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Modeling workers' behavior: A human factors taxonomy and a fuzzy analysis in the case of industrial accidents

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ABSTRACT

While 'Industry 4.0' drives for greater automation, human factors are still essential in certain domains, especially in industrial disaster management. Despite human factors are frequently cause of individual biases and errors, a systematic quantitative analysis of the correlation between them and the workers' response performance in case of an industrial disaster has never been conducted.

The aim of the present study is twofold: to design an original human factors taxonomy, which encompasses all the industrial worker's cognitive capabilities, physical skills, and psychological attitudes; to establish a correlation between each factor and the workers' response performance in case of an industrial emergency. A Fuzzy Analytic Hierarchy Process (FAHP) analysis has been conducted in collaboration with 44 subject matter experts by using an ad-hoc developed tool to investigate, in particular, two types of workers, the role of emergency manager and the emergency team member. Results reveal that the factors have not the same weight in determining the human response performance: cognitive and psychological aspects have a substantial influence on the emergency manager's response performance, while the emergency team member's response performance is more influenced by psychological and physical aspects.

Relevance to industry: Given the crucial role of cognitive, physical and psychological factors in modern human-centred industrial systems and especially in the field of industrial safety & security, this study represents a meticulous guide for safety specialists in the design of disaster management strategies, for recruiters and practitioners in the development of competency-based job descriptions and for new research works for the development of personality-gifted intelligent agents in industrial applications.

1. Introduction

The human-centricity of the Factories of the Future makes topical the understanding of how workers experience the factory environment. The industrial workers are not going to be substituted entirely by autonomously acting machines in the foreseeable future as human thinking, flexibility, ability to learn and to improve are still essential in the industrial context (Schlechtendahl et al., 2015). Industries shifting towards the Industry 4.0 paradigm are totally committed to developing models that can predict reliably operators' performance from different perspectives (Bommer and Fendley, 2018). The integration of traditional system and process modeling approaches with recent human behavior modeling techniques will enable a better prediction of an industrial system's behavior, a mitigation of human errors and, ultimately, the improvement of the industrial system's efficiency (Kannengiesser and Muller, 2013). However, it is our belief that a human behavior modeling effort also requires the analysis of works and theories with roots in social, cognitive, behavioral, ergonomic and personality sciences. Over the last decades, descriptive personality dimensions-based classifications, such as the Eysenck's EPQ (Eysenck and Eysenck, 1975), the 16 personality factors by Cattell et al. (1970), the "Big 5" model (Goldberg, 1990) and the "Five Factor Model" by Costa and McCrae (1992), acquired a large consensus even in the industrial domain. In parallel with these works, artificial intelligence and software engineering science have widely attempted to integrate psychological notions into rational personality-gifted computer-based agents in several domains. Some successful works date back to the '80s when Bratman (1987) included mental attitudes in the Belief-Desire-Intention (BDI) architecture, which received great attention and was extended by several authors, e.g. Jiang et al. (2007). As soon as modeling psychological intelligent agents became topical in the early 2000s, several approaches to represent the individuals' personality were developed,

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such as the PECS architecture proposed by Schmidt (2000), the FLAME model by El-Nasr et al. (2000), the Parameterized Action Representation by Badler et al. (2002), or the popular OCEAN model (Oren and Ghasem-Aghaee, 2003) and the ACT-R (Park et al., 2018). What emerges is that most of the theoretical behavioral models for rational personality-gifted computer-based agents focus only on a limited number of personality aspects (e.g. neuroticism, extraversion, psychoticism) and do not have an all-encompassing perspective on human personality (Elkosantini, 2015). In particular, applications in the industrial sector fully reflect this general trend: while the last years were marked by a growing interest in modeling human error and performance (Ergai et al., 2016), a lack of attention on psychological and physical traits, and in general on personality aspects, has been observed (Ardalan et al., 2015). A complete taxonomy of human factors related to an industrial worker is, therefore, missing in the literature. Such analysis should be attentively conducted especially in critical and challenging industrial operations, such as the industrial emergency management. Indeed, the emergency response team operating in an industrial site usually shows individual cognitive biases and teamwork errors during an emergency due to everyone's own personality, to dynamic events, time pressure, high risk and emotional involvement (Petrillo et al., 2017). Industrial accident response implies physically demanding work to be performed concurrently with cognitive tasks, which may affect mental workload or decrease performance, as demonstrated by Di Domenico and Nussbaum (2011). Human-human interaction and collaboration is also crucial to teamwork in industry (Pan and Bolton, 2018) and factors such as working conditions, adequacy of training, crew collaboration, availability of procedures and plan within hazardous industrial plants have been under investigation over the last years with the aim to understand the causes of human errors (Monferini et al., 2013), especially in the case of people acting on the basis of incomplete information (Reiman and Rollenhagen, 2011). Therefore, relevant research that considers human errors has recently increased in number (Kariuki and Löwe, 2007; Park and Lee, 2008) and the human factor emphasis in organizations is well robust (Village et al., 2013). However, a systematic analysis of how much the cognitive capabilities, physical skills, and psychological attitude affect workers' response performance in case of industrial emergency has never been conducted.

1.1. Study aims and contribution

The present study is intended to address two main aims:

1. To design an original human factors taxonomy which encompasses all the relevant cognitive capabilities, physical skills and psychological attitudes of a generic industrial worker;
2. To establish a correlation between each factor and the response performance in the case of an industrial emergency of two different types of workers – the emergency manager and the emergency team member.

Given the crucial role of cognitive, physical and psychological factors in modern human-centred industrial systems and especially in the field of industrial safety & security, this taxonomy articulated over three levels (3 spheres, 11 traits, and 50 facets) represents a meticulous guide for safety specialists in the design of disaster management strategies, for recruiters and practitioners in the development of competency-based job descriptions and for new research works for the development of personality-gifted intelligent agents in industrial applications. A Fuzzy Analytic Hierarchy Process (FAHP) analysis has been conducted in collaboration with 44 subject matter experts by using an ad-hoc developed collaborative tool to establish a correlation between the human factors in the taxonomy with the workers' response performance based on their experience and judgments. The final ranking of the factors and classification through the Pareto analysis convey the message that cognitive and psychological factors have a more substantial influence on the emergency manager response performance than the physical capabilities, while psychological and physical factors are crucial for the emergency team member. The ranking results have been validated again by the subject matter experts, who also provided some application-oriented comments to the resulting classification of the factors for the two professional figures under consideration.

2. A human factors taxonomy for the industrial worker

Starting from the analysis of the most relevant research works in the field of social, cognitive, behavioral, industrial, ergonomic, software engineering and human resource management sciences, an original human factors taxonomy for a generic industrial worker has been conceived and described in this section. An 'industrial worker' is everyone who carries out a manual and/or intellectual labor in an industrial context. Therefore, factory workers (performing manual or industrial labor in a mill or factory) as well as supervisors (or lower level), executive (or middle level) and administrative (or top level) managers are included in this definition.

The main goal of this taxonomy is to define systematically which are the human factors affecting somehow the behavior, response, decision-making and physical performance of an industrial worker in any possible industrial domain. Given the high heterogeneity of roles of an industrial worker, a comprehensive set of human factors was considered. This modeling effort resulted into an original human factors taxonomy structured on three hierarchical levels that will be denoted later in this article by a capital letter: spheres (S), traits (T), and facets (F).

In particular, the taxonomy includes 3 spheres, namely the cognitive, physical and psychological sphere. The 3 spheres (S1, S2, and S3) contain 11 traits (5, 3, and 3 respectively), which, in turn, include 50 facets, presented as positive 'abilities' of an industrial worker (the more the better). Spheres, traits, and facets are generally referred to as 'factors' (the root of the hierarchy) and can be grouped into 'clusters' if they have the same 'father' node in the hierarchical structure. The overall structure of the proposed taxonomy is depicted in Fig. 1, where the 15 clusters (represented by the yellow boxes) are identified by the prefix C- in Fig. 1.

Horizontal and vertical balance is the main design principle for this taxonomy:

- horizontal balance means that each cluster of factors is equally numerous;
- vertical balance means that all the branches of the hierarchy go equally deep into detail.

To comply with this requirement, every 'father' node has at least 3 (max. 5) 'children' nodes and all the traits have been equally explored in-depth (over three levels) and parcelled. The following paragraphs provide a systematic full-on description of the spheres and their nested traits and facets.

2.1. The cognitive sphere

The Cognitive Sphere (S1) represents the set of cognitive 'abilities' enabling the industrial worker to experience the working environment and act in it. Cognition is the mental process of acquiring information, process it, and move it into the bank of knowledge, where it can be retrieved for a subsequent analysis of problems and definition of rational solutions and decisions. An industrial worker (e.g. an assembly worker) is constantly exposed to a big amount of information that must be properly handled to make rapid decisions (e.g. read assembly instructions, took mental note of them and use that knowledge to commence the work). In this process, five cognitive traits come into play: