Estimation of communication reliability for human reliability analysis at nuclear power plants

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1. Introduction

Communication failure has been considered as one of contributors to accidents in safety-critical systems such as nuclear power plants (NPPs). A study by Lee et al. pointed out that poor communications or communication errors contributed to 20 incidents out of 27 that occurred in Korean NPPs from 2001 to 2007 [1]. Similarly, in the railway industry, approximately one-third of the incidents were attributable to communication error [2].

Although the success of communication is critical to the safety of NPPs, probabilistic safety assessment (PSA) does not consider the failure of communication. One of the reasons for this is the difficulty in estimating the communication error probability properly.

In this light, this study suggests a systematic approach to quantify the communication error probability for the PSA of NPPs. The process consists of four steps: 1) defining the communication error, 2) task analysis, 3) defining error modes, and 4) quantification. The defining the communication error step aims to define the scope of communication error analysis. The task analysis step identifies the contents of communication and categorizes them into a speech act scheme. The third step defines error modes that may occur in the communication protocols. The quantification step quantifies the probability of communication errors. Finally, the case study was conducted to validate the applicability of the proposed process.

2. Communication HRA process

This study suggests a communication HRA process to quantify the communication error probability for the PSA of NPPs. Below Fig. 1 Shows the communication HRA process suggested in this study. Detailed descriptions will be presented in the rest of this section.

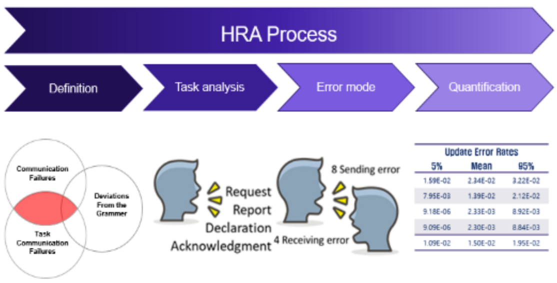

Fig 1. Communication HRA process framework

2.1 Defining the communication error

The first step defines the scope of communication error analysis. Gibson et al. defined three communication errors for railway track maintenance: communication failure, task communication error, and deviations from the grammar [3]. The communication failure is the case in which the communication goals of one participant are not adequately transferred to the other participant(s). The task communication error represents that a communication does not satisfy the requirements that the task places on communication, while the deviation from the grammar is an error that occurs when the communication does not comply with the grammar. Based on this taxonomy, this study defines the communication error for PSA of NPPs as a communication failure that causes the task failure, i.e., the intersection of communication failure and task communication error by the Gibson et al.'s taxonomy.

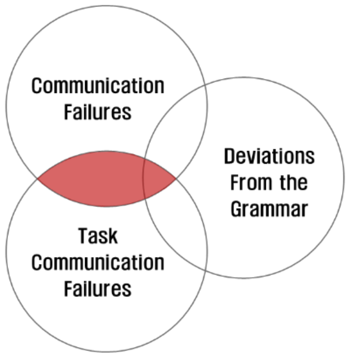

Fig. 2. Gibson's communication error definition

2.2 Task analysis

The task analysis identifies the normative communication for performing a task and categorizes them into a speech act scheme. This study developed a communication sequence diagram as shown in Fig. 3. The communication sequence diagram represents a normative communication protocol to perform procedural steps, including senders and receivers. In addition, it categorizes the protocol into one of four speech acts, i.e., Request, Report, Declaration, and Acknowledge [4].

-Request: a speech act that calls for the addressee to perform some action, either a physical act or a speech act.
-Report: express/communicate some current state.

-Declaration: A speech whose content matches reality or causes a match.
-Acknowledgement: the speaker has heard some report, or that he will perform the action indicated by a request.

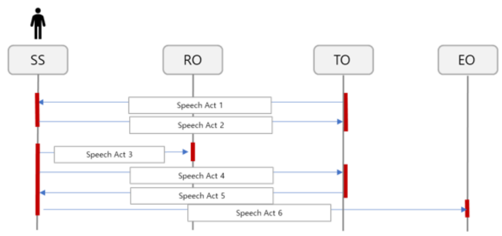

Fig. 3. Communication sequence diagram

2.3 Defining error modes

The third step defines error modes that may occur in the communication protocols. This study uses the definitions of communication error modes proposed by NUREG-1545 [5]. NUREG-1545 identifies the error modes of communication by categorizing sending and receiving errors, as shown in Table I.

Table I. Communication error modes in NUREG-1545

Error Modes	Description
Sending error	Message content is wrong
	Message content is inconsistent with other information
	Message content is inappropriate for the receiver
	Message production is inadequate
	Message is not sent
	Message is sent to the wrong place or person
	Message is sent at the wrong time
	Failure to verify that the receiver understands the message
Receiving error	Message is not sought
	Message is not found or is not used
	Message is misunderstood
	Receiver does not verify with sender correct understanding of the message

2.4 Quantification

Lastly, the quantification step aims to calculate the communication error probability by using Eq. (1).

(1) $Communication\ Error\ Probability = [Error\_Probability(Speech\ Act\ 1) + Error\_Probability(Speech\ Act\ 2) + \cdots + Error\_Probability(Speech\ Act\ n)\ ] \times Error\_Probabaility(Recovery\ failure)$

This study suggests the error probabilities of speech acts as shown in Table II. These error probabilities were derived with the observations of simulator training and non-informative Bayesian update [6]. Error probability (recovery failure) was calculated with Eq. (2).

(2) $Error\_Probability(Recovery\ Failure) = (Number\ of\ Recovery\ Failures)/(Total\ Number\ of\ communication\ error)$

Table II. Error probabilities of speech act

Speech Act	Updated Error Rates		
	5%	Mean	95%
Request	1.59E-02	2.34E-02	3.22E-02
Report	7.95E-03	1.39E-03	2.12E-02
Declaration	9.18E-06	2.33E-03	8.92E-03
Acknowledgment	9.09E-06	2.30E-03	8.84E-03
Recovery Failure	6.10E-05	1.52E-02	5.78E-02

3. Case study

This study applied the suggested method to analyze a communication error in the steam generator tube rupture (SGTR). The analyzed communication is as shown in Fig. 4 where the shift supervisor requests the isolation of damaged steam generator. In this communication, there are one Requests, two Reports, and one acknowledgement. The communication error probability can be calculated as 4.32E-04 as shown in Eq. (3),

(3) $[(0.0234\ \times 1) + (0.00139\ \times\ 2) + (0.0023\ \times 1)] \times 0.0152 = 0.000432$

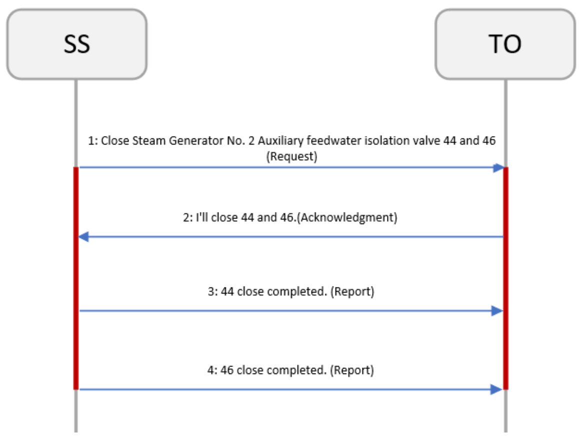

Fig 4. Sequence diagram of auxiliary feedwater isolation valve request communication

4. Conclusion

This study presented a method for analyzing communication errors. The method consisted of defining the communication error, task analysis, defining error mode, and quantification. In addition, a case study was also presented for a communication exercise in the SGTR scenario.

6. Acknowledgments

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