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Correlation Relationship of Performance Shaping Factors (PSFs) for Human Reliability Analysis

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1. Introduction

The rise in catastrophic accidents in nuclear power plants (NPP) has brought attention to human performance related studies. Human error has been directly linked to many major nuclear accidents. At Chernobyl for example, a test procedure was being conducted prior to the accident. The supervisors of the test allowed operators to disable and ignore main protection circuits and warnings that would have normally shut the reactor down [1]. At TMI-2, operators permitted thousands of gallons of water to escape from the reactor plant before realizing that the coolant pumps were behaving abnormally. The coolant pumps were then turned off, which in turn led to the destruction of the reactor itself as cooling was completely lost within the core [2].

Human also plays a role in many aspects of complex systems e.g. in design and manufacture of hardware, interface between human and system and also in maintaining such systems as well as for coping with unusual events that place the NPP system at a risk. This is why human reliability analysis (HRA) - an aspect of risk assessments which systematically identifies and analyzes the causes and consequences of human decisions and actions - is important in nuclear power plant operations. Any factor that influences human performance is designated as a performance shaping factor (PSF) or performance Influencing factors (PIFs) [3]. It either upgrades or degrades human performance; therefore it has an impact on the possibility of error. These PSFs can be used in various HRA methods to estimate Human Error Probabilities (HEPs). There are many current HRA methods who propose sets of PSFs for normal operation mode of NPP. Some of these PSFs in the sets have some degree of dependency and overlap. Overlapping PSFs introduce error in HEP evaluations due to the fact that some elements are counted more than once in data; this skews the relationship amongst PSF and masks the way that the elements interact to affect performance [4].

This study uses a causal model that represents dependencies and relationships amongst PSFs for HEP evaluation during normal NPP operational states. The model is built taking into consideration the dependencies among PSFs and thus eliminating overlap. The use of an interdependent model of PSFs is expected to produce more accurate HEPs compared to other current methods. PSF sets produced in this study can be further used as nodes (variables) and directed arcs (causal influence between nodes) in HEP evaluation methods such as Bayesian belief (BN) networks. This study was done to estimate the relationships between PSFs using correlation analysis and identify patterns in the PSFs using Principal Factor Analysis (PFA). The study is specifically based on Operational Performance Information Systems (OPIS) database.

2. Methodology

2.1 Selecting Performance Shaping Factors

Generally, PSF classifications are developed as to be suitable for a specific purpose and application area. A total of ten PSFs were used in this study. The PSFs used were adopted from [5]. These are second level PSFs selected considering accident management situational characteristics. They fall under the four main first level PSFs which are human, task, system and environment. Second level PSFs were used because the available human error event data did not provide enough details which would make it possible to use third level (high detail) PSFs. Figure 1 shows the set of PSFs used in our analysis.

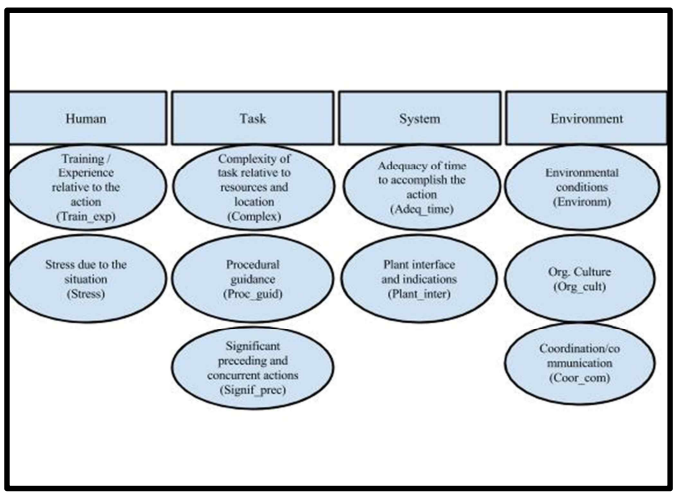

Fig. 1. PSFs Used in Analysis [5]

2.2 OPIS Database

Operational Performance Information System database was utilized in this study. This human events database was collected from various Korean nuclear power plants. It contains a timeline of human failure or success events and it indicates which PSF affects a particular event. Expert judgment was used in deciding matching each error event with relevant PSFs. Table 1 shows a sample of the database. For each human error event, a value of 1 was allocated on each PSF that is presumed to be an influence and a value of 0 was allocated to PSFs which are nominal.

Table 1. OPIS Data Sample

Event	Source File	NPP Unit	Stress	Time adequacy	Environment
Xhe1	20140228_한빛2호기_안전성평가보고서_최종-opis	HB2	1	0	1
Xhe2	20140106_한빛5호기_사망사고사건조사보고서-인적	HB5	0	1	1

2.3 Correlation Analysis and Principal Factor Analysis

Correlation provides a numerical measure of similarity between two variables thus giving a first glance into the relationship between variables. It is reported by a number between -1 and 1. An increasing linear relationship is indicated by 1 and a decreasing one is shown by -1. A zero correlation means no relationship exists between two variables. The variables in this study were the PSFs. The data used is binary as shown in the sample data table (table 1). Polychoric correlation was used for because human behavior data is believed to represent a latent continuous variable [4]. The Polychoric correlation technique on SAS 9.1 was used to compute the correlation matrix.

The Minres Principal Factor Analysis (PFA) was used to establish the relationship and latent influences among multiple PSFs. Principal Factor analysis is a multivariable technique is used to identify different patterns of the variance. It identifies new set of n factors that contain the same amount of variance as the original data. The first factor accounts for most of the variance than the second factor and so on. Important factors will be represented by high eigenvalues (large variance). Only factors with eigenvalues greater than 1.0 were considered for further analysis in this study because they justify more than their proportionate share of the original variance. A factor represents a group of PSFs that contribute more to human error than an individual PSF [6].

3. Results

The correlation table is presented in table 2. It shows the correlation matrix which indicates the relationship between a pair of PSFs. Fourteen correlations were too low, i.e. below $|0.1|$. They show weak relationship between PSFs. As rule of thumb in this study, relations above $|0.3|$ were considered for further discussion. The output of an un-rotated Minres FA is shown if table 3. Four factors were selected based on the shape of the scree plot shown in figure 2. The first four factors had eigenvalues greater than 1.0. From the fifth factor onwards, you the scree plot is almost flat, meaning that each successive factor accounts for smaller and smaller amounts of the total variance.

Table 2: Correlation matrix

	Org_cult	Complex	Train_exp	Stress	Environ	Signif_prec	Plant_inter	Adeq_time	Proc_guid	Coor_com
Org_cult	1.000									
Complex	0.293	1.000								
Train_exp	-0.137	0.176	1.000							
Stress	-0.067	-0.067	0.176	1.000						
Environ	-0.083	-0.083	0.348	0.360	1.000					
Signif_prec	-0.098	0.283	0.486	0.293	0.202	1.000				
Plant_inter	0.149	0.149	-0.130	-0.149	-0.186	0.218	1.000			
Adeq_time	-0.083	0.360	0.608	-0.083	-0.103	0.527	0.062	1.000		
Proc_guid	0.049	-0.214	-0.130	-0.214	-0.048	-0.120	-0.037	-0.048	1.000	
Coor_com	-0.228	0.293	0.143	-0.228	-0.284	0.048	-0.073	0.365	0.168	1.000

Table 3: Factor Analysis results for 10 PSFs

	Factor 1	Factor 2	Factor 3	Factor 4
Org_cult			0.523	0.464
Signif_prec	0.771			
Plant_inter			0.746	
Adeq_time	0.805	0.314		
Proc_guid			-0.385	0.699
Coor_com	0.341	0.633	-0.433	
Complex	0.535	0.343		-0.364
Train_exp	0.790			
Stress		-0.714		
Environ		-0.743		

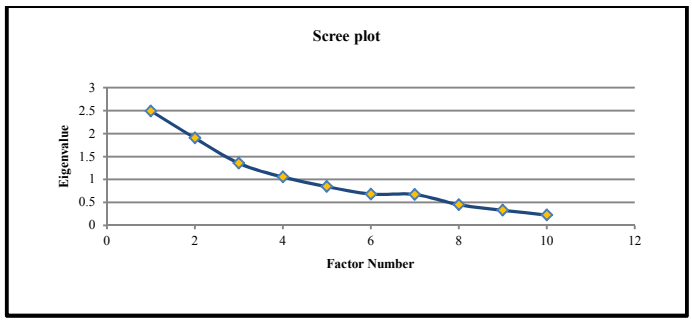

Fig. 2. Scree Plot

4 Discussions

4.1PSF Relationships

This section analysis the correlations in table 2 and discusses what can be concluded from them. High correlations i.e. above $|0.3|$ indicate causal links between the relevant PSFs. When forming a causal link model they are taken into

consideration.

Most of the correlations in table 2 are below $|0.1|$, this means that the relevant PSFs have very weak or no causal relationships. Three PSFs are linked positively to *Adequacy of time to accomplish the action.* These PSFs are *Complexity of task relative to resources and location, Training and experience relative to the action, and Significant preceding and concurrent actions.* The high correlation between these PSFs is justifiable. The time to carry out a task can be reduced if the team has enough training and experience. Also a complex and dynamic task can be completed by a team given adequate time. The time needed to complete a task is also affected by other tasks carried out concurrently or which were carried out before the present task. This is possible when the previous task is exhausting.

There are high correlations between *Environmental situation* and *Training and experience relative to the action* and between *Environmental situation* and *Stress due to situation*. A non-conducive working environment is more likely to increase stress levels in workers. Training and experience is also expected to be less effective if the working environment is not good. *Significant preceding and concurrent actions* also has a high correlation with and *Training and experience relative to the action* and *Adequacy of time to accomplish the action.* This is also expected because training and experience is required to carry out tasks concurrently and also the time required to do those tasks is important. Figure 3 summarizes the causal relationships between PSFs

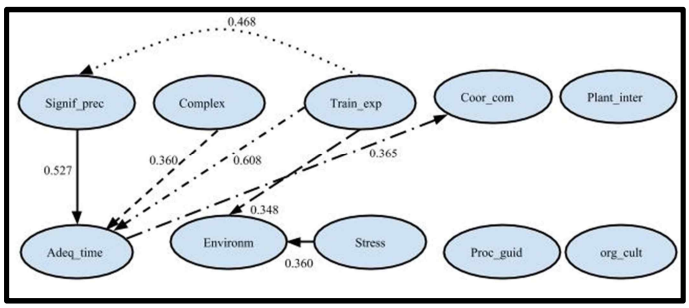

Fig. 3. Causal relationships between PSFs

4.2 Error Forcing Context

The principal factor analysis on the available OPIS data resulted in four factors. We call each factor an 'error forcing context (EFC)'. This describes a combination of PSFs whose combined effect is more likely to cause human errors compared to the PSFs standing alone. ECF1 involves *Significant preceding and concurrent actions*, *Adequacy of time to accomplish the action*, *Coordination and communication*, *Training and experience relative to the action*, and *Complexity of task relative to resources and location*. The relationship among the PSFs in this error forcing context gives an insight into how accidents can be prevented in an NPP. Training and experience in a certain task coupled with coordination and good communication in a team can improve the way a person understands a task, this in turn reduces the complexity of a task. A persons understanding of a particular task can be affected by a preceding and concurrent action. A task tends to be complex and confusing if they are not related or if they have nothing in common. From this EFC we can also derive the fact that if tasks are done concurrently, the time allocated for that task should be adequate for it to be carried out successfully to prevent errors.

EFC 2 is created by *Adequacy of time to accomplish the action, Coordination and communication, Complexity of task relative to resources and location, Stress due to situation,* and *Environmental conditions. Stress due to situation,* and *Environmental conditions* are negatively correlated with this error context meaning they are not contributors to the factor. This suggests that adequacy of time for a complex task and good communication or coordination in a team can be adequate to reduce human error given that the stress levels are low and the environment is suitable.

EFC 3 is made of four PSFs which are *Organizational culture, Coordination and communication, Plant interface and indications,* and *Procedural guidance. Coordination and communication and Procedural guidance* are negatively correlated to this factor. This suggests that the EFC is linked to enough or good procedural guidance and communication in the team. This EFC can thus be interpreted to mean that poor organizational culture will lead to unreliable plant interface system and indications. This could happen when poor maintenance is done on the system.

EFC 4 is only composed of three PSFs which are *Organizational culture, Procedural guidance and Complexity of task relative to resources and location. Complexity of task relative to resources and location* is negatively linked to this error forcing context. In this EFC we can infer that poor organizational culture results in poor procedural guidance. This will cause errors to be committed even during non-complex and dynamic situations. This EFC has the least variance which means that it is less important that the other factors. This makes sense because *Organizational culture* and *Procedural guidance* are not seen alone in many errors in the events data. Most organizations address these PSFs adequately such that they contribute less to error. Figure 4 shows a summary of how PSFs are linked to each error forcing context based on findings of this study.

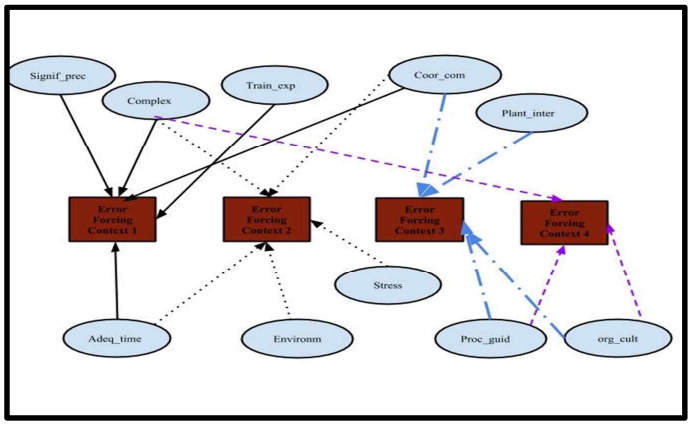

Fig. 4. HRA Causal Model Derived from OPIS Data

4. Conclusion

This study was conducted to determine causal relationships between PSFs and also find sets of PSFs (error forcing context) which contribute more to human error probabilities. These goals were achieved using correlation and principal factor analysis. The PSFs sets (four EFC) are believed to highly increase the chance of human performance errors during NPP operations if they happen to all affect a certain human event. Further studies would involve expanding the data set and carry out a similar study to validate these results. These results can be further used in evaluating human error probability for the NPP units from which the database was collected.

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