Reliability Engineering and System Safety 96 (2011) 849–860

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Modelling and assessment of dependent performance shaping factors through Analytic Network Process

Massimiliano De Ambroggi*, Paolo Trucco

Politecnico di Milano, Department of Management, Economics and Industrial Engineering, Piazza Leonardo da Vinci 32, Milan 20132, Italy

ARTICLE INFO

Article history:
Received 27 April 2009
Received in revised form
1 March 2011
Accepted 2 March 2011
Available online 11 March 2011

Keywords:
Human Reliability Analysis
Dependent performance shaping factors
Analytic Network Process
Cognitive simulation
Air Traffic Control

ABSTRACT

Despite continuous progresses in research and applications, one of the major weaknesses of current HRA methods dwells in their limited capability of modelling the mutual influences between performance shaping factors (PSFs). Indeed at least two types of dependencies between PSFs can be defined: (i) dependency between the states of the PSFs; (ii) dependency between the influences (impacts) of the PSFs on the human performance. This paper introduces a method, based on Analytic Network Process (ANP), for the quantification of the latter, where the overall contribution of each PSF (weight) to the human error probability (HEP) is eventually returned. The core of the method is the modelling process, articulated into two steps: firstly, a qualitative network of dependencies between PSFs is identified, then, the importance of each PSF is quantitatively assessed using ANP. The model allows to distinguish two components of the PSF influence: *direct influence* that is the influence that the considered PSF is able to express by itself, notwithstanding the presence of other PSFs and *indirect influence* that is the incremental influence of the considered PSF through its influence on other PSFs. A case study in Air Traffic Control is presented where the proposed approach is integrated into the cognitive simulator PROCOS. The results demonstrated a significant modification of the influence of PSFs over the operator performance when dependencies are taken into account, underlining the importance of considering not only the possible correlation between the states of PSFs but also their mutual dependency in affecting human performance in complex systems.

1. Introduction

One of the undisputed assumptions in all Human Reliability Analysis (HRA) methods is that the human performance depends on the conditions under which the tasks or activities are carried out [1,2]. These conditions, which can be related to both personal and environmental factors, have generally been referred to as performance shaping factors (PSFs) or performance influencing factors (PIFs). Although many authors have developed different competing lists of various lengths [1], there is a general agreement on the core set of these factors [3]. On the other hand, very different conceptual and analytical models are proposed for describing how these factors exert their influence on the human error probability (HEP); indeed if a PSF has an effect on human performance it is crucial to account for how this influence comes about.

One of the major challenges of modelling the influence of PSFs is how to represent and quantify the dependencies among PSFs [4]. Typically, HRA methods try to provide guidance as to how to treat dependencies at the level of the factor assessments; yet this guidance is hard to provide.

* Corresponding author. Tel.: +39 02 2399 4056; fax: +39 02 2399 4067.
E-mail address: massimiliano.deambroggi@mail.polimi.it (M. De Ambroggi).

0951-8320/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ress.2011.03.004

In general, it is possible to recognise two types of dependency among PSFs (Fig. 1):

- dependency between the states of the PSFs: the presence or the state of one PSF influences the state of another (e.g. a high level of stress increases the probability of low attention);
- dependency between the influences (impacts) of the PSFs on the human performance: the state of one PSFs increases the influence (impact) of another PSF on the HEP without changing its state (e.g. a poor state of the PSF "team factors" affects the influence of "personal factor" on the HEP).

Among HRA methods, which cope with dependency issues between PSFs, it is particularly worthy to cite the Information, Decision and Action in Crew Context model (IDAC) [5], the Cognitive Reliability Error Analysis Method (CREAM) [2], the Standardised Plant Analysis Risk-Human Reliability Analysis (SPAR-H) [6]. Some of them describe how the PSFs affect each other merely in a qualitative way (e.g. CREAM [2]), whereas some recent methods try to describe analytically the mutual dependencies among the states of PSFs and result in a very complex application that requires a great deal of effort by the analyst (e.g. IDAC [3]). Hallbert et al. [7] discusses how empirical data could be helpful for determining their size effect, their relative effects, as well as their interactions but they do not provide a procedure to guide the analysts on using these data.

This paper deals with the development of a framework for modelling the mutual influences existing among PSFs and a related method to assess the importance of each PSF in influencing the performance of an operator, in a specific context, considering these interactions (Fig. 1B). Furthermore, the proposed model allows to continue to use linear weighting methods for modelling the functional relationship between HEP and related PSFs (e.g. SLIM [8]), thus keeping the computational model relatively simple.

The paper is organised as follows. Section 2 summarises the state-of-the-art on modelling dependencies among PSFs. Section 3 introduces the theory of Analytic Network Process (ANP; [12–14]), its use for assessing dependencies among PSFs, and describes the proposed method based on the integration of ANP and SLIM. In order to test its applicability, the method has been included in the cognitive simulator PROCOS [9–11] and a pilot study in Air Traffic Control has been performed. By this way, using the same scenario and data reported in [11], the pilot study also returns a preliminary assessment of the variation of HEP estimates when a model of mutual dependent PSFs is used. Section 4 describes the pilot application, while Section 5 discusses the results. Finally, the last section summarises the main findings and the conclusions.

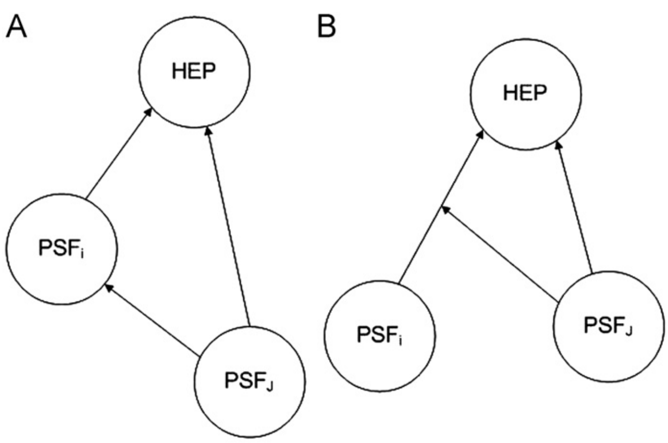

Fig. 1. Possible types of dependency between PSFs: (A) dependency between the states (the presence) of the PSFs and (B) dependency between the state of the PSFj and the impact of PSFi over the HEP.

2. State of art review of approaches to modelling dependencies among PSFs

A number of research studies assume and describe, at least in a qualitative way, the dependencies between PSFs, which should be taken into account in analysing human performance and assessing HEP [15]. To this end, considering a specific HRA study, the dependencies between the list of PSFs lying in the selected taxonomy can be postulated referring to these studies and with the support of experts with professional experience or knowledge in the reference domain.

Nevertheless, only few approaches deals with the mutual dependency between PSFs in a systematic way, thus our review has been particularly focused on CREAM [2], SPAR-H [6] and IDAC [3–5].

2.1. Cognitive Reliability Error Analysis Method (CREAM) [2])

The approach followed by CREAM to establishing the model of PSFs (called PIFs in the method) is to consider how much each one of the PSF may influence the state of the others [2]. Table 1 shows how the PSFs in the left-hand column are affected by the PSFs defined in the upper row. The model does not consider that a PSF category might depend on itself and that the presence of a specific PSF might modulate the impact of another PSF on HEP. The "+" sign denotes a direct influence (increase–increase, decrease–decrease) while the "−" sign denotes an inverse influence (increase–decrease, decrease–increase).

2.2. Standardised Plant Analysis Risk-Human Reliability Analysis (SPAR-H) [6]

The goal of considering PSFs relationships in SPAR-H is not an attempt to quantify mutual influences but only to provide guidance to support the analyst in a merely qualitative way.

Table 1
Mutual influences between PSFs within CREAM [2].

	Adequacy of organization	Working conditions	Adequacy of MI and operational support	Availability of procedures\plans	Number of simultaneous goals	Available time	Time of day	Adequacy of training and experience	Crew collaboration quality
Adequacy of organization	■								
Working conditions	+	■	+			+	+	+	
Adequacy of MI and operational support	+		■						
Availability of procedures\plans	+			■					
Number of simultaneous goals		-	-	-	■				
Available time		+	+	+	-	■	+		+
Time of day							■		
Adequacy of training and experience	+							■	
Crew collaboration quality	+							+	■