The Impact of ERTMS on Human Performance in Railway Operations – European Findings

Miss. Peri Smith¹,a, Mr. Miltos Kyriakidis¹,a, Dr. Arnab Majumdar¹,a, Prof. Washington Y. Ochieng⁵

¹ Centre for Transport Studies, Department of Civil and Environmental Engineering, Imperial College London, London, SW7 2AZ

p.smith10@imperial.ac.uk
m.kyriakidis@imperial.ac.uk
a.majumdar@imperial.ac.uk
w.ochieng@imperial.ac.uk

Tel: + 44 20 759 42705

SUBMIT DATE: 15/11/2012

WORD COUNT: 8,368 (including abstract & references)

¹ Corresponding author
The safety of railway system operations depends on several internal and external factors. In the case of the former this includes rail traffic rules, infrastructure, rolling stock reliability, organisational safety culture and human factors. In order to improve capacity and efficiency the railway systems in Europe, North America and Australasia have seen significant technological developments. Europe, for instance, is implementing the European Railway Traffic Management System (ERTMS).

However, transition to a more automated traffic management system requires amongst others, changes to infrastructure, rolling stock and/or operational procedures. Concerning the last, literature shows that train drivers, signallers and controllers have the highest impact on the safety of a railway network. Therefore, the reliability and safety integrity of the railway network is largely dependent on human factors and in particular, the performance of the human operators. This in turn is affected by a number of factors broadly known as Performance Shaping Factors (PSFs) with “deficiencies in communication” accounting for over 90% of incidents for the conventional railway system. Therefore, this paper investigates the influence of ERTMS and in particular of the Global System for Mobile Communications-Railway (GSM-R) on operators’ performance. 74 accident and incident reports of railway operations prior and post GSM-R implementation from several European railway organisations are analysed.

The results identify the communication related factors that affect human performance in the conventional and upgraded railway system based on the existing Railway-PSFs taxonomy. Finally, results show the positive impact of GSM-R implementation on operators’ performance.

Keywords: Railway safety, ERTMS, GSM-R, human performance, accident incident analysis, mitigation strategies, Difference-in-Difference (DID) analysis
1 INTRODUCTION

Railway systems constitute an important part of global transportation, e.g. more than 2,000 billion passengers-kilometres, and more than 9,000 billion tonne-kilometres, were transported in the world in 2010 [1]. The safety of the railway system depends on several internal factors including rail traffic rules, infrastructure reliability, organisational safety culture and human factors. In the past decade, these factors were responsible for about 22% of all railway accidents and incidents [2].

In order to minimise these factors and improve capacity and efficiency, the railway systems of Europe, North America and Australasia have seen significant technological development. There has been a progression from older, conventional signalling techniques to the application of automated technology. In Europe, the advanced European Railway Traffic Management System (ERTMS) is being implemented to enhance safety, simplify train operation and facilitate mobility for cross border traffic. As a part of this process, a number of countries have already, partially or entirely, replaced their legacy communication systems with the Global System for Mobile Communications – Railway (GSM-R) [3]. However, this transition to a more automated traffic management system requires amongst others, changes to infrastructure, rolling stock and operational procedures. Concerning the latter, it has been shown that train drivers, signallers and controllers (referred to as operators) have the highest impact on the safety of the railway network [4, 5]. Therefore, the reliability and safety integrity of the railway network depends largely on human factors. In particular, it depends on the performance of the human operators, which can be either enhanced or degraded by a number of factors such as training, working conditions, organisational factors and the time available to perform a task. Such factors are known as Performance Shaping Factors (PSFs).

This paper identifies and analyses the influence of the GSM-R component of ERTMS on operators’ performance. Accident and incident reports from a number of European railway organisations of operations prior and post GSM-R implementation are analysed. This analysis identifies the factors that most affect human performance in both cases based on an existing Railway Performance Shaping Factors (R-PSFs) taxonomy [6]. The selected reports are categorised according to the type of occurrence, frequency and severity of consequences. Subsequently, the reports are distinguished according to the year of occurrence, network design, location (e.g. station, open line) and type of operation. In addition, the immediate causes, such as excessive speed and contributing factors, such as signalling location or cabin layout, are defined. Finally, based on the concept of the difference-in-difference (DID) methodology the qualitative variation of the R-PSFs categories that influence operators’ performance prior and post GSM-R implementation is shown.

The findings are used subsequently to identify the areas that need further improvement following the installation of GSM-R. Additionally, mitigation strategies such as ergonomic or signalling design changes are proposed to achieve higher safety standards in railway operations.

The paper is organised as follows: Section 2 presents an overview of railway safety with regard to humans and capacity. Section 3 addresses the basic features of ERTMS and GSM-R architecture and the differences with the main conventional railway communication means. Section 4 gives a brief overview of the R-PSF taxonomy. Section 5 addresses the issues related to data selection, data limitations and the selected methodology for data analysis and presents the results. The paper, is concluded in section 6 highlighting the main findings and recommendations.

2 OVERVIEW

The safety of railway operations is a major concern for all relevant operational and regulatory bodies in every country with a rail network. The aim is for a highly reliable, excellent quality and safe railway system [7]. It is well recognised that a large number of railway incidents and accidents occur due to human performance [4], e.g. the catastrophic Ladbroke Grove train accident in the U.K. The U.S. Federal Railroad Administration safety data show that over the past decade, more than 30% of the total rail accidents were related to some extent to human factors [8]. In addition, a recent study [5] shows that at least 75% of fatal railway accidents in Europe between 1990-2009 were due to operational human errors, i.e. exceeding speed, signal passed at danger or passed at danger or
signalling/dispatching errors. Therefore, the interest in the area of human performance within railway
operations has increased significantly [9].

In Europe, the growth in demand both for passenger and freight operations have led to a
restructuring of the European railway transport network, aimed at highly safe and reliable railway
operations. In particular, the significant increase in international rail passenger demand [10] has
resulted in the introduction and implementation of the European Railway Traffic Management System
(ERTMS), a European Commission initiative. ERTMS, which primarily aims to enhance safe
operations, simplifies train operation and acts as a mobility enabler for cross border traffic. This is
made possible by the need for an interoperable railway network, through the creation of a unique
signalling standard. It is envisaged that a competitive and integrated network unrestricted by national
borders can be created through the application of this standard [11]. Due to the fact that European
railways have traditionally and historically been designed, operated and maintained on a national
basis [12], ERTMS targets the resolution of differences that have arisen over time with national
systems through the application of compatible and interoperable communication, control and
signalling methods.

Figure 1 shows the range of legacy train control command systems across Europe that will
become redundant upon deployment and application of ERTMS. In addition to the signalling aspect,
there are a number of areas that further warrant development towards a unified European network
including: increased procurement competition, reduced life-cycle costs, an increase in transport
capacity and technical and operational interoperability [13]. Figure 1 shows the variation in train
control command systems that are based on specific national requirements. However, this variation
can be viewed as inefficient due to the potential need for a driver to change train or a change of driver
at a national border, introducing the requirement for further driver training.

![Legacy Control Command Systems in Europe](image)

**FIGURE 1 Legacy Control Command Systems in Europe [12]**

The suggested installation of the ERTMS technology onto European railways will potentially
change a number of the tasks that the operators, mainly train drivers, currently perform when
executing a train service [14]. The introduction of a new in-cab driver machine interface may have an
impact on operators’ performance and the potential to make errors. Therefore, human factors and
especially the performance shaping factors that influence human performance should be assessed and
any implications for operators’ performance and potential errors identified. Given that “deficiencies in
communication” significantly contribute to the rail incidents/accidents, this paper focuses on the
GSM-R component of ERTMS, as this is the key method of communication and interface via the
Human Machine Interface for the train operator, signaller and other railway users such as
maintenance personnel and train guards.
3 ERTMS SYSTEM DESCRIPTION

The European Railway Traffic Management System (ERTMS) has four constituents: the European Railway Traffic Management Layer (ETML); European Operating Rules European Train Control System (ETCS) and the Global System for Mobile Communications – Railways (GSM-R). Both the ETCS and the GSM-R comprise the technical aspects of ERTMS and will bring about interoperability. A brief overview of these technical ERTMS components is presented in section 3.2.

Any operational change in GSM-R functionality from its normal state to a failed state will influence not only the technical subsystems that comprise it, but importantly the human interfaces which utilise the technology. Thus, the impacts of revolutionising the railway through migration to GSM-R, from legacy systems, including the National Railway Network (NRN) and Cab Secure Radio (CSR) and the subsequent impact on human factors are investigated in this paper.

3.1 Legacy Communication Systems

Railways require communication subsystems for their safe operational purposes. Radio communications are a means for track, train and operational control subsystems to interface and are a vital component of the railway.

Legacy voice telecommunication systems of Cab Secure Radio (CSR) and the National Radio Network (NRN) are in the process of being replaced by GSM-R. This is evidenced by the UK’s Crossrail project, which has implemented GSM-R, and the Great Western Mainline is in the process of decommissioning CSR.

The NRN is an analogue communication system, and consists of two radio networks working in tandem. The NRN telephones are usually hand portable or used on trains. The NRN has not been used in safety critical applications due to possible issues that could arise with miscommunication [15]. Miscommunication may arise from loss of coverage with the potential to create a hazardous environment where the driver and signaller cannot communicate or a driver is wrongly identified to the signaller. These would be significant NRN failures.

On the other hand, CSR is a method of secure radio communication between the train driver and signaller. The radio technology enables the driver to remain on the train rather than use a signal post telephone to communicate with the signaller. Furthermore, CSR interfaces with the train’s passenger announcement system.

The legacy systems above have faced a number of operational shortcomings during their lifetime. An example is an issue found with fault finding and fault reporting. There have been instances where the causes of faults could not be identified and subsequently, the reporting and recording of faults have been inconsistent [15]. This information could otherwise have been used to highlight deficiencies in coverage and faults. In addition to the legacy systems above, there are tens of different analogue communication systems across Europe, leading to issues with obsolescence, high maintenance costs and poor quality of service [16].

3.2 ERTMS Constituent Systems

3.2.1 European Train Control System (ETCS)

The European Train Control System (ETCS) is an Automatic Train Protection (ATP) control system for European railway networks that enables a train to adhere to interlocking (signals, points and set routes) decisions [17] and stop at the correct locations. Therefore, ATP prevents train collisions through translation of the route into a movement authority. Across Europe there are a range of train protection systems which utilise different technologies. Consequently different systems are required on-board rolling stock [18]. This is an example of the benefits of interoperability through implementation of a single system. The ETCS has three levels of increasing application, increasing from Level 1 to Level 3, with the signalling system design moving from trackside to on-board the train. This paper places emphasis on the communication system and thus the applicable ETCS level is
ETCS level 2. At this level of functionality, the train receives its movement authority via GSM-R and thus has a continuous train protection system [18]. The GSM-R is discussed in more detail below.

### 3.2.2 Global System for Mobile Communications-Railways (GSM-R)

GSM-R is a telecommunications system specific to railways, endorsed by the International Union of Railways, specified through functional and system requirement specifications [19] and mandated as a standard for European railways by the European Commission in 1997 [20]. Unlike commercial telecommunications, GSM-R, is less susceptible to variations in the market as it focuses on passenger usage, safety and reliability.

In accordance with the goals of ERTMS to provide an interoperable European railway network, the GSM-R component of ERTMS marks the replacement of a number of incompatible analogue communication systems for railways. This move away from analogue systems can be deemed as an inevitable process, as legacy components are often difficult to resource and replace due to the major shift in technology.

The differences in functionality offered by GSM-R to that of GSM lie in the frequency ranges, which can vary across Europe. The functions provided by these frequency bands include onboard signalling and communications such as passenger information.

Railway stakeholders via the Radio Spectrum Committee have raised concerns about the possibility of interference in the GSM-R frequency spectrum [21]; this follows 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 [22]. This infers that the quality of the GSM-R service could be degraded and consequently stakeholders believe the GSM-R frequency band should be protected. The issues raised via the Radio Spectrum Committee are justified and emphasis should also be on the reliability of GSM-R and how it affects GSM-R human related interfaces. Greater emphasis should be placed on this issue due to the fact that the subsystems that comprise the GSM-R network cannot be 100% reliable; thus the consequences posed to the railway of a communication system, that is suffering interference, can be severe.

There are a number of European cases that highlight the issues that have arisen with GSM-R networks that have suffered interference. In 2001 for example, the German deployment of GSM-R experienced no interference, however since 2006, due to increased usage of the neighbouring GSM band, interference problems have arisen with cases of loss of connection with passing trains. 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 MHz which has led to uncoordinated and unadvised deployment by UK operators [22]. The French from 2006 have carried out a detailed analysis of GSM-R disturbances, including severity and impact posed to the railway from interference. Table 1 shows examples of disturbances and the severity, the cases shown to be specific to ETCS have identified a high level of severity on urban routes.

<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>
3.3 Railway System and GSM-R Subsystem Architecture

The GSM-R offers a method of information transmission for a number of railway users and systems. This is demonstrated from a physical system perspective via the system architecture. The system architecture has been designed to identify key interfaces and points of integration. This section outlines the GSM-R architecture in the context of (i) a generic mainline railway system including points of human interfacing and (ii) via the technical architecture, which identifies the subsystems comprising the GSM-R.

The GSM-R system architecture has been used as a basis to identify the key GSM-R interfaces. These interfaces cover the train system, control centre and human interfaces, which are identified and specified in this paper (with help of subject matter experts) from the architecture in Figure 2 and include:

- GSM-R NSS to the Radio Block Centre
- GSM-R Voice (Driver) to the Route Control Centre
- GSM-R data modem (onboard) to the European Vital Computer
- GSM-R Trackside to GSM-R data modem (onboard)
- GSM-R data modem (onboard) to the Maintainer
- GSM-R Voice to Line-side Protection Systems

FIGURE 2 Generic Mainline Railway System Architecture

The architecture presents a high level generic view of the on-board rolling stock, track and operational systems with emphasis on systems that require a human interface. The architecture identifies that the main usages of GSM-R from a human machine interface is operationally 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. The system structure as outlined in Figure 2 emphasises the interface areas for GSM-R transmission. Figure 3 additionally provides a detailed view of the subsystems required for GSM-R communication. GSM-R technology as utilised at ETCS level 2 enables movement authority to be continuously transmitted to the train via the Radio Block Centre (RBC) and is made visible to the driver via the train cab display. The train's position and direction of travel is automatically reported at regular intervals to the trackside RBC [23]. Thus it can be said that the RBC is a vital interface in the ERTMS as it provides an interface for the signaller to observe and influence operational aspects [24].

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 [25]. Figure 3 captures the GSM-R architecture and is from two sources [26, 27]. The latter reference is an example based on the practical GSM-R implementation on the Deutsche Bahn (Germany). The GSM-R architecture can be broken down into four building blocks: Mobile Station (MS), Base Transceiver Station (BTS), 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 and is the control equipment for the whole network. The Base Station Controller (BSC) on the other hand manages the resources of the BTS, such as handover where the BTS additionally provides the channels by which communication is carried out between the mobile stations [28].

**FIGURE 3 GSM-R System Architecture [26, 27]**

**4 RAILWAY PERFORMANCE SHAPING FACTORS – THE R-PSFS TAXONOMY**

The importance of communication in railway operations has been highlighted in section 3. Furthermore, [6] identified that “communication” has a significant impact on human performance regardless of the type of operation or operator. It is one of the most significant factors that can lead
either to an accident or incident during railway operation. Therefore, it is important to investigate communications in relation to other factors that influence human performance.

A new and detailed Performance Shaping Factors (PSFs) taxonomy that focuses on Railway operations, R-PSFs, was introduced by Kyriakidis et al. [6]. The R-PSFs taxonomy has been derived from an extensive review of literature in transportation and other domains, including the nuclear, healthcare and offshore energy exploration and production industries. This taxonomy aims to:

- Identify, clearly define and categorise, those PSFs that influence human performance on railway operations, based upon their common characteristics.
- Assess (“weight”) PSFs according to each operator’s duties (e.g. train driver, signaller and controller) in order to propose mitigation strategies.
- Investigate and measure interdependencies between PSFs.
- Account for the distinction between dynamic and static PSFs.

Whilst a number of taxonomies for the railway industry were identified in the literature, these were either incomplete [29] or strongly orientated to one type of operator [30]. Hence there was a need for a new taxonomy focused on the railway industry, rather than simply adapting an existing one.

The R-PSFs taxonomy was developed based on the duties of the railway employees in order to provide researchers, experienced or novice, as well as operators and safety specialists in the field of HF with a simple and comprehensive tool. It defines the PSFs in detail and provides an example for each PSF to avoid potential misunderstandings amongst researchers. The new taxonomy contributes to the existing taxonomies, as it:

- Is based on railway employees’ duties, including maintenance or construction personnel.
- Clearly and precisely defines the PSFs – examples.
- Identifies the dependencies amongst PSFs.
- “Assesses” individual PSFs contribution on human performance.
- Is concerned with transferability.

The taxonomy is divided into seven main categories two of which contain the dynamic factors, i.e. those that are strongly related to the precise moment of the operation, while the remaining five contain the static factors. The categories are described as follows:

- Personal factors, e.g. dynamic or static, characterise every individual. For instance, an operator’s level of stress for a particular situation A is unique and can be different from the corresponding level of stress of any other operator.
- Task factors characterise features of the executed task such as its complexity.
- Team factors influence the operator as a member of a team, e.g. communication during shunting.
- Organisational factors have a significant impact on human performance at the workplace, as affected by the characteristics of the organisation for which people work. For instance, if a train driver fails to observe a signal due to fatigue, it is an issue that is related to personal factors. However, if the driver is tired due to long consecutive shifts then the issue is linked to the organisation, since it is responsible for shift patterns.
- System factors describe factors such as the quality and type of the equipment or the working conditions in terms of working environment.
- Finally, ambient factors include weather conditions at the moment of the operation.

Figure 4 shows the R-PSFs structure as well as a sample of the railway PSFs and illustrates the interactions between the operator, the executed task and railway PSFs. The structure of the taxonomy can be described as generic and therefore, it can be used in any other transport mode or industry, though the individual PSFs might change according to the attributes and features of the industry in which they are implemented.
More information about the taxonomy, its validation, assessment and the dependencies amongst its factors can be found in [6].

5 METHODOLOGY AND RESULTS

In total, 314 main line incident and accident reports were extracted from a number of European railways organisations. For the classification of the events, the definitions for the railway incidents and accidents, as given in the EU Directive 2004/49/EC [31] are used. Since this paper is focused on GSM-R, the analysis is mainly focused on “communication” related errors during railway operations. Therefore, 74 out of the 314 reports were identified as relevant and analysed further.

The collected reports were gathered either from publicly available sources such as the European Railway Agency Database of Interoperability and Safety (ERADIS) or the U.K. Rail Accident Investigation Board (RAIB) databases, or from railway organisations such as Network Rail in the U.K. and the Swiss Federal Railways (SBB). All the gathered reports contain information on the following: (i) type of railway, e.g. regional passenger train, (ii) occurrence type, e.g. accident or incident, (iii) associated event, e.g. train derailment, (iv) location, (v) time of the accident, (vi) immediate cause of the accident, e.g. train unable to stop and (vii) causal factor of the accident, e.g. train driver falls asleep, what PSFs played a role in that occurrence and the severity of its consequences.

The sources of the reports represent the majority of the situations experienced in railway operations, e.g. different types of networks, varying geography (U.K. and Switzerland), different regulations or different staffing. Therefore, the sampled data can be argued to be representative of the population of interest.

A preliminary analysis distinguishes the events according to their severity, year of occurrence, location (e.g. station and open line) and type of occurrence. In addition the contributing factors that led to the event based on the R-PSFS taxonomy are defined.

As described in section 3, the main potential communication errors within the GSM-R scheme are due to human machine interfaces, misunderstanding amongst employees or failure of GSM-R. These errors are expressed in the R-PSFs taxonomy from the following PSFs: HMI, Communication and Railway Communication Means respectively [6]. Therefore, in this paper the concept of the Difference-in-Difference (DID) (section 5.3) method is used to show the effect of GSM-R implementation for a given period of time between those railway organisations which have implemented GSM-R and those who have not.
5.1 Data reliability and limitations

The collected reports are official documents, which have been completed by authorised personnel, from different sources such as national transportation safety boards, independent national investigation bodies and railway operators. The literature shows [32, 33] that the reporting system in the countries where the reports were completed, despite their limitations is effective. Hence it can be assumed that the information they contain is reliable and sufficient to extract accurate outcomes.

The literature [33] also shows that the majority of the railway administrations/organisations concentrate on the events leading up to the accident and the causation during the reporting process. However, some of the reports unequally describe the immediate and latent factors that led to an event. Although the immediate causes are explicitly described this is not the case for the latent factors and especially for the performance shaping factors. Therefore, a simple approach is proposed to be followed and included in the reporting scheme in order to capture more information. This approach is based on a simple checking list, which contains the most frequent R-PSFs in railway operations as identified in [6]. The list, as shown in Table 2 consists of 12 R-PSFs (Level II) that are classified in 6 main categories (Level I). The 12 factors, as shown in [6] account for more than 90% of the railway incidents and accidents regardless of their severity. In addition to the 12 R-PSFs the investigation list identifies whether environmental conditions contributed to the event.

<table>
<thead>
<tr>
<th>Contributor factors</th>
<th>Main Contributing factors</th>
<th>Involved personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal factors</td>
<td>Training - Experience</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Other (please indicate)</td>
<td></td>
</tr>
<tr>
<td>Dynamic Personal</td>
<td>Distraction - Loss of</td>
<td></td>
</tr>
<tr>
<td>factors</td>
<td>concentration</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Perception - Interpretation</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Fatigue - Shift pattern</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Expectation - Familiarity</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Other (please indicate)</td>
<td></td>
</tr>
<tr>
<td>Task factors</td>
<td>Workload - Time pressure - Stress</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Other (please indicate)</td>
<td></td>
</tr>
<tr>
<td>Team factors</td>
<td>Communication - Teamwork</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Quality of Information</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Other (please indicate)</td>
<td></td>
</tr>
<tr>
<td>Organisational</td>
<td>Safety culture – SMS</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td>factors</td>
<td>Supervision</td>
<td>Yes ☐ No □</td>
</tr>
<tr>
<td></td>
<td>Quality of procedures</td>
<td>Yes ☐ No □</td>
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<td></td>
<td>Other (please indicate)</td>
<td></td>
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<tr>
<td>System factors</td>
<td>System design – HMI</td>
<td>Yes ☐ No □</td>
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<td></td>
<td>Other (please indicate)</td>
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</tr>
<tr>
<td>Environmental</td>
<td>Please indicate</td>
<td></td>
</tr>
<tr>
<td>factors</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SMS: Safety Management Systems, HMI: Human Machine Interface

5.2 Preliminary analysis

The 74 relevant reports were initially categorised based on the type of the event, with 12 serious accidents, 18 accidents and 44 incidents. The reports describe events that occurred during the period 1998-2011 in 14 different European countries. Signallers-controllers are involved in 54 of the events, passenger train drivers in 24 and freight train drivers in 13, since in some of the events more than one employee was involved. This distribution confirms that “communication related errors” are
mainly related to signallers-controllers, as shown in [6]. Misunderstandings in communication amongst employees were identified 77 times, HMI problems 12 times and inconsistencies with regard to the RCM, 11 times. However, of the 11 there was only 1 GSM-R system total failure.

Concerning the location of the occurrences, this was divided in two different ways, by identifying and grouping the common characteristics. In the first case the location was divided as follows:

- on open lines (including curves, points or gradient),
- in stations (including station points, platforms, depots or depot points),
- in yards,
- at junctions,
- at bridges or viaducts,
- in tunnels (entrance or the exit)
- at level crossings

In the second case, a new category, referred to as “points” is created. The new category comprises all points (including junctions) that exist in the railway network. The remaining categories are the same, therefore the complete second classification is described as follows: open lines (including curves and gradient), stations (including platforms and depots), points (including points on open lines, at junctions, in stations and depots), yards, bridges or viaducts, tunnels (entrance or the exit), level crossings.

With regard to the first categorisation, most of the events occurred on open lines and stations; 39 and 27 respectively. Concerning the second categorisation, while most of the events occurred on open lines, there is no difference between the events that occurred at points and stations; 39, 22 and 23 respectively.

The occurrences were classified as: train collision, train derailment, Signals Passed At Danger (SPADs) and operational irregularities. Operational irregularities and SPADs were found the most frequent types of incident. Although SPADs are caused mainly by train drivers [5], this paper has shown that signallers/controllers are also significant contributors to SPADs, due to wrong instructions given to the drivers. In the cases of accidents and serious accidents, train collision was found to be at least two times more frequent than any other type of occurrence, primarily due to misunderstanding in communication amongst signallers and train drivers. Finally, Table 3 shows the relationship of communication error events with the seven R-PSFs categories, as described in section 4.

**TABLE 3** R-PSFs Categories related to Communication Error Events

<table>
<thead>
<tr>
<th>Incident</th>
<th>Environmental</th>
<th>Organisational</th>
<th>Personal</th>
<th>Personal (dynamic)</th>
<th>System</th>
<th>Task</th>
<th>Team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>19</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HMI</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accident</td>
<td>6</td>
<td>59</td>
<td>17</td>
<td>40</td>
<td>22</td>
<td>9</td>
<td>83</td>
</tr>
<tr>
<td>Communication</td>
<td>3</td>
<td>52</td>
<td>15</td>
<td>28</td>
<td>5</td>
<td>7</td>
<td>77</td>
</tr>
<tr>
<td>HMI</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>9</td>
<td>13</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>RCM</td>
<td>1</td>
<td>3</td>
<td></td>
<td>3</td>
<td>4</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Serious Accident</td>
<td>1</td>
<td>32</td>
<td>8</td>
<td>5</td>
<td>15</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>Communication</td>
<td>20</td>
<td>5</td>
<td></td>
<td>7</td>
<td>3</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>HMI</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCM</td>
<td>1</td>
<td>9</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
inconsistencies. On the other hand no association was found between “HMF” (p=0.21>0.05), “RCM” (p=0.15>0.05) and the “type of operator”.

In addition, association (p=0.01<0.05) was found between the “location of event” and the “type of occurrence”. Log-linear analysis shows an association amongst the “type of occurrence - location of event - R-PSFs categories” (95% level of confidence).

Finally classification trees show that the “severity of event” is primarily related to the “type of operator”, followed by “R-PSFs categories”.

It is shown in Table 2 that “Team” such as “Teamwork” and “Workload” and “Organisational” such as “Safety culture” and “Training methods” R-PSFs categories dominant the contributing factors that lead to communication related railway incidents or accidents.

Therefore, the implementation of GSM-R, aims to improve the safety of railway operations by improving and eliminating the communication related errors. The next section assesses the effect of GSM-R on communication related railway accidents/incidents.

### 5.3 Difference In Difference methodology

DID methodology is used to measure the effect of a “treatment” for two groups at a given period in time. One of the groups is exposed to the treatment in the second period, but not in the first. The other group is not exposed to the treatment during either period [34].

The mathematical expression of the DID methodology can be obtained through a regression model as given in Equation 1.

$$ Y = \alpha + \beta T + \gamma P + \delta(T \cdot P) + \varepsilon $$  

where, Y is the outcome of interest, T is the time dummy variable, P is the dummy variable that captures possible difference between the two groups prior to GSM-R implementation, and T\*P the interaction of the two dummy variables. The \( \alpha, \beta, \gamma \) and \( \delta \) are the regression parameters to be estimated.

In this paper, the collected data was gathered from 14 different European countries. The treatment group comprises the countries that have already entirely implemented GSM-R such as: Norway, Sweden, Finland and France [3]. The control group is consisted of countries, which have either partially implemented GSM-R or they are still under the tender process. Amongst them are: U.K., Spain, Switzerland, Austria, Belgium and Czech Republic [3]. The literature indicates that 2008 can be used as the threshold year [3].

56 out of 74 reports are referred to the control group while the remaining 18 to the treatment. The reason for the big difference between the two bunches of reports is due to the limited number of events which occurred in those countries that implemented GSM-R. From the 18 reports belonging to the “treatment” group 10 of them describe events before 2008, while the remaining refer to events after GSM-R was completely implemented.

The analysis focuses on identifying the R-PSFs changes before and after GSM-R implementation, with regard to “Communication”, “HMF” and “RCM” R-PSFs.

Results in Table 4 indicate that there is no change in the R-PSFs for the “control” group in both periods. Therefore, any changes identified in the “treatment” group can be claimed to be caused due to GSM-R implementation.

As shown in Table 4, the R-PSFs for the “treatment” group change before and after GSM-R implementation. Although, no difference is identified for “RCM”, a change is observed for “HMF” and “Communication”.

With regard to “HMF” this change is shown by the lack of “System” category in the events after 2008. This can be explained by the fact that GSM-R interfaces, such as displays or equipment, provide more features to drivers. For instance, it allows drivers to call the most appropriate signalle/controller with regard to a train’s position via the Location Dependent Addressing feature. In addition, displays are more ergonomically efficient and user-friendly, having clearly marked buttons for emergency functions or fast dial buttons.
Concerning “Communication” although the predominant “Team” PSFs remain the same, a change is shown to “Personal” related PSFs pre and post GSM-R. “Personal” PSFs are no longer significant contributors. However, the “Organisational” factors; such as safety culture or training methods become significant. It is more likely that the events occurred as result of insufficient training or experience of the operators, immediately after GSM-R implementation due to the transition to the new model, rather than degradation in the safety culture performance of the organisations.

### TABLE 4 PSFs Affect “Communication” Pre and Post GSM-R

<table>
<thead>
<tr>
<th>PSFs Affect “Communication” Pre and Post GSM-R</th>
<th>Before 2008</th>
<th>After 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td>“Treatment” group</td>
<td>Control group</td>
</tr>
<tr>
<td>Communication</td>
<td>Team</td>
<td>Team, Personal</td>
</tr>
<tr>
<td>Human Machine Interface</td>
<td>System</td>
<td>System, Organisational</td>
</tr>
<tr>
<td>Railway Communication Means</td>
<td>System</td>
<td>Organisational</td>
</tr>
</tbody>
</table>

### 6 CONCLUSION

This paper has investigated, identified and quantified the influence of the GSM-R component of ERTMS on operators’ performance over the period 2008-2011. Accident and incident reports of railway operations prior and post GSM-R, from a number of European railway organisations were analysed. The analysis identified the factors that have the most significant influence on human performance in the conventional and upgraded railway systems. The analysis results have shown that the implementation of GSM-R does not have any negative influence on the performance of the operators. In particular, no “Personal” or “Personal dynamic” R-PSFs were identified as contributing factors to railway accidents and incidents after the implementation of GSM-R. Although communication errors remain as the predominant R-PSFs factor, their number has been reduced thus proving the positive aspect of GSM-R implementation. However, to assure the safety of railway operations, organisations should provide the necessary training to their employees after G-SMR implementation in order to maintain their operational capabilities.

Although, more reports should be investigated, this paper has introduced an approach to monitor the impact of new technologies on human performance. This on-going process provides a framework to assess whether the installation of new technologies improves the resilience and robustness of the system in order to achieve the maxima benefits.

### 7 ACKNOWLEDGMENTS

The authors are most grateful to The Lloyd’s Register Educational Trust for supporting this work.

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Mr. Miltos Kyriakidis
Dr. Arnab Majumdar
Prof. Washington Y. Ochieng


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