Train driver to drive on mainline railways is 21 not 18 years old. Younger aged staff may work in non-operational roles for example, where there are apprentices or yard workers.</td>
<td>Amended to reflect the correct driving age.</td>
<td>Head of Safety &amp; the Environment; Head of Operations Standards &amp; Training</td>
</tr>
<tr>
<td>Include questions that relate to changes in the radio communication technology. This can be used to gauge the driver's experience with the communication interface.</td>
<td>Questions have been included that discuss the interface with the GSM-R communication interface.</td>
<td>Head of Safety &amp; the Environment; Head of Operations Standards &amp; Training</td>
</tr>
<tr>
<td>Getting the ages of drivers instead of age bands might be better for doing statistics later on.</td>
<td>This comment has been used to revise the demographics section.</td>
<td>Academic (Field of helicopter safety management)</td>
</tr>
<tr>
<td>If there are possible certifications, it might be better to give them tick box options here. Or you might end up with people putting whatever they see relevant for the job, e.g. ISO 9000, accredited psychologist etc.</td>
<td>This comment has been used to revise the demographics section.</td>
<td>Academic (Field of helicopter safety management)</td>
</tr>
<tr>
<td>It might be confusing for operational staff if you include the definition of safety culture within the question.</td>
<td>The definition of safety culture has not been removed. It has been retained in the question because it is a key theme to be aware of before the questions are answered by the train drivers.</td>
<td>Academic (Field of helicopter safety management)</td>
</tr>
</tbody>
</table>

Table 5-8 SME review comments on pilot questionnaire
The questionnaires were revised following feedback from the aforementioned reviewers as shown in Table 5-8 this satisfies Step 4 of the process. The questionnaires cover four key areas as shown in Figure 5-12 and as per the original drafted questionnaire. Following revision of the questionnaire it was then administered to the train drivers. Distribution of the questionnaires was facilitated by train driver managers at Abellio’s driving school. A sample of the developed questionnaires is presented in Appendix I for both the conventional railway and the ERTMS signalled railway.

Steps 6 to 9 of the questionnaire development process (Figure 5-11) are addressed through the results explained in Chapter 6.

5.3.4 Train Driver Observations

An association between train driver behaviour and safety culture has been identified in research by industry organisations, such as the Health and Safety Executive (Health and Safety Executive, 2006). In particular the relation between the organisational aspect of safety culture and the resultant accident and incidents exhibited on conventional signalled railways has been highlighted.

Safety culture, discussed in Chapter 3 is a complex topic, more commonly researched in the fields of social and biological sciences. However, emphasis on safety culture has grown in the railway industry to aid understanding of user behaviour. In this thesis, the user behaviour of key importance to safety is that of the train driver due to the change in driving environment post implementation of modernised technology. Emphasis is placed on safety culture as a means to understand how and why things go wrong in the driving environment. In order to evaluate this, each task to be carried out by the train driver has been reviewed so that understanding can be attained of expected safety practices per task as described in the previous section. There are a number of other ways for evaluation, such as review of training manuals. However, the observational approach has the benefit of allowing real scenarios to be experienced.

Train driver behaviour is examined with respect to:

- Interactions with the signalling system,
- Communications which include interactions with the signaller/controller, and the
- Driver Machine Interface (DMI),

The importance of the DMI as a key interfacing system becomes more apparent following modernisation. The DMI represents an intelligent transport system but its optimal performance is dependent on interactions with the train driver. Successful observational analysis of this interface and interaction aims to facilitate improvements and minimise safety concern. It also provides first hand experience of the challenges faced by the driver.
The task of driving a train requires constant attention, skill and alertness. Observation of tasks enables demands, distractions and environmental factors to be reviewed. Mapping observations of what actually occurred to expected skill based safety culture behaviours and attitudes can draw out patterns in addition to areas of unfamiliarity. Roth and Patterson (Roth & Patterson, 2000) concur that realistic observations and conclusions can be drawn from field observations. The observations carried out are not as specific as what would occur in analysis by ethnography. As stated by (Farrington-Darby, Wilson, Norris, & Clarke, 2006)

‘An ethnography approach utilises methods such as observation (often participant observation whereby the research is immersed in the daily lives of the people being studied)’.

The observations employed in this thesis are restricted to the train environment, that is, a simulated cabin environment. The observations are exclusive of actions outside of the drivers shift such as lifestyle routines. It is noted that issues such as availability and the suitability of staff in relation to levels of experience may restrict the number of detailed observations that can be conducted.

The train driver has a number of risks to be cognisant of including collision, derailment, environmental conditions and equipment failure. The behaviour of the train driver in a given risk scenario is of critical importance largely because it can impact the safety of the railway environment. In particular, the safety of passengers and additionally the reputation of the organisation. Safety practices exhibited by train drivers can be aligned to the psychology of safety. This involves presentation of reasoned arguments which relate the train driver and interactions with the DMI system. The driving task can be seen to have one - to many interactions as shown in the example below Fig 5-13. The identified tasks should be carried out in addition to accepted practices, with consideration for legal requirements. The train driver faces a number of constraints which may be physical, environmental or chance occurrences.

**Figure 5-13** Train driver tasks and interactions

For example, within a new or modified train cab environment which has had considerable design development stress may be induced as a result of changes to lux levels. Additionally, obstructive equipment leading to eye strain and screen glare for example could also be a contributory factor. Screen glare in an extreme case could be hazardous, disabling the driver’s ability to read messages
or interfere with the driver’s line of sight. In the UK, drivers were still faced with the issue of screen glare on the Cambrian Line which utilises ERTMS technology. To minimise this, the train cab was adapted to reduce reflection in addition to alterations to the uniforms of train drivers to a darker colour.

In the case of demanding tasks, such as an accident scenario the driver will again be in a stressful environment which can alter behaviour and performance. Yerkes-Dodson’s law as presented by (Diamond, Campbell, Park, Halonen, & Zoladz, 2007) indicates that stress of a certain level can help focus. Conversely, the wrong amount of stress may have the opposite effect of being detrimental to clear thinking. This concept has been used by many in literature when addressing subjects such as performance in the financial sector (Ariely, Gneezy, Loewenstein, & Mazar, 2009). Translating this to the ERTMS-ETCS signalling environment, the train driver has a number of changes to adapt to. Observation of train driver operation can be used to highlight unfolding circumstances or it can be used as a means to mitigate against behaviours which have the potential to affect safety.

The factors which affect the driver and the number of tasks to be carried out have been considered in this section. However, the research task of observing the participant train driver carrying out their job requires consideration of additional factors aside from reviewing the level of adherence to specified tasks. This includes, recording behaviours and keeping a tally of behaviours. For effective observation of the drivers, understanding of the expected behaviours and tasks is required. This includes situational understanding of the degraded, normal and emergency modes of operation. Direct observations are more beneficial if the participants can be observed on a repeated basis. In an ideal case, what would constitute a good sample of observed data would be that obtained from a diverse group of participants, akin to those who completed the questionnaire. In addition to direct observation as a means for safety assessment, questionnaires and structured interviews have been shown to be viable methods and have been employed as illustrated in section 5.3. The alternative approach of interviews has the benefit of enabling control to be established. That is, the sequence of events can be prioritised with greater flexibility on time and location. However, interviews concentrate on thoughts, perceptions and motives. Observations are less flexible with respect to controlling the event. Nonetheless, observations have been chosen as an additional method for safety assessment as it can draw out actions and relationships that are unknown to the participant. For example, in the event of the participant showing reluctance to conform to required rules and regulations this is something that is more easily observed. Also an observation is within the realm of a real life situation and or environment.

Consideration has been made such that observations are unobtrusive. Observing the train drivers carrying out certain competencies, running scenarios or completing examinations in the simulator environment is an example of an unobtrusive observation. The train driver is watched via camera feed from the simulator to a control room akin to a railways operational control room. In a real environment the driver receives instructions from the actor role of the signaller or controller to whom the driver can communicate. In the simulated environment, the driver can carry out his actions without feeling the physical presence of an observer, negating any impact on driver actions. As an observer, no contact is made with the driver during their simulated journey to keep any potential distraction to a minimum.
However, in the event of a train driver carrying out actions which are not in accordance with specified task analysis the meaning has been queried with the driver following their period on the simulator. This is also so that meaningful behaviour can be documented.

The driver participants in the UK are unlikely to have experience of both conventional signalled railway in addition to a ERTMS signalled railway. However, any drivers having this experience of driving according to both railway systems would be of benefit to this research. In the UK, the level of ERTMS experience is undoubtedly incomparable to the level of experience held by train drivers throughout Europe. European countries such as Spain and Switzerland have advanced in their implementation of ERTMS and thus the train drivers have experience of both legacy and ERTMS train systems. For UK railways, ERTMS is still in its infancy in terms of operational usage and deployment. As train drivers transition to the ERTMS signalling system confidence in automation will have to be developed as driving practices change. It has been highlighted by (Mcleod, Walker, Moray, & Mills, 2005) that the level of trust placed in an automated system is directly related to how the system is interacted with by the human. Relating this to the railway environment, if the train driver regards the system as untrustworthy then it is highly likely that the system will be used incorrectly. The psychology behind this is outside the scope of this research, however is useful to be aware of as this as an influencing factor.

Existing driver observational analysis such as that carried out by (Luke, Brooke-Carter, Parkes, Grimes, & Mills, 2006) considered areas in their investigation, which include train driver visual strategies. This is an aspect which would also be useful for analysis as railways move away from conventional signalling to ERTMS signalling. Also, as train drivers adjust their operational strategies, this would support analysis. That is, in addition to task analysis it would be useful to understand where a driver places the majority of their attention. It is expected that visual concentration will be spread between the following environments, (i) the in cab Driver Machine Interface, (ii) marker boards placed along the trackside route, (iii) signals and the (iv) surrounding environment. However, the differences in behaviour exhibited by the driver in a technologically modernised environment are comparatively largely unknown and forms part of this research.

Other approaches to observe human behaviour have also been reviewed such as that carried out by (Pentland & Liu, 1999). Their research is based on a framework, the Markov Dynamic Model (MDM). This model has been reviewed because it aligns with the series of states of human behaviour that a driver progresses through. The methodology utilised in their research is based on the driver of a car, however, similarities can be made to the railway driving environment. The Markov Dynamic Model developed by (Pentland & Liu, 1999) demonstrates the states of driver operation. For a train driver, key states are those in which the train is being prepared, followed by its operational execution along a specified route as depicted in Figure 5-14.
Note: The ‘Doing nothing’ state as classified by Pentland et al is not applicable to the railway environment, this state has been categorised as a ‘pre-operational’ state.

Figure 5-14 States of train driver operation (Pentland & Liu, 1999)

This research includes detailed behavioural observation at the execution state. This is the state during which the train driver is driving along an operational route and carries out the majority of communication with the signaller or controller in addition to interfacing with the DMI and operational environment. The execution stage includes a large range of tasks with important aspects detailed in points (i) to (iii).

(i) the level of communication with the signaller and how this observably impacts driver actions;
(ii) the frequency of use of route preview based knowledge where the driver utilises route experience rather than sole reliance on the DMI for movement authority instruction; and
(iii) Monitoring of what causes most active communication and how it visibly impacts the task of driving.

Prior to execution of the driving task, (Pentland & Liu, 1999) employ a ‘Doing nothing’ state which for the railway industry equates to pre operational tasks outside of the physical train operation task. This includes related administrative tasks carried out by the driver as explained in Table 5-7 which details task analysis for train drivers. The various tasks carried out in the preparation stage are observed in addition to driver actions through to conclusion of the specified journey. Observation of driving activity has therefore been categorised into four main states, (i) pre operational (ii) train preparation (iii) train execution and (iv) the conclusion state. It is important to note that the task descriptions have been written such that they are simple and concise to aid understanding of solutions for recovery actions. In the event that any ambiguity is demonstrated this will be noted against the particular task, this is in addition to scenarios which appear to induce operator error.

The tasks and subtasks initially identified in Table 5-7 have been categorised based on the operational states. Activities have been selected, shown in orange which are deemed of particular importance to the safety culture exhibited in a safety critical environment. The action of a train driver can vary in a number of ways given the scenario and in some cases can be directly associated to the organisation. For example,
(i) If a SPAD occurs there may be immediate fear of disciplinary action.

(ii) If a train fails en-route in an unsafe location, for example outside of a station area a number of factors need to be considered. Such as, use of prescriptive procedures, which in fact can be impractical in an actual event. In cases such as this, it is not uncommon for passengers to start finding ways to alight a train. This is another example of an issue that could lead to driver blame.

(iii) Driver actions in the event of a significant communications failure whilst there is an emergency. A scenario such as this could occur but there is usually a means for back up communication.

A lot of these scenarios lead back to how the organisation will deal with the issue from both a safety perspective in addition to the perception of blame.

5.3.5 Development of Observational Scenarios

As discussed in the previous section, a number of situations can influence driver behaviour in addition to performance. This is also in addition to the pressure to drive as accurately to a set timetable as is possible. A train driver operates a train in a number of terrains and conditions, including tunnel and suburban sections. Due to the variability in conditions and operational procedures, observations of train driver behaviour are valuable to understand the best conditions for a safe driving environment. Observational scenarios presented in this thesis have been developed based on safety critical situations that can impose a range of risks to the safety of railways and their users. The scenarios detailed in this section are of applicability to both legacy signalled railways and to railways modernised through integration of the European Railway Traffic Management System (ERTMS) technology.

The observations, based on a conventionally signalled railway have been carried out in a simulated environment provided by Train Operating Company (TOC) Abellio. Abellio have a franchise which covers Greater Anglia railway routes. The simulated environment used for driver training and examination depicts a non factual UK railway route shown in Figure 5-16. The observational scenarios and examined railway route is replicated in either of the three available simulators which differ in internal design and layout. The internal simulator cabin design replicates the rolling stock cab design of the trains classes which run on Greater Anglia mainline railway routes.
The internal cab design of the train simulator replicates traction motor positions, seating positions, buttons, alarms and driver window positions to make the environment as realistic as possible to a passenger Electrical Multiple Unit (EMU) and has a typical configuration as shown in Figure 5-15 above. From the control room, for training purposes the trainer is able to present a number of scenarios to the driver. This ranges from weather conditions to trespassers which requires the train driver to operate as per the tasks in Table 5-7. An example of the route used to examine the train drivers is shown in Figure 5-16.
Figure 5-16 Non factual operational route scenario for conventionally signalled railway

Figure 5-16 depicts a non factual railway route from Stephen Street Station to Bird Hill Station. The route is signalled according to 3 and 4 aspect colour light signalling and utilises track circuit blocks. The route also contains level crossings, this introduces diversity and changes in operational procedures for the train drivers. The signaller in this example is located at Castle Hill signal box and
the Electrical Multiple Unit (EMU) is 4 cars in length for passenger service. The speed limits along the route are indicated, in addition to station locations, level crossings and a radio coverage location. Figure 5-16 is also an example of what a train driver uses inside their train cab for guidance whilst in transit.

Following assimilation of the tasks required to be conducted by the train driver and in particular those of interest to this research, the next step reviews the safety critical activities to be observed in the simulated environment. Figure 5-17 below depicts the key interfaces including human interfaces. Information flow is shown in three key areas:

- Between the signaller and the driver;
- Between the driver and the signalling system, and
- Between the signaller and the signalling system.

Figure 5-18 additionally depicts the ETCS element of signalling control which forms a subset of both the trackside and on-board train system signalling interface.

![Diagram](image)

**Figure 5-17** Key human interfaces - existing railway
Vital interfaces for the train driver have been shown in the figures above. Safety critical interfaces include the signaller in addition to the surrounding technical systems which include the DMI. It has been shown that ‘safety in operation depends fundamentally on the actions of the signaller and driver’ (Chapman, 2010). However, it should be recognised that there are also other operational human interfaces that maintain safe operation in various sectors of the railway system. However, the focus from an observational perspective for this research is on the driver as the train environment undergoes significant change.

### 5.3.6 Safety Critical Observational Scenarios

The scenarios shown below in Table 5-9 have been developed to further understand the interface between the human and technology in a safety critical environment. The scenarios are broad in range and the expected impacts on safety are outlined under the column heading ‘applicability of scenario’. The scenarios are based on literature review, which relate to the causes and consequences of accidents and incidents. To supplement the literature review the scenarios are also based on personal experience gained from safety briefings given to employees at Network Rail.
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Applicability of scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Data Entry</td>
<td>For conventionally signalled railways the train driver enters minimal data. This scenario has more bearing on an ETCS signalled railway where the task of data entry is required more extensively.</td>
</tr>
<tr>
<td>2 - Communications failure</td>
<td>Use of the GSM-R interface is to be examined and is of interest as Cab Secure Radio and National Radio Network systems are now defunct following the roll out of GSM-R technology.</td>
</tr>
<tr>
<td>3 - Perpetual communication</td>
<td>This is still a relevant issue and retained for analysis as perpetual communication can lead to driver distraction.</td>
</tr>
<tr>
<td>4 - Signal aspect change</td>
<td>This is of particular relevance for signal aspects changing to red. Historical cases of signals passed at danger show critical failures and an associated impact on human life.</td>
</tr>
<tr>
<td>5 - Tunnelled versus open route section driving</td>
<td>This is not expected to have a severe impact on safety and is monitored for information purposes.</td>
</tr>
<tr>
<td>6 - Train collision</td>
<td>In the worst case, there is the impact on human life. In a minor case a collision could occur during the process of coupling a train.</td>
</tr>
<tr>
<td>7 - Passenger Emergency Alarm Triggered</td>
<td>A valid scenario to understand the interface between the driver and passenger in the event of a safety issue.</td>
</tr>
<tr>
<td>8 - Brake failure</td>
<td>A brake failure could have any number of consequences such as a SPAD.</td>
</tr>
<tr>
<td>9 - Alteration of train length</td>
<td>This was deemed an important scenario for safety analysis. The train cars can be configured as a 4, 8 or 12 car. The train configuration is particularly important in platform areas, such as where the car length exceeds the platform length.</td>
</tr>
<tr>
<td>10 - Warning System Alarms</td>
<td>Driver response to warning alarms TPWS and AWS shall be analysed.</td>
</tr>
</tbody>
</table>

Table 5-9 Specific operational scenarios

5.3.7 Application of Observational Scenarios to European Railways

The developed scenarios detailed in Table 5-9 above are of relevance to both existing and modernised railways. The results of the prescribed scenarios are compared to research conducted by MTO Safety. MTO Safety is a consultancy organisation in Sweden who work in safety critical domains which range from the nuclear industry to railways. MTO Safety has carried out research of significance and applicability to this thesis. Specifically, their research relates to railway systems modernised by ERTMS.
MTO Safety has additionally carried out more in depth research in collaboration with the Swedish National Road and Transport Research Institute (VTI). VTI are funded by the Swedish Transport Administration. The research carried out by MTO Safety and VTI is based on Swedish railways modernised by ERTMS and can be mapped closely to the methods that have been used to collate the questionnaire and observation data for the simulated legacy signalled railway environment. The method of safety assessment conducted by this partnership is detailed in their report ERTMS-i-verkligheten (Nordlof & Kecklund, 2014) written and published in Swedish. In order to examine the results obtained by the research of MTO Safety and VTI it has been translated into English from Swedish. A brief process has been collated as shown in Figure 5-20 to summarise their research. This aids comparison to methods already carried out to assess the safety of existing railways as part of this research. The research carried out by MTO Safety and VTI has the additional benefit of not only utilising a simulated railway environment but also incorporating the use of operational passenger railways which implement ERTMS technology. As discussed earlier in this section, the simulated railway route for the railway signalled based on conventional signalling was a non-factual operational route. However, it contained enough complexity for adequate training and examination. It also sufficiently represents a mainline railway such that the scenarios that a driver may encounter can be confidently examined. The Swedish safety assessment on the other hand is based on three operational lines. Namely the (i) ATC2 Line (Stockholm to Sundsvall) (ii) the Ådal line and (iii) the Bothnia line, the latter two of which are fitted with ERTMS ETCS technology. The lines vary in design, complexity and topology as shown in the Figure 5-19 and briefly detailed below (Unife, 2014).

- The Ådal Line – This line transports both cargo and passengers, with a high degree of complexity due to the large number of level crossings totalling one hundred. The route combines a new line to an existing line of which 50km are new. The Ådal line runs with ERTMS level 2 technology, significantly this technology enables line capacity capability to increase from 8 to 10 trains per day to 50 to 60 trains per day.
- The Bothnia Line – this line is less complex than the Ådal line but has a large quantity of civil structures which include extensive tunnels and 140 bridges as part of its route. This line is also fully equipped with ERTMS level 2 technologies.
The safety assessment carried out in Sweden specifically maps to research objective 3, that is, to identify the behavioural changes that have occurred to users of modernised railway systems. The collaborating parties of MTO Safety and VTI explicitly state the purpose of their safety assessment as follows:

‘The purpose of this report was to investigate whether previously identified problem areas can be observed in real driving situations and to generally study the impact ERTMS has had on drivers and their driveability in a real environment’ (Nordlof & Kecklund, 2014) Pg 6.

Following review of their literature, a flow chart has been put together to capture and summarise the approach taken to assess the Swedish train drivers. The train driver participants are representative of train drivers at SJ, Sweden's largest train operator. The process also captures the data analysis techniques which are discussed in the results section. This allows for comparison to the data analysis performed for the Abellio data set which represents conventionally signalled railways. Point 4 within Figure 5-20 shows that there is insufficient railway literature that provides specific emphasis on the driving environment and the interface to the driver. Conversely, there is a wealth of information which relates to ERTMS technology and the various safety impacts of the various technical sub systems.
Steps 5 and 6 of the approach taken by MTO and VTI as shown in Figure 5-20 focus on the driver environment via questionnaire and observation. For this research, the scenarios that have been developed for both conventional and ERTMS signalled railways have been expanded in more detail to describe the impact of each scenario and the relevance in terms of safety management and safety culture. Analysis of the various observations provides further detail in addition to the FMEA analysis presented earlier on in this chapter. However, emphasis is on the train cab operational environment.
5.3.7.1 **Observational Failure Scenario 1 - Data Entry**
This has been examined in Chapter 4, Section 4-3.

5.3.7.2 **Observational Failure Scenario 2 - Communications Failure**
This has been examined in Chapter 4, Section 4-3.

5.3.7.3 **Observational Failure Scenario 3 - Perpetual communication**

During a journey the train driver will be in communication with the signaller, this can be for a number of reasons, such as to receive information or to communicate an event on the line. The level of communication between the train driver and signaller varies between the drivers and signallers alike. However, it should be noted that train drivers carry out a number of tasks whilst in transit and any communication is in addition to the primary driving task. There is potential for a train driver to become overloaded with tasks or information. In some cases, there may be miscommunication of information and at the worst disruption to driver operations. Included in this observation is the frequency of messages over the radio network and how this impacts driver operations. It is assumed that frequent messages or long lasting messages may cause significant distraction to a train driver.

5.3.7.4 **Observational Failure Scenario 4 - Signal Passed At Danger**

There are occasions when train drivers drive through a signal aspect in the danger state. The reasons for this occurrence can vary as can the consequence of passing a danger signal. Causal factors include (i) anticipation of a signal clearing, (ii) loss of focus on the driving environment to (iii) cancellation of AWS warnings without confirming the signal aspect. This scenario assesses the driver’s behaviour on approach to signals and potential influencing factors such as distraction. As shown in Figure 5-21, SPADs are ranked based on the severity of the imposed risk. Statistics for the year 2012/2013 show the overall category of SPADs at its lowest level. In the almost ten year time span of SPADs, the risks ranked as most severe have significantly decreased. This can be attributed to both improved training which includes significant emphasis on SPADs in addition to updates in technology.

 Furthermore, SPADs are categorised into classes, either a ‘Class A’ SPAD or ‘Class B’ SPAD. For example, a Category A SPAD is associated with a signal being passed whilst the aspect was clearly and correctly displayed in time for safe stoppage in front of the signal. In England and Wales CAT A SPADs have increased as shown in Table 5-10 (Network Rail, 2015), some of which have resulted in train derailment.

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</thead>
<tbody>
<tr>
<td>England &amp; Wales</td>
<td>255</td>
<td>272</td>
<td>247</td>
<td>234</td>
<td>274</td>
<td>277</td>
</tr>
<tr>
<td>Scotland</td>
<td>19</td>
<td>27</td>
<td>29</td>
<td>15</td>
<td>18</td>
<td>26</td>
</tr>
</tbody>
</table>

*Table 5-10 Category A SPADs in the UK (Network Rail, n.d)*
Figure 5-21 Chart 180 - Trend in the number of SPADs by risk ranking score (Office of Rail and Road, n.d)

5.3.7.5 Observational Failure Scenario 5 - Tunnelled versus open route section driving

This scenario considers what factors if any impact driver actions whilst in transit in tunnelled areas. This includes light conditions, spacing of signals and the effect of transitioning from a tunnelled area to an open route section of track. An example is drawn from construction of the Channel Tunnel. Debate and lobbying surrounded the impact on drivers driving through such a long tunnel in relation to factors such as fatigue or mesmerisation (Anderson & Roskrow, 2003). The Channel Tunnel is however an extreme case of tunnelling but nonetheless useful to consider.

5.3.7.6 Observational Failure Scenario 6 - Train collision

This scenario observes driver action when there is the potential for a train collision when two trains are incorrectly routed to approach on the same line. This includes use of emergency communication procedures.

5.3.7.7 Observational Failure Scenario 7 - Passenger Emergency Alarm Triggered

Depending on the rolling stock class, the reaction to the trigger of the passenger emergency alarm may be a partial brake. Alternatively the driver may have to take the action of stopping the train where detrainment is a viable action, which would most practicably and safely be at the next station.

5.3.7.8 Observational Failure Scenario 8 - Brake failure / Low Rail Adhesion

This has been examined in Chapter 4, Section 4-3.

5.3.7.9 Observational Failure Scenario 9 - Alternation of train length

A train’s configuration may consist of 4, 8 or 12 cars, for example, ‘the suburban network is limited to
A train driver must be cognisant of the train length as clearances at junctions for example may vary. This is in addition to the importance of car length for platform stopping positions. This observation will review driver behaviour in platform and junction areas.

5.3.7.10 **Observational Failure Scenario 10 - Warning System Alarms**

As part of a train's safety system, warnings are integrated to alert the driver. Warnings are there to signify non green signal aspects (for conventional signalled railways) and to monitor train speed so that it is maintained at a safe level. An emergency brake application may be applied if conditions are not met. However, this will not necessarily prevent the train from passing a signal at danger. This scenario observes the driver's acknowledgement of alarms and therefore adherence to alarms. For conventionally signalled railways the driver is provided with a visual indication in the train cab known as a 'sunflower' to show that they have acknowledged an alarm. ERTMS ETCS signalled railways on the other hand display via the DMI various warnings which relate to monitoring of the target speed.

![Figure 5-22 Overview of the main objects in the speed and supervision areas](image)

**Figure 5-22** Overview of the main objects in the speed and supervision areas (**European Railway Agency, 2010**) Pg 46

Figure 5-22 shows the key speed related information that is present on the DMI, Figure 5-23 on the other hand shows what is displayed on the DMI when intervention sets in, which occurs when the train speed exceeds the speed limit set for an intervention.
5.4 Summary

This chapter has carried out an assessment of safety based on the failure modes of safety critical systems. Mitigation measures that relate to safety culture were identified to address the failure, this includes training, operational procedures and methods of communication. The analysis demonstrates that failures can be mitigated by technical improvements in addition to safety culture practices. The comparison of European developments for railways that have been modernised by ERTMS showed that the lack of safety culture within an organisation could also inhibit progress. Examples include issues with stakeholder engagement, sharing knowledge on system developments and lessons learnt.

The operational tasks carried out by the driver are managed by procedures and can be represented in a number of ways as shown through the examples of HTA. This requires the full attention of the driver. The operational scenarios to be observed have been discussed in more detail with respect to the impact on safety. In some cases, safety can be improved by the speed of reaction to a situation or aggravated by a lack of understanding of the scenario.

An introduction to the driving environment which the safety assessment questionnaires and observations are centred upon, has highlighted the complexity of the interfaces and technology in the driving environment. The detail behind the questionnaire methodology in addition to the selected observational failure scenarios for safety assessment has been presented. The following Chapter now presents the results of the safety assessment in relation to the derived safety assessment process which incorporates safety culture as a mitigation to failure.
Chapter 6  Results

6.1  Background

Chapter 5 presented in detail failure mode analysis for existing and modernised railways to support the safety assessment that has been developed in this thesis. This is specifically via questionnaires and observational analysis. Where possible, these methods for safety assessment have been augmented with publicly available information and structured interviews. This chapter also uses the results of the observations and questionnaires to test the improved safety assessment process developed in Chapter 4.

The findings of 106 valid questionnaires in addition to observational cases to represent safety assessment analysis of an existing legacy signalled railway are presented in this chapter. To facilitate understanding of the impact of modernising European railways through the introduction of new technology, research carried out by MTO Sakerhet (Safety) and the Swedish National Road and Transport Research Institute (VTI) has been assessed.

Their research has been incorporated for comparison to the findings which have been obtained for existing conventionally signalled UK railways. MTO Sakerhet (Safety) are specialists and industry consultants in the safety domain. In particular, the Swedish safety consultants focus on human, technology and organisational related safety issues (Andersson & Rollenhagen, 2002) which are also the primary factors that constitute this research. The following subsections describe the key processes that have been utilised to support data analysis.

6.1.1  Research plan: Obtaining data

The initial research plan to issue the questionnaires designed for the analysis of ERTMS railways in the Netherlands was discontinued. The organisation in question was unable to proceed at the required schedule due to lack of resource and organisational change. However, the safety questionnaire that was developed for the train drivers of railways in the Netherlands is included in Appendix II for information. This now defunct questionnaire was written to compliment the questionnaire issued to Abellio Greater Anglia train drivers who have experience on UK mainline railways. As a result, data from Sweden which reflects ERTMS developments was utilised as described in Section 6.1.2 below.

6.1.2  ERTMS data from Sweden

The ERTMS data used in this thesis originates from research carried out by MTO Sakerhet (Safety). This research focuses on the usability and driveability of ERTMS on ERTMS fitted Swedish railway
lines (Nordlof & Kecklund, 2014). It also examines how drivers interact with the ETCS technology (Nordlof & Kecklund, 2014). This includes notifications and warnings that are presented on-board the train. In summary, their research investigates the impact of ERTMS on drivers in the operational environment. The data and statistics collected by MTO Sakerhet and VTI is analysed and compared to the data obtained from Abellio Greater Anglia, which is indicative of driving on conventionally signalled railways. This part of the research satisfies objective 3 ‘to identify the behavioural changes that have occurred to users of modernised railway systems’. As a result, observation of operational scenarios has been used to reinforce safe practices and to contribute to risk management. The method of observational analysis carried out by VTI differs to the method of observation carried out in this research, which solely employed the use of train simulators. VTI also made use of operational passenger routes to further validate results obtained from the simulated railway environment. The Swedish lines researched are the Ådal and Bothnia lines, both lines are fitted with ERTMS ETCS level 2 technology termed E2 in Sweden (Nordlof & Kecklund, 2014). The scope of their research is of particular relevance because not only does it capture ERTMS operation on a newly constructed line, as in the case of the Bothnia line but also integration of the technology into an existing railway as is the case of the Ådal line. The interest in this comparison can be related to mainline railway lines in the United Kingdom, the majority of which will have to integrate ERTMS technology and necessary subsystems on-board the train, trackside and wayside as railways harmonise. This aims to address and meet the European Union’s ideal for harmonised interoperable railways. The UK’s first attempt at implementing ERTMS was on the Cambrian line (Barrow, 2013) this line is not a complex route or heavily constrained by passenger usage. However, during development and incorporation of ERTMS technology a number of operational teething problems arose. This includes errors relating to release speeds and degraded mode speed limits. This resulted in trains travelling over long distances at slow speeds. Issues such as these have left the UK market with a wealth of lessons learnt material (Halcrow Group Ltd, 2012) which should be shared between stakeholders as the UK expands in its utilisation of ERTMS, for example as applied in the Crossrail project.

The research carried out by MTO Safety and VTI closely maps to the method of observation carried out for existing conventionally signalled railways i.e. use of a simulated environment. However, as previously noted the Swedish research is augmented with practical experience. The Swedish research specifically relates to driver training for the introduction of ERTMS technology whilst the UK research is based on existing conventionally signalled lines. MTO Safety and VTI have structured their research such that the qualitative data obtained from observations and interviews are summarised followed by statistical analysis.

As this research also utilises data that has been obtained from other sources in addition to that resourced through practical investigation, it is important to ensure that the Swedish data is of sufficient quality and validity for use as part of this thesis. The Swedish National Road and Transport Research Institute (VTI) satisfy this criteria as their works are certified by attainment of certification for quality management system ISO 9001 and environmental management system ISO 14001 (VTI, n.d). The organisation has good maturity with experience of providing independent and renowned research
across a number of industries with its library and information centre dating from the year 1920 (Sandstedt, 2012) (VTI, 2014). MTO Safety also has a wealth of experience in the safety domain working for a number of industries, which range from railways to the medical industry (MTO Sakerhet, 2013). Consequentially the data obtained from Swedish sources is deemed reliable and of good quality for use in this thesis.

The following subsections explain the results obtained from safety assessment of existing mainline railways and compares them to the Swedish results carried out by MTO Safety and VTI. The Swedish results have been further validated by interviews held in Linkoping Sweden with the SMEs from VTI who carried out part of the research on the Bothnia and Ådal signalled railways. The SMEs from VTI demonstrated the capability of the simulators and the software in regard to driver training. Furthermore, issues identified by the Swedish train drivers detailed within this chapter were simulated so that appreciation of the issues could be attained. The following sections also describe the statistical differences that have been identified and draw conclusions regarding the applicability of safety culture to mitigate risk or enhance safety practices.

Upon collection of all populated questionnaire material from UK drivers at Abellio Greater Anglia the responses were filtered to remove those which were deemed inadmissible. This included issues such as legibility, inconsistencies in responses or where there were multiple options selected. This filtering approach was consistent for each questionnaire response reviewed. In order to interpret the results of the questionnaire designed based on the 5 point Likert scale, the questionnaire was coded as a means to evaluate the data. The statistics modelling software IBM SPSS Version 22 offered an efficient alternative to Microsoft Excel to support analysis. The data analysis and results obtained conclude steps 7, 8 and 9 of the methodology required for questionnaire analysis as detailed in Chapter 5. In addition to the questionnaires, the second avenue to obtain data was via observational scenarios, of which the key findings are presented.

The following subsections present results of the characteristics of interest to this research, which affect the train driver in the railway environment. Prior to delving into the quantitative results the qualitative aspects of the questionnaire are reviewed to set the scene.

### 6.1.3 Desired Dataset Requirements

This research required datasets to be gained through questionnaire and observation of European railways that implement ERTMS technology. This aimed to provide constructive comparison to datasets obtained based on UK mainline railways. However, this like for like comparison could not occur due to organisational issues with the European organisation in the Netherlands who were in agreement to support this research. The questionnaire has therefore been compared to a dataset which has significant similarities to the type of information that would have been yielded from the study in the Netherlands as discussed in Chapter 5.
The population of train drivers who completed the questionnaire represent a sample of the larger employee group. Therefore the samples obtained are used to draw conclusions about the entire population of drivers. However, the validity of the questionnaire responses also impacts the accuracy of the dataset.

The sample size was constrained by the availability of train drivers, this varied based upon the training schedule for a particular week. As a result, the requirements for the obtained dataset include the following attributes:

- The level of train driver experience and training is clearly identifiable;
- The impact of the train design can be fully examined;
- Technical on-board interfaces to the train driver can be evaluated (this includes alarms and communication systems);
- The impact of failures can be observed;
- Causal factors and lesson learnt activities are demonstrated;
- Factors that can influence failure are observable such as distraction or workload;

6.1.4 Data Quality

Quality is viewed from two perspectives (i) that of the measured data, in addition to the (ii) quality of the questionnaire design.

The topic of quality has been examined in a range of academic literature, such as (Brancaleone & Chin, n.d.) and (Brackstone, 1999). A poorly designed questionnaire can affect the response rate and engagement of those participating. Furthermore, measured data also requires consideration of key factors as identified by (Brackstone, 1999) termed dimensions of data quality, examples of which are detailed below in Table 6-1.

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>a. Relevance</strong></td>
<td>Whether the data meets the initial research requirements.</td>
</tr>
<tr>
<td><strong>b. Accuracy</strong></td>
<td>The degree to which the statistical data correctly describes the phenomena to be measured.</td>
</tr>
<tr>
<td><strong>c. Timeliness</strong></td>
<td>The date at which information becomes available.</td>
</tr>
<tr>
<td><strong>d. Accessibility</strong></td>
<td>The ease in which data can be obtained.</td>
</tr>
<tr>
<td><strong>e. Interpretability</strong></td>
<td>The availability of supplementary information.</td>
</tr>
<tr>
<td><strong>f. Coherence</strong></td>
<td>The degree to which the statistical information can be brought together.</td>
</tr>
</tbody>
</table>

Table 6-1 Dimensions of data quality
6.1.5 Data Reliability

As stated in the methodology, the questionnaire was constructed based on the Likert scale. With a scale such as this, it is important that the reliability is tested. That is, if the questionnaire is conducted and completed at two different points in time, the same score should be arrived at (Field, Discovering Statistics Using IBM SPSS Statistics, 2005). Therefore, to test the reliability of the scale for each sub section of the questionnaire and hence validate its internal consistency, Cronbach’s Alpha (α) has been used as discussed in section 6.3.1. The reliability of a questionnaire can be tied to the validity of a questionnaire, that is, the questionnaire cannot be valid unless it is reliable (Nunnally & Bernstein, 1994). A good range for Cronbach’s α has been debated by a number of statisticians including (Field, 2005 and Nunnally and Bernstein, 1994) with good values ranging from α= 0.7 to 0.95. However, it is essential to note that a lower value does not totally invalidate its reliability because a low value can be attributed to poor correlation or an insufficient data set.

6.1.6 Descriptive Statistics

Initial quantitative analysis utilising descriptive statistics enables the collated data to be described in a useable format. For example, descriptive statistics are useful when considering means, medians, frequencies and standard deviations of demographic information. This has been presented in this thesis. There are various levels of descriptive analysis that can be carried out in addition to those mentioned above. More complex descriptive analysis methods include use of cross tabulations to assess the relationships between selected variables, all of which are possible to explore via the IBM SPSS tool.

6.1.7 Correlation Analysis

The descriptive section of the questionnaire as shown in Appendix II collates descriptive facts about the train drivers such as age, gender, length of service in their current role, length of service in the railway and weekly working hours. In order to evaluate the strength of linear relationships between variables and to identify how strong the relationship is Pearson’s $r$ is used. Pearson’s $r$ is a statistical method, which allows levels of correlation. Where correlation is defined here as: ‘a number that measures the strength and direction of a linear relationship between X and Y’ (Rumsey, 2009).

- Positive correlation - with this type of correlation both variables increase in value;
- Negative correlation – The variables act in an opposing way, as one variable increases in value the other variable decreases in value;
- Therefore figuratively, a value that approaches 1 or -1 shows a strong relationship. Conversely a value that is close to 0 identifies a weak relationship.
- No correlation – This is demonstrated when there is no increase or decrease in the other variable;
Correlations between the descriptive data have been calculated using IBM SPSS V22. The correlation table described further on in this chapter show the Pearson’s value, the Significance value and the N value. Evan’s classification of correlation is used here (Evans, 1996) whereby the following is suggested for r, which can be positive or negative:

- 0.00-.19 equates to a very weak r and indicates a negligible relationship.
- .20-.39 equates to a weak r and indicates a weak relationship.
- .40-.59 equates to a moderate r and indicates a moderate relationship.
- .60-.79 equates to a strong r and indicates a strong relationship.
- .80-1.0 equates to a very strong r and indicates a very strong relationship.

6.1.8 Ordinal Regression

Ordinal regression has been carried out as part of the data analysis using the Polytomous Universal Model (PLUM) (IBM SPSS V22). This method looks at rank ordering within data and makes the following assumptions:

(i) Likert items (the dependent variable) are ordinal variables.
(ii) One or more of the variables is continuous/ordinal/categorical (or dichotomous).
(iii) Proportional odds (parallel lines) – ‘The assumption is that the effects of any explanatory variables are consistent (proportional) across the different thresholds (by thresholds we mean the splits between each pair of categories of your ordinal outcome variable)’ (National Centre for Research Methods, 2011).

- Model fitting information is obtained via SPSS. This model fitting method indicates the measure of error in the model using the intercept only which is compared to the final model which uses the explanatory variable (National Centre for Research Methods, 2011). The comparison between the models looks for an improvement in the models fit via the -2 log likelihood and Chi Square results. A significant Chi Square (p<.0005) shows that there is an improvement and that better predictions can be made (National Centre for Research Methods, 2011).
- The next statistic output is the goodness of fit, which tests the adequacy of the model. Pearson’s Chi Square test is used to assess the goodness of fit. Using the Null Hypothesis, that the model has a good fit, this hypothesis is not rejected.
- The Test of Parallel Lines is used to test the Proportional Odds Assumption otherwise known as the Test of Parallel Lines (Statistical Consulting Group, n.d.). The Null hypothesis states that the location parameters (slope coefficients) are the same across the response categories (IBM SPSS, 2014). The Logit model has been used to estimate across all levels that comprise the response variable. For this model, since Chi Square > 0.05 the proportional odds assumption is upheld.
6.1.9  **Factor & Principle Component Analysis**

Factor analysis is a method commonly employed in statistics to assess an underlying data structure as demonstrated by (Wang & Liu, 2012). In their research, use of factor analysis provided an insight into the safety culture dimensions present in the Taiwan railway industry. Furthermore, this method for statistical analysis is used in a number of domains particularly in psychological research (Fabrigar, MacCallum, Wegener, & Strahan, 1999). This research however, employs a similar method, namely Principal Component Analysis (PCA). PCA is used to determine the key outputs and to determine how the data can be structured for further analysis.

As per the flow diagram depicted in Figure 6-2 exploratory factor analysis is reviewed as part of the data analysis. This method is also often and mistakenly interchanged with Principal Component Analysis (PCA). The theory behind this method focuses on reduction of data which is achieved based on specific inter-correlations within a data set. The fact that this method is exploratory relates to its objective, that is, to obtain initial relationships. The initial theories can then be verified or explored via confirmatory factor analysis (Wuensch, 2012). However, its ability to generate and represent a structure has been questioned and debated (Fabrigar et al., 1999). For example, it is highlighted that spurious factors may emerge if the sampling is inadequate, hence inhibiting underlying factors of importance and obscuring them (Cattell, 1978). On the other hand, this research has made use of the Principal Component Analysis (PCA) methodology to reach a conclusion about the underlying constructs to the questions posed to the drivers of mainline railways signalled conventionally. This method has been chosen as it is a good tool for practical analysis. The main difference between Factor Analysis and PCA is the outcome, which in the case of Factor Analysis are ‘factor’s and for PCA, the outputs are ‘components’. However SPSS extracts the components and labels them as factors.

There are different thoughts on the sample size required to give the best statistical results, nonetheless, relatively small samples of less than N=100 have proven ample. However, in an ideal scenario a sample of more than 300 would be more reliable (Field, 2009). The Kaiser – Meyer – Olkin (KMO) measure of sampling is employed prior to conducting the analysis. A KMO value within the range 0.5 to 1.0 indicates that analysis of factors/components is an appropriate method to utilise. However, within this range there is a further demarcation for sufficiency. For e.g. a KMO between 0.5 and 0.7 is mediocre, a KMO between 0.7 and 0.8 is good and a KMO between 0.8 and 0.9 is excellent (Field, 2009).
6.1.10 Potential Errors in a Dataset

During the process of data collection and subsequent data evaluation there is the potential for error to occur or be introduced. This ranges from erroneous responses to the survey questions, lack of response, to incorrect processing of the data. Further still, data may be omitted unintentionally which can impact the resultant conclusions that are drawn. In terms of the questionnaire design, use of SMEs to validate the questionnaire aimed to support mitigation against errors.

Ideally a greater sample size would have been employed such that the sampling error would be reduced.
6.2 Questionnaire Results: Supplementary Information

As described in Chapter 5, as part of the questionnaire structure train drivers were presented with the opportunity to supplement their Likert responses with additional commentary. As a result, qualitative data has also been gathered and is discussed in this section. The qualitative data gathered is a mixture of opinions based on driver observations and experience and satisfies the ‘interpretability’ data quality dimensions highlighted by (Brackstone, 1999).

As a starting point, the quality of the qualitative data was reviewed. This quality check included (i) determining whether the comments made sense and (ii) whether it is value added information. Following this, the data was analysed via content analysis. This approach entails interpretation of narrative data (Taylor-Powell & Renner, 2003). Interpreting the data allows connections to be identified. Following which coding of the data is possible. Coding or categorisation of the qualitative information means that patterns and coherent categories can be identified (Taylor-Powell & Renner, 2003). The coding is based on themes that have been identified as common. In a number of cases there are multiple applicable themes across the different sections examined in the questionnaire. As part of the data analysis the interpretation of the issues raised by the drivers are explored with recommendations made where applicable.

The questionnaire targeted responses in relation to three key areas, namely:

1. Staff training
2. The cab environment and technology and
3. General safety culture related questions

The qualitative results obtained from the supplementary comments have thus been presented to reflect the approach taken. This also aligns to the structure of the questionnaire. The response rate varied significantly for each of the three sections of the questionnaire. The first section had a very low response rate compared to the latter sections of the questionnaire. This can be attributed to a number of factors, for example, the issue may have already been addressed via the preceding Likert scale options of the questionnaire and as a result there were no further comments.
6.2.1 Supplementary Information: Staff Training

Of the 106 valid questionnaires received from the train drivers for the supplementary responses on staff training, a 2% response rate was obtained. This low response rate was unexpected, however as this section was supplementary it did not form part of the likert scale questions. A better response rate would have been useful for exploratory purposes to identify a greater depth of views. This figure of 2% is thus insufficient to draw detailed exploratory conclusions. However, shown below are examples of the issues raised relating to staff training:

1. There is use of briefings in addition to use of non-technical skills tools;
2. One particular driver commented that he passed out for BR as a driver and that this type of training was new.

The conclusion drawn from the commentary provided is that Abellio Greater Anglia is proactively placing emphasis on safety via briefings and soft skills training. This is required for character development and to promote engagement on key safety culture issues throughout the organisation. Furthermore, this format of training may be new to drivers who begun their career under a different railway regime. Thus a level of adaptation is required by both the organisation and employees.

6.2.2 Supplementary Information: The cab driving environment and technology

This section reviews the various responses that were made by the train drivers in relation to the train cab design. This includes the cab environment and technology. This also includes feedback about alarms within the cab environment and finally responses in relation to the perceived advantages and disadvantages of the design of a train cab.

6.2.2.1 Train Cab Design

As discussed at the start of this chapter, analysis of qualitative data can be simplified through use of coding. Coding has been used where common themes have been identified in the driver responses and as such the following coding has been applied.

1. Noise - Noi: Feedback from drivers that relate to noise issues.
2. Equipment – Equ: Feedback from drivers that relate to issues with equipment.
5. Safety Culture – SC: Feedback related to potential issues that could impact safety culture or occur as a result of poor safety culture.
6. Not Applicable – NA: Feedback not particularly applicable to the posed question. However, it is noted that the response may be applicable to the research as a whole so may be addressed elsewhere as is appropriate.

7. Other – Other issues raised.

Table 6-2 details the supplementary information received from the train drivers. Compared to the previous case which related to staff training, this has seen an improved response rate. For each case that details the driver response, the response has been supplemented with an interpretation that relates to the impact on safety. This for example, could be a safety impact for the drivers or to the organisation.
<table>
<thead>
<tr>
<th>Questionnaire ID</th>
<th>Other industry experience</th>
<th>Driver response on supplementary questions related to train cab driving environment</th>
<th>Coding</th>
<th>Interpretation of the Driver response</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td>The driving conditions when the weather is hot or cold are very bad. Noise levels are very high if equipment actually works.</td>
<td>HVAC, EQU and NOI</td>
<td>The internal environment has an impact on the comfort of the driver this includes the operation of the HVAC system. The ambient noise has been raised as an issue of concern emanating from the equipment. If this is a constant and significant problem and the noise is sufficiently high this can result in hearing loss induced by noise. The final issue relates to equipment malfunction and testing, equipment should have a testing and maintenance regime in place as part of good practice.</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>The cabs end up being too hot or too cold because they cannot be switched off, having to constantly switch between the two can be distracting.</td>
<td>HVAC and ERG</td>
<td>This is a HVAC issue, which is exacerbated by the design of the system. This driver also mentions the issue of distraction, this moves the focus away from the primary operational task.</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>Railway infrastructure is failing more than ever. It is good to have regular general calls, to allow us to keep customers informed.</td>
<td>NA</td>
<td>Marked as not applicable as it does not specifically relate to the design of the train cab. As infrastructure relates to civil structures such as track foundations. However it is appreciated that this may impact the driving style.</td>
</tr>
<tr>
<td>14</td>
<td>Automotive sales and customer service</td>
<td>In relation to question 13. Although greater safety levels are achieved, it is paramount that driver instinct does not give way to complacency.</td>
<td>NOI</td>
<td>This relates to communication channels and a positive comment has been made in relation to interfaces with the passengers.</td>
</tr>
<tr>
<td>22</td>
<td></td>
<td>Please be aware that we work shifts so hours can change week to week.</td>
<td>NA</td>
<td>NA to the train cab driving environment.</td>
</tr>
<tr>
<td>Questionnaire ID</td>
<td>Other industry experience</td>
<td>Driver response on supplementary questions related to train cab driving environment</td>
<td>Coding</td>
<td>Interpretation</td>
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<td>--------------------------------------------------------------------------------</td>
<td>--------</td>
<td>----------------</td>
</tr>
<tr>
<td>31</td>
<td>Automotive and aviation</td>
<td>The refurbished 317’s are not driver friendly. That is, no new cab layout, no new seat, no new windows, still the same as when they were made 30 years ago.</td>
<td>ERG and EQU</td>
<td>This driver has identified fault with the ergonomics and equipment modernisation within the 317 Stock. All of which can affect the operational style of a driver.</td>
</tr>
<tr>
<td>46</td>
<td>Banking</td>
<td>The driver respondent felt that there is greater trust in railway infrastructure. However noted that if you are asking passengers they would probably say their trust in the railway is not particularly good.</td>
<td>NA</td>
<td>NA to the train cab driving environment. This could be noted as a safety culture issue.</td>
</tr>
<tr>
<td>55</td>
<td>Construction / Royal Air Force</td>
<td>379 unit not good design in cab. Right hand side visibility is poor.</td>
<td>ERG and SC</td>
<td>Partial good design however poor visibility can induce a number of issues such as non-compliance to the HSW 1974 and compromised safety for the driver.</td>
</tr>
<tr>
<td>56</td>
<td>Finance, LGV Driving and Army</td>
<td>I would like driver hours and shifts to be investigated and revised. Too many drivers operate and begin work feeling tired and exhausted</td>
<td>SC</td>
<td>This is a safety culture issue that needs to be reviewed as a fatigued driver can act incorrectly in error with fatality as a possible consequence.</td>
</tr>
<tr>
<td>59</td>
<td>Airline</td>
<td>Conversely the quiet alarm (i.e. AWS alarm) are of greater concern.</td>
<td>NOI</td>
<td>Issue and associated impact of noise</td>
</tr>
<tr>
<td>73</td>
<td>-</td>
<td>Still a conflict between drivers and signalers as drivers find more out through customers on twitter before the signaler informs or differs from information given.</td>
<td>NA</td>
<td>It is assumed that this driver feels that there is a lack of communication of real time issues, faults and failures.</td>
</tr>
<tr>
<td>94</td>
<td>-</td>
<td>I don't think enough attention is paid when old cabs/traction units/locos are fitted with add-ons</td>
<td>ERG and EQU</td>
<td>Issue with design retrofit and the resultant ergonomics of using the equipment.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corridor units with gangway connections have poorer overall visibility</td>
<td>ERG and EQU</td>
<td>Poor visibility caused by design can induce a number of issues such as non-compliance to the HSW 1974.</td>
</tr>
<tr>
<td>104</td>
<td>-</td>
<td>New layout can only improve if the drivers are involved</td>
<td>SC, ERG and EQU</td>
<td>This driver implies that a better relationship, that is, a facet of safety culture needs to be formed between the train drivers and the organisation such that there is a cohesive working relationship. The drivers as the end users would benefit the design process in addition to operational representatives as first hand and lessons learnt information would be readily available.</td>
</tr>
</tbody>
</table>

Table 6-2 Supplementary Information – Train cab environment
A number of issues have been raised which do not specifically relate to the task of operating the train but instead relate to the factors which surround the driver such as noise. However, other important physical and functional issues such as equipment malfunction and ergonomic issues have also been raised in a number of cases.

The key findings from the train driver responses are summarised as follows:

- The impact of fatigue in two cases at the start of a shift in addition to fatigue towards the end of a shift. Fatigue can initiate a catalogue of errors; this has been verified by simulator studies (Thiffault & Bergeron, 2003). Use of simulators has shown the impact of fatigue on road drivers with a relationship to monotony. This is something that train drivers can also encounter dependent on the topology of the railway network. Therefore it is important to assess fatigue in relation to causation of accidents and incidents.

- Retrofitting – Incorporation of new components. This has shown to have a negative impact. As demonstrated by Western Railway in India who are phasing out retrofitted trains (Rao, 2013). Issues with train acceleration, deceleration and braking system have brought about this change. UK trains are less likely to have a propensity for such issues as the trains are built with sophisticated technology. However, this may be applicable to older trains.

- Compliance to legal frameworks this includes design issues that contravene the HSW.

- Ambient conditions (HVAC system control, the potential for back up and design redundancy of the HVAC system).

- Noise - from equipment, communication and external surroundings.

It is clear that whilst driving a train the driver will have to multitask. This requires safe operation of the train in an environment where there are instances of noise and distraction. The train has a number of safety systems which incorporate alarms; this includes the Automatic Warning System (AWS) and the Train Protection Warning System (TPWS). Both of these systems are briefly discussed in Chapter 2 of this thesis. Alongside these systems are other forms of communication and notification that is presented to the driver. This is therefore explored in the following subsection in relation to the question posed to the train drivers. That is, for it to be identified which alarms were found to be either too loud or distracting. The responses are depicted below in Table 6-3. This section of the questionnaire received good response from the drivers and common themes ‘coherence’ and ‘interpretability’ are demonstrated as per Table 6-1.
### 6.2.2.2 Cab Environment – Alarms Either too Loud or Distracting

<table>
<thead>
<tr>
<th>Questionnaire ID</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AWS on 315 unit.</td>
</tr>
<tr>
<td>2</td>
<td>AWS warning is too loud, especially on prep when it is done repeatedly.</td>
</tr>
<tr>
<td>4</td>
<td>AWS horns are loud on some trains.</td>
</tr>
<tr>
<td>5</td>
<td>none - there is occasional over use of general call.</td>
</tr>
<tr>
<td>7</td>
<td>AWS</td>
</tr>
</tbody>
</table>
| 8                | AWS horn  
|                  | Clear ping |
| 9                | Vigilance alarm |
| 10               | Vigilance alarm - distracting  
|                  | AWS can be loud on some units |
| 11               | None, the louder the alarm the better as it makes you more aware. |
| 12               | DSD, VIS |
| 13               | AWS alarm is far too loud in some cabs. |
| 20               | AWS horn is too loud.  
|                  | AWS alarms are sometimes too loud or too quiet.  
|                  | GSM-R sound can sometimes be distracting. |
| 24               | AWS is sometimes so loud it is painful. |
| 25               | AWS/radio  
|                  | PIS too bright |
| 27               | Vigilance can be distracting. |
| 28               | AWS/TPWS |
| 31               | AWS horns on some trains exceed 90db. |
| 32               | Some AWS warnings are very loud but seem to vary.  
<p>|                  | Some GSM-R announcements are maybe too repetitive in some circumstances. |
| 35               | The bell in some units can be too loud, I think the horn should be louder. |
| 38               | AWS |
| 39               | The GSM-R ringing for a general call. Maybe just ring for an incoming call. |
| 40               | Searching networks when GSM-R loses a network and the constant repeating of general call messages is distracting. |
| 41               | none |
| 42               | General calls are too frequent |
| 43               | Some AWS alarms can be very piercing. |
| 44               | AWS |</p>
<table>
<thead>
<tr>
<th>Questionnaire ID</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>AWS/TPWS alarm especially when the cab is opened up.</td>
</tr>
<tr>
<td>48</td>
<td>315 bell, 321 AWS warning horn and sometimes the vigilance device</td>
</tr>
<tr>
<td>49</td>
<td>TPWS</td>
</tr>
<tr>
<td>51</td>
<td>AWS too loud, vigilance is very distracting.</td>
</tr>
<tr>
<td>52</td>
<td>DSD left in F/R</td>
</tr>
<tr>
<td>54</td>
<td>AWS horn</td>
</tr>
<tr>
<td>55</td>
<td>Some AWS warning sounds are too quiet and some are too loud. There is no consistency.</td>
</tr>
<tr>
<td>56</td>
<td>AWS warning horn, DSD/VIS</td>
</tr>
<tr>
<td>58</td>
<td>AWS</td>
</tr>
<tr>
<td>59</td>
<td>Trivial alarm on new 379 which highlights the smallest of problems can be a distraction.</td>
</tr>
<tr>
<td>60</td>
<td>AWS alarm on certain units</td>
</tr>
<tr>
<td>62</td>
<td>Can vary unit to unit</td>
</tr>
<tr>
<td>63</td>
<td>On some units AWS warnings are often very loud</td>
</tr>
<tr>
<td>64</td>
<td>Sometimes AWS varies train to train</td>
</tr>
<tr>
<td>65</td>
<td>Desk opening TPWS test for 5 seconds</td>
</tr>
<tr>
<td>66</td>
<td>AWS sometimes</td>
</tr>
<tr>
<td>68</td>
<td>AWS</td>
</tr>
<tr>
<td>70</td>
<td>AWS / TPWS on some units</td>
</tr>
<tr>
<td>71</td>
<td>Fault warning on the 379 unit</td>
</tr>
<tr>
<td>76</td>
<td>AWS / TPWS</td>
</tr>
<tr>
<td>77</td>
<td>AWS depending on what you are driving.</td>
</tr>
<tr>
<td>80</td>
<td>AWS</td>
</tr>
<tr>
<td>81</td>
<td>AWS warning horn can be too loud.</td>
</tr>
<tr>
<td>82</td>
<td>AWS bell</td>
</tr>
<tr>
<td>85</td>
<td>AWS</td>
</tr>
<tr>
<td>86</td>
<td>AWS warning horn</td>
</tr>
<tr>
<td>89</td>
<td>AWS</td>
</tr>
<tr>
<td>90</td>
<td>AWS Bell</td>
</tr>
<tr>
<td>91</td>
<td>AWS on some units</td>
</tr>
<tr>
<td>92</td>
<td>AWS/TPWS</td>
</tr>
<tr>
<td>93</td>
<td>Varies by cab</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>94</td>
<td>Vigilance</td>
</tr>
<tr>
<td>99</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>On some units the AWS alarms/bells are quite noisy even after reporting.</td>
</tr>
<tr>
<td>102</td>
<td>Vigilance TWPS</td>
</tr>
<tr>
<td>103</td>
<td>AWS</td>
</tr>
<tr>
<td>106</td>
<td>none</td>
</tr>
</tbody>
</table>

**Table 6-3** Supplementary Information – Alarms
Table 6-3 and Figure 6-1 present the response from train drivers in relation to the alarms which were found to be either loud or distracting. Table 6-3 provides direct quotations and descriptions. Some drivers identified more than one alarm type as being in this category. The Automatic Warning System (AWS) alarm in the main was found to be too loud or distracting. This was followed on a lesser scale by the GSM-R system alarm which has been categorised to also include general call and the Driver Safety Device (DSD) both of which are via cab radio. Comparatively, a small percentage (approximately 6%) of the responses received stated that neither of the alarms were either too loud or distracting with one particular respondent indicating that alarms are a good feature because ‘the louder the alarm the better as it makes you more aware’ (Questionnaire ID 11). This is clearly converse to the majority of statements. Of particular interest was the following statement ‘AWS is sometimes so loud it is painful (Questionnaire ID 24). Being subject to noise over a long period of time can cause damage to the ear in addition to discomfort. This issue needs to be raised to management to ensure driver well being is not compromised. Further to this, there are also instances of drivers stating that there is not enough consistency in the AWS system pitching across the train stocks (Questionnaire ID 63 and 64). There are a number of implications that can be associated with alarm design and the impact on the drivers. This includes a medical problem known as alarm fatigue, this is a subject which has been significantly researched in the field of patient safety.
(Sendelbach & Funk, 2013) within the medical industry. Unlike the medical industry, the alarms issued to the train drivers are not likely to be false alarms. However, there is still the risk of overloading the senses.

The comments provided by the train drivers are part of the wider picture that comprise railway safety. As the results have not only drawn focus to the issue of the alarm pitch or to the distraction factor that can arise it is recommended based on this sample of responses that more research in carried out in relation to the impact of AWS alarms which could potentially lead to design optimisation (AAMI, 2011).

The train drivers have also highlighted GSM-R communication as an issue. Specifically in instances where there is a general call which is usually broadcast to trains in a specific area. This may be a distraction if the call is not particularly applicable to the train driver. Also in an emergency, either a point to point call, that is between the signaller and a driver directly can occur. Alternatively, an emergency group call which is signaller communication to multiple trains can also occur (Rail Safety and Standards Board, 2012). GSM-R is a significant change for some drivers as there was previously the option for drivers to deregister from the GSM-R network and switch to the National Radio Network (NRN) (Rail Safety and Standards Board, 2012). NRN is no longer operational; therefore this is no longer an option. It is pointed out that there would be a preference for the GSM-R ringing to occur when there is a specific point to point call rather than for all general calls. Also, the repetitive nature of some of the general calls could also be reduced. It is also considered that repetition may have adverse effects on a driver, leading to the possibility of an impact on the prioritisation of operational tasks. This is not proven, but is merely an assumption and would need significant further study to verify this presumption. Although in terms of learning, repetition is known to be a common tool to aid memory.

This section has focused on the alarms that have been indicated as either being either too loud or distracting, it is also noted that other alarms were also raised in this category but to a lesser degree than those discussed.
6.2.2.3 Cab Environment – Advantages and Disadvantages of Cab design

As per section 6.1.2.1 coding has been implemented to assess the train driver responses in relation to what was found to be either an advantage or disadvantage of the train cab design detailed in Table 6-4. The themes developed marry to those identified previously in Section 6.1.2.1 and are detailed as follows:

1. Noise - *Noi*: Feedback related to noise issues. This could be noise emanating from in cab equipment or cab design which allows outside noise into the train cab.
2. Equipment – *Equ*: Feedback related to issues with equipment, this includes equipment malfunction.
5. Safety Culture – *SC*: Feedback related to potential issues that could impact safety culture or occur as a result of poor safety culture.
6. Not Applicable – *NA*: Feedback not particularly applicable to the posed question. However, it is noted that the response may be applicable to the research as a whole so may be addressed elsewhere as is appropriate.
7. Other – Other issues raised that do not fall into the categories above but are of applicability or of interest to this research.
<table>
<thead>
<tr>
<th>Questionnaire ID</th>
<th>Advantage of cab design</th>
<th>Coding</th>
<th>Disadvantage of cab design</th>
<th>Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>315 unit good space</td>
<td>Erg/Des</td>
<td>Buttons in silly places</td>
<td>Erg/Des</td>
</tr>
<tr>
<td></td>
<td>379 unit comfortable</td>
<td></td>
<td>Air conditioning does not always work</td>
<td>HVAC</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td></td>
<td>Noise can be a distraction e.g. heating and air fans</td>
<td>HVAC, Noi</td>
</tr>
<tr>
<td>3</td>
<td>Air con and heating</td>
<td>HVAC</td>
<td>Area is quite cramped, small working area</td>
<td>Erg/Des</td>
</tr>
<tr>
<td>4</td>
<td>The driver's view</td>
<td>Erg/Des</td>
<td>Temperature control and vibrations</td>
<td>HVAC</td>
</tr>
<tr>
<td>5</td>
<td>Clear view ahead</td>
<td>Erg/Des</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>New technology aids driving</td>
<td>Equ</td>
<td>Often noisy air conditioning units</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Less room due to cramming in equipment</td>
<td>Erg/Des, Equ</td>
</tr>
<tr>
<td>9</td>
<td>Good space, much room</td>
<td>Erg/Des</td>
<td>Not enough drink holders which is vital in summer</td>
<td>Other – Comfort related</td>
</tr>
<tr>
<td>10</td>
<td>Keeps you alert</td>
<td>Noi</td>
<td>Too hot in summer, often very loud with air con on</td>
<td>HVAC</td>
</tr>
<tr>
<td>12</td>
<td>Good design for ease of use</td>
<td>Erg/Des</td>
<td>Air con controls hot/cold no 'off'</td>
<td>HVAC</td>
</tr>
<tr>
<td>13</td>
<td>Equipment, controls close to hand</td>
<td>Erg/Des, Equ</td>
<td>Noise, temperature when the air con is defective.</td>
<td>HVAC</td>
</tr>
<tr>
<td>14</td>
<td>Class 379 is comfortable, climate controlled with excellent safety systems</td>
<td>HVAC</td>
<td>All units can have faults that affect concentration and or safety.</td>
<td>Equ</td>
</tr>
<tr>
<td>18</td>
<td>Better view of lie ahead with larger windows</td>
<td>Erg/Des</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>Good heating</td>
<td>HVAC</td>
<td>AWS horn is too loud</td>
<td>Noi</td>
</tr>
<tr>
<td>21</td>
<td>Keeps you alert</td>
<td>Noi</td>
<td>AWS could cause distraction</td>
<td>SC</td>
</tr>
<tr>
<td>22</td>
<td>Clean</td>
<td></td>
<td>Cramped conditions, too much to look at and check</td>
<td>Erg/Des, Equ</td>
</tr>
<tr>
<td>24</td>
<td>Cheap to maintain</td>
<td>NA</td>
<td>Uncomfortable</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cold in winter</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Poor view</td>
<td>Erg/Des, Equ</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Old technology</td>
<td>Erg/Des, Equ</td>
</tr>
<tr>
<td>25</td>
<td>Less announcements</td>
<td>NA</td>
<td>Brake gauge too bright - PIS</td>
<td>Equ</td>
</tr>
<tr>
<td>28</td>
<td>Modern cabs are more comfortable and ergonomic</td>
<td>Erg</td>
<td>Sometimes discomfort can aid concentration</td>
<td>Erg/Des</td>
</tr>
<tr>
<td>33</td>
<td>Everything is there</td>
<td>Erg, Equ</td>
<td>Noisy</td>
<td>Noi</td>
</tr>
<tr>
<td>34</td>
<td>More information and help</td>
<td>SC</td>
<td>Too cluttered</td>
<td>Erg/Des, Equ</td>
</tr>
<tr>
<td>35</td>
<td>No real advantage, but I think a bin should be placed in the cabs.</td>
<td>NA</td>
<td>Sometimes cold in the cabs.</td>
<td>HVAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Better concentration</td>
<td>SC</td>
<td>Uncomfortable environment</td>
<td>Erg/ Des</td>
</tr>
<tr>
<td>37</td>
<td></td>
<td></td>
<td>Potential distractions</td>
<td>Other</td>
</tr>
<tr>
<td>38</td>
<td>Air conditioning is better for cab environment.</td>
<td>HVAC</td>
<td>Some driving positions are uncomfortable (i.e.) 153 desk does not have enough room.</td>
<td>Erg/ Des</td>
</tr>
<tr>
<td>41</td>
<td></td>
<td></td>
<td>Poor comfort, wind noise, heating fan in 321 blows hot air in face and there is no direction.</td>
<td>HVAC</td>
</tr>
<tr>
<td>44</td>
<td>315/317 - Good air con and heating system when working. It would be better if the air con could stay on when the cab is not in use.</td>
<td>HVAC</td>
<td>379 is too noisy and the air ventilation is poor.</td>
<td>HVAC</td>
</tr>
<tr>
<td>46</td>
<td>-</td>
<td></td>
<td>Are driver's asked their opinions with designs?</td>
<td>Other</td>
</tr>
<tr>
<td>47</td>
<td>-</td>
<td></td>
<td>379 - low visibility for spatial awareness</td>
<td>Erg/ Des</td>
</tr>
<tr>
<td>48</td>
<td>Most used controls are close to hand</td>
<td>Erg/ Des</td>
<td>Maintenance: air con, wipes, cleanliness</td>
<td>Equ</td>
</tr>
<tr>
<td>49</td>
<td></td>
<td></td>
<td>Noise from TPWS and AWS can hurt the ear.</td>
<td>Noi</td>
</tr>
<tr>
<td>50</td>
<td>None</td>
<td>SC</td>
<td>Too noisy, cramped, dirty, air con is no good.</td>
<td>Noi, HVAC</td>
</tr>
<tr>
<td>52</td>
<td>More comfortable, better air conditioning</td>
<td>HVAC</td>
<td>379 visibility is restrictive, there is more working out /across to second man's side. Obviously, the more time spent in these units you become more familiar. Views can be restrictive due to centre/middle structure (379 unit)</td>
<td>Erg/ Des, SC and Equ</td>
</tr>
<tr>
<td>53</td>
<td>-</td>
<td></td>
<td>Not enough room</td>
<td>Erg/ Des and Equ</td>
</tr>
<tr>
<td>54</td>
<td>None</td>
<td>SC</td>
<td>Cabs are cramped, noisy, hot and dirty and have not been upgraded for years.</td>
<td>Erg/ Des and Equ</td>
</tr>
<tr>
<td>55</td>
<td>When air conditioning is working it is an advantage</td>
<td>HVAC</td>
<td>379 unit fans are too noisy and almost a distraction</td>
<td>Noi</td>
</tr>
<tr>
<td>56</td>
<td>360 Comfortable/easy to use AWS cancel</td>
<td>Equ</td>
<td>AWS difficult to depress</td>
<td>Equ</td>
</tr>
<tr>
<td>57</td>
<td></td>
<td></td>
<td>321 uncomfortable</td>
<td>Erg/ Des</td>
</tr>
<tr>
<td>58</td>
<td>Better seating</td>
<td>Erg/ Des</td>
<td>Too hot in summer and cold in winter</td>
<td>HVAC</td>
</tr>
<tr>
<td>58</td>
<td>AWS sound</td>
<td>Noi</td>
<td>AWS sound too often, habituation</td>
<td>Noi</td>
</tr>
<tr>
<td>Page</td>
<td>Issue</td>
<td>Subsection</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
<td>------------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>Noise</td>
<td>Noi</td>
<td>Limited visibility with the interconnecting door design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seat comfort</td>
<td>Erg/ Des</td>
<td>Erg/ Des/SC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air conditioning</td>
<td>HVAC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>Air conditioning is usually of a high standard</td>
<td>HVAC</td>
<td>Uncomfortable seating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Too many DIDs fitted in a small space</td>
<td>Erg/ Des and Equ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>Newer train are good</td>
<td>No reasoning provided - NA</td>
<td>Old</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No leg room on older trains</td>
<td>Erg/ Des and Equ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>-</td>
<td>-</td>
<td>View</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Noise</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Comfort</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erg/ Des and Equ</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>-</td>
<td>-</td>
<td>Sometimes the TPWS is in three different positions on the 321 units (visual indicators)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erg/ Des and Equ</td>
<td></td>
</tr>
<tr>
<td>67</td>
<td>Keeps the driver alert</td>
<td>Noi</td>
<td>Headaches on long shifts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SC/Other</td>
<td></td>
</tr>
<tr>
<td>68</td>
<td>Air conditioning (in summer)</td>
<td>HVAC</td>
<td>AWS can be too loud</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Noi</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>Newer and cleaner environment</td>
<td>Erg/ Des</td>
<td>Was not designed with a driver in mind</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erg/ Des/Equ</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>Any indication is better than none surely</td>
<td>Erg/ Des, Equ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>Keeps concentration up if flagging</td>
<td>Noi</td>
<td>Cramped</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erg/ Des, Equ</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>Main windows give good views</td>
<td>Erg/ Des, Equ</td>
<td>Hard to get the seating comfortable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>On-board cameras are good</td>
<td>It is assumed this is in relation to DOO.</td>
<td>Hard to see things on your right close up</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erg/ Des, SC and Equ</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Single handle is not as easy to use</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>-</td>
<td>-</td>
<td>Air conditioning can make it uncomfortable for the driver</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HVAC, Noi</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td>-</td>
<td>-</td>
<td>Instrument lights too bright at night</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erg/ Des, Equ</td>
<td></td>
</tr>
<tr>
<td>78</td>
<td>All controls are at hand</td>
<td>Erg/ Des, SC and Equ</td>
<td>Visibility on right hand side is reduced</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erg/ Des, SC and Equ</td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>Air conditioned</td>
<td>HVAC</td>
<td>Seat</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erg/ Des</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Noise levels</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Noi</td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>Controls are within reach</td>
<td>Sometimes the door or window gets stuck</td>
<td>Erg/ Des</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>Air conditioning</td>
<td>HVAC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heating fails frequently</td>
<td>Equ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>86</td>
<td>Narrow field of view</td>
<td>Erg/ Des/SC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>89</td>
<td>Air con too noisy</td>
<td>Noi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>Poor HVAC</td>
<td>HVAC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Limited visibility</td>
<td>Erg/ Des/SC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor brightness of buttons</td>
<td>Erg/ Des/SC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>Uncomfortable seats</td>
<td>Erg/ Des/</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Review of the responses from the train driver’s (shown in Table 6-4) show a surprisingly high number of responses that pertain to non-technical issues. In particular, responses which relate to issues that affect the personal comfort of the driver, that is, the Heating, Ventilation and Air Conditioning System. It is accepted that temperature control can influence train driver actions. For example, an overly heated environment can induce drowsiness; which could in turn lead to lack of concentration in the train cab environment. It is recognised by the American Automobile Association that approximately 12.5% of crashes and 16.5% of fatal traffic accidents are as a result of drowsiness (Stutts, Wilkins, & Vaughn, 1999). The reference to HVAC by the respondents has been included to show that it is an issue that is deemed of importance to the train drivers.

Conversely, a number of points of interest have been found which are of greater applicability and are therefore examined below:

Due to modernisation of the railway system there has been a need to incorporate newer technology to provide specified functions into the existing cab layout. This has drawn responses from the train

<table>
<thead>
<tr>
<th></th>
<th>Good air conditioning</th>
<th>HVAC</th>
<th>Noisy cab</th>
<th>Noi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comfortable seating</td>
<td>Erg/ Des</td>
<td>Airflow</td>
<td>HVAC</td>
<td></td>
</tr>
<tr>
<td>Air conditioning</td>
<td>HVAC</td>
<td>Air conditioning is very noisy</td>
<td>Noi</td>
<td></td>
</tr>
<tr>
<td>Heating when working correctly</td>
<td>HVAC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decent seats</td>
<td>Erg/ Des</td>
<td>Draughts, leaks and poor heating</td>
<td>HVAC</td>
<td></td>
</tr>
<tr>
<td>Room</td>
<td>Erg/ Des</td>
<td>When there is no air conditioning</td>
<td>HVAC</td>
<td></td>
</tr>
<tr>
<td>Air conditioning</td>
<td>HVAC</td>
<td>Clutter with retro fitted equipment</td>
<td>Erg/ Des/Equ</td>
<td></td>
</tr>
<tr>
<td>Any cab that is separated from passenger noise is good</td>
<td>Erg/ Des</td>
<td>Drivers seating is not ergonomic and can be uncomfortable</td>
<td>Erg/ Des</td>
<td></td>
</tr>
<tr>
<td>Seating position is totally unsuitable for Driver Only Operation (DOO) on 315 unit</td>
<td>Erg/ Des</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seats around doors and windows allow too much noise</td>
<td>Erg/ Des/Noi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air conditioning and heating is good on class 315</td>
<td>HVAC</td>
<td>Air conditioning and heating is poor on class 315</td>
<td>HVAC</td>
<td></td>
</tr>
<tr>
<td>321 bogie noise is often loud</td>
<td>Noi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cab window on a 315 units when open you can’t hear a thing when another train is level with yours</td>
<td>Noi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The trains I drive were built in the 1980s</td>
<td>Erg/ Des/SC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6-4 Supplementary information - Advantages and Disadvantages of Train Cab Design
drivers, which specifically relate to the layout of equipment and redesign of the driving cab on certain classes of train.

A case related to ergonomics and design of the driver's cab is demonstrated by the Amsterdam Metro (Van der Weide, Frieling, Malle, & Miglianico, 2013). This project dealt with replacement of the life expired rolling stock with a modernised design. As part of their design there was the requirement to comply with Dutch legislation, such that:

‘The aim of the “Arbowet” is to prevent accidents (safety) and to avoid illnesses caused by work (health)’ (Van der Weide, Frieling, Malle, & Miglianico, 2013).

Essentially the redesign of the driver’s cab should not negatively impact the health or safety of the driver. The Health and Safety Executive on the other hand also examine work related ill health in regard to rail operatives (Health and Safety Executive, 2015). Their evidence indicates that a figure between 2% - 6% annually is representative of those railway operatives who suffer ill-being ‘caused or made worse by work’ (Health and Safety Executive, 2015). Specific excerpts from the driver responses are shown in the bullet points below and indicate cases where there seems to be detriment to the health of the train drivers. The Health and Safety at Work Act 1974 (UK Government, 1974) place responsibility on both employees and employers. Employers should sufficiently address the risk, via risk assessment of the issues that could be causing potential ill health issues. The employees should also take action and engage with the employer where it is felt that there is an impact on health. However, an employee may be fearful of addressing such issues.

- Questionnaire ID 49: Noise from TPWS and AWS can hurt the ear.
- Questionnaire ID 67: Headaches on long shifts.
- Questionnaire ID 58: Habituation – driver ceases to respond to stimulus.

It is essential that the train driver has a clear line of sight in order to safely operate the train. That is, a clear line of sight to the equipment within the train cab. Furthermore, a clear line of sight of the driving route outside of the train cab is also required. The drivers have indicated that there is a disadvantage with the train cab design, where the physical design has brought about a restriction to the line of sight. This brings about an associated increase in workload. This is due to the driver having limited visibility. This has been specifically associated to the class 379 rolling stock. Another issue that has been raised also relates to design and ergonomics. The seating has been raised as not being fit for Driver Only Operations (DOO). DOO is required by the driver to view the passengers on the platform and between the interface with the train. DOO enables the train driver to have safety critical control of the train doors (Rail Safety and Standards Board , 2015). Equipment malfunction has also been highlighted as an issue that can arise in the driving environment. The majority of the issues raised, from equipment malfunction, to ergonomic issues, poor cab design to lack of visibility all have impacts on safety to varying degrees and they are shown to range from the physical impact to functional operation. Conversely, a number of advantages can also be highlighted which relate to space and
equipment. However, there are a couple of instances which refer to there being no advantages that can be associated with the train cab design.

From a safety culture perspective, specifically looking at the relationship between train drivers and an organisation. One driver (Questionnaire ID 46) rhetorically asks whether drivers are actually asked their opinions about the designs. The overall conclusion drawn is that the relationship between an organisation utilising employee involvement could be improved and this could subsequently prevent re-design which can often occur if an environment or product is not fit for purpose. There are a number of physical design and ergonomic related issues that can impact the operation and performance of the train driver. Retrofitting the train cabs often leads to more equipment being fit into the same space profile. As a result the train cab becomes a cluttered, cramped and restrictive environment for the train drivers as has been highlighted in a number of cases as a disadvantage.

6.2.3 Supplementary Information: General Safety Questions

This section presents the final set of data from the supplementary responses provided by the train drivers. This section of the questionnaire followed a Likert set of questions that related to the safety culture displayed by an organisation. From the surveyed drivers who provided additional information, their responses are presented verbatim below in Table 6-5.

<table>
<thead>
<tr>
<th>Questionnaire ID</th>
<th>General supplementary information related to safety culture</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>New technology reduces the driving experience. This can make drivers lazy as you're not driving, you're monitoring a computer.</td>
</tr>
<tr>
<td>17</td>
<td>Cab design on 379 has made vision poor. Also uncomfortable with leg position. It is hard to change drive position if fatigued (stand up). Dealing with safety concerns depends on money to the organisation. The organisation is more reactive than proactive.</td>
</tr>
<tr>
<td>24</td>
<td>Many learning sessions are used to spread management propaganda.</td>
</tr>
<tr>
<td>32</td>
<td>I feel the safety brief days could be a lot better in terms of training and discussing specific issues in more depth and over more time. They could also be more frequent than every 6 months, maybe quarterly and maybe contain more of a practical element.</td>
</tr>
<tr>
<td>43</td>
<td>It is one thing to report a safety issue but it can take months to get anything done about it. It usually takes a lot of pestering to even get an update on progress. In our train cabs, new equipment (such as GSM-R) has been installed but old (redundant) equipment is just left in situ gathering dust, impairing views and cluttering.</td>
</tr>
<tr>
<td>94</td>
<td>I don't think some safety issues are taken seriously. Some walking routes and break locations are in poor condition. Cost is always an issue.</td>
</tr>
</tbody>
</table>

Table 6-5 Supplementary Information - Safety Culture
From the responses above, clear opinions have been presented. Training has been highlighted in a negative regard, firstly for being infrequent and secondly it is seen as a tool for management to relay their non-impartial ideas and plans. The training that is provided by the organisation is not expected to be impartial in the opinion of the author as the safety interests of the organisation are being promoted with an expected outcome that changes driver behaviour in the operational environment for the better. From an organisational perspective, cost has also been raised as a key issue in regard to response and rectification of safety concerns. In general, if a driver feels that their safety concerns are not being resolved or actioned this may prevent them from reporting in the future. As identified in the previous section, equipment design and layout is a factor that impacts safety, as it increases clutter. In a lot of cases, equipment has become redundant and is no longer in use. Organisations therefore need to address the issue of re-design and removal of non-functioning equipment. Looking forward to the development, one respondent feels that further modernisation of trains will reduce the level of interaction that will be replaced by a monitoring role. As discussed in the comparison to European developments further on in this chapter this could partially be the case. This is in terms of there being increased monitoring of the DMI.

There are a number of alternative methods to measure and analyse qualitative information. This includes grounded theory (Charmaz, 2014) which builds theory from qualitative data and involves comparative analysis. However, whichever method is employed it is necessary prior to evaluation to consider the depth of detail to enable sufficient qualitative analysis. Furthermore, when interpreting the data, care should be taken not to introduce personal biased viewpoints.

The next section of the results now reviews in detail the information gained from questionnaire options in relation to staff training, the cab environment and general safety culture within the organisation. The supplementary responses provided in the previous section have enabled the drivers to include more information based on their experience and personal opinion.

Applying the responses from the supplementary information to the derived safety assessment process in Figure 4-17. The information provided by the train drivers is extremely valuable, it provides first hand insight into the daily issues and concerns and can otherwise be used by an organisation when conducting lessons learnt activities. This can feed into risk assessment workshops, in particular when reviewing risk mitigation and risk causation factors.
6.3 Questionnaire Results: Analysis of Train Driver Responses

A number of methods have been used to analyse the responses from the train drivers as discussed in Section 6.1. Figure 6-2 below provides a pictorial overview of the methods utilised to carry out data analysis.

![Methodology for data analysis](image)

**Figure 6-2 Methodology for data analysis**
6.3.1 **Reliability of the questionnaire**

Table 6-6 below indicates the level of reliability of the questionnaire scale in the three key subsections, with good reliability attained for questions related to staff training and safety culture. However, a low Cronbach’s alpha has been calculated for questions which relate to the train cab driving environment. For this case, as Cronbach’s α is particularly weak, emphasis is also given to results provided by the supplementary information and observations where applicable to support any conclusions drawn.

<table>
<thead>
<tr>
<th>Reliability Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Staff training methods</td>
</tr>
<tr>
<td>Train cab driving</td>
</tr>
<tr>
<td>environment</td>
</tr>
<tr>
<td>General safety questions</td>
</tr>
<tr>
<td>– safety culture</td>
</tr>
</tbody>
</table>

*Table 6-6 Cronbach's Alpha for the three sections of the questionnaire*

6.3.2 **Conventional Signalled Railways: Descriptive Statistics**

As discussed above, there are a number of statistical methods available to explore the data set obtained from questionnaires and observational studies. A number of methods have been reviewed; some of these methods have been employed whilst others did not yield useful results. Subsequently, the approach involved in data analysis has involved an element of trial and error.

The descriptive statistics have been analysed as a starting point, this utilises data from the opening of the questionnaire and is a useful aid to help describe the dataset.

The number of valid questionnaires completed by the train drivers participants totalled N=106 (103 male, 3 female). The significant demographic features of the train drivers are shown in Table 6-7. Furthermore, the breakdown between those drivers who are qualified, compared to those in training is shown in Table 6-8. Taking an initial look at the average values, the age of the driver participants is approximately 43 years, working on average 5 days per week with an average of 15 years length of service in the railway industry. 35 hours per week is most frequently worked by the drivers, with drivers working up to 50 hours in instances. As shown in Table 6-8 from the 106 driver participants approximately 91% are fully trained with the remainder in training.
### Table 6-7 Descriptive statistics - Abellio Greater Anglia Train drivers

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th>Length of service in current role</th>
<th>Length of service in railway industry</th>
<th>Age of respondent</th>
<th>Hours worked per week</th>
<th>Days worked per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Valid 106</td>
<td>106</td>
<td>106</td>
<td>104</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Missing 0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Mean</td>
<td>12.1792</td>
<td>15.0958</td>
<td>43.61</td>
<td>36.34</td>
<td>5.08</td>
</tr>
<tr>
<td>Std. Error of Mean</td>
<td>1.01259</td>
<td>1.08527</td>
<td>.854</td>
<td>.327</td>
<td>.095</td>
</tr>
<tr>
<td>Median</td>
<td>9.0850</td>
<td>11.2500</td>
<td>44.00</td>
<td>35.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Mode</td>
<td>6.00</td>
<td>6.00</td>
<td>43</td>
<td>35</td>
<td>5</td>
</tr>
<tr>
<td>Variance</td>
<td>108.686</td>
<td>124.849</td>
<td>77.249</td>
<td>11.089</td>
<td>.903</td>
</tr>
<tr>
<td>Range</td>
<td>40.17</td>
<td>39.50</td>
<td>36</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>Minimum</td>
<td>.25</td>
<td>.92</td>
<td>25</td>
<td>34</td>
<td>4</td>
</tr>
<tr>
<td>Maximum</td>
<td>40.42</td>
<td>40.42</td>
<td>61</td>
<td>50</td>
<td>7</td>
</tr>
</tbody>
</table>

### Table 6-8 Descriptive statistics – Railway qualification Abellio Greater Anglia Train drivers

<table>
<thead>
<tr>
<th>Railway qualification status</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td>6</td>
<td>5.7</td>
<td>5.9</td>
<td>5.9</td>
</tr>
<tr>
<td>In training</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qualified</td>
<td>96</td>
<td>90.6</td>
<td>94.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
<td>96.2</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Missing</td>
<td>4</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>106</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Examples of the descriptive statistics with their distributions indicated are presented graphically above in Figure 6-3 to compliment Table 6-7 and to more readily show the statistics for age and the number of hours worked per week. Variation in the hours worked per week can be attributed to drivers working additional shifts or standby shifts. Standby shifts may be required to cover the shift of an unscheduled absentee employee for example.

The descriptive means of the remaining sections of the questionnaire have also been reviewed. In particular, to ascertain whether there are any extreme positive or negative biases or indications towards the following topics (i) alarms (ii) training or (iii) safety culture related questions. The following resulted were obtained:

(i) **Alarms**: A positive bias (agreement) was shown towards alarms aiding driving with a mean = 4.08. This indicates that alarms are beneficial to the driving environment and train operation. Furthermore, there was a negative bias (disagreement) to there being too much information in
the form of alarms with a mean = 2.67. This contradicts some of the statements presented by the drivers as part of their supplementary information responses.

Furthermore, reviewing age to ascertain whether there are any differences across the age groups with respect to alarms the following has been identified as shown in Figures 6-4 to 6-6. As shown in Figure 6-4 there are marginal differences in the responses made by those respondents who are less than 43 years compared to those aged over 43 years in relation to there being too much alarm information. Figure 6-5 on the other hand shows that across the age groups there was a more positive bias to alarms being too loud. Figure 6-6 shows that responses in relation to alarms being distracting where spread between responses where 20.8%=strongly disagree, 27.4%= disagree and 22.6%=agree. The impact of age showed a slight difference with respondents over 43 years agreeing that alarms are more distracting.

Overall it can be surmised that age does not have a significant bearing upon the responses made in relation to train cab alarms.

**Figure 6-4** Descriptive representation of age versus too much information in the form of alarms
Figure 6-5 Descriptive representation of age versus alarms being too loud

Figure 6-6 Descriptive representation of age versus alarms being distracting
(ii) **Training:** All responses that related to the training carried out by Abellio training managers were positive and yielded bias towards agreement/strong agreement. In particular, agreement related (a) to there being sufficient levels of training with a mean = 4.33 (b) rigorous assessment with a mean = 4.26 as shown in Figure 6-7 and (c) failure scenarios being fully examined as part of training with a mean = 4.23.

![Figure 6-7 Frequencies of responses to rigorous assessment as part of training](image)

(iii) **Safety culture:** A negative (disagreement) bias towards incentives being offered by management staff was shown with a mean = 2.71. A neutral / no opinion bias was shown towards safety concerns being acted upon by management staff with a mean = 3.19 furthermore, a mean = 3.36 in relation to safety concerns being listened to by management staff. A negative bias was also shown about feedback from management in relation to safety concerns that have been raised by the respondents as shown in Figure 6-8. This response suggests that safety culture and management is an area, which respondents may not wish to comment on. Furthermore it highlights the need for greater engagement between management and operational staff to discuss the processes and procedures to address safety concerns raised by the train drivers.
Figure 6-8 Frequencies of responses in relation to safety culture

The demographic data such as age, gender and length of service which has been collated to describe the candidates, also offers the flexibility to ascertain whether there are further relationships between the demographics and with other variables in the dataset. For example, relationships may be found between opinions on safety management and safety training in relation to age and gender categorisations. Or they could be related to whether views on safety show a correlation to the length of service paid to a rail organisation. These relationships have been examined in correspondence to the subsections which make up the questionnaire and specifically focus on (i) Staff Training (ii) the Train Cab Driving Environment and (iii) General Safety Questions (safety culture).

Therefore, and in contrast to the descriptive statistical analysis and to gain understanding in relation to the research objectives further data analysis is performed. This is used to identify whether there are
any interesting constructs which can be developed and to confirm thoughts on the outcomes of specific variable relationships. The correlation analysis presented in the following section is presented to assess patterns within the descriptive section of the questionnaire. This is followed by an assessment of the reliability of the likert data followed by exploratory analysis to validate relationships.

6.3.3 Correlation Analysis: Descriptive Data

Reviewing the correlations in Table 6-9 to the descriptions of \( r \) described in section 6.1.7, the following is concluded:

- There is strong, positive and significant correlation between the age of the respondent and the length of service in the driver’s current role \( (r=.607, N=106, p<.001) \).
- There is a strong, positive and significant correlation between the age of the respondent and the length of service paid to the railway industry \( (r=.638, N=106, p<.001) \).
- There is a very strong, positive and significant relationship between the length of service paid by a driver to the railway industry and the length of service in their current role \( (r=.876, N=106, p<.001) \).

Conversely, a very weak and negative correlation was found between the number of hours worked and the age of the respondent. Furthermore, weak correlations were found between the number of hours worked and the length of service in either their current role or in the railway industry as a whole.

<table>
<thead>
<tr>
<th></th>
<th>Age of respondent</th>
<th>Length of service in current role</th>
<th>Length of service in railway industry</th>
<th>Hours worked per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of respondent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson Correlation (r)</td>
<td>1</td>
<td>.607**</td>
<td>.638**</td>
<td>-.008</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.000</td>
<td>.000</td>
<td>.935</td>
</tr>
<tr>
<td>N</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>104</td>
</tr>
<tr>
<td>Length of service in current role</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson Correlation (r)</td>
<td>.607**</td>
<td>1</td>
<td>.876**</td>
<td>.026</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.792</td>
</tr>
<tr>
<td>N</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>104</td>
</tr>
<tr>
<td>Length of service in railway industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson Correlation (r)</td>
<td>.638**</td>
<td>.876**</td>
<td>1</td>
<td>.029</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.768</td>
</tr>
<tr>
<td>N</td>
<td>106</td>
<td>106</td>
<td>106</td>
<td>104</td>
</tr>
<tr>
<td>Hours worked per week</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson Correlation (r)</td>
<td>-.008</td>
<td>.026</td>
<td>.029</td>
<td>1</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.935</td>
<td>.792</td>
<td>.768</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>104</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6-9 Correlation between descriptive data
It is concluded that the identified correlations do not necessarily provide a conclusion of causal relationships. For example, in the most strongly correlated case it is not conclusive that the length of service spent in the railway industry predetermines the length of service that a driver conducts in their current role. Or that age affects the length of service spent in their current role or in the industry as a whole. However, these three topics show a strong to very strong correlation. Therefore, the positive relationship between the groups are highlighted.

6.3.4 Ordinal Regression Results

6.3.4.1 Impact of gender

Of interest to this research is the difference between the male and female gender groups. In this instance, gender could not be explored in detail to determine whether women answered in a particularly different manner to males. This is because the railway industry has a significant disparity between the ratio of male to female train drivers, with males accounting for the majority of respondents. Therefore, in relation to the aspects of data quality there is not sufficient coherence between the dataset representative of males and females to draw accurate statistical conclusions.

6.3.4.2 Ordinal Regression: Findings Based on Age

This section tests the impact of age across the ordinal likert scale for selected sections of the questionnaire, which addresses training methods, the cab environment and general safety culture questions. Table 6-10 below summarises the findings of the test of parallel lines.
Table 6-10 Test of parallel lines the impact of age across the ordinal scale

Note: The null hypothesis states that the location parameters (slope coefficients) are the same across response categories a (a. Link function: Logit).

Across all the likert question responses with age as the explanatory and independent variable the goodness of fit indicates that the model fits the data well as in each case p >0.05. However, across the groups the pseudo R indicates that age explains an extremely small portion of the responses on either of the selected questions, which relate to training methods, the cab environment or general safety culture questions. The Null hypothesis, as described in section 6.1.8 is upheld across the cases and the parallel lines assumption is satisfied as the P value is high and the Chi square value is greater than 0.05 as shown in Table 6-10. As a result, this analysis indicates that age has no significant impact on the response category selected by the train drivers.
6.3.5 **Exploratory Factor Analysis & Principal Component Analysis**

The outcome of PCA is discussed according to the layout and design of the questionnaire. Therefore staff training is reviewed as a starting point.

### 6.3.5.1 **Staff Training**

The importance of driver training heavily relates to safety practices. If a driver is not adequately trained they will not perform tasks effectively and it is likely that the driver will place less emphasis on safety. Training of drivers in the railway organisations examined has shown it not to be a standalone process, it is an on-going process and is required to ensure that accident and incident trends are kept at a minimum. In literature from Fleet Safe, who provide guidance, planning, tools and resource in relation to driver training they state why training is important:

- ‘Management and motivation of drivers through supervisory example, coaching and leadership.
- Appropriate organisation and allocation of driving work.
- The provision of suitable vehicles and equipment that is safe and reliable. Competent drivers cannot drive safely in, for example, a poorly maintained vehicle.’ (FleetSafe, 2009)

In addition, the Good Practice Guide to Train Driver Training produced by RSSB (RSSB, 2013) relates driver training to the use of simulators.

‘Development through practical experience is crucial to attain the required level of competence. The use of simulation exercises and simulators may be necessary for some activities. Any risks arising from the assessment, development or training itself should be controlled’ (RSSB, 2013).

Simulators have proved to be an effective alternative to route driving where it is not practicable to use operational passenger hours for example.

This section of the questionnaire relates to the driver training that has been provided in either the operational railway environment or by other methods, such as, the use of simulators. More specifically, the questions analysed in this section concern the training that has been received which enables driving on conventional signalled railways. The feedback attained is explored initially via Principal Component Analysis.

Principal Component Analysis was carried out on the eight items which focused on training, with orthogonal rotation. The orthogonal rotation is used to maximise the loading on a particular component and thus provides greater clarity of data. Use of KMO as discussed in Section 6.1.9 verified the sampling adequacy, KMO = 0.921 which can be categorised as superb (Field, 2009). For the individual values, the KMO values were all >0.695, sufficiently above the acceptable 0.5 level. Use
of Bartlett's test of sphericity $\chi^2(28) = 555.169$, $p < 0.001$ indicates that there is a sufficiently large correlation for Principal Component Analysis. For each of the 8 linear components relating to training methods, analysis drew out one component with an eigenvalue greater than 1 which accounted for 64.49% of the variance also clearly presented on the generated Scree plot. Table 6-11 presents the factor loadings after rotation. As part of this process, loadings $<0.4$ are suppressed, with clusters found only under one component.

<table>
<thead>
<tr>
<th>Questions: Train Driver Training Component Matrix</th>
<th>Factor = 1 (a=1)</th>
<th>Rotated factor loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training relating to the failure scenarios (such as operation during signal failure) has been supplied and is useful</td>
<td>.937</td>
<td>.182</td>
</tr>
<tr>
<td>Sufficient levels of training have been received to enable understanding of a conventional signalled railway</td>
<td>.915</td>
<td>.177</td>
</tr>
<tr>
<td>Training is followed by examination or assessment.</td>
<td>.905</td>
<td>.175</td>
</tr>
<tr>
<td>Training methods have included a mixture of operational training in the train cab environment, technical briefings and or use of simulated environments</td>
<td>.860</td>
<td>.167</td>
</tr>
<tr>
<td>I fully understand signalling principles relevant to the driver role (such as speed profiles and operating conditions).</td>
<td>.851</td>
<td>.165</td>
</tr>
<tr>
<td>Appropriate training has been received to enable driver operation on a legacy signalled railway</td>
<td>.793</td>
<td>.154</td>
</tr>
<tr>
<td>Any concerns raised about safety have been appropriately addressed through training or have been clarified and resolved by management.</td>
<td>.720</td>
<td>.140</td>
</tr>
</tbody>
</table>

Table 6-11 Factor loadings: Train driver training

Summary: Staff Training

Table 6-11 shows that all of the seven variables load onto one factor. The response regarding concerns raised about safety being appropriately addressed through training and resolved by management indicates the lowest factor loading. However, the loading is above 0.5.

6.3.5.2 Train Cab Driving Environment

As discussed in section 5.3.2 the train cab environment is a safety critical interface for the driver. As a result, this section explores the likelihood for commonalities in the responses. Akin to the questions which related to train driver training this section also makes use of exploratory analysis via Principal Component Analysis to assess the underlying and applicable factors.

The Principal Component Analysis carried out for the train cab environment is based on the 11 items with orthogonal rotation. Use of KMO as discussed in Section 6.1.9 verified the sampling adequacy, KMO = 0.687 which is categorised as mediocre based on (Field, 2009). For the individual values, the
KMO values were all greater than or equal to 0.5, therefore meeting the criteria. Use of Bartlett's test of sphericity $\chi^2(55) = 227.072$, $p<0.001$ indicates that there is sufficiently large correlation for Principal Component Analysis. For each of the 11 linear components relating to the driving environment analysis drew out four components with eigenvalues greater than 1 which accounted for 65.11% of the variance cumulatively, also clearly presented on the generated Scree plot. The percentage of the variance in the factors before rotation shows that factor 1 = 27.877 compared to factor 2 = 16.094, factor 3 = 11.292 and factor 4 = 9.847. After rotation, factor 1 = 21.242, factor 2 = 20.835, factor 3 = 11.532, factor 4 = 11.501. This shows that there are four factors with values equal to the initial eigenvalues and retained for interpretation. Rotation is used to optimise the factor structure. Table 6-12 below presents the factor loadings and Table 6-13 presents the factor loadings after rotation, as part of this process, loadings $<0.4$ are suppressed.

<table>
<thead>
<tr>
<th>Questions: Train Cab Environment Component <strong>Matrix</strong></th>
<th>Factor Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alarms are of benefit to the driver and aid safe driving.</td>
<td>-.801</td>
</tr>
<tr>
<td>Visual and audio alerts sufficiently notify the driver of safety critical locations / signals</td>
<td>-.696</td>
</tr>
<tr>
<td>Too much information is provided to the train driver in the form of alarms and or warnings</td>
<td>.668</td>
</tr>
<tr>
<td>The in cab train alarms are often distracting</td>
<td>.656</td>
</tr>
<tr>
<td>The level of driving skill has degraded due to the change in the train cab design</td>
<td>.576</td>
</tr>
<tr>
<td>It is easy to confirm entered data (such as driver identity data) is correct.</td>
<td>-.424</td>
</tr>
<tr>
<td>The in cab alarms are too loud</td>
<td>.633</td>
</tr>
<tr>
<td>Train data consists of too many digits and there is potential for error</td>
<td>.452</td>
</tr>
<tr>
<td>Driver procedures are clearer and more understandable using GSM-R communication</td>
<td>.496</td>
</tr>
<tr>
<td>There is greater trust in railway infrastructure due to the enhanced levels of communication and track monitoring equipment</td>
<td>-.428</td>
</tr>
<tr>
<td>There has been a noticeable increase in driver workload following the change to the radio/ communication equipment.</td>
<td>.441</td>
</tr>
</tbody>
</table>

**Table 6-12 Component Matrix: Train Cab Environment**
Questions: Train Cab Environment Rotated Component

<table>
<thead>
<tr>
<th>Questions</th>
<th>Factor Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is easy to confirm entered data (such as driver identity data) is correct.</td>
<td>.781</td>
</tr>
<tr>
<td>Visual and audio alerts sufficiently notify the driver of safety critical locations / signals</td>
<td>.767</td>
</tr>
<tr>
<td>Alarms are of benefit to the driver and aid safe driving</td>
<td>.756 -.425</td>
</tr>
<tr>
<td>The in cab train alarms are often distracting</td>
<td>.776</td>
</tr>
<tr>
<td>The in cab alarms are too loud</td>
<td>.709</td>
</tr>
<tr>
<td>Too much information is provided to the train driver in the form of alarms and or warnings</td>
<td>.667</td>
</tr>
<tr>
<td>The level of driving skill has degraded due to the change in the train cab design</td>
<td>.657</td>
</tr>
<tr>
<td>There has been a noticeable increase in driver workload following the change to the radio/ communication equipment.</td>
<td>.798</td>
</tr>
<tr>
<td>There is greater trust in railway infrastructure due to the enhanced levels of communication and track monitoring equipment</td>
<td>-.651</td>
</tr>
<tr>
<td>Train data consists of too many digits and there is potential for error</td>
<td>.734</td>
</tr>
<tr>
<td>Driver procedures are clearer and more understandable using GSM-R communication</td>
<td>.643</td>
</tr>
</tbody>
</table>

Table 6-13 Factor loadings: Train cab environment

Summary: Train Cab Environment

Addressing the factor loadings across the eleven variables, the first factor loading strongly correlates with three of the eleven variables with values greater than 0.7. This indicates that the responses which relate to cab alarms, visual and audio alerts and confirmation of data vary as a group. Therefore, a relationship is shown between the train drivers and audible alarm interfaces with the highest loading in relation to the confirmation of data entry correctness in addition to visual and audio alerts. To describe the second underlying factor, the value of -.425 is a very small figure, significantly smaller than 0.7 and indicates that it is not useful to incorporate for description of the second factor loading. However, there are strong loadings for the responses, which pertain to alarms that are loud and distracting. The third factor loads strongly on whether the train drivers think there has been a noticeable increase in driver workload following the change to the radio/communication equipment. The fourth factor also has two significant loadings, which relate to procedural elements of data entry and communication. The loading for alarms align with the response provided in the supplementary section of the questionnaire which identified the AWS alarm as being particularly loud and or distracting.
6.3.5.3 General Safety Questions

The questions posed in this section of the questionnaire focus on the topic of safety culture in the context of a railway organisation. The term ‘Safety culture’, previously discussed in Chapter 3 refers to ‘the product of individual and group values...that determine the commitment to an organisation’s health and safety management’ (Health and Safety Executive, 1993) in addition to technical safety issues.

It has been evident throughout this research that there is a correlation between an organisation, particularly management interaction and staff behaviour. As a consequence, this section aims to understand the approaches to management of safety issues and the perceptions of train drivers. This shall verify the supplementary responses provided by a number of train drivers and previously discussed in Section 6.2 of this chapter.

Exploratory Principal Component Analysis (PCA) was implemented in the same manner as it was used for questions relating to training methods and in relation to the train cab environment. The Principal Component Analysis carried out relating to safety culture from a management and organisational perspective is based on 8 items with orthogonal rotation. Use of KMO as discussed in Section 6.1.9 verified the sampling adequacy, KMO = 0.770 which is categorised as good, based on (Field, 2009). Use of Bartlett’s test of sphericity \( \chi^2(28) = 246.922, p<0.001 \) indicates that there is a sufficiently large correlation for Principal Component Analysis. For each of the 8 linear components relating to general safety questions, analysis drew out two components with eigenvalues greater than 1 which accounted for 57.76% of the variance cumulatively, also clearly presented on the generated Scree plot. The percentage of the variance in the factors before rotation shows that factor 1 = 41.157 compared to factor 2 = 16.598. After rotation, factor 1 = 34.799, factor 2 = 22.956. This shows that there are two factors with values equal to the initial eigenvalues and thus retained for interpretation.
The two factors extracted using SPSS guides the focus of research into the groupings of the underlying factors of the questions related to safety. Before rotation as shown in Table 6-14, the loading was high on the first factor. This slightly changes after rotation as shown in Table 6-15 with an additional loading onto the second factor. In all cases, loadings <0.4 have been suppressed.
Summary: General Safety Questions

Responses to safety culture related questions resulted in two PCA loadings. High loadings, which vary as a group, include those which relate to safety concerns and the response by management. This represents the first component loading. The second component loading relates to the relationship between technology and the organisation.

This indicates that the components can be reduced to key components and that management and technology play a significant role. For example, this aligns to the issues raised, whereby some driver respondents identified that resolution of issues by management is somewhat driven by budget. Furthermore, the process to receive feedback on issues raised is a time consuming one, with drivers having to frequently enquire on progress.

The PCA methodology employed has demonstrated a key assumption. Specifically that high loadings represent significant dynamics between data. This is compared to loadings lower in value. This has proved a valuable tool to reduce the group variables and has validated qualitative responses presented by the train drivers.
Correlation analysis has been used to further assess association between two variables. This could either be positive or negative in correlation. Using the IBM SPSS software a number of options are available to assess correlations. This includes Kendall’s tau-b, Pearson’s and Spearman’s Rho which can be represented in matrix form (IBM SPSS, 2014).

Correlations are on the scale (+1) to (-1), with a value closer to 1 giving an indication of the strength of the correlation between the variable. A zero value indicates that there is no correlation.

The questionnaire data is unlikely to be normally distributed, therefore Pearson’s correlation is not useful for this data set. Spearman’s Rho and Kendall Tau-b is used for measurements of driver respondent attitude as indicated by the Likert scale.

Specific correlations for analysis have been identified for the UK data set, this enables mapping to correlations carried out by Swedish researchers MTO Safety and VTI based on ERTMS application.

### 6.3.6.1 Train Cab Design & Environment

The following correlations were selected to assess relationships with the train cab design:

<table>
<thead>
<tr>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>The level of driving skill has degraded due to the change in train cab design (CE11)</td>
</tr>
<tr>
<td>Kendall Tau = (-0.031)</td>
</tr>
<tr>
<td>The level of driving skill has degraded due to the change in train cab design (CE11)</td>
</tr>
<tr>
<td>Kendall Tau = (0.288)</td>
</tr>
<tr>
<td>The level of driving skill has degraded due to the change in train cab design (CE11)</td>
</tr>
<tr>
<td>Kendall Tau = (0.271)</td>
</tr>
<tr>
<td>The level of driving skill has degraded due to the change in train cab design (CE11)</td>
</tr>
<tr>
<td>Kendall Tau = (-0.200)</td>
</tr>
</tbody>
</table>

Table 6-16 Correlations which relate to Train Cab Design (part 1)
Correlations which relate to the level of driving skill degrading due to the train cab design are shown with respect to (i) too much information in the form of alarms and warnings (ii) distraction caused by cab alarms and (iii) visual and audio alerts. The results indicate that these are significant correlations as shown in Table 6-16. The relationship and emphasis on alarms tie in with results obtained from the supplementary responses from the train drivers. The responses indicate that AWS alarms were either too loud or distracting in the majority with additional responses in relation to the other alarms and alerts. These correlations also pertain to the degradation of driving skill due to the amount of information and alarms.

Following the specific correlations to the train cab design and alarms, further correlations have been made within the data set, which specifically relate to alarms and notifications. The correlations identified as significant are shown in bold in Table 6-17 below. Table 6-17 shows the following statistically significant relationships:

1) A degradation in driving skill due to cab design with alarms as discussed above.
2) Too much information in the form of alarms and alarms being distracting. In other words and as expected too many alarms can impact the priority task of driving which can have a negative affect in terms of workload. A significant negative correlation is shown between there being too much information in the form of alarms and the alarms sufficiently notifying the driver of safety critical locations. Specifically focusing on the AWS alarm, the alarm is sounded on approach to a signal that is not in the green state. Therefore the driver is sufficiently notified which explains the correlation. However, there is still the chance that the driver may not adhere to the warning. This may be due to the terrain, route or signal location which may induce the feeling of too much information being fed to the driver. In a case such as this, the system will intervene and brake the train. This ties in with the final significant negative correlation between alarms being distracting and the alerts sufficiently notifying the train driver.
<table>
<thead>
<tr>
<th>Correlations</th>
<th>Degradation in driving skill due to cab design</th>
<th>Too much information in the form of alarms</th>
<th>Alarms are distracting</th>
<th>Visual and audio alerts sufficiently notify the driver of safety critical locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kendall’s tau_b</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degradation in driving skill due to cab design</td>
<td>Correlation Coefficient 1.000</td>
<td>0.288**</td>
<td>0.271**</td>
<td>-0.200’</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed) 0.000</td>
<td>0.00</td>
<td>0.001</td>
<td>0.016</td>
</tr>
<tr>
<td>N</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>104</td>
</tr>
<tr>
<td>Too much information in the form of alarms</td>
<td>Correlation Coefficient 0.288”</td>
<td>1.00</td>
<td>0.373**</td>
<td>-0.164’</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed) 0.000</td>
<td>0.00</td>
<td>0.00</td>
<td>0.047</td>
</tr>
<tr>
<td>N</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>104</td>
</tr>
<tr>
<td>Alarms are distracting</td>
<td>Correlation Coefficient 0.271”</td>
<td>0.373”</td>
<td>1.000</td>
<td>-0.306”</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed) 0.001</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>N</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>104</td>
</tr>
<tr>
<td>Visual and audio alerts sufficiently notify the driver of safety critical locations</td>
<td>Correlation Coefficient -0.200’</td>
<td>-0.164’</td>
<td>-0.306”</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed) 0.016</td>
<td>0.047</td>
<td>0.00</td>
<td>104</td>
</tr>
<tr>
<td>N</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td><strong>Spearman’s rho</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degradation in driving skill due to cab design</td>
<td>Correlation Coefficient 1.000</td>
<td>0.337”</td>
<td>0.315”</td>
<td>-0.228’</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed) 0.000</td>
<td>0.00</td>
<td>0.001</td>
<td>0.020</td>
</tr>
<tr>
<td>N</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>104</td>
</tr>
<tr>
<td>Too much information in the form of alarms</td>
<td>Correlation Coefficient 0.337”</td>
<td>1.00</td>
<td>0.437”</td>
<td>-0.193’</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed) 0.000</td>
<td>0.00</td>
<td>0.00</td>
<td>0.050</td>
</tr>
<tr>
<td>N</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>104</td>
</tr>
<tr>
<td>Alarms are distracting</td>
<td>Correlation Coefficient 0.315”</td>
<td>0.437”</td>
<td>1.000</td>
<td>-0.363”</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed) 0.001</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>N</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>104</td>
</tr>
<tr>
<td>Visual and audio alerts sufficiently notify the driver of safety critical locations</td>
<td>Correlation Coefficient -0.228’</td>
<td>-0.193’</td>
<td>-0.363”</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed) 0.020</td>
<td>0.050</td>
<td>0.00</td>
<td>104</td>
</tr>
<tr>
<td>N</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>104</td>
</tr>
</tbody>
</table>

Table 6-17 Correlations which relate to Train Cab Design (part 2)

The supplementary responses provided an initial insight into perceptions of GSM-R technology. Use of GSM-R technology came second to AWS in the category of notifications found to be too loud or distracting. Table 6-18 presents the correlations specific to GSM-R. No correlation was found between GSM-R technology improving the clarity of procedures and management acting upon safety concerns. However, a small significant correlation was found at the 0.05 level which relates to GSM-R technology and the enjoyability of driving. One can only assume that the GSM-R system layout or ergonomic configuration may yield limited benefits over the now defunct in cab radio communication systems Cab Secure Radio.
Correlations  | Driving is more enjoyable following changes to the train cab design | Safety concerns raised are acted upon by management staff  
--- | --- | ---  
Driver procedures are clearer with new GSM-R technology  | Kendall's tau\textsubscript{b}: 0.183  
Spearman's rho: 0.212  | Kendall's tau\textsubscript{b}: 0.081  
Spearman's rho: 0.095  
Significance level | @ 0.05 | No significance  

Table 6-18 GSM-R correlations which relate to Train Cab Design (Part 3)

6.3.6.2 Training methods & Technology

This section reviews the results of correlations between questions related to training methods and technology.

The first correlation specifically relates to relationships between training and the correctness of data. This is a topic of particular interest for modernised railways which have a greater level of data entry input. However, for the legacy railway, a positive significant correlation of 0.206 for Kendall’s Tau-b was found at the 0.05 level. This may suggest that particular training methods are necessary in order for data to be entered correctly. Alternatively, that these training methods are effective, however, statistics for this interaction would have to be provided to concur with this assumption.

Table 6-19 does not identify any correlations between GSM-R procedures and the correctness of data. This is a surprising outcome because

‘A GSM-R process of matching the Registration data entered by the driver with data held in the signalling system in order to enable calls to be routed to the correct signaller’ (ATOC, 2014) Pg 5 is required. Therefore an element of correlation is expected. On the other hand, a positive correlation is identified between training methods and the clarity of driver procedures with GSM-R. This may indicate that training has a positive impact on following GSM-R procedures. Another correlation, with negative significance is shown between there being too many digits and confirming the correctness of data. This is an expected correlation, as a complex sequence of too many digits could affect the correctness of data.
<table>
<thead>
<tr>
<th>Correlations</th>
<th>Mixture of training methods</th>
<th>Confirming data correctness</th>
<th>Too many digits</th>
<th>Driver procedures are clearer with new GSM-R technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kendall's $\tau_b$</td>
<td>Correlation Coefficient</td>
<td>1.000</td>
<td>.206*</td>
<td>-.032</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.206*</td>
<td>.020</td>
<td>.716</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>99</td>
<td>96</td>
<td>95</td>
</tr>
<tr>
<td>Confirming data correctness</td>
<td>Correlation Coefficient</td>
<td>.206*</td>
<td>1.000</td>
<td>-.190*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.020</td>
<td>.025</td>
<td>.025</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>96</td>
<td>103</td>
<td>101</td>
</tr>
<tr>
<td>Too many digits</td>
<td>Correlation Coefficient</td>
<td>-.032</td>
<td>-.190*</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.716</td>
<td>.025</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>95</td>
<td>101</td>
<td>101</td>
</tr>
<tr>
<td>Driver procedures are clearer with new GSM-R technology</td>
<td>Correlation Coefficient</td>
<td>.256**</td>
<td>.008</td>
<td>.153</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.004</td>
<td>.921</td>
<td>.073</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>97</td>
<td>102</td>
<td>101</td>
</tr>
<tr>
<td>Spearman's $\rho$</td>
<td>Correlation Coefficient</td>
<td>1.000</td>
<td>.236*</td>
<td>-.035</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.236*</td>
<td>.021</td>
<td>.736</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>99</td>
<td>96</td>
<td>95</td>
</tr>
<tr>
<td>Confirming data correctness</td>
<td>Correlation Coefficient</td>
<td>.236*</td>
<td>1.000</td>
<td>-.219*</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.021</td>
<td>.028</td>
<td>.865</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>96</td>
<td>103</td>
<td>101</td>
</tr>
<tr>
<td>Too many digits</td>
<td>Correlation Coefficient</td>
<td>-.035</td>
<td>-.219*</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.736</td>
<td>.028</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>95</td>
<td>101</td>
<td>102</td>
</tr>
<tr>
<td>Driver procedures are clearer with new GSM-R technology</td>
<td>Correlation Coefficient</td>
<td>.289**</td>
<td>.017</td>
<td>.182</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.004</td>
<td>.865</td>
<td>.068</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>97</td>
<td>102</td>
<td>101</td>
</tr>
</tbody>
</table>

Table 6-19 Correlation between Training Methods and Technology
6.3.7 Observational Analysis Results for a Conventional Signalled Railway

The results of observational analysis are discussed in this section and are based on a conventional signalled railway. This railway is a simulated environment specifically used for train driver training. There are a number of factors to note when carrying out observations of a driver in a simulated environment; this includes feel and depth perception. In a train simulator, the driver will have greater difficulty judging length and distances whereas in an operational environment this is an inherent sensation. This allows a train driver to determine how fast a train is coming towards them on the adjacent line in addition to determination of stopping distances upon entry into a platform.

From observation of the train drivers the majority demonstrated a proactive approach to safety. For example, drivers made use of verbal announcements to themselves. This proved an important tool for the drivers to remind themselves in a particular safety critical scenario. For example, some drivers would announce the speed limit based on the reading on the speed limit board to remind them of the speed that they should be adhering to. Other drivers made announcement of the signal aspect. For example, if it was a double yellow or single yellow, some drivers employed memory ditties. Phrases such as ‘single yellow, red ahead’ this was a tool to remind themselves that the next signal would be a danger signal. Other phrases included ‘pause for doors’; this was used by drivers who had come to a standstill at a platform. This was to remind themselves to pause before opening the passenger doors. Thus ensuring that the train doors were enabled on the correct side for passengers to alight onto the platform. Issues such as these are avoided on metro systems as the trains have correct side door enable functionality in built in the signalling system.

Another good practice carried out by all observed train drivers was execution of the brake test. A brake test ensures that the brakes are fully functional and it is a vital safety feature on the trains. It was positive to see that this was a process that was integral to driver actions.

Following compilation of scenarios intended to be observed, the scenarios were then discussed with a trainer manager at Abellio Greater Anglia Training School. Unfortunately, due to the regime of the training program not all of the scenarios could be replicated verbatim in the simulated environment. As a result, justifications for differences in the developed scenarios are explained in Table 6-20 below. Alternative scenarios were observed and are further discussed in the results.
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Justification for scenario change / Applicability of scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Data Entry</td>
<td>For conventionally signalled railways the train driver enters minimal data. This scenario has more bearing on an ETCS signalled railway where the task of data entry is required more extensively. Not possible for this to be simulated.</td>
</tr>
<tr>
<td>2 – Communications failure</td>
<td>Use of the GSM-R interface is to be examined and is of interest as cab secure radio systems are now defunct following the roll out of GSM-R technology.</td>
</tr>
<tr>
<td>3 - Perpetual communication</td>
<td>This is still a relevant issue and has been retained for analysis to determine whether there is any impact on workload and or the ability to multitask.</td>
</tr>
<tr>
<td>4 - Signal aspect change</td>
<td>This is of particular relevance for signal aspects changing to red. Historical cases of signals passed at danger show critical failures and an associated impact on human life. In the most sever cases non-adherence to signals can result in legal action.</td>
</tr>
<tr>
<td>5 - Tunneled versus open route section driving</td>
<td>The simulated topology did not have extensive tunneled areas for effective coverage.</td>
</tr>
<tr>
<td>6 - Train collision</td>
<td>This scenario cannot be modelled in the train simulator. An alternative scenario of permissive working, specifically, a train coupling i.e. more than one train in a section is the nearest to simulating trains colliding.</td>
</tr>
<tr>
<td>7 - Passenger Emergency Alarm Triggered</td>
<td>Valid scenario to understand the interface between the driver and passenger in the event of a safety issue. This could not be simulated due to the prescribed training material. However, alternative examples with passengers are detailed in the results.</td>
</tr>
<tr>
<td>8 - Brake failure</td>
<td>This is not possible to simulate, an alternative is low rail adhesion, which can be brought about by rail contamination such as leaf fall. In this case, the driver’s control over the brakes would appear diminished. Therefore, simulation of low rail adhesion is observed.</td>
</tr>
<tr>
<td>9 - Alteration of train length</td>
<td>This was deemed an important scenario for safety analysis. The train cars can be configured as a 4, 8 or 12 car train configuration. This is particularly important in platform areas where correct stopping distances must be maintained.</td>
</tr>
<tr>
<td>10 - Warning System Alarms</td>
<td>Driver response to warning alarms TPWS and AWS shall be analysed.</td>
</tr>
</tbody>
</table>

Table 6-20 Adapted observational scenarios
Table 6-20 has presented the scenarios that can be observed through use of the train simulators as they form an integral part of Abellio Greater Anglia’s training program. The simulators included traction classes EMU 379, EMU 315 and DMU 170. Further observations have also been made which are of relevance to safety culture and technology. This additional analysis is detailed following review of the results in Table 6-21.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Data Entry</td>
<td>Not possible to simulate.</td>
</tr>
<tr>
<td>2 - Communications Failure</td>
<td>The observed examples, which related to GSM-R, were addressed by the use of emergency call to the signaller or from the signaller. When a driver initiates a call a procedure is followed whereby the driver states their identifier and the situation. This is also necessary for auditing purposes as discrepancies may be raised in accident investigation situations for example. Alternatively, the signaller has the option to issue a group call or a one to one call to a particular driver. There were no instances where there was an issue with the physical GSM-R replicated system or functionality. As a result, the impact of a GSM-R communications failure could not be evaluated.</td>
</tr>
<tr>
<td>3 - Perpetual communication</td>
<td>Observing train drivers in receipt of calls whilst carrying out operational tasks drew the following results:</td>
</tr>
<tr>
<td></td>
<td>- Communication to drivers who were on approach to a platform in the majority of cases saw drivers ignore the call and respond once safe entry into the platform area was complete. For e.g. Driver B stated the following in regard to perpetual communication. No response was made to the signaller because it was not an emergency call. Thus it was more essential to take time and stop the train safely. This information was obtained following the training / examination activity via structured interview.</td>
</tr>
<tr>
<td></td>
<td>- Driver C: In this scenario, train drivers in a specific area were issued with an emergency group call. Driver C responded to the signallers group call. The signaller instructed the driver not to interrupt as the signaller had announced that it was an emergency group call. In this case, interruption should be kept to a minimum to avoid confusion and misinterpretation of messages.</td>
</tr>
<tr>
<td></td>
<td>- Driver E was tested to observe the response to communication whilst on approach to a signal. In this case Driver E ignored the call from the signaller until it was safe to respond.</td>
</tr>
<tr>
<td>4 - Signal aspect change</td>
<td>- Driver C responds to double yellow and single yellow aspects.</td>
</tr>
<tr>
<td></td>
<td>- Driver A announces double yellow aspect.</td>
</tr>
<tr>
<td></td>
<td>- Driver A made use of DRA when there was no sight of the signal aspect when on a curved part of track.</td>
</tr>
</tbody>
</table>
| 5 - Tunnelled versus open       | No significant observations were made on this scenario. This has been limited by the simulated...
<table>
<thead>
<tr>
<th>Route section driving</th>
<th>route design.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 - Train collision</td>
<td>The potential for train collision: Driver C sighted a car on the railway line. Driver C conducted an emergency call and stated the required emergency support, that is, for both lines to be blocked on approach to the tunnel.</td>
</tr>
<tr>
<td>7 - Passenger Emergency Alarm Triggered</td>
<td>This was not able to be simulated as detailed in Table 6-20.</td>
</tr>
<tr>
<td>8 – Low rail adhesion</td>
<td>Simulating low rail adhesion enabled train drivers to understand braking techniques. Low rail adhesion caused by the scenario of slippery conditions (environmental conditions) could impact passengers, for example causing the train to pass its stopping position. In this case passengers would not be able to leave the train and in serious cases there have been instances of passengers trying to leave the train through attempting to manually open doors. Observation of Driver D who had passed the stopping position showed demonstration of correct operational procedures. That is, to contact the signaller and notify them of the slippery rail conditions. Driver D then notified the train guard not to open the doors whilst the train driver prevented the door release function. Driver E noted that there was no wheel slip activation, and called to report this, in this case the driver was instructed by the signaller to check whether the sanders fixed to the traction were operational. Driver E confirmed the correct working of the train system. This scenario allows train drivers to understand and receive training on braking techniques for low rail adhesion.</td>
</tr>
<tr>
<td>9 - Alternation of train length</td>
<td>Not all trains driving on a route are configured to the same car length. The length of a train can impact efficiency, particularly for freight trains which carry large loads. The length of a train is also important for passenger trains in platform areas. In relation to the scenario 8 above a train can pass the specified car stopping position associated to its train length because of slippery conditions. In more severe cases a train can erroneously not only pass the car stop board but the danger signal with a resultant SPAD. In this case the driver reported the stopping error due to slippery conditions which caused the train to slide.</td>
</tr>
<tr>
<td>10 - Warning System Alarms</td>
<td>Driver B delayed in cancelling AWS alarm. The driver then called the signaller to state what had occurred. Driver B was given the permission to carry on. Following this, Driver B was consistent in deactivation of / reset of the AWS alarm.</td>
</tr>
</tbody>
</table>

**Table 6-21** Results of simulator observations
6.3.7.1 Additional Observations

1. Railway Topology: A level crossing is damaged on the route ahead. The driver is informed by the signaller and issued with instructions. Ideally, the driver would note and relay the instructions back to the signaller, however, driver actions vary as follows:

Driver A took on too much information from the signaller and incorrectly repeated instructions back to the signaller. This driver then went on to carry out an incorrect action. Instead of braking at the level crossing the driver proceeded at reduced speed. If a user of the level crossing was in the vicinity this could have resulted in an accident. Level crossings often have issues with trespassers or cars on the line. A wealth of publicly available information documents this. Following the training, the structured interview with Driver A revealed that he felt that he repeated the information in his own way, to his understanding. He understood what was said but agreed that he did not repeat back verbatim. In this case, the preferred and safer action would be to stop the signaller and clarify the actions. This would have avoided driver error.

2. Proactive Communication:

- Drivers in general have shown proactive behaviour and conduct good safety practices. For example, reporting missing speeds on trackside signage. This is of particular safety benefit to new drivers or for drivers with poorer route knowledge who have a lower perception of speeds in certain parts of the railway network.

- Driver C was informed not to stop at ‘Castle Hill’ station due to a security alert. Driver C continued and adhered by not stopping at Castle Hill. However the guard was not informed in sufficient time, consequently, passengers were not informed until the station stop had been passed. This presents a case where communication with the railway users was inadequate as there potential to inform them in a timely manner.

6.3.8 Summary of Results for the legacy Signalled Railway

Analysis of the data obtained from Abellio Greater Anglia train drivers has presented a number of issues. For example, in a number of cases and for particular questions the train driver respondents have steered away from extreme views. That is there was a lack of significant strong agreement or strong disagreement, with the neutral option selected in a number of cases. To a certain extent, this has inhibited responses on topics such as opinions on management. The drivers may see responses to selected questions as controversial and therefore opted for a more impartial view. However, the questionnaires were obtained confidentially with data obtained for research purposes only. Therefore, to prevent this and to gain more insight into opinions a 4 point scale would be used with the ‘Not Applicable’ / ‘Neutral’ option removed if this study was to be conducted again.

A meaningful output from the results is that the drivers are more readily open to comment on technology. This includes its use in the operational environment. Driving has shown to be negatively
affected by a number of factors. Primarily, communication (voice / alarms) and alerts have been identified as significant factors. Furthermore, train cab design, redesign and retrofitting are areas which would benefit from greater discussion between the management levels within the organisation and the front line workers.

Based on observations in the simulated environment, response from the drivers highlighted the difference in the frequency of events. In the simulated environment there are more events than would actually occur in a typical day in the life of a train journey. As a result, the drivers would operate differently in a real environment compared to the simulated environment. The drivers have shown to be very consistent in terms of checking the safety of the train before performing operational duties. Also, the drivers successfully make use of memory aids such as note taking to ensure that there are records of instructions provided by the signaller. The observational results were slightly constrained by the training program which could not be align directly to the scenarios selected for the research.

The training environment and the trainers proved effective and efficient. The follow up sessions after examination and training proved informative with no blame directed to drivers who made errors. Rather the approach taken was to tackle the root cause of the problem.

Finally, from the questionnaire responses and supplementary responses it is seen that the well being of a driver can be affected by extremes of any factor. This could be noise, heat, cold or workload, all of which have been mentioned in the responses from the train drivers. This is not easily observed in the simulated environment where a shorter period relative to operational driving is spent in the simulator. The drivers should be able to discuss these issues with management, however the reality of such a situation may vary between driver and manager.
6.4 Results: European Railway Modernised by ERTMS

The data obtained from the research carried out by MTO Safety and VTI has been translated into English from Swedish to ascertain the issues of applicability and in relation to this research. The Swedish researchers identified that the most accurate way to collate data was via observational assessment. This included use of recorded video camera footage. This also ensured that the maximum amount of information could be gathered on train driver operation in an ERTMS enhanced railway environment. The cameras recorded two areas, the track environment in addition to the train cab environment focusing on the DMI (Nordlof & Kecklund, 2014). This enabled particular analysis to be carried out on the train driver’s interaction with the ETCS DMI. In total, six drivers were observed on numerous train runs over a period of four months.

The train drivers were observed in model X55 class of train, the most recent train model for Swedish railways. This train type is 4 cars in length and has a top speed of 200kmh (Briginshaw, 2012). Prior to observing the train drivers a number of assumptions were made. For example, that they had a certain or minimum level of professional qualification. Unfortunately, MTO Safety found that conducting observations in the operational passenger environment posed certain limitations, such as the inability to test variations of safety critical scenarios. This is something that is more flexibly tested in a simulated operational environment as provided by VTI. Observations of the train drivers yielded a number of areas for discussion detailed in the following sections.

The methodology carried out by MTO Sakerhet (Safety) and VTI to examine the quantitative data obtained from their questionnaire was via the following process:

- Descriptive statistics: means and frequency analysis.
- Analysis of relationships within the data set: via T-Test, variance analysis, regression analysis and through use of correlation studies.

The questionnaire structure sufficiently maps to that used to analyse responses from UK drivers with experience on legacy signalled railways. That is, the Likert scale was used to determine views from respondents with response options which ranged from ‘Not at all’ to a ‘Very large extent’. This equates to strongly disagree to strongly agree as has been used for analysis of the Abellio train driver responses in the UK.

6.4.1 Descriptive Statistics: General Findings Related to Training

- Difference in the training styles: some drivers received training on certain features whilst other train drivers have received training in all features. This means there is a variability in the level and depth of the material that the drivers are train on.
- 54.9% of train drivers whilst undergoing practical training after five round trips along an operational route stated that they felt either ‘pretty unsafe’ or ‘very unsafe’. Based on this, the Swedish researchers carried out correlation analysis to examine whether there was an
relationship between ‘the feeling of safety after training’ compared to ‘how sufficient the training was for sufficient operation of the train’. No statistically significant relationship was found.

- A further correlation was carried out to ascertain whether there was a change in stress levels before, during or after an operational journey. The results indicate that the level of stress decreased upon completion of the operational task. The levels of stress were shown to significantly decrease during the run once the driver had gained more practical experience. This is indicated by the mean values, which rated at 3.0 before driving to 3.14 whilst driving. Following significant practice this dropped from 3.17 to 1.7 for perceived stress. This evidences that practice changes a driver’s perception of the train cab environment and in particular new technology.

### 6.4.2 Descriptive Statistics: Training and the Cab Environment

The approach taken by MTO Safety and VTI was to assess aspects of training in specific relation to the train cab interface. In particular, the DMI component of the train cab. The descriptive statistics as shown below in Table 6-22 indicate the mean and standard deviations for responses in relation to training on specific operational functions that are presented on the DMI. This includes the distance indicator, slope profile and speed reference.

<table>
<thead>
<tr>
<th>Stats</th>
<th>SD Error</th>
<th>N</th>
<th>Range</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
<th>Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Training on the distance indicator</strong></td>
<td></td>
<td>25</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>3.76</td>
<td>1.091</td>
<td>-0.317</td>
</tr>
<tr>
<td><strong>Training on the slope profile</strong></td>
<td></td>
<td>25</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>3.4</td>
<td>1</td>
<td>-0.38</td>
</tr>
<tr>
<td><strong>Training on the speed bow</strong></td>
<td></td>
<td>25</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>4.04</td>
<td>0.79</td>
<td>-0.073</td>
</tr>
<tr>
<td><strong>Training on the speed reference</strong></td>
<td></td>
<td>25</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2.88</td>
<td>1.364</td>
<td>0.127</td>
</tr>
<tr>
<td><strong>Training on the thrust (traction) reference</strong></td>
<td></td>
<td>25</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2.6</td>
<td>1.291</td>
<td>0.202</td>
</tr>
<tr>
<td><strong>Valid N (listwise)</strong></td>
<td></td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 6-22 Descriptive Statistics on Training with respect to the DMI*
Based on the results presented above, and from the observational studies that were conducted there are clear differences in driver responses. In particular, in relation to the importance of information. The driver responses highlighted the importance of the planning area on the DMI. Furthermore, the descriptive statistics indicate the importance of training on speed functions. There were variations across the driver responses in relation to perceptions of the distance indicator. This was primarily because of the strict braking curves that are enforced by the signalling system which forces the drivers to lose speed too far in advance, therefore negating the value of the distance indicated. This was a design feature that the drivers recommended for improvement. In addition to the technical downsides, human factor design issues were raised in relation to use of colour. It was found that some colours were indistinguishable such as the use of the grey scale of colours on the speed arc. Furthermore, the drivers were unaware of the significance of the changes in the shade of grey and when it had changed to either light or dark grey. The drivers also raised a recommendation on training in regard to the symbols used, such as the target point / End of Authority (EOA) within the planning area. Such as, the colour for the EOA could be shown in red, followed by an indication of rate changes and the associated size of the changes. This is significant, because the current system is designed in order that a rate reduction could be anywhere in the region of between 5km/h and 80km/h.

Issues with the speed information displayed on the DMI in addition to issues with rates of speed reduction or increase has led to drivers becoming distrustful of the system. Furthermore, compared to railways that do not implement ERTMS the drivers have become less able to predict the behaviour of the train and information displayed whilst in transit due to inconsistency.
6.4.3 The Train Cab Environment: Interfacing with the DMI

The Ådal Line, compared to the Bothnia Line has an increased level of complexity due to its topology. Drivers with experience of the Ådal Line have identified the impact of topology as a topic of significance. ERTMS implementation, in terms of its effects on drivers has shown a variation based on the complexity and topology of a network. It has been identified by the train drivers, that on more complex routes there is an increase in workload. It was found that demand is shared between the DMI and the external environment on a more frequent basis. The Ådal route complexity arises because of level crossings in addition to urban landscapes. With an additional risk posed because of both authorised and unauthorised users of level crossings. This was also demonstrated by UK drivers, where errors were observed because of misinterpretation of instructions from signallers specific to regions of the network where there were level crossings and the likelihood of a trespass.

Another impact of the topology on the driver’s interface with the train display is the resultant speed changes and gradients that are displayed to the driver. This means that the flow of information to the driver is increased. Furthermore, specific issues have been identified by the drivers in relation to specific vehicle types. The X55 vehicle is sensitive to speed changes and quickly rolls up to a specified speed or down in relation to the braking curves. Therefore a driver would need no more than a telephone call for distraction to be caused and for their attention to be moved away from the DMI. The propensity to multitask is significantly reduced in addition to the pressures of the driver trying to adhere to the operational timetable. The UK drivers managed distraction well in safety critical locations, such as on approach to station platform areas. However, the legacy cab environment does not have this level of technology demand.

Due to safety design which requires a train to adhere to braking profiles, emergency interventions can be enforced by the signalling system. Interventions have shown to affect driving style, with drivers exhibiting less cognitive workload but an increase in stress in some cases. The drivers have learnt to adapt the train system to suit them. For example, to avoid and reduce the number of interventions that cause a train to brake the drivers alter the cruise control speed. The drivers set the cruise control 5km/h below the current cruise control, this allows for greater speed margins. As a result, driver workload decreases with less active monitoring of the DMI needed to keep in line with the adjustments in speed. The downside of changing the cruise control is that difficulty may arise with keeping to schedule. Two further alternatives have been employed by the train drivers to enhance the comfort of drivability. Drivers have been observed to vary the setting of the reference indicator between the original setting and the speed control setting reduced by 5km/h. The final adaptation to the driving style was to change from cruise control to traction control. Traction control allows the driver to control speed manually using the throttle lever. Use of the throttle enabled better drive on the Ådal topography, which has many inclines. This was not necessary on the Bothnia Line. There may be more adaptations of drive settings, however these results are representative of those observed from the analysis by MTO Safety. The researchers identified that those drivers who alternated between the
original setting and speed control faced a greater chance of distraction due to tight intervention margins.

However, as found via structured interviews and discussions with drivers of legacy railways, route knowledge is always of benefit to driving. Drivers of ERTMS railways concurred with this due to the changeability of the notifications displayed on the DMI. The observations and interviews of drivers on the ERTMS signalled Ådal line considered route knowledge a necessity due to route complexity.
6.4.4 European Railways: Correlation Analysis

This section reviews statistical analysis and builds upon the observational data obtained on the practices carried out by Swedish train drivers.

<table>
<thead>
<tr>
<th>Correlation ID</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Text message content</td>
<td>Support provided by the text message</td>
<td>Scale very low to very large. Significant correlation: T-test showed a significant difference. Drivers felt the text messages had good content (mean = 3.79)</td>
</tr>
<tr>
<td>2</td>
<td>Ability to see symbols on the DMI</td>
<td>Usefulness of the feature in the planning area</td>
<td>Scale very difficult to very easy. Statistically significant correlation</td>
</tr>
<tr>
<td>3</td>
<td>Driver’s understanding of the DMI features</td>
<td>Time to see and act on information presented on the DMI</td>
<td>Statistically significant correlation because the drivers know where to look because they have an understanding of the system. Therefore they have the ability to anticipate and expect information.</td>
</tr>
<tr>
<td>4</td>
<td>Driver underestimation of the potential to absorb information from the DMI</td>
<td>Time to see and act on information presented on the DMI</td>
<td>No significant difference.</td>
</tr>
<tr>
<td>5</td>
<td>How well the train cab is designed</td>
<td>Ability to absorb information from the DMI and see the symbols in the planning area</td>
<td>Statistically significant correlation. Scale very bad to very good. Indicated a good cab design made it easier for train drivers to assimilate information. Also, a strong correlation between seeing the symbols within the DMI planning area and the ease of information absorption.</td>
</tr>
</tbody>
</table>

Table 6-23 Correlation Results: ERIS Data
6.4.5 Summary of European Data Analysis

The results reported by MTO Sakerhet (Safety) which encompasses research by VTI and data from ERIS is summarised in this section. As stated earlier on in this chapter, this research is documented in Swedish. Therefore, to implement their findings into part of this thesis for comparison to UK data their findings have undergone translation into English. The significance of their research relates to the impact of ERTMS developments on train drivers.

Topology

The physical architecture and natural landscape of a railway can impact the workload that is imposed on a train driver. This has been demonstrated by comparison of the complex Ådal line to the less complex Bothnia Line. Variability and adaptation has been seen by drivers on complex routes in the aim to reduce workload and to support multi tasking between the train cab and the external railway environment.

Driver machine interface (DMI)

The amount of information displayed to the driver and the changeability of the information on the DMI has forced drivers to continually focus on the DMI. The drivers in Sweden have been observed to prioritise information on the DMI based on what is considered important. This information ranges from text messages to speed changes. This means that the train drivers are increasing the amount of work they have to do by conducting this information filtering process whilst driving the train.

Training and Education

Driver training and education is essential especially when adaptation is required because of new technology such as ERTMS. The results on education, show that education influences the driver's perceived usefulness of the DMI interface. Therefore training needs to be structured to reduced variability in training techniques.

Simulators

As seen with the UK results, simulators offer an alterative to training in the operational environment. However, the level of training that can be achieved in a simulator depends on the maturity of the software that the simulator training models are based on to an extent. Whilst implementation of ERTMS undergoes fine-tuning, simulators are an ideal environment for driver training in a safe environment. There are however limitations which include depth perception because it is a static environment.

The key results from the research by MTO Sakerhet (Safety) identifies that the introduction of ERTMS differs depending on the topography of the railway. Introduction of ERTMS technology into existing lines was found to be more complex and problematic than its introduction onto new lines. This is an issue that not only affects the other existing lines in Sweden due to integrate ERTMS technology, but
this will also be a factor that affects the lines in the UK as the routes are existing with a large amount of legacy technology.

Further to the research carried out on legacy UK railways, which has been compared to research carried out by MTO Safety and VTI into railways modernised by ERTMS. The Belgian Infrastructure Manager Infrabel (Infrabel, 2013) has also carried out analysis in relation to the impact of ERTMS. Belgium utilises ERTMS technology on the rail network as part of the aim for a safer network. Belgium also have the TBL1+ system, which is a driver support system installed on their railways for additional protection which is also compatible with ETCS. The research carried out by Infrabel specifically focuses on train categories, where an error can be made during data entry and makes comparison to conventional signalling as shown in Table 6-24 below.

<table>
<thead>
<tr>
<th>Train category</th>
<th>Error During Data Entry</th>
<th>ETCS Signalling</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cant deficiency</td>
<td>✓</td>
<td>Over speed</td>
<td>Wrong speed supervision</td>
</tr>
<tr>
<td>Type of train and brake position</td>
<td>✓</td>
<td>Wrong supervision/ SPAD/ Possibly over speed</td>
<td>Wrong speed supervision error could be critical</td>
</tr>
<tr>
<td>Maximum train speed</td>
<td>✓</td>
<td>Wrong supervision/over speed</td>
<td>Wrong supervision</td>
</tr>
<tr>
<td>Train length</td>
<td>✓</td>
<td>Wrong supervision/over speed</td>
<td>Wrong supervision</td>
</tr>
<tr>
<td>Axle load</td>
<td>×</td>
<td>Wrong supervision/over speed/derailment</td>
<td>Wrong supervision</td>
</tr>
<tr>
<td>Gauge</td>
<td>×</td>
<td>Collision with an obstacle (in the event of a wrong route)</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Braking performance (Single moderate error)</td>
<td>✓</td>
<td>Wrong supervision/ covered by safety margins in braking curves</td>
<td>Wrong supervision</td>
</tr>
<tr>
<td>Braking performance (Single critical error)</td>
<td>✓</td>
<td>(hauling trains) (Train sets) Wrong supervision/over speed/SPAD</td>
<td>Wrong supervision Long braking distance leads to over speed or SPAD when the actual braking performance is not sufficient for that route and that maximum speed (error during train preparation)</td>
</tr>
<tr>
<td>Braking performance (Multiple critical error)</td>
<td>✓</td>
<td>Wrong supervision/over speed/SPAD</td>
<td>Wrong supervision Long braking distance leads to over speed or SPAD when the actual braking performance is not sufficient for that route and that maximum speed (error during train preparation)</td>
</tr>
</tbody>
</table>

Table 6-24 ERTMS and Conventional Systems (Infrabel, 2013)

Table 6-24 demonstrates the significance of data entry and it shows that an error is also likely to be made with an ERTMS system as it is with a conventional train system. In both cases, wrong data entry in the various train categories can result in an impact on safety such as SPADs or alternations of braking performance. Therefore as detailed in Chapter 5 For ETCS trains, the DMI is the interface between the train driver and the vehicles computer, the European Vital Computer (EVC). The EVC is a core train system as it supervises the train’s movement whilst feeding a range of information to the driver via the DMI’s graphical user interface. A driver with limited route knowledge may not appreciate
the impact of incorrect data entry compared to a driver with greater experience and knowledge of a train’s performance. Therefore in addition to training of the new technology, sufficient training should be given on a particular topology.

6.4.6 Summary of Results

Simulators

Use of simulators to carry out observations of the train drivers had a number of benefits and drawbacks. Train simulators are used as a key part of driver training, driver assessment and or rehabilitation following errors on track and also to support research as shown in this thesis. The following advantages and disadvantages have been identified following observational analysis.

<table>
<thead>
<tr>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Safety critical failure conditions can be simulated without experiencing the consequences of a dangerous environment.</td>
</tr>
<tr>
<td>2 Simulators provide the opportunity to test, retest and practice a particular scenario. This is of particular benefit to a driver if they are facing difficulty in a particular area. A real operational environment cannot be used for this, unless in operational test track area.</td>
</tr>
<tr>
<td>3 Simulators provide instant variability in weather conditions to manipulate the environments that a train driver can encounter.</td>
</tr>
<tr>
<td>4 Simulators are a quick way to collate data and are unrestricted by operational constraints.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Some simulators are not configured to simulate all possible safety critical scenarios; this is a software development and cost constraint issue.</td>
</tr>
<tr>
<td>2 If a simulator is not realistic enough this could induce incorrect actions from a driver, actions that would not be carried out in the actual operational environment. For example, the simulators used by Abellio for the UK railway where good in terms of design and train replication. However, with all simulators that are not on a motion axis there is the issue with lack of the movement sensation.</td>
</tr>
<tr>
<td>3 There was one incident where a train driver felt slightly sick akin to motion sickness, the causes and reasons for this would need more detailed research. As this could affect other drivers in training also.</td>
</tr>
</tbody>
</table>
Ideal Data

This research would have potentially yielded more significant results if the questionnaire that was translated into Dutch for railway drivers in the Netherlands could have been implemented. This would have provided a like for like comparison to the data set obtained based on UK drivers with experience on legacy railways.

As ERTMS has a large focal point on board the train in terms of signalling interfaces and interactions with the train driver, it would have been beneficial to have carried out observations during actual passenger operational hours. This may have yielded more observations when the driver was under pressure and significant workload on complex routes.

Data related to DMI data entry was not easily available and literature research on interactions with this interface is limited as organisations may consider this material to be sensitive. It has been comparatively easy to source information which details how the DMI data entry procedure should ideally perform. This is shown in technical requirements specifications.

In closing, analysis of ERTMS has been dependent on data from organisations that have made developments with implementation of this technology. The Swedes have significantly developed software that if time had permitted would be tested to determine issues that affect driveability.

6.5 Summary Failure Scenario Analysis

This chapter has presented in detail the results for safety assessment of mainline railways. The railways investigated differ based on their configuration, which is, conventional signalling compared to ERTMS signalling technology. It has been shown that given the complexity of railways and the level of system integration required for operation. Which includes traffic control, the train system and track, railway safety levels on existing railways are of a high standard with a range of protection systems and procedures in place to maintain good safety practices. Comparing existing railways to ERTMS railways in Sweden it is seen and evidenced that modernisation of railways attempts to further improve safety.

The initial failure scenarios identified from literature review and personal experience in the railway industry related to a broad spectrum of scenarios. This included technical system failures to operational related failure scenarios. The safety assessment process has therefore tested failures that are likely to occur on the railway, specifically within the driving environment.

Reviewing the results of safety assessment in relation to UK and Swedish results. The failure scenarios examined align to the hazard analysis section of the improved safety assessment process. That is, the hazards have been identified, with possible failures determined. Each case has as an output where change is required. This could be in the form of training, system redesign or requirements change. All of which are costly initiatives. Competency has proved to be an important
factor required at all levels, from the operator to the trainer this could be in regard to use or misuse of equipment. Aspects of review, such as post training discussions with the driver trainers has shown to be an essential part of the review and evaluation process. However, lessons learnt is an area which needs greater emphasis and could be improved through interactive group discussions. This would also encourage the reporting culture. The improved derived safety assessment process is thus deemed to be exhaustive as it covers all the aspects of safety culture identified through analysis of the questionnaire and observation results.
Chapter 7  A New Safety Case for Modernised Railways

7.1 The Need for a Safety Case

As discussed in the previous chapters and shown through the results of safety assessment in Chapter 6, safety has a number of influencing factors. The safety assessment process developed in this thesis and presented in Chapter 4 integrates practices to improve safety culture alongside the common existing methods of hazard analysis. Key changes to the process include user competency and integration of lessons learnt activities. A common issue found in the UK and from cases in Asia show that processes related to safety practices are in place, however, understanding is not comprehensive or the training has not been fully effective as demonstrated by failures. A robust safety assessment process is required for a SMS so that the safety case is adequately informed. Safety critical industries manage safety in a number of ways and commonly demonstrate the safety of a system through use of an argument termed a safety case. The use of a safety case can vary dependent on the scale and technical complexity of a project. Existing and modernised railways are both large in scale and complexity and require subsets of safety cases to formulate an overarching safety case.

As discussed in the aims and objectives of this thesis, the output of this research produces a safety case for railway industry application. This research has made use of ERTMS technology railway developments and the resultant derived safety assessment process to create a safety case. The derived safety case can be tailored for implementation by a range of safety critical industries in addition to railways. In order to arrive at the derived structure a number of features desirable to a safety case have been determined based on literature review in addition to the derived safety assessment process.

Safety critical industries often question the level of safety analysis required or try to determine whether a safety case is necessary. A safety case, be it in the form of a detailed argument or in the form of another structured format provides a means for an organisation to promote its safety reputation through demonstration of clear safety responsibility. A safety case is a clear and concise platform to demonstrate roles, responsibilities, accountabilities, design assumptions, expectations and importantly the safety culture demonstrated throughout an organisation. In summary, a safety case demonstrates adherence to the safety management system in a clear and concise format.

The railway industry, akin to other safety critical industries has historically faced a number of severe failures in safety. This includes accidents and incidents resulting in harm to people, damage to the environment, damage to infrastructure assets and to organisational reputation. As a consequence, railway organisations utilise methods to improve safety, which have been garnered from other safety
critical industries. In particular, lessons have been learnt from the Nuclear and Oil & Gas industries where precedents have been set on aspects such as safety management.

As stated throughout this thesis, safety culture in the railway is receiving more awareness as a subject, however better integration into Safety Management Systems is required. This is in order to manage it as part of day-to-day organisational processes. The subject of safety culture is not a pure science but it is essential to incorporate it in relation to safety cases and it is discussed in the context of the obtained results. The data obtained from the observation and questionnaire activities detailed in Chapter 6 of this thesis have been used to create a comprehensive safety case. The safety case is mapped to safety culture for the modernised railway environment. However, before relating the framework to modernised railways the following subsections introduce case studies from which lessons learnt have been drawn upon.

7.2 Railway System Safety Case

As Chapter 2 demonstrated through production of system architecture, a systematic approach is a viable and effective option to interrogate the complexity of a railway system. Furthermore, system architecture is the basis from which risk analysis can be performed. However, In addition to the physical system interrelationships, the specific operational parameters that a system should achieve to enable it to function safely should also be evaluated.

Therefore, in order for a railway system design to maintain the goal of providing a safe system for train control and train operation the system is required to be:

(i) Maintainable – the system has the ability to be easily restored in the event of failure;
(ii) Flexible - has the ability to be fully integrated with either legacy systems or newer systems and be
(iii) User friendly - the system (even a complex system) should be easily understood to allow unhindered operation by all sufficiently trained operators;

In the event of a railway system failing, user (operator/maintainer/controller) and passenger safety is seen as a priority. As passenger demand and usage continues to increase, even more attention needs to be paid to the safety of railways. Employee safety has also seen increased emphasis as an area of importance, largely because and as seen in Chapter 5 the human interface with technology is continually changing and developing. For these reasons, operational concept scenarios, system functionality and hazard scenarios for railways need to be clearly defined by organisations. These are key aspects of the derived safety assessment process and support the railway system safety case.

The use of a safety case aims to maintain a consistent approach to safety by mitigating a multitude of issues. The attributes of a safety case have therefore been surmised as follows:
1. A means of providing assurance that safety measures are in place and that the SMS has been complied with.
2. A tool used by an organisation to promote safety and gain public confidence in the railway.

7.2.1 Uses of a Safety Case

The application and value of safety cases as a safety management tool within the UK mainline railway industry has been driven in the first instance by changes in organisational management. A shift in UK railway ownership has seen the move away from railways privatised by Railtrack, later to go into liquidation to transformation via the emerging not for profit Infrastructure Manager Network Rail. Network Rail place strong emphasis on safety management; particularly, in terms of railway development and fragmentation which has seen a shift in organisational structure in areas such as stakeholder input.

Organisational fragmentation and restructure brought the likelihood of introducing risk into the railway environment. In addition to organisational restructure, emphasis on the usefulness and application of safety cases in the railway industry stems from recommendations following the Ladbroke Grove railway crash, otherwise known as the Paddington railway crash in Lord Cullen’s inquiry (Cullen, 2001).

Lord Cullen debated and assessed the safety case as a tool for safety management, utilising industry expertise to aid debate. Industry expert views on the usage of a safety case varied considerably, ranging from ‘it is not appropriate for ongoing day to day operations where the risks of existing systems were already known and understood’ (Cullen, 2001) Pg 86. To the opinion that a safety case was not necessarily the correct document and that instead the use of a combination of prescriptive rules, alongside competent management was a better alternative (Cullen, 2001). The Health and Safety Commission however, found the safety case to be a crucial and important tool to effectively manage safety. This view contradicted other expert opinions such as the view that auditing was a sufficient enough method to evaluate safety. The Cullen inquiry also discussed broader areas of what a safety case should cover as identified by industry experts and railway stakeholders. Ultimately, a safety case was deemed to be an invaluable tool to enable safety to be managed via a systematic approach (Cullen, 2001).

The term ‘safe’ or ‘safety’ has a number of facets that determine its level of importance. This includes hazards, risks, residual risks, risk mitigation and methods by which risks are validated. A safety case captures elements such as those mentioned and is a means to demonstrate through pragmatic arguments or quantitative methods that the railway system in question is safe.

Use of Defence standard 00-54 issue 4’s definition of a safety case is presented below:
‘A structured argument, supported by a body of evidence that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment’ (Ministry of Defence, 2007).

The definition above shows that emphasis is also placed on the body of evidence which assures the safety of a railway system which includes outputs of the SMS. A safety case for the purpose of this discussion is deemed to be an ‘argument’ which documents ‘why’ and ‘how’ the railway system is safe through supporting evidence.

This definition is demonstrated by London Underground’s contractual safety case (Tube Lines Limited, 2004). This safety case is a declaration of commitment to manage safety and a tool for demonstrating how safety risks are identified and controlled for the physical underground railway system. For this safety case, London Underground as infrastructure controller, has had to consider the behaviour of the system under all potential operational scenario conditions as all responsibility for safety resides with them. This responsibility extends to those suppliers who perform works on behalf of London Underground. The safety case also identifies how risk is potentially increased which includes aspects such as asset upgrade, asset removal or through use of external sub contractor services to conduct engineering activities. For the case where there is use of external services to complete project deliverables, differing methods of working / safety practices to that of London Underground may be in use. Aspects such as this have the potential to be problematic and a risk to safety, this is largely because consistency and control is not maintained throughout the organisation.

7.2.2 Structuring a Safety Case

The structure of a number of safety cases has been studied through review of literature. The structure of a safety case is important as it provides the basis by which safety arguments are presented. Some organisations such as the Office for Nuclear Regulation (ONR) use the term safety case and safety assessment interchangeably (Senior, 2013). This is not the approach taken by the railway industry whereby the safety assessment process is seen as a major contributor to the detail of a safety case.

Safety cases can be structured and presented in a number of ways. A comparison of the structure of safety cases in a number of industries highlights various issues. Literature from the nuclear industry significantly highlights why structure is important. The Office of Nuclear Regulation (ONR) prescribes that the safety case structure should be centred on the importance of the hazard (Senior, 2013). Additionally, the ONR indicate a logical structure to the safety case is achieved in a number of ways. For e.g. for large scale projects, a tiered approach to a safety case can aid its usability.

The construction of the safety case for the automatic metro in Copenhagen takes this exact route as depicted in Figure 7-1, this shows the dependencies of safety cases (Wigger, 2001). Figure 7-1 shows the tiered approach, which segregates safety assessment for sub systems which build upon safety plans, safety requirements and hazard analysis of the sub systems. This approach demonstrates that there are significant dependencies on underlying plans and quantitative analysis.
Research by (Kelly, 2003) has examined the detail of managing complex safety cases in which a number of specific and relevant points about the structure of a safety case are made. In particular, where benefits and disadvantages are often found and how this can impact the safety which the safety case is intending to argue. Key points of relevance include:
1. Concurrency and timescales: Multiple workstream activities to produce the safety case can take place. This enables separate teams to work concurrently.
2. Alterations or amendments: If change is required to a safety case, then due to the separate layers of the safety case, only those parts requiring modification will change. Therefore this avoids rework to the entire safety case argument.

Further to the benefits presented above which relate to a tiered approach to safety cases, certain standards also provide prescriptive guidance. Specifically, CENELEC standard EN50129: 2003 is used as it specifies the following key elements:
• A System Definition (or sub system definition) – part 1;
• A Quality Management Report – part 2;
• A Safety Management Report – part 3;
• Technical Safety Report – part 4;
• A Related Safety Case – part 5;
• Conclusion to safety case – part 6;
Each of the parts is a significant document in itself, formulated from a number of sections. For e.g. the Technical Safety Report looks into the effects of failures, the impact of external influences on operation and assurance for example. The overall conditions for safety acceptance are also detailed in this standard and this is achieved through adherence and evidence of safety and quality management in addition to functional and technical safety (British Standards, 2003).

In summary, the structure provided by this standard relates in practical terms to safety acceptance of the system in question. The particular detail of this standard pertains to ‘Railway applications – Communications, signalling and processing systems - safety related electronic systems for signalling’ (British Standards, 2003). When analysing this standard, a number of issues should be considered, such as:

(i) Understanding which parts of the safety case can be carried out concurrently;
(ii) Conversely, to identify what cannot be carried out concurrently and hence relies on a succession of events;
(iii) Whether there is the skill set in place to conduct the required activities;
(iv) Whether safety culture is adequately addressed and there are significant improvements in safety, based on lessons learnt and that safety is instilled within an organisation;

A core focus of this research is safety culture, with a significant part of this research involved in improving the way safety practices are implemented and understood within the realms of a safety case. Specifically focusing on standard EN50129, which advises at European level how to demonstrate safety. The element which tackles safety culture is via part 2 of the safety case structure which pertains to quality. The quality report includes aspects such as organisational structure, personnel competency and training, documentation and records, all key to an effective safety culture. A practical example of a Quality Management Report (QMR) is demonstrated by Delta Rail. Delta Rail carried out a QMR for equipment at the Integrated Electronic Control Centre owned by Network Rail and this forms their safety case (Delta Rail, 2012). Delta Rail specifically refers to standard EN50129 as the baseline that has been used to structure their safety case in addition to the Yellow Book and Common Safety Methods (discussed in Chapter 4), which is core to the derived safety assessment process. The approach taken in Delta Rail’s safety case is summarised in Table 7-1 (Delta Rail, 2012).
In Delta Rail’s safety case, aspects such as human factors are addressed via standards in relation to ergonomics. However, in this case, there were no specific contractual requirements put upon Delta Rail in relation to human factors. As a result, their approach was to only assess developments which resulted in a change to a user interface and to produce a subsequent human factors report.

As part of Delta Rail’s safety assessment, consideration is also given to evidence that can demonstrate a well established safety culture. However the details of this are not expressed further within their document. It is only assumed that requirements have been met which relate to:

- Personnel safety issues,
- Training material and training assessment and
- Briefing material for key stakeholders’

This method, employed by Delta Rail has utilised the framework set out by CENELEC standard EN50129 where it is deemed applicable to their particular system. However, it is noted that there is very little emphasis on human interfaces and the importance of safety culture in its entirety. This is probably due to the system being software centric. However, the human still has many points of interface. This safety case, like many focuses on the technical aspects such as technical system performance with little emphasis on safety culture. Back to the definition of safety culture, ‘the product of individual and group values...that determine the commitment to an organisation’s health and safety management’ (Health and Safety Executive, 1993) in addition to technical safety issues.

This definition of safety culture has not been explicitly defined within the structure of Delta Rail’s safety case. In Chapter 4, review of safety culture via the Railway Safety Directive showed Great Britain have rated themselves to be at the ‘implementing’ stage. This is somewhat reflected in the
safety case authored by Delta Rail as sufficient emphasis has not been placed on the human and organisational elements of safety culture.

7.2.2.1 Goal Structure Notation

Safety cases can be complex and weighty documents and as demonstrated through review of literature, can be time consuming to construct. Factors such as these depend on the system being interrogated. To address this, industries such as the railway industry are ever increasingly focusing on the method of safety case construction. This focus aims to reduce the cost and time spent on developing safety cases through use of software tools. However, the safety case should always maintain its role as a means to argue that there is effective safety management of hazards and system interfaces.

To address the complexity that safety case construction entails, a number of approaches and notations are available, these include ‘Weighted Factor Analysis’, the ‘Adelard Safety Case Development Manual’ in addition to ‘Goal Structure Notation’ as discussed by Fararooy (Fararooy, n.d.). The method described in this section is Goal Structure Notation (GSN), largely because this is the method that is in use and documented across the railway industry, in both metro and mainline railway system organisations. GSN also provides an alternative to the prescriptive methods detailed in standard EN50129 for creation of a safety case.

GSN offers a targeted and holistic approach to assess a system. The methodology behind GSN is a complex one and as such the GSN Community Standard has been developed to provide instruction on its use (Origin Consulting, 2011).

The standard highlights that the arguments presented using GSN can aid assurance of safety critical systems as explained below:

‘0.2.3 – In practice, an assurance case will have a particular focus. For example, a safety case will demonstrate that a given system is acceptably safe in a given context’ Pg 9

‘0.2.4 – In order that assurance cases can be developed, discussed, challenged, presented and reviewed amongst stakeholders, and maintained throughout the product lifecycle, it is necessary for them to be documented clearly. The documented argument of the assurance case should be structured to be comprehensible to all safety case stakeholders. It should also be clear how the evidence is being asserted to support this argument. By appealing to core concepts or argumentation, GSN helps to address these objectives’ Pg 9 (Origin Consulting, 2011).

The concept behind GSN is largely relationship focused. This is summarised as follows, a method to:

1. demonstrate the association between goals and sub goals;

2. show how claims are supported by solutions;
3. demonstrate the relationship of an argument in a given context.

An example of its implementation is presented by Kelly et al. (Kelly & McDermid, 1997) whose research focuses on the reuse of patterns and common structures. Reuse of patterns, if handled incorrectly, can introduce problems. As seen in cases described throughout this thesis, systems may not necessarily be safe in a modified context; therefore reuse of a pattern may not effectively demonstrate its safety. Therefore reuse should be handled carefully.

The method behind GSN is depicted in the figure below. GSN employs a top down approach to ensure satisfaction of a goal. In this case G1- the goal to satisfy is that system x is safe. A strategy S1 of an argument is employed within a given context C1. The argument in this case, then feeds to further goals which need to be satisfied. Figure 7-2 also uses different types of arrows to link between the various symbols. An arrow with a hollow head indicates that the relationship is contextual whilst the solid arrow indicates evidential or inferential relationships (Origin Consulting, 2011).

![Figure 7-2 Extensions for Structural Abstraction (Kelly & McDermid, 1997)](image)

Further to the example above which provides an outline of the use of GSN, additional examination of the process shows how the goal is satisfied. This is primarily demonstrated through evidence or via a ‘solution’ in GSN terminology.

In summary, the GSN structure indicates the claim at top level, in this case, that a system is safe. This is followed by an argument in its various contexts and closed with evidence, which can be quantitative results or analysis. Figure 7-3 below is not legible, however it has been included to show the potential
complexity involved in the satisfaction of a goal. The solutions are shown in the orange circles with the framework presenting a clear hierarchical structure.

Use of GSN, may however be restricted to a certain extent by how advanced the various sub systems are in terms of their design. However, when constructing a safety case it is advised to start development from the earliest feasible stage.
Figure 7-3 System GSN - Cambrian Line (Network Rail, 2008)
Making use of the theory and concept of GSN, it is now related to Chapter 5, which focused on safety assessment associated with safety culture. Chapter 5 included a review of the train driver interfaces; this is also examined using GSN from the perspective of safety. The relationships shown in Figure 7-4 have been drawn up to demonstrate what could be expected to satisfy a safety argument for train drivers interfacing with new technology.

**Figure 7-4 Example of GSN structure for the Train Cab Driving Environment**

The GSN depicted above is theoretical as it has not been examined by Subject Matter Experts. However, based on personal experience in the railway industry, the construct depicted above is feasible. This example starts with the goal to be satisfied that ‘the in cab driving environment is safe’. This is a broad ranging goal and could encompass arguments which range from ergonomic issues to use of technology. As the safety assessment in this thesis revolves around technology and in particular the driver interface, the arguments presented relate to safety of the DMI in addition to operability hazards. The potential respective solutions could include evidence such as drivability assessments to confirmation of operational hazards by a Safety Review Panel (SRP). Additionally, the top goal (G1) feeds down to a sub goal (G2) relating to risk management and an associated claim that all hazards have been identified. This method pictorially demonstrates that safety can be argued in a clear and consistent way but can become complex for large detailed systems. However, it is noteworthy to add that the evidence that feeds into the top level goal is particularly important as evidence supports not only the top level safety case but the sub system safety cases.
7.3 Defining a Safety Case

The factors that are vital for the development of an effective and efficient safety case have been identified in the previous sections of this chapter. Following review of prominent safety case studies, commonly implemented tools used to demonstrate safety in addition to European standards have been discussed. This section subsequently develops a railway safety case based on the results of the safety assessment process.

In order to ensure that safety can be demonstrated according to best practice, there must be an underpinning structure to the safety case. The safety case is therefore designed so that it meets standard EN50129 and as highlighted in research by Kelly (Kelly, 2003) that it demonstrates important factors, which include:

- Clarity - the framework should enable complex systems in addition to less complex systems to be demonstrated as safe.
- Linkage - It should appropriately link a system via interfaces and dependencies.
- Traceability - Retain historical information where applicable so that traceability can be maintained.
- Flexible - Safety cases should be seen as live documents which can be updated when deemed significant.

As seen from the bulleted examples above, to develop the safety case the initial step was to determine the safety case structure that is used to demonstrate the standard of safety management. In terms of its physical design two distinct activities need to be demonstrated in the safety case, specifically (i) the arguments in their relative context and (ii) evidence.

Throughout this research, the theme of safety culture has been evident as a key factor to manage safety. Therefore establishing a safety case requires the following aspects of safety culture as shown in Figure 7-5 to be demonstrated.

![Figure 7-5 Safety Culture Elements of a Safety Case Framework](image)
The cultural elements of collaboration and safety responsibility have been determined and proven via safety assessment in Chapter 5. However, the various tools to support safety such as ‘peer assist’ and ‘principles and guidance’ originate from recommendations via the UK Nuclear Safety Case Forum (Page, Sutton, & Murphy, 2014). The relevance of which shall be detailed throughout this section.

However, as pointed out by (Hopkins, 2013), when developing a safety case, involvement from unions should also be included to account for the fact that ‘employer and employee interests are not the same’ (Hopkins, 2013) Pg 4. This quote relates to each circle that comprises Figure 7-5 as employer and employee views may differ in terms of safety responsibility, collaboration and safety tools. Unquestionably, employees need more input into safety regimes as they are at the front end of daily operations. It is seen that the most mature regimes for safety have employee liaison and that ownership of the safety case should be seen as a combined team responsibility. This is largely because regardless of whoever signs the document as owner, there remains reliance on subject matter expertise, lessons learnt and tools for guidance. Collaboration is another key facet, operational staff i.e. those who operate in control rooms and manage daily operations under normal, degraded and emergency modes will have first hand expertise. Thus it is most valuable to utilise skills such as these.

From Figure 7-5 above, the safety case construct should address hazards within the realms of safety culture. Therefore as shown in Figure 7-6 safety culture within a safety case should relate to procedures, technology and the human interface.

![Figure 7-6 Railway system basic relationships](image)

Safety culture is exhibited most identifiably between humans and prescribed procedures in addition to exhibition between humans and the use of technology. The link between procedures and technology is slightly more difficult to evaluate in terms of safety culture. However, it is usually prescriptive in terms of guidance in the form of manuals. For example, there have been instances where the operational procedures in place make use of the available technology but do not exhaustively cover degraded or failed modes of operation in addition to the human interface. This is demonstrated by the safety incident that occurred in 2011 in the locality of Kentish town (Rail Accident Investigation Branch, 2012). This operational scenario involved a train stranded for over 3 hours due to loss of
traction. In this time frame passenger facilities ceased operation (toilets, air conditioning, in addition to passenger communication) with the eventual action of passengers disembarking the train at various intervals. This caused numerous issues for the driver as passenger alarms were activated on a number of occasions. In events such as this, another train can be used to recover a failed train. In this instance the train sent to pull out (via coupling) the failed train was also hampered because of the passenger alarms activating which resulted in uncertainty over the passenger door safety. As a result, the driver over rode the safety system to test coupling of the train. The passengers were still alighting the train without instruction. This incident was not standalone as similar occurrences happened in the past which this TOC had encountered. The RAIB resultantly made a number of recommendations, examples of which are stated below:

- ‘Train Operating Companies and Network Rail routes over which they operate, should review existing protocols, or jointly develop a new protocol, for stranded trains in accordance with the contents of ATOC/Network Rail Good Practice Guide’ (Rail Accident Investigation Branch, 2015) Pg 2.
- ‘First Capital Connect should carry out a review of its management processes to examine why it did not identify and address deficiencies in emergency preparedness prior to the incident. The lessons learnt from this review should lead to changes in management systems’ (Rail Accident Investigation Branch, 2015) Pg 3.

This case shows a number of issues occurred including sub system failures that worsened the event. Also, the TOC did not follow operational procedures as per training for incident handling, identify their own shortcomings or learn from similar past incidents. A significant lack of safety culture has been exhibited in this particular case study, a factor that needs to be demonstrable as part of any safety case.

Focus needs to be brought to issues such as these as not enough emphasis is placed on culture in practice. Therefore, what is needed from the framework is a clear way to demonstrate the actual level of safety and safety margins. This is obtainable from quantitative statistical analysis using existing data on incident and accident statistics. The RSSB for example aim for collaborative agreement on risk via the Industry Shared Risk Database (ISRD) in support of safety management system development (Rail Safety and Standards Board, n.d).

Safety case development has now moved on in terms of scope and coverage. Further developments and guidance in relation to safety cases now require security and specifically cyber security to be addressed as part of their formulation. This is largely due to the increased vulnerability that technology advancement introduces. This is a topic of increasing applicability to European railways and particularly for integrated railways. However, the extent of a cyber threat is not fully understood yet but it has reached such prominence that the UK government have committed to support the cyber industry.
‘Though the scale of the challenge requires strong national leadership, Government cannot act alone. It must recognise the limits of its competence in cyberspace. Much of the infrastructure we need to protect is owned and operated by the private sector. The expertise and innovation required to keep pace with the threat will be business-driven.

Similarly, though we can improve our defences domestically, the internet is fundamentally transnational. Threats are cross-border. Not all the infrastructure on which we rely is UK-based. So the UK cannot make all the progress it needs to on its own. We will seek partnership with other countries that share our views, and reach out where we can to those who do not’ (Cabinet Office, 2011) Pg 22.

As a result, the RSSB, a key stakeholder in terms of industry railway research have started to examine the effects of cyber security on railways and have produced guidance on effective management of cyber attack.

Significant work has been carried out by the cyber security industry such that a preliminary cyber security framework has been developed. This can significantly support and guide the railway industry in their application of cyber security management, as the railway industry does not have exhaustive domain expertise in this subject. The key elements of the cyber security framework are compared in this section to those outlined by the nuclear industry and applied to the railway industry.

Comparatively, the forum guide from the nuclear industry does not outline a specific framework but highlights key factors required in a safety case. These factors ensure that the safety case is usable, and focus is therefore drawn to its preparation. Aspects of safety management include that the safety case is ideally ‘home grown’ with clear direction and support provided by the safety case owner. To support the usability of the safety case it should employ a clear sentence structure, have minimal repetition and include visual presentation (Page, Sutton, & Murphy, 2014). As described briefly above, the nuclear industry forum also identifies a number of toolkits as used by various industries that have enabled their safety cases to be usable. A brief outline and summation of the various tool kits is presented below:

- Tool 1: Nuclear Safety Requirements Specifications and Statement of Safety Case Strategy;
- Tool 2: Issues Register and Technical Forum;
- Tool 3: Peer Assist;
- Tool 4: Safety Case Health Check;
- Tool 5: Recognition Statements;
- Tool 6: Principles and Guidance;
- Tool 7: Proportionality Matrix;
- Tool 8: Safety Case IT Tools; (Page, Sutton, & Murphy, 2014)
These tool kits provide a range of methodologies as they originate from different industry SMEs. It can be seen across the tool kits that there are a number of elements that crossover, however, there also exist some areas that are not captured in each tool kit. The key areas that are covered include:

- The use of stakeholders and technical working groups to fully evaluate safety issues:

Therefore for the railway safety case there needs to be emphasis on competence and clear demonstration of collaboration an essential part of an effective safety culture.

- Risk profiling and Hazard Analysis:

It is essential to understand risk; this includes management of technical, operational and business risk. The consequences of badly managed risk can damage not only the business but staff morale, attitudes in the railway environment and potentially blame culture. The fear of blame can lead many to under report accidents or incidents which in turn contribute to a less safe railway.

The guidelines for a ‘Right First Time Safety Case’ (Page, Sutton, & Murphy, 2014) have shown the benefits of collaboration through the use of nuclear industry domain expertise. Although there are differences in approaches to formulation of a safety case this forum has demonstrated that through collaboration even industry competitors can work together to achieve a common safety goal.

Another useful method for safety case development and to this research is that developed by the Centre for the Protection of National Infrastructure (CPNI). The CPNI safety framework has elements which specifically correlate to the railway industry. This is largely because their framework focuses on ‘industrial automation and related safety systems’ (Centre for the Protection of National Infrastructure, 2015) Pg 5 which the railway can be classified as. The framework developed by the CPNI goes a step further than the traditional design for industrial control systems which primarily focuses on reliability and safety. This approach in addition to reliability and safety encapsulates the serious threats that can be caused by a breach in security. Security is particularly applicable to the railway industry as the consequence of a serious threat can have a number of outcomes. This includes an impacted operational service, unauthorised control of technical and or operational processes to loss of highly confidential material. Due to the consequences of an impacted security system the railway industry should start to focus on developing test environments specifically for cyber attack. In the case of ERTMS technology which introduces novelty across European railways, dedicated environments for system integration testing already exist. This type of environment may also provide an opportunity for cyber security testing to be incorporated. However, for railways that are yet to introduce or modernise ERTMS technology this type of test environment is a rarity.

Focusing again on the CPNI framework, it incorporates good practice, governance, vulnerabilities and other key factors. The railway industry can draw upon aspects such as management of third party risks in addition to selection and implementation of security frameworks. However, CENELEC standard EN50129 already covers a number of the ‘core elements’ discussed and raised by CPNI. Using the information gained from best practice by the CPNI the railway industry should move
towards a safer design that incorporates more focus towards multiple protection systems. As discussed by the CPNI (Centre for the Protection of National Infrastructure, 2015) a dedicated firewall for industrial control systems could provide safety benefit. Additionally and as highlighted via the safety assessment in Chapter 5 the CPNI also found that the safety of control systems are insufficient without having a procedural training element in place (Centre for the Protection of National Infrastructure, 2015). The framework developed for industrial control systems is shown below in Figure 7-7, in addition to abstracts of its core key elements. Their approach focuses on 8 core elements which cover governance, strategy and supporting key activities. The railway industry whilst carrying out risk assessment and quantitative analysis as a necessity make use of SMEs. The CPNI endorse this type of working arrangement and recommend for industrial control systems, that a way forward is to manage system safety risks throughout a project and system lifecycle. For the most effective safety case this would require an appointed SME or pool of SMEs who would remain for the project duration. That is, from the requirements elicitation stage to the decommissioning stage. SMEs in practical terms are expensive resources so the feasibility in relation to safety would most probably need to be examined.
Figure 7-7 Abstract of Framework Overview (CPNI, 2015)
Utilising best practice from the nuclear industry in addition to good practice from the cyber security industry the following structure has been devised as being optimal. The structure is generic and can be utilised by any safety critical industry. Furthermore, it can be implemented as a support for industries that are trying to bring more focus to the topic of safety culture to their organisations.

As per the opening of this section, the following is required to be met in the safety case:

(i) Clarity, (ii) systematic linkage between interfaces and dependencies, (iii) traceability and flexibility in line with system developments.

This means that the safety case should demonstrate understanding of the system, such that risks can be identified and managed throughout the project lifecycle. This requires extensive system understanding across the range of asset levels which can be presented using a system architecture description. Through interface linkage and understanding of dependencies a system has greater protection as this type of analysis feeds into risk assessment and risk management throughout any project life cycle. A flexible safety case structure allows for improvements and rectifications to be made as systems often develop and have emergent properties that can be unforeseen. The aspects discussed are in support of what has been developed by CENELEC standard EN50129. Amongst all these elements is the key factor of exhibited behaviour, which is often impacted by the operational environment.

As a result, the safety case developed in this thesis also focuses on environmental dimensions. As seen by the ERTMS case study, supplementary results provided by train drivers related to factors such as ambience, space and perception; all of which are important to daily working. As a result, Bitner’s framework has been reviewed as it researches servicescapes which relates to physical surroundings and service environments with particular relation to employees and customers (Bitner, 1992). The research carried out by Bitner focuses on a number of topics including human behaviour. Bitner explains ‘that until the 1960’s psychologists largely ignored the effects of physical settings in their attempts to predict and explain behaviour’ (Bitner, 1992) Pg 59.

Although this servicescape framework specifically explains understanding of an environment in relation to service organisations this can also be reflective of the railway industry. As a result, Bitner’s framework shown in Figure 7-8 has been adapted to change the focus away from customers to the organisation, to see how it can tie into the relationship between an employee and an organisation. Bitner’s framework indicates that environmental dimensions can be of influence to both employee and customer behaviour; this is also augmented by other factors such as cognitive and physiological factors.
Figure 7-8 Framework for Understanding Environment - User Relationships in Service Organisations (Bitner, 1992)
Figure 7-9 Adaption of Bitner’s Framework (Bitner, 1992) for Understanding Environment - User Relationships in Service Organisations
Figure 7-9 which adapts Bitner’s framework shows the relationship between an organisation and employee and that the outputs are the result of safety culture. In the case of a train driver, environmental dimensions such as ergonomics, heating and ambient conditions are examples of what feeds into their perception of the driving environment. In addition to this, the internal responses from train drivers show the impact of cognitive and physiological factors on a train driver’s actions. This framework can be applied to any type of sector including cyber security and the possible outcomes of a cyber attack on an organisation. The organisation from a management perspective has an important role to play and as such, equivalent analysis in terms of internal responses and behaviour by management should be examined. As a result and due to the importance of safety culture it is reflected in the safety case as defined below. It has been additionally noted when developing a safety case that a sufficient amount of detail needs to be covered. However, it must also be clear, traceable and flexible.

The railway safety case structure depicted below in Figure 7-10 is explained as follows:

- The safety case demonstrates safety and acceptable mitigations to risks. Therefore the design, function and interrelationships of various sub systems need to be defined. This means the system definition is determined by its (i) functioning systems, (ii) ability to manage vulnerabilities, (iii) clear understanding of environmental dimensions in addition to the (iv) organisational and individual cultural traits required to make the system function in the most feasibly safe environment. These key elements formulate the basis for the system requirements. However, based upon experience, requirements do not usually include cultural aspects, except in the context of adhering to standards or through validation of requirements through use of competent staff. Therefore, adding this cultural dimension is a valuable topic to incorporate at the start of any safety case lifecycle so that it can be mapped throughout.

- CENELEC standard EN50129 is prescriptive and thorough, in terms of safety management and refers to CENELEC standard EN50126. That is, the safety management process should ensure reliability, maintainability and availability of a system. This is applicable and still required as part of the safety case. Technical safety pertains to the failure modes, system operation, testing and effects from a quantitative perspective. As discussed earlier on, risk management and prevention is one of the aims that the safety case shall demonstrate.

- The system definition, Safety Management and Technical Safety (shown in blue) need to include thorough descriptions and analysis for cyber security due to the impacts of such threats.

- The enablers to ensure a system is safe is human centric, therefore there is the requirement for subject matter expertise throughout the safety case process. As mentioned in the previous point, there must be a direct means to manage system vulnerabilities, with appropriate expertise to resolve and prevent potential high risk issues. Additionally, all staff at every level need appropriate and adequate training to help them perform their duties and to encourage proactive working. Underpinning the enablers mentioned above are European and local rules and regulations which facilitate harmonised operations of railways.
Figure 7-10 Key attribute of the derived generic Safety Case

Enablers can be used to remedy, re-engineer, protect and isolate risk and hence optimise the safety demonstrated by the safety case, this is in addition to validation.

7.3.1 Summary

As discussed in earlier chapters of this thesis, statistics show the impact of incidents, severities and failure modes in terms of risk. Demonstration of risk management and analysis in a safety case is one of the most vital tasks. CENELEC standard EN50129 stipulates the use of safety targets (British Standards, 2003). Use of targets can be considered as one of the best ways to express the quality of an operational railway. Swiss Federal Railways (SBB) who have ERTMS ETCS equipped lines and trains approach risk in their safety case in a number of ways, specifically by carrying out:

- Review of existing trackside risk analysis
- Review of existing train system risk analysis
- Review of all failure modes and faults (Kehrli, Hesse, & Bauer, 2009)

This process can often lead to amendments to system requirements and create the need for new safety risk assessments if the requirements are significantly changed. Furthermore, this is dependent on the findings and outcomes from the reviews bulleted above in addition to justifications by SMEs. In terms of actual figures for UK railways, the Office of Rail Regulation publishes figures for risk, safety and performance. The ORR has a vision for ‘an ever decreasing overall safety risk’ (Office of Rail Regulation, 2014) Pg 3. However, key safety facts still show that total fatalities across mainline railways has not significantly decreased. This includes passenger, public and workplace harm. For the years 2002/2003 to 2013/2014 the figures were 273 and 315 respectively and for the same timeframe 508 and 494 respectively for major injuries (Office of Rail Regulation, 2014). The latter depicting major injuries show a marginal decline.

Clearly, the problem is beyond technical safety and as demonstrated by the model adapted from Bitner’s framework, it is culture that needs to be addressed. Moving forward in technological developments, cyber threat in addition to safety culture are the areas that will need more focus. This is particularly important as trains and railway systems become more integrated across Europe. Across country borders integration increases the level of threat and susceptibility to cyber attack such as hacking.

This approach shown in Figure 7-10 still draws upon European standards in addition to the safety assessment process as a core to the key components and structure of a safety case. However in terms of practical implementation, organisations need to place greater emphasis on development and training. This includes the impact of environmental dimensions faced by key operational staff such as train drivers. Environmental dimensions and internal perceptions significantly impact resultant behaviour and actions in terms of commitment to safety.
Chapter 8
Conclusions and Future Work

This chapter presents the major findings of this research, which addresses the introduction of new technology into an existing railway system and the impact on safety. The approach taken in this research is consistent with the research objectives detailed in Chapter 1. As a result, this chapter draws conclusions based around the original objectives set. Following review of the research objectives, this chapter outlines the key contributions and achievements of this research. In closing, potential future work is presented.

8.1 Satisfaction of Research Objectives

In order to demonstrate fulfilment of the research objectives, the aims and objectives are reiterated in this section. The aim of this thesis is to specify a safety case which utilises an innovative approach of safety culture analysis to identify all aspects necessary to demonstrate the level of safety in a technically modernised railway system. This aim was met through the objectives specified below:

- **Objective 1**: Design and develop a system architecture that is representative of railways signalled based on conventional methods. Based on this, develop architecture that presents changes to the railway as the result of new technology.
- **Objective 2**: Investigate the technical developments of railway systems including functionality, operation, risk, severity and counter measures in the form of safety culture and methods of human interaction with new technology.
- **Objective 3**: Identify behavioural changes in train drivers who have experience of existing and modernised railway systems.
- **Objective 4**: Specify a safety case for the railway industry.

8.2 Conclusions

This section demonstrates how the objectives presented in section 8.1 have been achieved and the associated benefits provided by this research in relation to practical application.

8.2.1 Design and Development of system Architecture

Development of system architecture was a necessary part of this research. System architecture is an essential part of system design and evaluation. It enables visualisation and understanding to be attained of critical system interfaces and interactions from a technical, functional and operational
perspective. Importantly, system architecture is used as a basis to perform safety risk analysis and supports methods such as FMECA. Chapter 2 details how the system architecture was derived for a legacy railway. This is followed by a representation of the change to the architecture as a result of new technology integration.

The main challenges encountered during development of system architecture for both the legacy (existing) railway in addition to modernised railways were:

i) Determining the level of detail to represent the entire railway system.
ii) Interpreting the technical complexity of the sub systems.
iii) Determining how to visually present the system architecture to facilitate understanding and clarity of the railway system in both the existing and modernised state of design.

Ultimately, development of the system architecture was facilitated through use of a Systems Engineering approach. This approach requires consideration and understanding of how the system is required to perform and its dependencies. Once appreciation of this is attained, the systems can be more easily interlinked. This is the basis and backbone that enabled Objective 2 to be satisfied. Once a sense of the systems, relationships and functionality had been attained, system operation, failures and counter measures were reviewed. This crucially included human interactions. Human interaction with a failing or failed system has shown to be through adherence to procedures or set methods for system rectification. This failure scenario in addition to operation and maintenance of systems is the key interface between humans and technology. Safety culture was found to be a very complex subject and difficult to assess as a means of mitigation against failure. This was particularly because it relates to the mind-set of a human in an organisation, of which the specific detail would formulate a separate study. Therefore, the next section discusses the training aspect behind safety culture within a typical organisation.

8.2.2 Safety Culture Training

Regardless of the industry, which includes railways, an organisation reviews their safety performance. If there are concerns, it is recommended that the safety culture within the organisation is reviewed and steps taken to address any potential failings. This is due to the fact that safety culture in an organisation is a driver for safety management. Individual effort is not sufficient in safety critical environments such as the railway. It is ideal to have a whole organisation approach towards safety management so that safety can become inherent.

If it is identified that safety culture is lacking and not enough is being done within an organisation to protect human life, a structured program on safety culture training should be implemented. Specifically, the training should target the key elements that define safety culture to enable a positive approach, particularly:

- Have in place working rules that detail effective controls against hazards;
- A clear risk management process and structure;
Utilisation of lesson learnt information - lesson learned activities can contribute to reduction of safety events such as near misses (IOSH, 2015).

The Safety Culture Maturity Model produced on behalf of the Health and Safety Executive by the Keil Centre (Keil Centre, 2001) is a method that can be employed by organisations. This tool can be used to assess how mature the organisation is with respect to elements of safety. However, it is important to note that this model assumes the following conditions:

- The organisation has a sufficiently developed Safety Management System;
- That safety failures are not due to technical failures and hence the cause of accidents;
- The organisation in question is compliant with laws relating to health and safety;
- Safety focus is not only driven by the threat of prosecution but the aim to prevent accidents;

From the above, it can be seen that the role of the human and human behaviour is an essential facet to create good safety culture within an organisation. The Safety Culture Maturity Model (SCMM) shown below in Figure 8-1 shows the stages that an organisation cycles through.

![Safety Culture Maturity Model](image)

**Figure 8-1 Safety Culture Maturity Model (Keil Centre, 2001)**

At each level of this process the organisation can identify where they are and what further work is required to reach the next level in the SCMM. Each level has criteria that needs to be achieved and is a means by which the organisation at all levels can engage. The author whilst working for Network Rail gained experience of and engaged in the SCMM process. This occurred via workshops across the engineering disciplines.

Based on the observational studies conducted at Abellio Greater Anglia’s training school, this organisation has shown that as part of their training, they proactively discuss and teach better behaviours. This is to aid safety in the operational environment. Abellio Greater Anglia also make use of briefing sessions. However, based on review of commentary from the driver respondents a number of concerns were raised. Including, that the briefing sessions were a way to spread management
This particular employee felt that the level of engagement with management was used to disseminate information that was biased and met the political needs of the organisation. Furthermore, the frequency of briefings occurs on a six monthly basis. For the safety critical train driver role this is not regular enough. Particularly if there is an expectation from the organisation that the briefings should support a proactive change to safety behaviours and safety culture. Finally, the issue of cost has been raised as a factor that limits employee development. Training in the form of workshops, practical exercises or other means can be expensive to an organisation and thus limit the frequency of such development methods.

8.2.3 Human Interaction and behaviour

As discussed and shown in the results from Abellio Greater Anglia train drivers, a significant proportion of the driver respondents discussed the driving cab environment. This was specifically in terms of comfort, ambient temperature, ergonomics (in particular the cab design) and retrofitting. These issues were raised based on the existing train cab interface to the driver. The train driver is shown to be a key actor in the railway environment. This is akin to other safety critical environments such as Air Traffic Management and the Nuclear Process Control environment. This is because the train driver plays a crucial and key role in normal, degraded and emergency states of operation. Based on review of existing railway technology followed by modernised railway technology it is shown that the railway cannot work without the human. For this reason, the safety culture exhibited by humans has been researched. It is therefore recommended that if an organisation has sufficient financial resource the following areas be examined:

- Investigate behavioural trends of drivers in certain classes of train especially those where the drivers have raised poor visibility and ergonomics as issues. From this, conclude why humans in safety critical roles perform certain actions that can be a detriment to safety.
- Review procedures - question whether the procedures in place provide sufficient safeguards for humans in all operational roles.
- Competencies of staff should be fully examined and where required further training provided to enhance skill sets and understanding.
- Conduct exhaustive operational concept scenarios otherwise known as Day In The Life Of (DITLO) activities to assess factors such as workload.
- Communication: Ensure communication paths between staff and management is clear and without blame. A very positive outcome of the drivers who underwent simulator training and from the responses showed that no blame culture was evident at Abellio Greater Anglia. The trainers positively taught and examined areas and related any faults to a realistic event to aid appreciation.

Equally, the data based on Swedish research from MTO Sakerhet and VTI showed that the driver interface and ERTMS signalling technology had a significant impact on driver behaviour. However, this was aggravated by the topology of the railway. The issue of workload significantly increased
where the topology was complex, this led to self-management by the drivers of traction effort to make the speed changes more manageable. This reduced the stress otherwise present and caused by the need to adhere to the numerous speed changes on the DMI whilst monitoring the environment external to the train cab. The UK train drivers also raised increased workload in the instances where there was poor cab design and increased equipment within the space envelope. Therefore the issue of workload needs further analysis in the various scenarios of train operation.

Training on ERTMS is underway in Sweden, in particular VTI expertise (Peters, Lidstrom and Abadir) has been used to start driver training through use of ERTMS simulation software. Structured interview with VTI has yielded the following points of interest to this research:

- Train drivers new to the railway domain have limited knowledge of the technology developments intended for European railways with respect to ERTMS.
- Trainee drivers have a positive outlook on the use of simulators for training on ERTMS technology. Furthermore a consensus was achieved amongst the participants that simulators are the most effective tools for training outside of the operational environment. This was specifically because mistakes could be made in a safe environment with the opportunity to practice particular and often more complex operational scenarios.
- Currently, in the UK Train Operating Companies carry out simulator training in-house. A similar practice shall occur in Sweden with larger companies delivering training and smaller companies outsourcing to organisations with specialism to receive their training.
- Failure scenarios are included as part of training to enable the train drivers to have an appreciation of what could occur in the operational environment.
- The drivers confirmed the issue of workload in relation to speed changes which they found to be irritating, as it moved focus away from the external railway environment to the DMI. Furthermore, as a subsystem, the DMI was found to be a distraction. This was particularly for those drivers who have experience of driving on lines signalled by conventional signalling methods, which employ trackside signals.

Use of simulators for training on the respective systems both in the UK and Sweden has shown to be an excellent method to teach drivers safe practices. This method is more effective than other methods such as briefings. Drivers should ideally learn through interactive workshops such as shown and developed by the Keil Centre and through the simulated environment. The benefit of the simulator is that software can be tailored and updated to replicate specific safety scenarios. For future UK railways and train systems that will incorporate the new ERTMS technology the train design as a priority needs to be reviewed and defunct equipment that is no longer functional should be removed. A cramped environment in addition to new technology could worsen human behaviour and increase the amount of workload.

This research has shown the benefits that simulators provide for evaluation of driver safety related behaviour.
Overall, it has been demonstrated that the subject of safety has many dimensions a number of which can be related to safety culture. The key facets in relation to Objective 3 have been discussed. This has been particularly demonstrated by train drivers who are key users of railway systems and whom have a range of views on the key areas that comprise the topic of safety culture.

Based on the safety assessment results and to better this research, the questionnaire material that was collated for UK railways would also be deployed to an equivalent European organisation that had implemented ERTMS. This would have enabled the results to be more closely correlated. Furthermore, in terms of the questionnaire design, the questionnaire results would have been more useful if respondents were obliged to put an ‘agree’ or ‘disagree’ response rather than providing a neutral option. This is because a neutral response may be provided by a respondent for a number of reasons, such as, distrust in the use of the questionnaire, no opinion to a genuine neutral feeling towards the particular question posed. However, (Oppenheim A., 1966;1992) shows that there are benefits of a neutral response. For example,

‘It has been argued that some people give a ‘don’t know’ response in order to avoid thinking or committing themselves; but do we really want to obtain ‘forced’ response which are virtually meaningless’ (Oppenheim A. N., 1966,1992) Pg 129.

However, in contrast to this, the responses to the supplementary questions were beneficial as they sufficiently supported findings in relation to the cab environment, technology and safety culture.

From a UK railway industry perspective, the findings based on the experience of ERTMS in Sweden and other European railways can be used as a ‘leading indicator’. That is, the practical and simulated driver experience of ERTMS and the DMI can be used to predict the behaviour of UK drivers on ERTMS topology in the UK. The benefit of the Swedish data is that it presents a worst-case scenario of the interface to the DMI in addition to a normal case, which is based on the complexity of a railway network topology. Therefore, comparisons can be drawn and training material developed for expected operational issues. Training material includes simulation software, furthermore, lessons learnt could be obtained from expertise in simulation from organisations such as VTI in Sweden.

The findings from the safety assessment also align to Bitner’s framework (Bitner, 1992) as discussed in Chapter 7. It was shown that environmental dimensions impact behaviours, which include an employee’s willingness to stay in a company or carry out specific tasks. As discussed, this also includes the complexity of emotional and cognitive understanding. Based on the findings of the safety assessment, the structure required to create a pragmatic safety case was derived. This also incorporated review of key European standards, best practice in non-railway safety critical industries and railway security.

Based on findings from the safety assessment and literature review, it is found that for safety to be effectively demonstrated in a safety case, a number of areas need to be proven. This includes:
• Understanding of the holistic system, this could be a railway, nuclear or navigation system and the associated system requirements.

• Understanding and analysis of system risks. Risks are now more sophisticated given the wealth of technology. As shown by the ‘Sobig’ virus, (Information Week, 2003) disruption can be caused to safety critical and importantly passenger environments, as was experienced by the railway in New York. This computer virus caused the network to shut down because of affected signalling and dispatching (Information Week, 2003). ERTMS technology is designed for high-speed mainline trains, if a virus such as Sobig infected the ERTMS signalling system the impact on safety could be potentially catastrophic. Therefore, as cyber threats are known, more emphasis needs to be placed on integrated cyber security techniques for data security.

• Training and knowledge sharing are tools of good practice, which would aid risk evaluation and aid harmonisation activities across Europe. As discussed in the first review of European railways that implemented ERTMS technologies the differences across the countries in working methods significantly hindered the development of an integrated approach to European railway safety.

• Finally, the safety case must make use of key enablers, such as Subject Matter Experts and standards, to ensure that safety is addressed from every possible angle.

This thesis has documented and satisfied the objectives specified in Chapter 1. This has been attained through exploration of the complexity of railway systems as a case study. Literature review highlighted specific issues in relation to safety management, safety culture and the lack of academic research on the topic of the driving environment and the interface between humans and technology. Safety assessment based on questionnaires, semi structured interviews and observations have been carried out and has utilised driver experience on existing and modernised railways. The results of this have been discussed in Chapter 6 and are summarised earlier on in this chapter.

This research has identified the need for the safety case to be underpinned by SME expertise, adherence to good practice and application of a systems engineering approach. This will support the evaluation of system complexities and simplify construction of an effective safety case.
### 8.3 Future Work

- Based on the knowledge attained from structured interviews with other research groups with specialisms in cognition and simulation. It would be of benefit for railway organisations to work collaboratively on the interaction between train drivers and technology. This would include more specific scientific analysis of driver behaviour. For generic safety critical industries, this can be equated to interactions between key operational users and technology.

- Train system design requires more involvement from the train drivers as end users. This is in addition to the impact of alert systems on driver behaviour. Supplementary results from the train drivers included issues raised about health, such as pain in the ears as a result of alarms. Visibility issues because of poor cab design, the feeling of discomfort and being cramped because of the increased amount of equipment in the train cab. The issue of fatigue has also been raised. These topics are not conducive to a role that requires alertness and safe operation.

- Future simulation tools for driver training in the UK should be evolved to simulate exact railway routes rather than fictional routes. This will allow drivers to adjust their behaviour and learn more readily how to transition between concentration on the DMI and the external environment in a realistic operational setting.

- Development of an interactive training plan that is routinely managed rather than dissemination of safety critical material via 6 monthly briefings.

- Railway incident and accident statistics have shown that safety is improving with the aid of safety and monitoring systems. However more work is required into the causation of accidents. As in the case of Sweden where train drivers have adapted the driving methods the same could occur in the UK. Therefore, training needs to encompass and have foresight about the impact of new technology.
8.4 Publications associated with this research

8.4.1 Conference Publications and Proceedings


8.4.2 Journal Publications


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Appendices
APPENDIX I: System Architecture
System Architecture designed to indicate the system interfaces on Network Rail's Crossrail route (Smith, 2012)
Appendix II: Questionnaire Material
I. Questionnaire for drivers of conventional signalled railways;

II. Questionnaire for drivers of ERTMS signalled railways;
(i) Questionnaire for drivers of conventional signalled railways

Train driver questionnaire:

The information collated from this questionnaire will be used for research purposes only. All respondents can gain feedback on the outcome of the questionnaire analysis. A slip is provided with contact details.

Section 1: Staff Particulars

Please answer all questions and mark all applicable options with a cross as shown here ☐

<table>
<thead>
<tr>
<th>Age</th>
<th>21☐  22☐  23☐  24☐  25☐  26☐  27☐  28☐  29☐  30☐  31☐  32☐  33☐  34☐  35☐  36☐  37☐  38☐  39☐  40☐  41☐  42☐  43☐  44☐  45☐  46☐  47☐  48☐  49☐  50☐  51☐  52☐  53☐  54☐  55☐  56☐  57☐  58☐  59☐  60☐  61☐  62☐  63☐  64☐  65☐  Above 65☐</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male ☐  Female ☐</td>
</tr>
<tr>
<td>Length of service in current post</td>
<td>Years ☐  months ☐</td>
</tr>
<tr>
<td>Length of railway industry service (if different from above)</td>
<td>Years ☐  months ☐</td>
</tr>
</tbody>
</table>
| Other industry experience (E.g. Automotive) | ____________________________
| Railway qualification | Qualified ☐  In training ☐ |
| Please provide details of certification achieved to become a train driver: | ____________________________
| Driving task frequency (shift pattern) | Hours per week: ____________________________
| Days per week: ____________________________
| Standby shift (if applicable): ____________________________ |
Section 2: Staff Training

This section of the questionnaire relates to driver training that has been provided in either the operational railway environment or by other methods, such as, the use of simulators.

Mark one option with a cross: 1=strongly disagree, 5=strongly agree 3= No opinion/neutral

1. Training methods have included a mixture of operational training in the train cab environment, technical briefings and or use of simulated environments.
   1☐ 2☐ 3☐ 4☐ 5☐

2. A Sufficient level of training has been received to enable the concepts of signalling principles to be understood.
   1☐ 2☐ 3☐ 4☐ 5☐

3. Training is followed by rigorous examination or assessment.
   1☐ 2☐ 3☐ 4☐ 5☐

4. Appropriate training has been received to enable driver operation on a legacy signalled railway.
   1☐ 2☐ 3☐ 4☐ 5☐

5. I fully understand signalling principles relevant to the driver role (such as safety distances and operating conditions).
   1☐ 2☐ 3☐ 4☐ 5☐

6. Training relating to the failure scenarios (such as operation during signal failure) has been supplied and examined.
   1☐ 2☐ 3☐ 4☐ 5☐

7. Any concerns raised about safety have been appropriately addressed through training or have been clarified and resolved by management.
   1☐ 2☐ 3☐ 4☐ 5☐

8. Training activities were carried out by:
   a. Internal staff ☐
   b. An external organisation ☐
   c. Both internal and external training providers ☐

Please add any additional comments you may have in the 'supplementary information' area below:

Supplementary information

________________________________________

________________________________________

________________________________________

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Section 3: Train cab driving environment

This section relates to the driving environment and includes changes to the physical layout, ergonomics, procedures and the introduction of new equipment. This enables understanding of how design of the cab environment impacts train driver operations.

Applicable options to be crossed: 1=strongly disagree, 5=strongly agree 3 = No opinion/neutral

1. It is easy to confirm the correctness of data entered (such as driver identity data).
   
   1□ 2□ 3□ 4□ 5□

2. Data consists of too many digits which may cause incorrect data to be entered.

   1□ 2□ 3□ 4□ 5□

3. There has been a noticeable increase in driver workload following the change in communication equipment.

   1□ 2□ 3□ 4□ 5□

4. Driver procedures are clearer and more understandable using GSM-R communication.

   1□ 2□ 3□ 4□ 5□

5. Too much information is provided to the train driver in the form of alarms and or warnings.

   1□ 2□ 3□ 4□ 5□

6. Alarms are of benefit to the driver and aid safe driving.

   1□ 2□ 3□ 4□ 5□

7. The in cab train alarms are often distracting.

   1□ 2□ 3□ 4□ 5□

8. The in cab alarms are too loud.

   1□ 2□ 3□ 4□ 5□

9. Please identify which alarms are either too loud or distracting ________________________________

10. Visual and audio alerts sufficiently notify the driver of safety critical locations / signals

    1□ 2□ 3□ 4□ 5□

11. The level of driving skill has degraded due to the change in the train cab design

    1□ 2□ 3□ 4□ 5□
12. Explain the advantages or disadvantages in the train cab design (this can include noise, vibration or temperature for example).

**Advantage:**

**Disadvantage:**

13. There is greater trust in railway infrastructure due to the enhanced levels of communication and track monitoring equipment

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Please add any additional comments you may have in the ‘supplementary information’ area below:

**Supplementary information**

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
**Section 4: General questions**

This section of the questionnaire focuses on the topic of safety culture in the context of the railway organisation. The term ‘Safety culture’, refers to ‘individual and group values...that determine the commitment to an organisation’s health and safety management’ (HSE, 1993). This section aims to understand approaches to management of safety issues. As per the other sections any additional information can be included below.

**Applicable options to be crossed**: 1=strongly disagree, 5=strongly agree 3 = No opinion/neural

1. The task of driving a train is more enjoyable following changes to the train cab design and improved technology.
   1⃝ 2⃝ 3⃝ 4⃝ 5⃝

2. Safety could be improved through the introduction of new technology which continuously and accurately monitors train location and speed.
   1⃝ 2⃝ 3⃝ 4⃝ 5⃝

3. I feel confident to raise any concerns about safety to direct management or senior.
   1⃝ 2⃝ 3⃝ 4⃝ 5⃝

4. Safety concerns raised about the job are listened to by management staff.
   1⃝ 2⃝ 3⃝ 4⃝ 5⃝

5. Safety concerns raised about the job are acted upon by management staff.
   1⃝ 2⃝ 3⃝ 4⃝ 5⃝

6. Incentives are proffered by the organisation to improve safety (Such as rewards for reporting incidents).
   1⃝ 2⃝ 3⃝ 4⃝ 5⃝

7. The organisation via management, always provide feedback regarding any concerns raised.
   1⃝ 2⃝ 3⃝ 4⃝ 5⃝

8. Regular learning sessions are provided on the subject of safety and quality improvement.
   1⃝ 2⃝ 3⃝ 4⃝ 5⃝

**Supplementary information:**

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
(ii) Questionnaire for drivers of ERTMS signalled railways

Trein Driver Vragenlijst:

The information collated from this questionnaire will be used for research purposes only. All respondents can gain feedback on the outcome of the questionnaire analysis. A slip is provided with contact details.

Deel 1: Personeel Details

Please answer all questions and mark all applicable options with a cross as shown here.

<table>
<thead>
<tr>
<th>Leeftijd [Age]</th>
<th>21  □  22  □  23  □  24  □  25  □  26  □  27  □  28  □  29  □  30  □  31  □  32  □  33  □  34  □  35  □  36  □  37  □  38  □  39  □  40  □  41  □  42  □  43  □  44  □  45  □  46  □  47  □  48  □  49  □  50  □  51  □  52  □  53  □  54  □  55  □  56  □  57  □  58  □  59  □  60  □  61  □  62  □  63  □  64  □  65  □  meer dan 65  □</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duur van het dienstverband in huidige functie [length of service in current post]</td>
<td>Jaar [years]_____ maanden [months]_______</td>
</tr>
<tr>
<td>Lengte van de spoorwegindustrie dienst indien anders dan hierboven [length of railway industry service if different from above]</td>
<td>Jaar [years]_____ maanden [months]_______</td>
</tr>
<tr>
<td>Andere ervaring in de industrie (bijvoorbeeld, automotive) [Other industry experience (for example, automotive)]</td>
<td></td>
</tr>
</tbody>
</table>
### Deel 1: Spoorweg kwalificatie

<table>
<thead>
<tr>
<th>Spoorweg kwalificatie [railway qualification]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gekwalificeerde [qualified] □  In opleiding [in training] □</td>
</tr>
<tr>
<td>Gelieve nadere bijzonderheden over de relevante certificering [please provide details of relevant certification]</td>
</tr>
</tbody>
</table>

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### Deel 2: Opleiding van het [staff training]

Dit deel van de vragenlijst heeft betrekking op de opleiding van treinbestuurders die is voorzien in een van beide de operationele spoorweg milieu of door andere methoden, zoals het gebruik van simulatoren.

[This section of the questionnaire relates to driver training that has been provided in either the operational railway environment or by other methods, such as, the use of simulators]

#### Mark een optie met een kruis eselectie:

1 = Zeer mee oneens, 3 = Geen mening / neutral, 5 = helemaal mee eens

---

1. Training methoden hebben een mix van operationele training in de trein cabine milieu opgenomen, technische briefings en of het gebruik van gesimuleerde omgevingen.  
[Training methods have included a mixture of operational training in the train cab environment, technical briefings and or use of simulated environments].

   1□  2□  3□  4□  5□

2. Een voldoende niveau van de opleiding is ontvangen om de concepten van seingevingsprincipes mogelijk worden begrepen.  
[A sufficient level of training has been received to enable the concepts of signalling principles to be understood].

   1□  2□  3□  4□  5□

3. Opleiding wordt gevolgd door grondig onderzoek of assessment  
[Training is followed by rigorous examination or assessment].

---

### Rijtaak frequentie (schakelpatroon)  
Driving task frequency (shift pattern)

<table>
<thead>
<tr>
<th>Rijtaak frequentie (schakelpatroon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uur per week [hours per week]:</td>
</tr>
<tr>
<td>Dagen per week [days per week]:</td>
</tr>
<tr>
<td>Uren werken op stand-by shift [Stand-by shift hours if applicable]</td>
</tr>
</tbody>
</table>

---

### Uur per week [hours per week]:  

---

### Dagen per week [days per week]:  

---

### Uren werken op stand-by shift [Stand-by shift hours if applicable]:
4. Een passende opleiding hebben ontvangen waarin de bestuurder in staat stelt om te werken op de oudere gesignaleerd spoorwegen.  
[Appropriate training has been received which enables a driver to operate on legacy signalled railways].

5. een passende opleiding hebben ontvangen waarin de bestuurder in staat stelt om te werken op gemoderniseerde spoorwegen (gemoderniseerd door ERTMS)  
[Appropriate training has been received which enables a driver to operate on modernised railways (modernised by ERTMS)]

6. Ik begrijp het concept van ERTMS en de beperkingen  
[I fully understand the concept of ERTMS and its limitations]

7. Opleiding met betrekking tot ERTMS faalwijzen zijn verstrekt  
[Training relating to ERTMS failure modes has been provided].

8. Opleiding met betrekking tot algemene rampscenario's zijn verstrekt  
[Training relating to general failure scenarios has been provided].

9. De bezorgdheid gerezen over de veiligheid op adequate wijze aangepakt door middel van training of zijn verduidelijkt en opgelost door het management.  
[Any concerns raised about safety have been appropriately addressed through training or have been clarified and resolved by management].

10. Opleidingsactiviteiten worden uitgevoerd door  
a. interne medewerkers ☐  
b. een externe organisatie ☐  
c. Zowel interne als externe opleidingen ☐

Voeg eventuele aanvullende opmerkingen die u heeft in de 'aanvullende informatie' gebied hieronder:  
[Please add any additional comments you may have in the 'supplementary information' area below].

______________________________________________________________________________________________
Deel 3: Trein cabine rijomgeving [Train cab driving environment]

Dit gedeelte heeft betrekking op de cabine milieu en omvat wijzigingen in de fysieke lay-out, ergonomie, de procedures en de introductie van nieuwe apparatuur. Dit kunnen begrijpen hoe ontwerp van de cabine milieueffecten treinmachinist operaties.

This section relates to the cab environment and includes changes to the physical layout, ergonomics, procedures and the introduction of new equipment. This enables understanding of how design of the cab environment impacts train driver operations.

Mark een optie met een kruis ☐:
1= Zeer mee oneens, 3= Geen mening / neutral, 5= helemaal mee eens

1. Het is gemakkelijk om de juistheid van de ingevoerde gegevens (zoals driver identiteitsgegevens) bevestigen.
   [It is easy to confirm the correctness of data entered (such as driver identity data)].
   1☐ 2☐ 3☐ 4☐ 5☐

2. Gegevens bestaan uit te veel cijfers die ertoe kunnen leiden onjuiste gegevens te worden ingevoerd.
   [Data consists of too many digits which may cause incorrect data to be entered].
   1☐ 2☐ 3☐ 4☐ 5☐

3. Er is een merkbare toename van de werkdruk voor de bestuurder als gevolg van de verandering in de communicatie geweest apparatuur.
   [There has been a noticeable increase in driver workload following the change in communication equipment].
   1☐ 2☐ 3☐ 4☐ 5☐

4. Driver procedures duidelijker en begrijpelijker met behulp van GSM - R communicatie
   [Driver procedures are clearer and more understandable using GSM-R communication]
   1☐ 2☐ 3☐ 4☐ 5☐

5. Te veel informatie wordt aan de machinist verstrekt in de vorm van alarmen en of waarschuwingen.
   [Too much information is provided to the train driver in the form of alarms and or warnings].
   1☐ 2☐ 3☐ 4☐ 5☐

6. Alarms zijn van voordeel voor de bestuurder en de hulp veilig rijden.
   [Alarms are of benefit to the driver and aid safe driving].
   1☐ 2☐ 3☐ 4☐ 5☐

7. De in de cabine de trein alarmen zijn vaak storend.
   [The in cab train alarms are often distracting].
   1☐ 2☐ 3☐ 4☐ 5☐
8. De in de cabine alarmen zijn te luid.
[The in cab alarms are too loud].

   1☐ 2☐ 3☐ 4☐ 5☐

9. Gelieve aan te geven welke alarmen zijn ofwel te luid of storend:
[Please identify which alarms are either too loud or distracting]:


10. De hoogte van de communicatie met de signaalgever is toegenomen met het ERTMS-systeem
[The amount of communication with the signaller has increased with the ERTMS system]

   1☐ 2☐ 3☐ 4☐ 5☐

11. Het niveau van het rijden vaardigheid afgebroken door de overdracht van voor besturing / opdracht in de trein
[The level of driving skill has degraded due to the transfer of signalling control/command to onboard the train].

   1☐ 2☐ 3☐ 4☐ 5☐

12. Visuele en audio-waarschuwingen van de bestuurder van de veiligheid kritieke locaties in voldoende mate op de hoogte
[Visual and audio alerts sufficiently notify the driver of safety critical locations].

   1☐ 2☐ 3☐ 4☐ 5☐

[Explain the advantages or disadvantages in the ERTMS train cab design (this can include noise, vibration, temperature for example)].

   VOORDEEL [Advantage] _______________________________________________________

   NADEEL [Disadvantage] _____________________________________________________

14. Er is meer vertrouwen in de spoorinfrastructuur als gevolg van de verhoogde niveaus van communicatie en track bewakingsapparatuur
[There is greater trust in railway infrastructure due to the enhanced levels of communication and track monitoring equipment].

   1☐ 2☐ 3☐ 4☐ 5☐
Deel 4: Algemene vragen

Dit deel van de vragenlijst richt zich op het thema van de veiligheidscultuur in het kader van de spoorweg organisatie. De term 'veiligheidscultuur' verwijst naar "individuele en collectieve waarden ... die bepalen de inzet voor de gezondheid en de veiligheid van het beheer van een organisatie" (HSE, 1993). Dit gedeelte heeft tot doel begrijpen benaderingen van het beheer van de veiligheid. Zoals aangegeven in de andere rubrieken eventuele extra informatie kan hieronder worden begrepen.

Mark een optie met een kruis ☐:
1= Zeer mee oneens, 3= Geen mening / neutral, 5= helemaal mee eens

1. De taak van het besturen van een trein is leuker volgende wijzigingen in de trein cabine ontwerp en verbeterde technologie.
[The task of driving a train is more enjoyable following changes to the train cab design and improved technology].

   1☐  2☐  3☐  4☐  5☐

2. Veiligheid is die voortdurend verbeterd door de introductie van nieuwe technologie en houdt precies trein locatie en snelheid .
[Safety is improved through the introduction of new technology which continuously and accurately monitors train location and speed].

   1☐  2☐  3☐  4☐  5☐

3. veiligheid verstoord door de verwijdering van spoor signalen
[Safety is compromised due to the removal of trackside signals].

   1☐  2☐  3☐  4☐  5☐

4. Ik heb er vertrouwen in om het even welke zorgen over de veiligheid bij direct beheer of het senior management te verhogen
[I feel confident to raise any concerns about safety to direct management or senior management].

   1☐  2☐  3☐  4☐  5☐

5. Veiligheid bezorgdheid over de baan worden beluisterd door leidinggevend personeel
[Safety concerns raised about the job are listened to by management staff]

   1☐  2☐  3☐  4☐  5☐
6. Veiligheid bezorgdheid over de baan worden gehandeld op mijn leidinggevend personeel.
[Safety concerns raised about the job are acted upon my management staff].

7. Incentives worden uitgestoken door de organisatie om de veiligheid te verbeteren (Zoals beloningen voor het melden van incidenten).
(Incentives are proffered by the organisation to improve safety (Such as rewards for reporting incidents)).

8. De organisatie via het beheer, altijd feedback geven over eventuele bezwaren
(The organisation via management, always provide feedback regarding any concerns raised).

9. Regelmatig leren sessies worden verstrekt op het gebied van veiligheid en verbetering van de kwaliteit
(Regular learning sessions are provided on the subject of safety and quality improvement).

Voeg eventuele aanvullende opmerkingen die u heeft in de 'aanvullende informatie' gebied hieronder:
[Please add any additional comments you may have in the 'supplementary information' area below].

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________