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The human performance railway operational index—a novel approach to assess human performance for railway operations

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ABSTRACT

Human error and degraded human performance are associated with more than 80% of all railway accidents worldwide. Research on human performance and human reliability has highlighted the importance of the contextual factors associated with human errors, known as performance shaping factors (PSFs). A major shortcomings of current Human Reliability Analysis techniques, which employ qualitative and quantitative methods for assessing the human contribution to risk, lies with their little capability to model the dependencies among PSFs and to quantify their impact on human performance. This paper presents a novel approach to assess human performance accounting for the dependencies among the relevant PSFs, referred to as Human Performance Railway Operational Index (HuPeROI). The HuPeROI is developed on the integration of the Analytic Network Process and Success Likelihood Index Methodology, using the insights of 52 front-line, managerial and human factors railway personnel, and was demonstrated in three different types of railway operations: regional, high-speed and underground. Findings show that the HuPeROI can be efficiently used to assess operators' performance as function of the quality of the relevant R-PSFs. Regulatory bodies and other stakeholders can implement the framework within their safety management systems to improve safety of railway operations.

1. Introduction

Human error and degraded performance are involved in for more than 80% of major railway accidents [1]. European data indicates that at least 75% of fatal railway accidents between 1990 and 2013 occurred due to human errors by operators [2,3]. Furthermore, the data from the US railroads shows that during the last decade [4] more than 37% of all train accidents were, to some extent, attributed to human factors. Research shows that it is the train drivers, signallers and controllers (referred to as the "operators") who mostly affect the railways in terms of safety [5], and therefore, the analysis of the performance of such railway operators is essential for enhancing railway safety. Throughout the continuous development of railway human factors (HFs) research [6,7], different approaches, based on the principles of Human Reliability Analysis (HRA),[1] have been developed to study human error and analyse human performance.

As early as 1996 Hudoklin and Rozman [10] discussed railway traffic personnel reliability, identified the most critical operational errors and provided error probabilities. Vanderhaegen [11] later introduced a non-probabilistic approach to identify both tolerable and intolerable sets of human behavioural degradations, which may affect railway system safety. The approach was applied to railway scenarios focusing on performance degradation associated with three behavioural factors, i.e., acquisition, problem solving and action. Whilst providing useful insights, both approaches fail to account for one of the fundamental elements in the analysis of human performance, i.e., that the performance depends on the context and the conditions under which the tasks or activities are conducted [12–15]. Such conditions, broadly known as performance shaping factors (PSFs), are defined as "*all the influences that enhance or degrade human performance*" [12, p. 170], such as age, working conditions, team collaboration, mental and physical health, work experience or training.

A major limitation of current HRA techniques lies with their restricted ability to account for the dependencies among the factors that affect human performance and to subsequently quantify the impact of each factor on performance [16]. With respect to the railway domain in particular, the relevant literature [6,7,11,17–21] indicates that very few performance analysis techniques are based on the concept of PSFs. Table A1 in the Appendix highlights the main features of these approaches. However, there is lack of a comprehensive classification of the factors affecting the performance of personnel in the railway do-

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[1] Human Reliability Analysis (HRA) is generally described as the use of systems engineering and behavioural science methods in order to render a complete description of the human contribution to risk and to identify ways to reduce that risk [8,9].

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main [22], thus Kyriakidis et al. [23] introduced recently an approach to identify the critical factors that influence the performance of railway operators, culminating in the Railway-Performance Shaping Factors (R-PSFs) taxonomy.

Based on the R-PSFs taxonomy, this paper presents a novel framework, referred to as the Human Performance Railway Operational Index (HuPeROI), that by assessing human performance as function of various PSFs enhances the safety of railway operations. The HuPeROI, for the first time, introduces an approach that quantifies the impact of each of the factors on human performance and accounts for all the dependencies amongst these factors. In line with previous research [12,16], the HuPeROI identifies both direct and indirect dependencies. The former describes the impact of a particular PSF on human performance whilst ignoring the presence of other R-PSFs, while the latter represent the influence of a particular PSF on human performance due to its relationship with other R-PSFs. Given the lack of empirical data, subject matter experts (SMEs) were employed to assess the influence of the PSFs on human performance. Based on the assessments, researchers, train operators, infrastructure managers, regulators and other relevant stakeholders can gain better understanding of how the PSFs influence railway operators performance. In addition, the approach supports all relevant stakeholders in estimating the relative likelihood of different human operational errors and thereby to assist in prioritizing resources so as to enhance the safety of operations by mitigating the influence of the contributing factors on human performance.

The HuPeROI was developed by integrating the Analytic Network Process (ANP) and Success Likelihood Index Methodology (SLIM) techniques. The framework was demonstrated in a case study for three different types of railway operations: regional, high-speed and underground, and assisted in defining the influence of each individual factor on human performance as well as indicating the relative likelihoods of different human errors.

The railway industry in Europe is legally bound after Articles 4(3) and 9(1) of the Directive 2004/49/EC [24] to introduce and implement a harmonized effective safety management system (SMS) in order to ensure the safe management of its operations. It has been recognized that well established safety management systems add value to the industry by improving overall performance, introducing operational efficiencies, enhancing relations with customers and regulatory authorities, and finally by building a positive safety culture [25]. The European Union Agency for Railways, former European Railway Agency (ERA), highlights the importance of HFs research within the SMS, and in order to assist this, it has introduced a list of factors that may influence the performance of railway employees in their workplace. However, this list "*is not intended to be a "check list", rather a collection of examples of the most usual factors which might impact staff performing tasks*" [25, p. 76]. Furthermore, the ERA presents a large number of principles, tools, methods, and techniques used in human factors research [25], but does not recommend any particular methodology that could universally be used by the industry. While the goal of the Agency is to promote a systematic integration of human factors into European railway operations [26], to date railway organisations implement alternative methodologies for the same research scenarios leading to different, non-comparable results. Thus, we argue that the HuPeROI methodology can be used to bridge this gap, by providing the relevant stakeholders with a robust universal methodology first to better understand the role of humans in railway operations, second assessing the performance of railway operators in their workplace, and third enhance safety by being integrated into the SMS of the railway organizations.

This paper is organized as follows: Section 2 describes briefly the elements of the R-PSFs taxonomy. Section 3 introduces the underpinning theory for the HuPeROI development, while Section 4 illustrates the implementation of the HuPeROI in a case study for the railway industry. Section 5 presents the results of the study, and finally, Section 6 summarises the finding and their implications before concluding in Section 7.

2. The railway performance shaping factors taxonomy

The R-PSFs taxonomy was developed following an extensive literature review in the field of HFs and HRA techniques, in addition to the analysis of 479 railway accident and incident reports worldwide. The results were corroborated by a Subject Matter Experts (SMEs) study. This process led to a list of 43 factors, classified into the seven main categories [22,23]: dynamic personal factors, personal factors, task factors, team factors, organisational factors, system an environmental factors. Table A2 in the Appendix illustrates the complete R-PSFs taxonomy.

In addition to the identification of the factors, their interactions were investigated, given that this has received scant attention in the literature [14,16,27,28]. Based on the dependencies between R-PSFs, a network of dependencies amongst the R-PSFs categories was developed, as illustrated in Fig. 1. The dependency between two categories is established when at least one R-PSF included in one of the two categories has an influence on, or is influenced by at least one factor of the second category, e.g., familiarity on distraction. These are known as outer dependencies. A number of inner dependencies is also established to indicate that, within the same category, at least one factor has an influence or is influenced by another factor, e.g., fatigue on distraction.

Finally, further to the full version of the R-PSFs taxonomy, a reduced version known as the R-PSFs lite was introduced consisting of 12 R-PSFs or combination of R-PSFs, responsible for more than 90% of all occurrences. To corroborate our statistical findings towards narrowing down the list of factors, we consulted two SMEs with a profound knowledge in the field of Human Factors: The Head of the RSSB's HFs group and the Chair of Work and Organisational Psychology of ETH Zurich. Our purpose was to ensure that the combined factors constitute rational, acceptable (based on the given definitions), and scientifically robust integrations that could further be used to describe and investigate human performance within the context of the railway accidents. Both SMEs verified that the combination of factors was rational and appropriately justified, thus the R-PSFs lite could be used, to study the contribution and influence of each of the most significant R-PSFs on human performance. The HuPeROI was developed upon the twelve largest contributing factors, as shown in Table 1.

3. The underpinning methodologies for the HuPeROI development

3.1. The analytic network process (ANP)

The Analytic Network Process (ANP) [29] supports decision making and allows researchers to systematically study all types of dependencies (i.e., higher-level elements on lower-level elements and vice versa) within the elements of a system. The methodology is developed using the concept of pairwise comparisons and introduces the notion of a supermatrix, i.e., a square matrix whose elements are themselves matrices of column priorities, which represents the result of dependence within and between the elements of the system, and it has been used in several problems that involve the interaction and dependence of higher-level elements on lower-level elements [16,30–33].

In this paper, the methodology is used to define the contribution or importance (priorities) of each identified R-PSF on human performance. The generic structure of the model is developed on a network of clusters, their constituent elements and interdependencies [33]. The interdependencies between clusters are identified, i.e., when elements of one cluster are either connected with other elements within the same cluster (*inner* dependence) or with elements of another cluster (*outer* dependence) [33]. Here, the clusters and elements comprise of the R-PSFs categories and R-PSFs elements respectively.

The pairwise comparisons are performed by answering the question: "*given a control criterion, a parent cluster (element) of the network and a pair of clusters (or elements) that are both linked to the parent cluster (element), by how much more does a given member of the pair influence that*