Reliability Engineering and System Safety 167 (2017) 595–601

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

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

# A quantitative measure of fitness for duty and work processes for human reliability analysis

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A R T I C L E  I N F O

*Keywords:*
Human reliability analysis
Work processes
Fitness for duty
Safety culture
Quantitative measure
Performance shaping factor

A B S T R A C T

Fitness for duty and work processes have been recognized as important performance shaping factors (PSFs) for human reliability analysis (HRA). However, current HRA methods offer no or limited guidance for determining PSF levels, so analysts have relied on their expert judgment during the selection of such levels. In this study, we propose a practical framework to quantitatively measure the levels of socio-psychological PSFs using human error data, based on plant experiences. This methodology calculates the error occurrence intervals and their moving average for a certain error cause reported in inspection reports. The proposed framework is applied to the HuRAM+ (Human related event Root cause Analysis Method plus) database as a case study. The usefulness and requirements of the proposed framework are then discussed.

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## 1. Introduction

Human reliability analysis (HRA), which is recognized as an important element of probabilistic safety analysis, is performed to systematically identify causes and consequences of human errors, and to predict the probability of error occurrences [1–2]. Many kinds of HRA methodologies have been developed, and most of them include mathematical functions employing performance shaping factors (PSFs) or situational contexts to quantify human error probabilities (HEPs) [2–3]. Hence, each method provides a set of significant PSFs coinciding with its purpose, and some articles also review the PSFs concerned during HEP quantification [4–5].

Fitness for duty and work processes have also been considered important PSFs for HRA [5–6]. The SPAR-H (Standardized Plant Analysis Risk Human Reliability Analysis) method addresses the definitions of the two factors as follows [6]:

> “Fitness for duty refers to whether or not the individual performing the task is physically and mentally fit to perform the task at the time. Things that may affect fitness include fatigue, sickness, drug use (legal or illegal), overconfidence, personal problems, and distractions [6].”

> “Work processes refer to aspects of doing work, including inter-organizational, safety culture, work planning, communication, and management support and policies [6].”

The importance of these factors can be illustrated by the following statements. According to the incident report of Japanese nuclear power plants, 25% of human error incidents were caused by improper communications [7]. Insufficient motivation to follow regulations or procedures was also a major cause of the Chernobyl accident [8]. Fatigue is closely connected to previous severe events, such as the incidents of Bhopal or Exxon Valdez [9]. Thus, fitness for duty is addressed by many guidance documents [10,11].

One characteristic of both fitness for duty and work processes is that they are closely associated with safety culture and organizational factors. Work processes include safety culture issues by definition [6]. In addition, the elements of fitness for duty, such as fatigue related to overwork, stress issues, and overconfidence, are also mentioned as symptoms of an inadequate safety culture, or as evaluation attributes of the safety culture [12,13].

Another characteristic of these two factors is that there is no evident framework to rate or evaluate their levels. To include a PSF in a quantitative HRA model, the following three issues at least should be resolved [14]: (1) significant factors to risks should be identified, (2) the identified factors should be measured, and (3) the quantitative relationship between the factors and human reliability should be estimable. Most popular HRA methods provide lists of PSFs that affect HEPs, and mathematical functions that calculate an HEP using the levels of PSFs [6,15–19]. However, they offer no or limited guidance for rating PSF levels [20]. In the K-HRA method, for example, there are decision trees or criteria to determine the levels of PSFs, such as stress,

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http://dx.doi.org/10.1016/j.ress.2017.07.012
Received 10 November 2015; Received in revised form 11 July 2017; Accepted 18 July 2017
Available online 19 July 2017
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human-machine interface, and procedure quality, from observable information [19]. However, because the K-HRA method does not consider fitness for duty and work processes as significant factors of HEPs, the decision criteria for the two factors were not developed. By lack of explicit guidance for PSF ratings, analysts rely on their expert judgment during the selection of PSF levels, which increases uncertainty [20]. Because work processes and fitness for duty entail more social and psychological aspects of human behaviors than other PSFs, no HRA methods have proposed a framework that objectively rates them yet.

In this study, we propose a framework to measure the level of fitness for duty and work processes using human error data based on plant experience. This methodology calculates the error occurrence intervals and their moving average for a certain error cause from the information on error causes reported in inspection reports like the HERA (Human Event Reliability Analysis) and HuRAM+ (Human related event Root cause Analysis Method plus) databases [21,22]. Essentially, this methodology can be used for estimating the levels of any PSFs under the assumption of sufficient human reliability data. However, it is expected that the levels of PSFs such as quality of documents, suitability of interface, and intrinsic complexity of given tasks, that are affected by the attributes of the given tasks and contexts, would be determined by observing the relevant surrogates [23]. Therefore, the method in this paper focuses mainly on the evaluation of the two socio-psychological PSFs: fitness for duty and work processes.

The outline of this paper is organized as follows. In Section 2, we define the elements of fitness for duty and work processes in order to clarify their attributes. In addition, some previous attempts to evaluate these PSFs are introduced. Section 3 explains the quantification process for the levels of the PSFs. Section 4 presents a case study that evaluates an element of fitness for duty. The usefulness, requirements, and limitations of the proposed framework are discussed in Section 5.

## 2. Related work

### 2.1. Elements of fitness for duty and work processes

To easily understand the nature of fitness for duty and work processes, it is required to deconstruct their definitions with key examples or elements, because the concepts of PSFs include a wide range of issues in personal or social aspects [6]. Table 1 shows some examples from the related literature that describe the meanings of the two factors. There exist discrepancies in the definitions of work processes among different studies in the literature, such as descriptions of the relationship between work processes and safety culture, or inclusions of the document quality into work processes. However, it is confirmed that fitness for duty encompasses physical or mental suitability of individual operators to given tasks, while work processes comprise coordination and communication, management support, supervision, procedure compliance, morale and motivation, strategy handling given situations, and corrective action programs. According to [25], the quality of documents is an important trait of safety culture. However, in this study, document quality is not considered as an element of work processes, because many reports distinguish it as a separate PSF, namely procedure quality [4,5,19,24].

### 2.2. Previous works evaluating PSFs

It is known that the states of organizational factors are difficult to define, control, and measure [26]. As shown in the examples of Table 2, some HRA methods consider fitness for duty and work processes to be important PSFs, and present their effects on the HEPs. However, these methods do not provide any unambiguous guidelines to evaluate the levels of PSFs. The recent models of organizational factors using Bayesian belief networks mostly focus on the relationships between organizational factors and human reliabilities, instead of stating the determination of the PSFs themselves [26].

Some measures to estimate the procedure compliance levels, which can be seen as an element of work processes, have been proposed [32,33]; however, these measures are co-related with other factors, such as procedure quality, and mismatch between plant situations and procedures. In addition, they do not fully reflect some portions of the two PSFs, for example communication issues.

It is possible to evaluate the levels of fitness for duty and work processes using the assessment techniques of safety culture or organizational factors. Safety culture is mainly assessed through interviews, observations, surveys, audits, or document analysis [13–14,34–37]. However, these assessment methods require high costs for several reasons. First, in the cases of interviews, observations, or surveys, in order to evaluate the level of safety culture for the entire organization, beyond the perceived safety level of individuals, a large amount of data should be collected. Second, the audit-based assessment requires analyzers to ensure high understandings of both the human/organizational factors and the socio-technical nature of the target system [34]. Finally, because each method has its own coverage or limitation, it is often recommended to evaluate the safety culture by incorporating two or more methods [13,34]; hence, these evaluation processes are easily more resource-intensive [37]. To sum up, although the existing approaches to safety culture evaluation is very significant for ensuring safety, it is required to develop a complementary approach, which can be more practically or efficiently used.

Statistics from historical accident data can provide unbiased and quantitative information [37]. Some risk models considering organizational factors such as SAM (System-Action-Management) and ASRM (Aviation System Risk Model) have also addressed the use of historical data [38–39]. However, which statistic is suitable for work processes and fitness of duty has not been sufficiently discussed yet. The number of accident occurrences, or the annual accident frequency related to organizational factors, is a plausible candidate [37]. However, these statistics, obtained from long-term data, deemphasize the recent trends of the organizational events.

## 3. Proposed measure

### 3.1. Use of plant experience data

We propose a measure to evaluate fitness for duty and work processes from plant experience data such as the HERA or HuRAM+ [21,22]. Experience data is preferred for quantifying the two factors, for the following reason: as mentioned in the previous section, it is not cost-efficient to evaluate the levels of fitness for duty and work processes with conventional methods. Although simulator training data or laboratory experimental data can also offer important information about human reliability [40], the psychological states of participants can be different due to insufficiency of reality in the simulators, or the Hawthorne effect of participants [41,42]. Because the factors that deal with the motivational or internal states of crew behaviors, including fitness for duty and work processes, are latent and sensitive to situational contexts, highly realistic data is acceptable to investigate these factors. For example, the SPAR-H method recommends using event inspection reports for identifying the levels of fitness for duty [6]. Finally, plant experience data allows scrutinizing organizational factors or tendencies in terms of a whole organization, instead of each individual personnel. Since many prospective HRA methods usually predict an HEP of an unspecified operator, quantitative information from experience data acquired in a similar location, nation, or business culture can be used for measuring overall organizational characteristics.

### 3.2. Moving average of HERI

The use of statistics from plant experience data assumes that the occurrence frequency of past events caused by work processes or fitness of duty issues is a significant indicator of the current or future levels of the

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