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# A Methodology To Incorporate The Safety Culture Into Probabilistic Safety Assessments

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## 1. Introduction

Recently, the safety issues related to nuclear safety culture have occurred increasingly. The quantification tool has to be developed in order to include the organizational factor into Probabilistic Safety Assessments. In this study, the state-of-the-art for the organizational evaluation methodologies has been surveyed. This study includes the research for organizational factors, maintenance process, maintenance process analysis models, a quantitative methodology using Analytic Hierarchy Process, Success Likelihood Index Methodology. The purpose of this study is to develop a methodology to incorporate the safety culture into PSA for obtaining more objective risk than before.[1-2]*

## 2. Methods and Results

### *2.1 State-of-the-Art of The Methodology*

The organizational factor analysis of Periodic Safety Review(PSR) includes appropriateness whether an organization affects a safety of nuclear power plant or not. In PSR, a lot of evaluation item exist. At first, there is a performance goal, safety goal and safety culture of emphasizing productivity more than safety. Also, there is a organic composition method of operating and systematic management of person, groups and external technologies. In the last, there is a reflection procedure of failure experience, training facilities and plans, QA plan and regular QA audits, regulatory compliance and etc.[1]

The important organizational factors for safe operation of nuclear power plant are as in the following. (Safety Knowledge, Attitude toward Plant Operation, Choice of Plant Performance Goals, Lines of Responsibility and Communication)

The organizational factors affect human error in aspects of intention formation and intention activity. The one is cognitive activity to diagnose and determine what action is appropriate in a given situation. The other is performing the determined action. The cognitive activity of intention formation consists of conscious workspace and knowledge base. To select the saved information, 4 factors are affected by similarity matching and frequency gambling.

The issues for understanding initiating events and complete set of the sequence of accidents is a critical problem.[3-4]*

### *2.2 Maintenance Process*

The maintenance process is defined as the standardized sequence for a special purpose. The maintenance process is useful to connect the organizational factor to PSA. The multiple defenses in maintenance process are shown in Fig.1. One or more organizational factors could affect the quality and efficient of maintenance process.

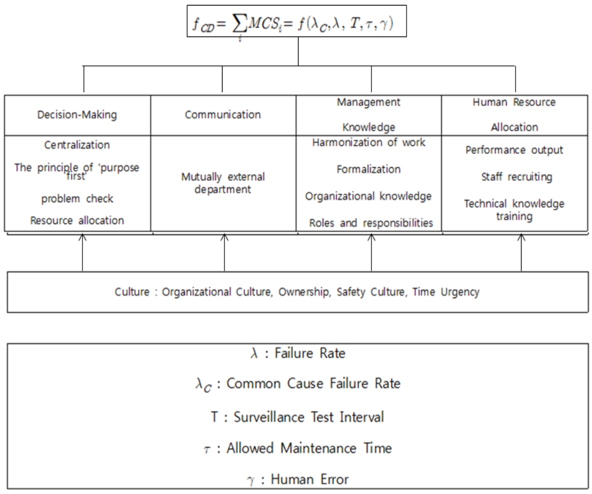

Fig. 1. The influence of organization factor onto PSA

The maintenance program in NPP has meant to testing and corrective maintenance. Testing is a maintenance process to satisfy technical regulations and surveillance requirements. Otherwise, corrective maintenance is meant to repair the faulty device. The flow diagram is shown in Fig. 2.

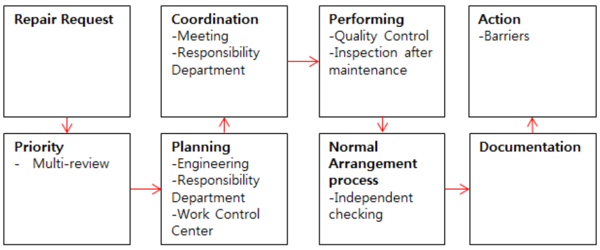

Fig. 2. Flow diagram of maintenance maintenance process

### *2.3 The influence of organizational factor onto unavailability*

The organizational factors indirectly affect the change of unavailability. The average unavailability of one-out-of-two system under the sequential testing is expressed as (1).

$$q_{avg} = q_R + q_C + q_D + q_{TM} \quad (1)$$

Where,
$q_R$: Contribution of independent failure
$q_C$: Contribution of dependent failure
$q_D$: Contribution of failure on demand
$q_{TM}$: Contribution of testing and maintenance

Contribution of testing and maintenance can be expressed on detail by (2).

$$q_{TM} = \gamma_0[\gamma_1 + (1-\gamma_1)Q + (2-\gamma_1)(\lambda_R + \lambda_C)(\frac{\tau}{2}) + \frac{2\tau_r}{\tau} + 2f\tau_m] \quad (2)$$

Where,
$\lambda_C$ : Common cause failure rate
$\gamma_1$ : Probability of 2nd component failure, if 1st failure occurred by testing and maintenance error
$\gamma_0\gamma_1$ : Dependent error
$\gamma_0 Q$ : The one component fails by HE, the other fails by demand
$2\gamma_0 f\tau_m$ : The one component fails by HE, the other fails by maintenance

The human errors caused by organizational affect the NPP's safety. The frequency of initiating events and availability of safety systems might be changed by human errors. In other words, the errors that have not been corrected could increase the frequency of initiating events in the duration of maintenance.

We can know the potential dependence among unavailability, human errors, organizations and management. And, we can know that the parameters of $q_{avg}$ are the correlated variables. For example, if an error caused by maintenance team not be corrected, it will have been until post-maintenance testing. If so, $\tau_m$ with unavailability will increase.[4-5]*

### *2.4 Analysis model using the AHP methodology*

The AHP(Analytic Hierarchy Process) methodology calculates the relative importance weights. And, the AHP obtains the data of $\lambda_{max}$ and C.R related to consistency. It is the input data of analysis model using the SLI methodology. And, it offers the instrument to systematize the inspection of maintenance process.[6]

### *2.5 Analysis model using the SLI methodology*

PSA doesn't include the correlation among parameters, such as Candidate Parameter Groups (CPGs) from organizational factors. This model includes re-quantification of MCSs as new probability calculates coupling among CPGs. The whole flow diagram of this model is shown in Fig. 3.

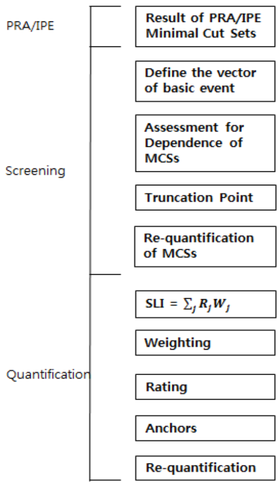


Fig. 3. Analysis model using the SLI methodology[3]

For the first step, screening, we define the basic event vector as below

$$(WP, CPG, WU, ID) \quad (3)$$

Where,
WP: Work/Maintenance Process
CPG: Candidate Parameter Groups
WU: Working Unit/Department
ID: Checking systems and components

CPG is defined as below,

RE: failure of rearrangement ($\gamma$)
MC: error of instrument calibration ($\gamma$)
UM: unavailability by maintenance ($\tau_m$)
FR: running failure on demand ($\lambda_R$, Q)
CCF: common cause failure ($\lambda_C$)
TR: allowed time for restoring

The analysis of maintenance process using AHP makes 4 work units as below,
Operation (OP)
Mechanical Maintenance (MM)
Maintenance of Electronic-device (ME)
Instrumentation & Control(IC)

Table 1. Candidate Parameter Group Ratings

| | CCF | FR | UM | TR | RE | MC |
|---|---|---|---|---|---|---|
| CCF | 0.1 | 0.01 | 0.1 | 0.01 | 0.1 | 0.1 |
| FR | 0.01 | 0.1 | 0.1 | 0.01 | 0.1 | 0.1 |
| UM | 0.1 | 0.1 | 0.5 | 0.1 | 0.5 | 0.5 |
| TR | 0.001 | 0.01 | 0.1 | 0.1 | 0.1 | 0.1 |
| RE | 0.1 | 0.1 | 0.5 | 0.1 | 1.0 | 0.5 |
| MC | 0.1 | 0.1 | 0.5 | 0.1 | 0.5 | 1.0 |

Table 2. Work Unit Ratings

| | MM | ME | IC | OP |
|---|---|---|---|---|
| MM | 1.0 | 0.5 | 0.1 | 0.1 |
| ME | 0.5 | 1.0 | 0.1 | 0.1 |
| IC | 0.1 | 0.1 | 1.0 | 0.1 |
| OP | 0.1 | 0.1 | 0.1 | 1.0 |

The total rating is obtained as below,

$$R_{ij} = R_{WP,ij} \cdot R_{CPG,ij} \cdot R_{WU,ij} \cdot R_{ID,ij} \quad (4)$$

$$(0 \leq R_{ij} \leq 1)$$

Where,
i,j: number of basic events

MCS would be excluded in screening process, if one of the $R_{ij}$ can't exceed the threshold, in applying the truncation value into minimum value. Therefore, it is recommended to apply the truncation value into maximum value.

In the case of SLIM, we consider the conditional probability. It can be understood by seeing below

$$f_{MCS} = f_{IE} \cdot p_1 \cdot p_{2|1} \quad (5)$$

To obtain the value of $p_{2|1}$, define $SLI_{2|1}$ as below,

$$SLI_{2|1} = \sum_j R_j \cdot W_j \quad (6)$$

Where,
$W_j$: the standardized importance weighting factor for $j_{th}$
$R_j$: the rating of organizational factor for $j_{th}$

Each result of SLI is the conditional probability following the occurrence of previous event. If there are 2 basic events, both weighting factors of event 1 and event 2 couldn't be used independently. But, the combination of these weighting factors leads to the dependence of 2 basic events. The effective weighting factor can be expressed by,

$$W_{2|1,j} = \frac{W_{1j} \cdot W_{2j}}{\sum_i W_{1i} \cdot W_{2i}} \quad (7)$$

If the 3 event W3|1,j and W3|2,j can be obtained by (7). And, the bigger one might be used to calculate SLI. The value of $p_{2|1}$ is needed to obtain $SLI_{2|1}$. We can get the value of $p_{2|1}$ using (6), (7) as below,

$$\log(p_{2|1}) = aSLI_{2|1} + b \quad (8)$$

Where,
a, b : the calibration constant

$$\log(p_2) = a \cdot (SLI_{2|1} = 5) + b \quad (9)$$

$$\log(p_u) = a \cdot (SLI_{2|1} = 1) + b \quad (10)$$

The value of $p_2$ is the lower anchor point on the assumption that it is same as the conditional probability of the event 2. The value of $p_u$ is the upper anchor point.

## 3. Conclusions

The organizational factor considered in nuclear safety culture might affect the potential risk of human error and hardware-failure. In order to incorporate organizational factors into PSA, a methodology needs to be developed. Using the AHP to weigh organizational factors as well as the SLIM to rate those factors, a methodology is introduced in this study. The safety culture impact index to monitor the plant safety culture can be assessed by applying the developed methodology into a nuclear power plant. The qualitative methodology suggested in this study can be utilized to incorporate the quality of the plant organization into the quantitative safety of a nuclear power plant.

## Acknowledgements

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