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Data based framework to identify the most significant performance shaping factors in railway operations

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ABSTRACT

Human performance is a major contributor to railway incidents and accidents. The literature shows that it is operators, i.e. train drivers, signallers and controllers, who mainly affect the railway system in terms of safety. Numerous studies have investigated the influence of such operators on the railway system, but are usually based on studies from other domains and cannot be reliably applied to railway specific operations. This paper presents a framework to identify the most significant human performance factors, known as Performance Shaping Factors (PSFs), which influence the performance of railway operators. These Railway-Performance Shaping Factors (R-PSFs) are derived from an extensive literature review, together with an analysis of 479 railway operational incidents and accidents over the past 15 years worldwide. Subject Matter Experts in the railway domain subsequently validated the identified factors. Statistical analysis of the railway operational incidents and accidents is subsequently conducted, following data quality checks. Based upon the Pareto principle, 12 R-PSFs account for more than 90% of the accidents and incidents, regardless of the severity of the event. Results from the analyses indicate the contribution of each individual R-PSF to the occurrence of a railway incident or accident, and highlight the importance of specific R-PSFs either individually or in combination for features related to specific types of accidents and incidents. The findings of the analysis can be used to direct resources more efficiently towards the development of sound solutions for improving the performance of railway operators. In addition, based upon the R-PSFs, a checklist of human performance factors is developed which can be used for investigation purposes and to collect human performance measures in a consistent and logical manner. The proposed checklist and its usage can greatly improve safety management systems of railway organisations.

1. Introduction

The railway system is a major component of the economy of most countries, daily transporting millions of passengers as well as millions of dollars worth of goods from origin to destination (Dhillon, 2007). Therefore, the relevant operational, regulatory and governmental bodies of every country with a rail network aim for a safe, highly reliable, and excellent quality railway system (Wilson et al., 2007). Whilst the definition of a railway system can be broad, in this paper it includes only the infrastructure, rolling stock and frontline railway employees, i.e. train drivers, signallers, controllers, conductors, train crew, maintenance and station personnel (Kyriakidis, 2013; Murtagh, 2011).

The safety of railway operations within this system depends on several factors including rail traffic rules, infrastructure and rolling stock reliability, organisational safety culture and human factors (Hollnagel, 1998). In recent years, interest in the area of human factors within railway operations has increased significantly (Priestley and Lee, 2008).

A large number of railway accidents occur due to degraded human performance (Dhillon, 2007), which is described as the human capabilities and limitations that have an impact on the safety and efficiency of operations (Maurino, 1998). In Europe, Evans (2011) shows that at least 75% of the fatal railway accidents between 1990 and 2009 were due to human error, e.g. exceeding speed, signal passed at danger or signalling/dispatching error.

The literature shows that it is the train drivers, signallers and controllers (referred to as operators) who mostly affect the network in terms of safety (Dhillon, 2007). Several studies have been conducted in the field of Human Factors (HFs) and human performance in the railway domain (Wilson et al., 2007) to identify those factors, broadly known as Performance Shaping Factors (PSFs), that affect human performance in railway operations. However, most of

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these studies are based on previous research in the field of Human Reliability Analysis (HRA) from other domains, which are ill-suited to the rail industry and can be difficult to apply reliably to railway specific operations (Rail Safety and Standards Board, 2004). This is explained by the fact that such techniques investigate human errors and the factors that affect human performance related to the industry for which they were developed. Thus, they do not consider the types of human errors that railway employees and, in particular, railway operators may generate. Subsequently, they can only provide limited insights with respect to the errors that usually occur in railway operations. Recently, the Rail Safety and Standards Board (RSSB) (Rail Safety and Standards Board, 2012) has introduced a new technique, referred to as Railway Action Reliability Assessment, to estimate Human Error Probabilities for railway operations. However, it is beyond the scope of this technique to provide a detailed list of factors that affect the performance of operators, e.g. it ignores the safety culture or the safety management of an organisation (Rail Safety and Standards Board, 2012, p. 15).

Given the current limitations, this paper introduces a framework to identify, define and quantify the most significant PSFs that affect human performance in railway operations[1]. Maintenance or design personnel are not included and furthermore, accidents or incidents either due to passengers, trespassers or third parties' responsibility, e.g. level crossing accidents caused by car drivers, are also ignored.

This paper presents the integrated results of the follow up to a previous study by Kyriakidis et al. (2012b). In their initial study, Kyriakidis et al. (2012b) introduced a framework to develop and assess a Performance-Shaping Factors taxonomy for railway operations, referred to as the Railway Performance Shaping Factors taxonomy (R-PSFs). The authors developed their taxonomy based on an extensive literature review in the field of human factors and subsequently validated against the findings derived from the analysis of 179 railway accident and incident reports, as well as targeted interviews with Subject Matter Experts. To enhance the findings of their first study and to extend the representative nature of the R-PSFs taxonomy, the authors analysed 300 additional railway accident and incident reports.

In total therefore, the results of the analysis of 479 accident and incident reports worldwide were used to validate and update the Railway Performance Shaping Factors (R-PSFs) taxonomy. Subsequently, the twelve most important R-PSFs were defined, which comprise the deductive version of the taxonomy, referred to as the *R-PSFs lite*. The purpose of this version of the R-PSFs taxonomy is threefold. First, it provides a simple and more flexible version of the R-PSFs taxonomy for both investigative purposes and statistical analyses. Second, it highlights the factors that primarily affect operators performance and keep both operators and investigators alert about these factors. And finally, it can be used to quantify (''weight'') the contribution of each individual R-PSF on the performance of operators and eventually to assess human performance for several railway operational scenarios. For this, a novel technique, referred to as the Human Performance Railway Operational Index (HuPeROI), has been developed by implementing the Analytic Network Process (Saaty and Vargas, 2006) and the Success Likelihood Index Method technique (Embrey et al., 1984). However, it is beyond the scope of this paper to present the HuPeROI.

To ensure the highest level of safety, organisations implement a Safety Management System (SMS), which is in effect a systematic approach to safety that strives to assess and continuously improve the safety of an entire system. Key to the success of a SMS is the assessment of all system components and their interactions for hazards and associated safety risks. Amongst the most challenging aspects in implementing an accurate SMS for railway organisations is to determine the human performance aspects of safety risk in a consistent manner. The importance of the framework presented in this paper lies in assisting railway organisations tackle this challenge in a robust, logical manner and thereby incorporate it is an essential element in their SMS. Furthermore, such a well-implemented SMS is also useful for regulatory purposes as it states the minimum standards requirements necessary for an organisation to show its genuine dedication to safety.

This paper is organised as follows: Section 2 presents in summary the framework for the R-PSFs development, as firstly introduced in Kyriakidis et al. (2012b). Section 3 describes the collected data, while Section 4 addresses the issues of data reliability and limitations. Section 5 then presents the context of data analysis, while Section 6 demonstrates the results as well as the implications of the results for the SMS. Finally, Section 7 addresses the areas of concern and charts the future research directions.

2. Framework for the development of the R-PSFs taxonomy

The need for a performance shaping factors taxonomy focussed on the railway industry and especially on railway operations was detailed in (Kyriakidis et al., 2012b). This new taxonomy is based on the duties of the railway operators in order to provide researchers, as well as operators and safety specialists in the field of HFs, with a simple and comprehensive tool. It defines the R-PSFs in detail and provides an example for each R-PSF to avoid potential misunderstandings. The R-PSFs taxonomy contributes to the existing taxonomies, as it: (i) is based on railway operators' duties, (ii) clearly and precisely defines the R-PSFs – including providing examples for each R-PSF, (iii) identifies the dependencies amongst R-PSFs, (iv) ''assesses'' individual R-PSFs contribution on human performance and (v) aims to be transferable.

Fig. 1 illustrates the holistic framework used to develop the R-PSFs taxonomy.

First, an extensive literature review was conducted in the field of HFs to identify the possible PSFs. This identified 248 PSFs that considered the duties of the train drivers, signallers and controllers as specified in railway operational manuals, e.g. (Network Rail, 2008a,b,c). However, there was considerable overlap between many of those PSFs and therefore, they have been combined on the basis of their common characteristics and definitions (when available), and when necessary, renamed and redefined. This process led to a list of 43 factors, classified into seven main categories. Two of these categories contain dynamic factors, which are factors strongly related to the precise moment of the operation, i.e. the dynamic personal and environmental factors. The remaining five categories comprise of static factors, i.e. the R-PSFs that have less association with the time of the occurrence.

The categories are described as follows:

- *Dynamic Personal* factors, embrace factors that characterise and affect individuals' performance *and are strongly* related to the precise moment of operation/occurrence. These factors include, amongst others, operators' levels of stress, distraction, fatigue and vigilance.
- *Personal* R-PSFs encompass the factors that characterise and affect the performance of an individual *but are not strongly* related to the precise moment of operation/occurrence. Therefore they are considered as static factors. Personal factors embrace operators' levels of training and experience, physical conditions and other intrinsic characteristics.

[1] This study considers as railway operation ''*any train movement from one point to another or during a shunting operation*''.