Impact of Correlation between Performance Shaping Factors on Their Multipliers

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Abstract: Human reliability analysis (HRA), which calculates the human error probability (HEP) is important in PRA. SPAR-H is one of the HRA methods and it refers to factors that affect human activities as performance shaping factors (PSFs). SPAR-H considers eight PSFs and each PSF has level and corresponding multipliers. The quantitative correlations among PSFs have been reported, and the multipliers are expected to change by considering these correlations. In this study, we evaluated the impact of the correlation between PSFs of stress and complexity on multiplier since a positively large correlation coefficient has been reported for these PSFs. In reevaluating the multipliers considering the correlation, we used the conditional expectation of multivariate normal distribution, assuming that the multipliers follow a normal distribution and that the standard deviation of the coefficients of each PSF is equal. As a result of the evaluation, we found that the ratio between original multiplier and multiplier considered correlation is from 0.52 to 1.9. This result indicates that the correlation between PSFs could have a significant impact on HEP.

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1. INTRODUCTION

There has been a growing awareness of the need to reduce the risk of accidents at nuclear power plants (NPPs) and make them safer after the accident at Fukushima in 2011. For improving the reliability of the risk analysis, the study regarding the multi-unit analysis, treatment of the correlation of components, and human reliability have been performed [1-4]. It has been reported that approximately 80% of accidents that occur at NPPs are caused by human error, indicating that human error is an important component of accident risk at NPPs [5,6]. Human errors at NPPs include failure to control the water level in steam generators, and the causes of human errors include lack of written procedures for a certain task and poor communication of information among operators [7,8]. The causes of human error can be identified and analyzed by Human Reliability Analysis (HRA). Human Error Probability (HEP) is also calculated by the HRA to evaluate human error quantitatively [9, 10]. Since the first HRA method, THERP, was developed [11], numerous HRA methods have been developed [12,13]. SPAR-H is one of the HRA methods. In this method, factors that may influence human activities are called Performance Shaping Factors (PSFs) [14]. PSFs are used in HRA to calculate HEP and taken into account by the multiplier in SPAR-H [15]. Many HRA methods, including SPAR-H treat PSFs as independent factors but PSFs have been reported to be correlated rather than orthogonal [13,15-19]. Ignoring correlations may double-count the impact of PSFs and overestimate or underestimate HEPs [16]. The correlation coefficients of PSFs in the SPAR-H method have been evaluated from accident reports in Korean NPPs by Park et al. In this paper, the impact of the correlation between the stress and complexity on the multiplier since this correlation is thought to exist inherently.

2. REVIEW OF SPAR-H

2.1. Background

SPAR-H is an HRA methodology developed by Idaho National Laboratory in 1994 [14]. The SPAR-H methodology is based on a human psychological information transfer model and considers “diagnosis model" and "action model" for operators responding to an accident in NPPs. SPAR-H considers PSFs not only negatively affect HEPs, but also positively affect HEPs: for example, if operators have a deeper understanding of the system due to years of experience and training, the HEP is expected to be lower at nominal. In SPAR-H, HEP is calculated using eight PSFs (Available time, Stress, Complexity, Experience/Training, Procedures, Ergonomics/HMI, Fitness for duty, and Work processes), which are defined so that the SPAR-H can cover as wide range as possible. The SPAR-H simplifies and generalizes the approach of the THERP method. The multipliers of SPAR-H are established based on THERP [20], but the origin of the database used to calculate the multiplier in THERP is not clear well [12].

2.2. Definition of Complexity and Stress

The correlation coefficients of the PSFs used in the SPAR-H method have been calculated by Park. In the eight PSFs, this study takes complexity and stress as examples to evaluate the impact of correlation on multiplier. In this section, the definition and multiplier of each PSF are explained.

2.2.1. Complexity

The complexity refers to the difficulty of performing a task in a given situation; the more difficult the task is to perform, the more likely it is that human error will occur. Complexity takes into account mental aspects such as memory, knowledge, and comprehension, as well as physical aspects such as performing complex tasks. In order to complete certain complex tasks, Higher technical and comprehension skills are required, and complex tasks are considered to involve multiple events.

The level for Complexity in SPAR-H [14]:

> Highly complex- Very difficult to perform a task. Often vague about what needs to be diagnosed or done. Many factors are involved, so operators have to diagnosis and action at the same time. diagnosing and taking action at the same time (i.e., unfamiliar maintenance tasks requiring high skills).
> Multiplier for diagnosis and action = 5
>
> Moderately complex- Somewhat difficult to perform a task. There is some ambiguity in what needs to be diagnosed and done. Multiple factors are involved, perhaps operators have to action diagnosis at the same time. (i.e., evolution that takes place periodically through many steps).
> Multiplier for diagnosis and action = 2
>
> Nominal- Not difficult to perform a task. There is little ambiguity. Single or few variables are involved, operators rarely diagnosis and action at the same time.
> Multiplier for diagnosis and action = 1
>
> Obvious diagnosis- Diagnosis is greatly simplified. Problems become obvious and difficult for operators to misdiagnose. The most persuasive reason for this is that valid and/or converging information becomes available to the operator. Such information may include automatic actuation indicators or additional sensory information such as smell, sound, or vibration. Receiving such compelling cues helps operators to diagnose easily.
> There is no obvious action PSF level assignment available to the analyst. Actions that are easy to perform are included in the nominal complexity rate.
> Multiplier for diagnosis = 0.1

2.2.2. Stress

The stress in SPAR-H refers to the degree of undesirable conditions or situations that prevent the operator from completing the task easily. Stress includes mental stress, excessive workload, and physical stress. Stress also includes aspects such as reduced attention span and muscle tension. Anxiety and tension associated with the severity of the situation also have an impact. Environmental factors such as noise and poor ventilation are called stressors, and they may cause mental or physical stress to the operator. Moderate stress can be considered nominal, because it may improve operator performance, while extreme stress can negatively affect operator performance.

The level for Stress in SPAR-H [14]:

Extreme- A level of terrible stress that regrade the performance of many operators. This is more likely to occur when the stressor suddenly happens, and the stressful situation lasts long time. This level is also associated with perceived threats to physical health, self-esteem, and personal status, and is considered qualitatively different from a low degree of high stress (i.e., a catastrophic failure can be extremely stressful for operators because of the potential for radioactive release).
Multiplier for diagnosis and action = 5

High- A level of stress higher than nominal level. (i.e., multiple instruments or annunciators alarming at the same time and unexpectedly, loud continuous noise making it difficult to concentrate on perform, consequences of task be a threat to plant safety).
Multiplier for diagnosis and action = 2

Nominal- A level of stress that helps operators to perform well.
Multiplier for diagnosis and action = 1

3. HOW TO CALCULATE MULTIPLIER CONSIDERING CORRELATION

Park calculated correlation coefficients from trouble reports at Korean NPPs [17]. The Operational Information System (OPIS) database was used to quantitatively analyse the interrelationships among the eight PSFs in SPAR-H. Table1 shows the correlation coefficients between PSFs of SPAR-H. The coefficient between complexity and stress is 0.588; this indicates that stress and complexity have relatively strong correlation.

Table 1 Correlation coefficients between PSFs

	Available time	Stress	Com-plexity	Experi-ence/Training	Proce-dures	Ergo-nom-ics/HMI	Fitness for duty	Work Processes
Available time	1.0							
Stress	0.651	1.0						
Com-plexity	0.524	0.588	1.0					
Experi-ence /Training	0.350	0.379	0.458	1.0				
Proce-dures	0.313	0.288	0.413	0.646	1.0			
Ergo-nomics /HMI	0.283	0.127	0.376	0.418	0.367	1.0		
Fitness for duty	0.297	0.593	0.417	0.201	0.178	-0.046	1.0	
Work processes	0.467	0.379	0.526	0.475	0.604	0.323	0.137	1.0

When calculating the multiplier considering correlation, we assumed that there is a correlation in the large amount of empirical data used to calculate the multiplier for PSF. For instance, when the HEP is expected to increase 5 times in a situation where the influence of complexity is strong, the multiplier of complexity can be set to 5 if stress and complexity are independent of each other. However, if these PSFs are correlated, the multiplier of complexity will be smaller than 5 because the HEP will increase 5 times, including the effect of stress. In this study, when calculating the multiplier considering the correlation, the conditional expectation of the bivariate normal distribution is used, assuming that the multiplier follows a normal distribution, and the standard deviations of stress and complexity are equal. Let us consider a situation where PSF[A] and PSF[B] affect HEP and other PSFs are nominal condition. We assume that the HEP is increased N times in the situation that the influence of PSF[A] is strong and calculate the expected value ${x'}_A,\ {x'}_B$ considering correlation. In this situation, ${x'}_A,\ {x'}_B$ satisfies

$$ {x'}_A {x'}_B = N \qquad (1) $$

Using conditional expectation of the normal distribution, the expected value ${x'}_B$ of PSF[B] in the situation satisfies

$$ x'_B = E(x_B | x_A = {x_A}') = \mu_B + \rho \frac{\sigma_B}{\sigma_A} ({x_A}' - \mu_A) \qquad (2) $$

where, ρ is a correlation coefficient between PSF[A] and PSF[B], μ_A and μ_B are respectively expected values of PSF[A] and PSF[B], and σ_A and σ_B are respectively standard deviations of PSF[A] and PSF[B].

Substituting equation (2) into equation (1) and summarizing for x_A, we obtain a quadratic equation as

$$ \rho \frac{\sigma_B}{\sigma_A} {{x'}_A}^2 + \left(\mu_B - \rho \frac{\sigma_B}{\sigma_A} \mu_A \right) {x'}_A - N = 0 \qquad (3) $$

${x_A}'$ obtained by equation (3), is a multiplier considering a correlation.

4. IMPACT OF CORRELATION ON MULTIPLIER

This chapter shows the impact of considering correlations on multiplier.

4.1. Evaluation using correlation coefficients

Using the correlation coefficient reported by Park, we evaluate the change in multiplier by considering correlation. The correlation coefficient between stress and complexity is 0.588. The multipliers considering the correlation is shown in Table2. M refers to multiplier used in SPAR-H, and M' refers to multiplier considering correlation. M'/M means the ratio of M' to M. According to Table2, the ratio of complexity is from 0.52 to 1.9, the ratio of stress is 0.52 at minimum. This result means that the correlation between PSFs could have significant impact on HEP.

Table 2 Comparison of multipliers of complexity and stress

PSF	Complexity			Stress		
Multiplier	M	M'	M'/M	M	M'	M'/M
	5	2.59	0.52	5	2.59	0.52
	2	1.53	0.77	2	1.53	0.77
	1	1	1	1	1	1
	0.1	0.19	1.9			

4.2 Discussion of the multiplier for the change of correlation coefficients

In this section, we discuss the change of multiplier for correlation coefficients between complexity and stress in the range from 0 to 1. Table3 and Figure1 show the change of multiplier considering correlation. The analysis shows that the change in multiplier is large when the correlation coefficient is small. The change is considered to be increased due to the consideration of correlations from the case where PSFs were assumed to be independent. At any multiplier of SPAR-H, multiplier approaches to 1 when considering correlations. When the correlation coefficient is 1, the influence of complexity and stress on HEP is considered equal, so the multiplier considering correlation is the square root of the multiplier of SPAR-H.

Table 3 Multiplier considering correlation between complexity and stress

Correlation	M'			
	M=0.1	M=1	M=2	M=5
0	0.100	1.000	2.000	5.000
0.1	0.110	1.000	1.844	3.882
0.2	0.121	1.000	1.742	3.385
0.3	0.135	1.000	1.667	3.079
0.4	0.151	1.000	1.608	2.864
0.5	0.171	1.000	1.562	2.702
0.6	0.194	1.000	1.523	2.573
0.7	0.220	1.000	1.490	2.467
0.8	0.250	1.000	1.461	2.378
0.9	0.282	1.000	1.436	2.302
1	0.316	1.000	1.414	2.236

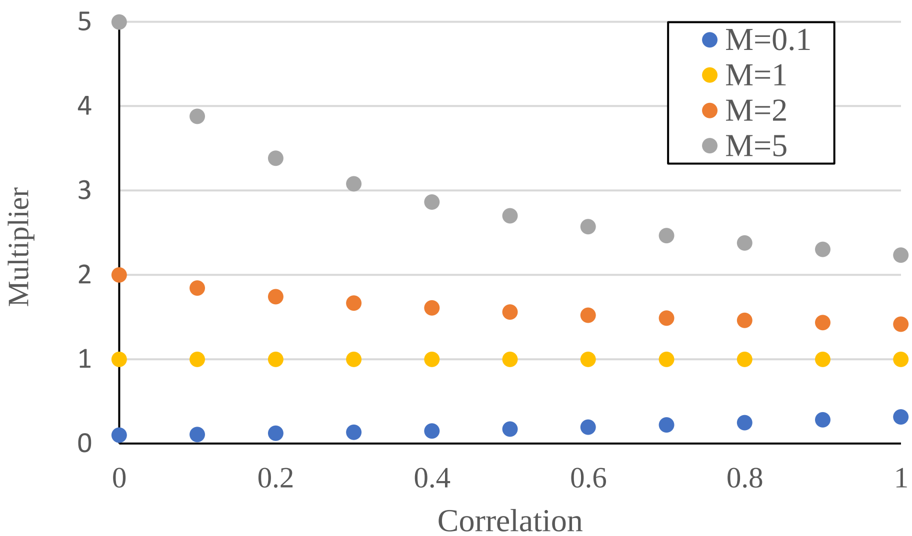

Figure 1 Multiplier considering correlation between complexity and stress

5. CONCLUSION

Since the accident at Fukushima, there has been a growing awareness of the need to reduce accident risk at NPPs. HRA quantitatively evaluates human errors that occur in NPPs by calculating HEP. SPAR-H, one of the HRA methods, refers to factors that may affect human activities as PSFs, and it has been pointed out that these PSFs are non-orthogonal and correlated, and the correlation could have a significant impact on HEP. In this study, we evaluated the change in multiplier by considering the correlation between stress and complexity among the eight PSFs. In the evaluation, multiplier considering correlation was calculated using the conditional expectation of the bivariate normal distribution, assuming that multiplier follows a normal distribution and that standard deviations of all PSFs are equal. The evaluation result shows that the ratio between original multiplier and multiplier considered correlation is from 0.52 to 1.9. This result indicates that taking correlations into account could have a significant impact on the HEP.

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