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The use of a process mining technique to characterize the work process of main control room crews: A feasibility study

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ABSTRACT

In terms of supporting HRA (Human Reliability Analysis) practitioners, one of the urgent issues is to establish a set of objective criteria for determining the proper level of PSFs (Performance Shaping Factors), which are crucial for estimating the likelihood of HEPs (Human Error Probabilities). From this concern, the feasibility study of process mining techniques to characterize the work process of MCR (Main Control Room) crews is presented in this study. Three kinds of information requirements that are essential for determining the quality of the work process are first identified, and the application of process mining techniques is then introduced to address those requirements. As a case study, we illustrate the process mining techniques with communication logs that were collected from MCR crews exposed to simulated off-normal conditions. As a result, three kinds of insightful information (i.e., a work flow, time and spatial information along with a given work flow, and the flow of keywords describing what kinds of symptoms and/or knowledge were considered by MCR crews) are soundly extracted from communication logs. Consequently, it is expected that process mining techniques are effective for identifying a set of necessary information that would helpful for assessing the quality of the work process in an objective manner.

1. Introduction

The operational experience of socio-technical systems such as railroad networks, commercial airplanes, and NPPs (Nuclear Power Plants) clearly demonstrated that any significant event (i.e., incident and/or accident) could trigger enormous casualties including severe environmental damages and incalculable financial losses. One of the typical examples is the Fukushima accident on March 11, 2011 [45,8]. In this regard, it is very important to emphasize that a human performance related problem (e.g., human error) is one of the determinants resulting in significant events [18,20,3,5]. Subsequently, in order to enhance the operational safety of socio-technical systems through minimizing the likelihood of human error, a lot of practical approaches have been deployed for several decades across many industrial sectors.

From this standpoint, one of the most disseminated approaches is to identify and manage vulnerable tasks (i.e., error-prone tasks) by applying various kinds of HRA (Human Reliability Analysis) techniques [21,22]. In other words, if HRA practitioners are able to identify plausible error forcing factors (e.g., PSFs; Performance Shaping Factors) for a given task context, effective countermeasures that are helpful for reducing the likelihood of human error can be drawn by deducing how to eliminate the associated PSFs. In this light, the catalog of PSFs being typically considered for scrutinizing the performance of human operators who are working in the MCR (Main Control Room) of NPPs was proposed by many researchers [10,16,26,6]. Here, for the sake of convenience, the term of ‘MCR crew’ and ‘MCR crew members’ are henceforth used for representing ‘a crew working in the MCR’ and ‘human operators included in an MCR crew,’ respectively.

One of the interesting points is that the catalog of PSFs appears to be quite unanimous. For example, a couple of PSFs such as *experience and training*, *crew (team) dynamics*, *work process*, and *communication* are commonly emphasized for identifying a situation in which MCR crews and/or MCR crew members are apt to make an error. Unfortunately, even though the catalog of common PSFs is already known, there are times when HRA practitioners are not able to clearly elucidate the nature of a situation due to the ambiguous definition of a certain PSF. For example, Table 1 compares working definitions on the *work process* being used in diverse industrial sectors.

From Table 1, without loss of a generality, the work process can be regarded as all kinds of activities pertaining to identifying the nature of a situation and planning to cope with it. The challenge is

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Table 1
Working definitions on the work process.

	Working definition	Reference
1	"A work process is defined as the way in which organizations create products, services or policies. It is a succession of structured and interconnected activities across time and space which, starting from one or more identifiable inputs, result in one or a set of defined outputs in the form of products or services."	Vandenbroucke et al. [36], p. 59
2	"A work process comprises a set of activities through which information and knowledge are transferred, converted and generated, many times tacitly, among group members."	Nunes et al. [28], p. 2538
3	"[…] a work process is a collection of interrelated actions in response to an event that achieves a specific result."	Theißen et al. [35], p. 680
4	"Formally, a work process is defined as a standardized sequence of tasks designed within the operational environment of an organization to achieve a specific goal."	Davoudian et al. [4], p. 89
5	"Work processes refer to the way of working and the mechanics of work, such as the care taken in reading procedures, and, more generally, in performing individual work."	Lois et al. [26], p. 2-28
6	"Work processes refer to aspects of doing work, including inter-organizational, safety culture, work planning, communication, and management support and policies."	Hallbert et al. [10], p. 38

that, to some extent, these definitions seem to be so vague that it is not easy for HRA practitioners to properly state the quality of the work process (e.g., *good, neutral,* and *poor*) in a consistent way. That is, since all the definitions summarized in Table 1 do not designate any specific properties that are able to provide evident and/or firm criteria in specifying the quality of the work process, HRA practitioners need to draw a subjective decision based on their understanding, knowledge and experience. This means that the inventory of representative instances should be determined, which allows HRA practitioners to properly state the quality of the work process being possessed by a given MCR crew in a systematic manner.

From this concern, it is remarkable that Hallbert et al. [10] suggested four subcategories of the representative properties along with the sixth definition of Table 1, such as (1) planning and scheduling, (2) supervision and management, (3) conduct of work, and (4) PIR (Problem Identification and Resolution)/CAP (Corrective Action Plan). Based on these representative subcategories, Table 2 summarizes a couple of positive and negative instances that are frequently observable from MCR crews [14].

Table 2
Positive and negative instances frequently observed from MCR crews; reproduced from [14].

Dimension	Instance
Positive	Quick identification of key information
	Determining appropriate procedure to use in unique situation
	Complex system interactions identified and resolved
	Difficult or potentially confusing situation well understood
Negative	Self-check LTA (Less Than Adequate)
	Inadequate staffing/task allocation
	Procedural adherence LTA
	Recognition of adverse condition/questioning LTA
	Poor understanding of the situation/problem

For example, one of the positive instances shown in Table 2 is the *quick identification of key information*. This instance indicates that the quality of the work process will move to a positive direction (e.g., *good*), if MCR crews quickly identified key information in the course of conducting a required task. In contrast, the quality of the work process perhaps goes to a negative direction (e.g., *poor*), if they misunderstood a situation and/or problem at hand (i.e., the last negative instance in Table 2). This means that the positive and negative instances summarized in Table 2 can be used as the catalog of key indicators (or probes) that have to be assessed from the point of view of specifying the quality of the work process.

In this regard, it is very important to point out that Kelly [15] has proposed to discover process models from event logs (e.g., chronological records storing the manipulation of MCR crew members). As a result, the behavioral sequence of MCR crew members to cope with a simulated off-normal condition (hereafter referred to as a *work flow*) was successfully visualized, which is useful for comparing their behaviors with a standard process being specified in a series of procedures. In addition, Kim et al. [17] developed a VPP (Variability of Procedure Progression) measure that is able to distinguish how much MCR crews differently conduct a series of procedures to cope with on-going situations. Based on the work flow and/or VPP measure, therefore, it is anticipated that several instances (such as 'Determining appropriate procedure to use in unique situation' and 'Procedural adherence LTA') can be properly evaluated in a consistent manner.

However, the assessment of other instances seems to be still subjective. For example, the meaning of 'Quick identification of key information' could vary from person to person because of different understanding on the word of *quick*. Similarly, the implication of 'Poor understanding of the situation/problem' will be varied with respect to HRA practitioners unless they commonly share an overall picture illustrating how an MCR crew reached such understanding. Accordingly, in order to minimize these subjectivities, it is necessary to develop a method or technique that can provide additional information helpful for manifesting the key indicators. Otherwise, it is highly expected that the variability of HRA results becomes consequential because of the subjective and inconsistent decision on the associated instances, which could largely depend on specific HRA methods being used or the different knowledge/experience of HRA practitioners [29,30,9].

In order to address this issue, this paper applied a process mining technique to the analysis of communication logs gathered from MCR crews, which is known as one of the versatile applications in discovering a unique process, control, and data structure being involved in a system. In other words, if not only event logs (which mainly focus on a behavioral sequence; refer to Kelly [15]) but also communication logs can be used as a source of information to characterize the work process of MCR crews, it is promising that more insightful information can be soundly extracted. Moreover, the extracted information from communication logs would be crucial for understanding the semantics of the responses of MCR crew members with respect to the nature of an on-going situation. In this study, the communication logs that were gathered from a training scenario are analyzed to exemplify the application of process mining techniques to characterize the work process of MCR crews in NPPs. As a result, it is expected that process mining techniques are effective for providing insightful information with respect to the work process of MCR crews from three different aspects: (1) a work flow, (2) time and spatial information along with a given work flow, and (3) the flow of keywords describing what kinds of symptoms and/or knowledge were considered by MCR crews.

The structure of this paper is organized as follows. First, from the point of view of specifying the quality of the work process, a couple of minimum information requirements are manifested in