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A novel speech-act coding scheme to visualize the intention of crew communications to cope with simulated off-normal conditions of nuclear power plants

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ABSTRACT

Many researchers have commonly pointed out that the characteristics of crew communications is one of the most important factors affecting the operation safety of complicated process control systems. From this concern, a couple of speech-act coding schemes were developed from the point of view of 'what was done by crew members?' In this study, a novel speech-act coding scheme was developed, which allows us to see the contents crew communication from a different angle – 'what was the communication intention of crew members?' To this end, the communication contents uttered by MCR operators who were faced with various kinds of simulated off-normal conditions were collected from the full-scope simulator of domestic NPPs. Then, the novel speech-act coding scheme was developed by involving additional yardsticks (such as *Means, Acceptance criteria*, and *Constraints*), which are useful for elucidating the nature of communications from a task description perspective. As a result, the novel speech-act coding scheme was proposed, which consists of 45 behavioral task categories and the associated definitions. Although the novel speech-act coding scheme proposed in this study is still a preliminary version, this would be a good starting point to enhance the quality of crew communications through visualizing their communication intentions.

1. Introduction

The working environment of human operators who have to accomplish diverse tasks for operating socio-technical systems can be represented by several keywords, such as complex, dynamic, and uncertain. One of the practical solutions to ensure the safe operation of these systems is to perform the required tasks as a crew (or team) instead of an individual. This means that not only the performance of individual human operators but also a crew performance is essential for the safe operation of the socio-technical systems including NPPs (Nuclear Power Plants) [1–3]. In this light, many researchers have commonly pointed out that one of the key factors affecting a crew performance is communication characteristics among crew members [4].

For example, Waller et al. and Liu and Li claimed that reliable communication is very important because it allow crew members not only to exchange critical information but also to share an identical mental model with respect to a situation at hand [5,6]. In addition, Park and Park et al. empirically showed that the performance of human operators working in the MCR (Main Control Room) of NPPs (hereafter referred to as MCR operators) strongly depends on the characteristics of crew communications, such as the level of communication cohesion among crew members and the amount of communications being exchanged by crew members [7,8]. Moreover, Crichton et al. reported that inappropriate communications (e.g., *not verifying information being exchanged* or *unclear/non-specific instructions passed on*) were frequently observed from human operators exposed to simulated drilling environments, which result in the degradation of a crew performance [9]. Similarly, in terms of CRM (Crew Resource Management) originated from the NASA (National Aeronautics and Space Administration) in 1979, Helmreich et al. emphasized that the failure of successful communications in a cockpit is one of crucial causes deteriorating the safety of aircraft operations [10]. Accordingly, in terms of the safe operation of the socio-technical systems, it is believed that one of the critical issues is to reduce communication related errors by enhancing the quality of crew communications. This implies that it is necessary to develop a framework or method, which is helpful to clarify the characteristics of crew communications in a systematic manner.

In this regard, it is reasonable to assume that the characteristics of crew communications can be scrutinized from two different angles [7].

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The one is the structure of crew communications (i.e., how crew members can communicate with each other?) and the other is the contents of crew communications (i.e., which kinds of communication contents were exchanged by crew members?). For example, many researchers have investigated the effect of a communication structure on a crew performance by diverse techniques such as empirical observations and social network analysis [7–9,11–14].

In addition, Kanki and Foushee proposed a speech-act coding scheme that is useful for analyzing the communication contents of cockpit crews [16]. This speech-act coding scheme consists of 18 behavioral task categories with specific definitions including *Command* (a specific assignment of responsibility by one group member to another), *Inquiry* (request for factual, task-related information; not a request for action), *Observation* (recognizing and/or noting a fact or occurrence relating to the task), and *Suggestion* (recommendation for a specific course of action). Similarly, in order to scrutinize the contents of communications uttered by MCR operators, Min et al. suggested a modified speech-act coding scheme comprising 15 behavioral task categories, such as *Command-manipulation* (a specific assignment of responsibility by one group member to another to manipulate an object), *Command-others* (an order to do anything other than manipulating an object), *Acknowledgment* (a statement to indicate that a message was received), and *Reply* (a statement used to respond to an inquiry or other message that involves more information than a simple acknowledgment) [17].

As a result, it was discovered that there are significant relations between communication contents and the associated crew performances [18–21]. For example, Foushee and Manos pointed out that human error rates decreased in proportion to the increase of specific communication contents, such as *Observation* and *Acknowledgment* [22]. In addition, under an off-normal condition, Ujita et al. reported that about 30% of the total speech amount being uttered by human operators was dedicated to the announcement of important process parameters (e.g., pressure, water level, and temperature) [15]. Similarly, Kim et al. also emphasized that MCR operators largely focus on specific communication contents including *Inquiry* and *Command* when an off-normal condition has occurred [23].

However, existing speech-act coding schemes appear to be insufficient for identifying the nature of communication contents because they are only able to reflect a single facet of behavioral task categories: *what was done by crew members?* For example, let us consider the following arbitrary segments excerpted from communication contents uttered by MCR operators.

- Check pressurizer pressure is stable.
- Investigate the leak location of Tank 01.
- Verify the status of Valve 01 after the close of Valve 02.

According to the behavioral task categories of an existing speech-act coding scheme, these three utterances should be marked as a unitary code (e.g., *Command* or *Command-others*). However, in reality, it is evident that the abovementioned utterances fall into three different behavioral task categories in terms of their intentions (or purposes): (1) collecting the information of a process parameter, (2) investigating a failure location, and (3) collecting the status information of a specific component along with a given sequence. For this reason, a speech-act coding scheme was proposed in this study, which allows us to visualize the characteristics of crew communications under off-normal conditions from an alternative angle. It should be noted that the term of a *novel speech-act coding scheme* will be used hereafter, which consists of behavioral task categories distinguished from the point of view of a communication intention – i.e., *what was the communication intention of crew members?* Fig. 1 briefly depicts an overall process to develop the novel speech-act coding scheme with respect to the intention of crew communications.

As shown in Fig. 1, the very first step is to collect the contents of crew communications. After that, it is necessary to distinguish communication segments that share similar communication intentions. Then, the utterances of each communication segment should be analyzed in order to identify the categories of behavioral tasks. With this process, however, two kinds of technical challenges should be resolved, which are marked as $\boxed{1}$ and $\boxed{2}$ in Fig. 1. That is, we need firm standards for not only how to distinguish communication segments from communication contents but also how to properly identify behavioral task categories from the utterances.

With respect to the first technical challenge, therefore, several generic tasks and their intentions were identified from the review of existing literature, which can represent a series of required tasks to operate diverse process control systems including aviation systems, railway systems, manufacturing systems, and production systems. Furthermore, in terms of the second technical challenge, additional yardsticks (such as *Means, Acceptance criteria,* and *Constraints*), which are effective for elucidating the intention of each utterance from a task description perspective were applied to the analysis of utterances.

In order to develop a novel speech-act coding scheme, the communication contents of MCR operators who face various kinds of simulated off-normal conditions were collected from the full-scope simulator of domestic NPPs. Then, based on the catalog of genetic tasks and the associated intentions, the collected communication contents were subdivided into communication segments. After that, all of the utterances distinguished from the communication segments were analyzed in detail. Finally, a novel speech-act coding scheme was proposed, which contains 45 behavioral task categories.

The structure of this paper is as follows. First, in Section 2, the catalog of generic tasks extracted from the review of existing literature will be provided. Then, key elements for describing a task will be explained in Section 3, which play a critical role for identifying the categories of behavioral tasks from utterances. Section 4 will describe how to develop the novel speech-act coding scheme from communication contents collected from MCR operators, which consists of 45 behavioral task categories. Finally, the limitations of this study will be discussed with a concluding remark in Section 5.

2. Identification of communication segments

As already stated in Section 1, one of the technical challenges to develop a novel speech-act coding scheme is to separate communication segments from communication contents in a systematic manner. That is, since the ways of communications observable from MCR operators would be quite different from each other, it is essential to develop a firm standard that allows us to properly distinguish meaningful communication segments from actual communication contents. To this end, it is possible to define that each communication segment is a part of communication contents which share an identical intention. In other words, since sharing task-related information is one of the key functions expected from crew communications, it is natural that the intention of crew communications will be largely depend on the nature of required tasks. This means that the catalog of generic tasks is indispensable for clarifying meaningful communication segments, which can properly represent the nature of tasks to be conducted by MCR operators. In this light, it is expected that the review of diverse process control tasks would be a good starting point because an NPP is one of the typical process control systems.

For this reason, many documents issued from diverse industrial sectors were reviewed in detail, which specify essential tasks needed for the operation of process control systems. For example, Rassmussen claimed that process control tasks can be expressed by the combination of eight task types [24]: (1) *Activation* (detecting and/or recognizing the need of a human operator's intervention), (2) *Observation* (gathering information and/or symptoms), (3) *Identification* (clarifying the status of a system at hand), (4) *Interpretation* (comprehending the nature of the current status), (5) *Evaluation* (assessing the consequence of the current