Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 24-25, 2024

Evaluation of Communication Error Probabilities Among Main Control Room Operators During Emergency Situations in Nuclear Power Plants

Taewon Yang[a], Jonghyun Kim[b*]
[a] *Department of Nuclear Engineering, Chosun University, 10 Chosundae 1-gil, Dong-gu, Gwangju, Republic of Korea, 61452*
[b] *Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea*
**Corresponding author: jonghyun.kim@kaist.ac.kr*

Keywords : Communication, Human Reliability Analysis, Performance Shaping Factors, Nuclear Power Plants

1. Introduction

Communication is one of the most critical tools for decision-making in disaster situations. It facilitates effective decision-making by enabling the sharing of situational awareness among personnel, discussing response strategies, and supporting the efficient allocation of resources [1]. Furthermore, communication errors can directly lead to accidents or exacerbate existing ones. In fact, an analysis of human errors that occurred in South Korea between 2001 and 2007 found that communication failures were either a direct or indirect cause in 20 cases [2].

However, despite this importance, communication errors are not considered in Human Reliability Analysis (HRA) that provides Human Error Probabilities (HEP) for Probabilistic Safety Assessment (PSA). To date, communication in Nuclear Power Plants (NPPs) has only been utilized as a Performance Shaping Factor (PSF) in a few HRA methods [3]. While many researchers have made efforts to incorporate communication error probabilities, most have only conducted qualitative analyses of communication. Also, some provided quantitative error probabilities but lacked quantifiable evidence based on actual communication data.

This paper introduces a method for assessing communication error probabilities (CEP) in human failure events (HFEs) during emergency situations in NPPs. Section 2 explains the methodology used for collecting and classifying communication data. Section 3 analysis of the communication data and the identification of communication errors. In Section 4, CEPs are evaluated, and a case study is conducted to estimate the CEP for an HFE. Finally, Section 5 summarizes the paper and outlines future research directions.

2. Collection and Classification of Communication Data

In this study, communication data was collected from MCR simulator training video recordings made during the HuREX study [4]. The simulator training was conducted in a full-scope environment simulating the APR-1400, with teams consisting of five operators (i.e., SS, STA, RO, TO, EO). This research analyzed 14 video sessions involving two teams and seven different emergency scenarios. Table 1 presents the seven emergency scenarios that were analyzed.

Table I: The List of Emergency Scenarios

No	Scenario
1	Loss of Forced Cooling with Partial Loss of Component Cooling Water
2	Main Steam Line Break inside Containment with OC* and LDP** Failure
3	Small Loss of Coolant Accident with Safety Injection Failure
4	Station Black Out
5	Steam Generator Tube Rupture with OC and LDP Failure
6	Reactor Coolant System Cooldown at Remote Shutdown Console
7	Loss of All Feedwater

*OC: Operator Console
**LDP: Large Display Panel

The collected communication data was classified using the concept of speech acts. A speech act is a linguistic concept that categorizes messages based on the intention of the sender in conveying information to the receiver [5]. In this study, the messages were categorized into four types: Request, Report, Declaration, and Acknowledgement, with the definitions of each shown in Table 2.

Table II: The List of Speech Acts

Speech act	Definition
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.

The classification of communication resulted in a total of 3,803 messages identified across the 14 video sessions. Table 3 presents the frequency of occurrences for each type of speech act.

Table III: The Frequency of Speech Acts

Speech act	Request	Report	Declaration	Acknowledgement
Number of occurrences	1,544	1,561	305	393

Meanwhile, during this process, the communication data is transcribed from audio recordings in the video files into text form in an Excel file. This transcription facilitates the efficient identification of communication errors and the calculation of error frequencies for each type of speech act. Figure 1 below provides an example of a transcribed communication script.

MCR Team.1_Scenario 1				
Start*	Sender	Receiver	Communication script	Speech act**
0:00:20	SS	BO, STA	At 10:03 am, the reactor was manually trip, so let's proceed with the Standard Post-Trip Action (SPTA) procedure.	Dec
0:00:36	BO, STA	SS	Yes.	Ack
0:00:41	RO	SS	SS, the Reactor Coolant Pumps (RC	Rq
0:00:44	SS	RO	Yes.	Ack
0:00:51	RO	SS	All four RCPs have been stopped.	Rp
0:00:56	SS	STA	STA, please request the Mechanical Department to restore the Component Cooling Water (CCW) as quickly as possible.	Rq
0:01:00	STA	SS	Yes, understood.	Ack
* Times for the start of communications measured from the start of simulator				
** Rq: Request / Rp: Report / Dec: Declaration / Ack: Acknowledgement				

Fig. 1. An example of a communication script

3. Identification of Communication Errors

In this section, communication errors are identified and the error probabilities for each speech act are evaluated based on the communication scripts and video data. In this study, a communication error is defined as any instance where the message sent by the sender is either incorrectly received or not received at all by the receiver. There are three methods for identifying communication errors.

3.1 Error detection through script analysis

In the communication script, there are expressions that can indicate the occurrence of a communication error. A typical example is "ask back," where the receiver, after receiving a message, requests the sender to resend the message. This indicates that the receiver did not properly receive the original message, signifying both the occurrence of a communication error and an attempt at recovery. Such communication errors can often be identified simply by analyzing the script.

3.2 Analysis of the Consistency Between Communication and the Ongoing Procedure

In the emergency situations at a NPPs, operators rely on procedures to carry out diagnosis and corrective actions. It is therefore essential to ensure that communication is appropriately aligned with the conditions specified in the procedure. For instance, the SS may need to verify whether the current status of a specific device meets the conditions outlined in the procedure. In this case, the instructions given by the SS to the board operators (BOs) (i.e., RO, TO, EO) must accurately convey the conditions specified in the procedure.

3.3 Analysis of Consistency Between Communication and Plant Status

When a BO carries out a task as instructed by the SS, corresponding changes occur in the NPP status. If the plant's status deviates from the intended outcome communicated, a communication error may be suspected. Additionally, when a BO reports the NPP status to the SS, there may be discrepancies between the reported values and the actual plant status. These discrepancies might not necessarily indicate a communication error but could instead reflect a task error (e.g., incorrect reading of an indicator). Therefore, it is essential to analyze not only the communication scripts but also the video recordings to ensure that no errors occurred during the operators' task performance.

Through the above analyses, 44 communication errors were identified among the 3,803 speech acts. Additionally, 43 of the 44 communication errors were successfully recovered. Table 4 below shows the occurrence frequencies of communication errors and recovery failures for each speech act.

Table IV: Frequency of Communication Errors and Recovery Failures by Speech Act

Speech act	Request	Report	Declaration	Acknowledgement
Number of occurrences	1,544	1,561	305	393
Number of Error	24	20	0	0
Number of recovery failure	1	0	-	-

4. Estimation of Communication Error Probability

In this study, we conducted a non-informative Bayesian update to estimate the CEPs for each speech act and the probability of recovery failure. Unlike the standard Bayesian update, which adjusts the probability distribution of a prior population based on new data, the non-informative Bayesian update is used when there is no prior population. It allows us to estimate the prior probability distribution based on limited data.

For this purpose, we utilized the United States Nuclear Regulatory Commission's (U.S.NRC) Reliability Calculator, as illustrated in Figure 2. This tool facilitated the non-informative Bayesian update for each speech act's error probability and recovery failure probability. The results of this update are presented in Table 5.

Fig. 2. The Reliability Calculator

Table V: CEP for Each Speech Act

MCR Team	PSF	p-value	Exp(B)
Team 1	Complexity	0.570	1.333
	Noise	0.622	1.341
	Procedure	0.421	1.582
	Seriousness	0.017	0.260
Team 2	Complexity	0.292	1.942
	Noise	0.906	0.939
	Procedure	0.381	0.581
	Seriousness	0.497	1.475
Team 1 + Team 2	Complexity	0.297	1.499
	Noise	0.564	1.250
	Procedure	0.988	1.006
	Seriousness	0.186	0.603

Based on these results, a case study was conducted to evaluate the CEP for a selected HFE. The HFE chosen for this study is "Operator fails to open MSADV to remove steam from SGs." This event occurs when an operator fails to remove heat from the secondary side of the NPP during an accident using the MSADV.

To analyze this event, we referred to the relevant procedures and conducted a task analysis, identifying five tasks that operators need to perform and ten necessary communications required to carry out these tasks. Figure 3 illustrates the sequence of tasks and the corresponding communications needed for each task in the form of a sequence diagram.

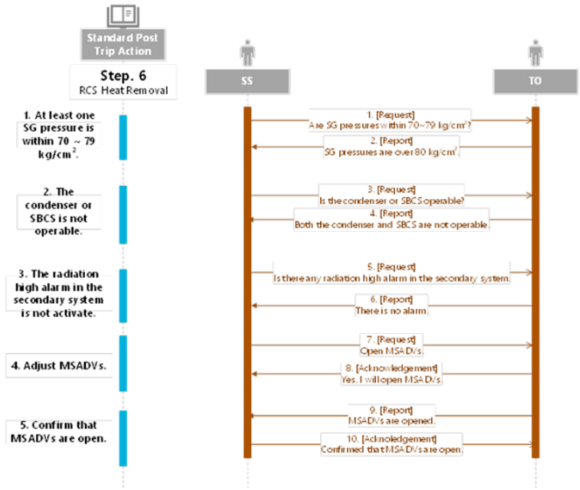

Fig. 3. Tasks and Communications Related to the HFE

The probability that the HFE will fail due to communication errors can be calculated by summing the error probabilities of all the speech acts occurring during task and multiplying by the probability of recovery failure. This is expressed mathematically in Equation 1.

$$(1)\quad CEP = [Failure\ P(Speech\ Act\ 1) + Failure\ P(Speech\ Act\ 2) + Failure\ P(Speech\ Act\ 3) + \dots + Failure\ P(Speech\ Act\ n)] \times Failure\ P(Recovery)$$

Referring to Figure 3, the communications required by the operators consist of 4 Requests, 4 Reports, and 2 Acknowledgements. By applying the CEP for each speech act from Table 5 into Equation 1, the communication error probability for the HFE "Operator fails to open MSADV to remove steam from SGs" can be estimated at 0.00396.

5. Conclusions

This paper introduced a method for evaluating the quantitative CEPs in NPPs during emergency situations based on empirical data. Communication data during emergencies were collected from simulator training videos and classified according to speech act types. Subsequently, communication errors were analyzed, and non-informative Bayesian updates were employed to estimate the CEP and recovery failure probabilities for each speech act. Finally, a case study was conducted to assess the CEP for a specific HFE.

While this study evaluated the CEP for normative communication, it did not consider the impact of performance shaping factors (PSFs). Future research will focus on identifying PSFs that influence communication errors and analyzing their impact to update the CEP accordingly.

REFERENCES

[1] ALI, Kamran, et al. Disaster management communication networks: Challenges and architecture design. In: 2015 IEEE International Conference on Pervasive Computing and Communication Workshops (PerCom Workshops). IEEE, 2015. p. 537-542.
[2] Y. H. Lee, J. W. Lee, et al, The Casebook on Human Error In Nuclear Power Plant, Korea Atomic Energy Research Institute, 2007.
[3] Barriere, M., et al. "Technical basis and implementation guidelines for a technique for human event analysis (ATHEANA)." NUREG-1624, Rev 1.1 (2000).
[4] Jung, W., Park, J., Kim, Y., Choi, S. Y., & Kim, S. HuREX–A framework of HRA data collection from simulators in nuclear power plants. Reliability Engineering & System Safety, 194, 106235, 2020.
[5] Searle, J. R. A taxonomy of illocutionary acts. 1975.