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A Study on the Construct Validity of Safety Culture Oversight Model for Nuclear Power Operating Organization

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1. Introduction

The term 'safety culture' was first introduced in 1980s by International Nuclear Safety Advisory Group(INSAG) in the analysis report of the 1986 Chernobyl accident [1]. Since then safety culture has been emphasized as an important basis for achieving high level of nuclear safety. During the last 30 years, the IAEA and international nuclear communities have worked toward conceptualization and development of safety culture and its improvement mechanisms. In Korea, the safety policy statement declared in 1994 by government stressed the importance of safety culture and licensees were encouraged to manage and conduct their self-assessments. A change in regulatory position about safety culture oversight was made after the event of SBO cover-up in Kori unit 1 and several subsequent falsification events. Since then KINS has been developing licensee's safety culture oversight system including conceptual framework of oversight, prime focus area for oversight, and specific details on regulatory expectations, all of which are based on defence-in-depth (DiD) safety enhancement approach [2].

1.1 Overview of Safety Culture

The connation of the term 'safety culture' has great diversity due to the broad dimensionality of the concept and long history of use in various fields of industry. Besides IAEA, nuclear industry such as WANO and INPO, regulatory bodies including US NRC, UK ONR, CNSC of Canada have adopted different notions and key characteristics for communication and practical use. The most widely adopted definition of safety culture of IAEA is "that assembly of characteristics and attributes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance". IAEA has developed five-dimensional model of safety culture which include; safety is a clearly recognized value, leadership for safety is clear, accountability for safety is clear, safety is integrated into all activities, and safety is learning driven. IAEA also suggested 37 characteristics clustered into the 5 dimensions which represent desired attributes of nuclear facilities. Many of the regulatory guidelines and technical documents published by IAEA and other nuclear communities are based on the IAEA safety culture model.

US NRC defined safety culture in 2011 in the safety culture policy statement as "the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment". The high-level set of traits further characterizing areas important to a positive safety culture include; leadership safety values and actions, problem identification and resolution(PI&R), personal accountability, work processes, continuous learning, environment for raising concerns, effective safety communication, respectful work environment, and questioning attitude.

Although the concept of safety culture has existed for decades, there also have been debates on the definition of the concept and its associated characteristics. Comparison of the definition, themes or dimensions of various safety culture model shows that the approach and implementation can be different from country to country. This shows the importance of suitable model which is based on sound understanding of the national culture and industry characteristics.

1.2 KINS safety culture model

One purpose of safety culture oversight is to verify that licensees foster a healthy safety culture in their organization. Independent framework which fit best for the assessment is necessary for regulatory use. KINS has developed the preliminary definition of safety culture for regulatory oversight as "that assembly of behavioral patterns, core values and basic beliefs shared by individuals in organization about the importance of safety". E. Shein's 3-level model of organizational culture is adopted and value-neutral expression is used [3]. The four basic areas of prime focus for oversight, which are human performance, management for improvements, safety conscious working environment, and leadership & organizational control, are derived to maintain and strengthen the integrity of four organizational elements respectively. Safety culture characteristics (factors) are derived in each area for which regulatory expectations and reference standard are developed. That is, KINS model assumes that safety culture is composed of 13 traits stems from 4 organizational elements that describe areas important to keep healthy safety culture. Figure 1 shows overall structure of KINS safety culture model.

1.3 Purpose of the study

Although the IAEA safety culture model has been widely used over 20 years with a presumption of healthy safety culture leads good safety performance, its validity has not been proved yet. Recently conducted validity study of the IAEA model in Spanish NPP could not support the correspondence between the IAEA's attributes and the dimensions proposed by the model [4]. However, empirical study conducted by US NRC with INPO in US NPPs showed supportive result in both structure of the model and the safety performance [5]. It is shown that there is a positive relationship between safety culture and NPP performance. Nine safety culture factors were identified in US study with Cronbach's alpha value of each factor ranging from 0.78 to 0.96.

The primary purpose of this paper is to assess the validity of KINS safety culture model, to identify the factors that comprise the concept of safety culture in Korean nuclear power industry. Considering that the model is new and the target structure of the factors is known in advance, main focus is laid on the construct validity. The construct validity will be established by testing various aspects of validity of the model such as content validity, convergent validity, discriminant validity, and internal consistency. A survey is developed and conducted in one NPP to get empirical data which will be used for meta-analysis. Criterion-related validity of the model could not be shown because the survey is conducted only once in one plant.

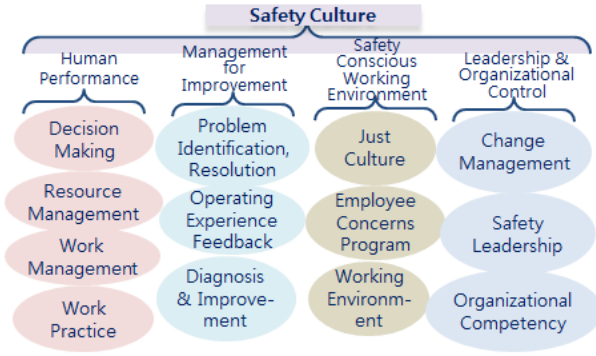

Figure 1. Overall structure of KINS safety culture model

2. Development of the Survey

2.1 Development of the survey

The purpose of the survey is to identify the conformity of respondents' answer with the suggested model. Therefore, the survey items should represent the characteristics of the KINS safety culture model well. To ensure content validity of the model, the survey items should not lose any desired characteristics of safety culture. Therefore, the survey items are derived from KINS safety culture model and also by referencing other publications which were obtained in previous research including US NRC and IAEA's safety culture characteristics and attributes [3]. For each thirteen traits of suggested safety culture model, desired characteristics are derived by referring to US NRC and IAEA's safety culture characteristics, attributes, and survey questionnaires used in self or independent assessment. For example, 'Changes are systematically managed according to their safety significance' represents one desired characteristic of the change management trait. By cross-checking the items with IAEA and US NRC model, adequate content validity could be assured.

Survey administration plan is also developed according to the guidelines suggested by US NRC and IAEA [6,7]. Negative questions are included in the survey to discriminate undependable respondents. Draft survey item consisted of 76 items with 10 negative questions. The items were not grouped as hypothesized to prevent any propensity which can be resulted by answering successive similar questions. The survey also included demographic questions asking respondents to indicate their work group (e.g., operations, engineering, safety), job position, age and work experience. The draft survey items and survey administration plan were reviewed by specialized survey research company Gallup Korea.

NPP employees are asked various questions regarding their perceptions of the extent to which them or their organization valued safety related issues. Survey participants were asked to rate their degree of agreement with each statement using a 7-point Likert scale ranging from strongly disagree to strongly agree. Each item also included a "do not know/no opportunity to observe" response option. The "don't know" option is coded as missing data so as not to skew the average of the answer.

2.2 Survey administration

The survey was conducted in one nuclear power plant of Korea in February 2015. The survey was administered by the author of the current study who was always present during the administration. Each of the respondents was provided with written instructions which introduces purpose of the survey and how the survey is completed. Anonymity was emphasized that no identifying information was required. At the end of the survey, respondents could write down recommendations or comments about the survey or safety culture freely.

The total number of the respondents was 85, which is about 22% of the total plant employees. Respondents containing many blanks or "do not know" are screened out. 70 respondents provided valid answers and their responses were retained for subsequent analysis. Considering valid respondents' demographic information, the sample was representative of the population under study by including all groups of employees in the NPP.

3. Analysis of the Survey Results

3.1 Descriptive Analysis of the survey result

Descriptive analysis is conducted first to aid the interpretation of the survey and its result. Table 1 provides the numbers of survey items, means, standard deviations, and Cronbach's alpha for the overall measure of safety culture and each of the factors. Most of the means fall between a value of 5 and 6 on the 7-point scale, which correspond to the response options of "somewhat agree"(5) and "agree"(6).

Cronbach's coefficient alpha is used to statistically test the internal consistency of a factor [4,5]. The values can range from 0 to 1.0 with higher values indicating better reliability where reliability refers to the extent to which consistently measures the same underlying construct. The minimum criterion for acceptable reliability is considered a value greater to 0.7. The overall measure of safety culture demonstrated adequate internal consistency with a Cronbach's alpha of 0.99. It is noteworthy that previous studies showed lower values with 0.98 for US and 0.97 for IAEA model.

Table 1. Factor labels, number of survey items, and descriptive statistics

Factor labels	# of items	Mean	SD	Cronbach 's alpha
Safety culture (overall; SC)	65	5.34	1.38	0.99
1.Decision making (DM)	6	5.37	1.31	0.85
2.Resource management (RM)	5	5.42	1.43	0.86
3.Work management (WM)	5	5.71	1.14	0.88
4.Work practice (WP)	3	5.63	1.26	0.68
5.Problem identification & resolution (PI&R)	4	5.53	1.14	0.94
6.Operating experience feedback (OEF)	4	5.61	1.21	0.93
7.Diagnosis & Improvement (D&I)	7	5.49	1.25	0.94
8.Just culture (JC)	5	5.35	1.42	0.95
9.Employee concerns program (ECP)	5	5.04	1.47	0.95
10.Working environment (WE)	6	4.98	1.56	0.96
11.Change management (CM)	3	5.02	1.52	0.89
12.Safety leadership (SL)	7	5.27	1.43	0.94
13.Organizational competency (OC)	5	5.06	1.46	0.83

3.2. Exploratory Factor Analysis

Principal components analysis (PCA) is performed to identify influential factors underlying in the survey answers. The underlying hypothesis is that the survey result reveals common shared theme of "safety culture" because all the survey items are intended to measure the conformity with 'good' safety culture characteristics. It is also hypothesized that the survey result reveals multiple distinct factors which corresponds to individual factors of KINS safety culture model. This hypothesis is tested with three different combinations of data sets. Table 2 provides the identified factor label, # of meaningful items, and % variance accounted for in each interpretable factor for the three scenarios. Nine factors are chosen from PCA because 10th or more factors gave eigenvalues less than 1.0. The items with factor loadings of 0.26 or greater are judged as meaningful.

Table 2. Results of PCA with a 9 Factor solution

	65 items, 70 data	61 items, 70 data	65 items, 54 data
1st	SC, 64, 57.1%	SC, 59, 57.5%	SC, 65, 57%
2nd	RM, 5, 5.3%	RM, 5, 5.3%	RM,WM, 9, 5.5%
3rd	DM, 6, 3.9%	DM, 6, 3.9%	JC, 4, 4.1%
4th	JC, 5, 3.3%	JC, 3, 3.2%	OEF, 2, 3.4%
5th	OC, 5, 2.8%	N/A, 4, 2.7%	DM, 5, 3.2%
6th	N/A, 3, 2.2%	OC, 4, 2.2%	N/A, 2, 2.5%
7th	SL, 2, 1.9%	WP, 2, 2.0%	D&I, 1, 2.2%
8th	N/A, 2, 1.9%	ECP, 2, 1.9%	PI&R, 3, 1.7%
9th	ECP, 2, 1.6%	-	WE, 1, 1.7%
Overall	80%	78.7%	81.3%

The first factor accounts for over the half of variance, and it has positive factor loadings for all the items ranging from 0.26 ("Fatigue of workers are properly managed not to influence work practice") to 0.92 ("Managers invest appropriate time and resource to safety"), 0.74 in average. It seems clear that the first factor represent "safety culture" of the organization and other factors are closely related to this safety culture. The SC accounts for half of the survey answers and nine factors accounts for 80% of the variance overall. The factors RM, DM and JC emerged consistently which show stable accountability as independent traits. Except for the "Change management", other twelve traits of the model were identified sporadically. These unstable factors still have meaning if they demonstrate adequate reliability. Cronbach's alpha can be used as a confirmatory measure in factor analysis because it measures the strength or precision of a factor by measuring consistency in responses among items. As shown in Table 1, all factors but WP has high reliability with Cronbach's alpha over 0.8. It is confirmed that the suggested safety culture factors have adequate internal consistency. This means that most of the factors have reliability as an individual construct.

3.3. Confirmatory Analysis

Discriminant and convergent validity of the KINS model which have 4 dimensions with 13 traits is verified through correlation analysis. Regarding convergent validity of the model, inter-class correlation, correlation coefficient between safety culture overall and individual trait, should be high enough, e.g., over 0.8. For the discriminant validity of the model, inter-factor correlation, correlation coefficient among different factors or different dimensions, should be in adequate range. It is recommended that inter-factor correlations range from 0.7 to 0.95 [8]. Table 3 provides Pearson correlation coefficient calculated for all combinations of

factors. Inter-class coefficients are all over 0.85 and 0.91 in average shows strong support for their positive relation. Inter-factor correlations are all around recommended range except the factor WE*. Inter-class correlations are higher than inter-factor correlations which support the multiple traits structure of KINS model depicted in Figure 1.

Table 3. Intercorrelations among safety culture overall and 13 factors

	SC	1	2	3	4	5	6	7	8	9	10	11	12	
1	.91	-												
2	.91	.8	-											
3	.89	.83	.9	-										
4	.85	.74	.79	.80	-									
5	.92	.83	.87	.84	.82	-								
6	.89	.84	.82	.85	.74	.86	-							
7	.93	,81	.86	.84	.79	.91	.88	-						
8	.90	.79	.80	.73	.75	.84	.73	.81	-					
9	.94	.83	.80	.76	.77	.83	.78	.85	.87	-				
10	.88	.79	.70	.66*	.66*	.71	.73	.79	.83	.9	-			
11	.89	.76	.83	.81	.77	.82	.79	.82	.78	.83	.73	-		
12	.93	.87	.82	.84	.76	.83	.79	.82	.82	.88	.81	.83	-	
13	.95	.86	.86	.82	.83	.86	.82	.88	.86	.88	.83	.83	.85	-

It is assumed that the four dimensions of upper level shown in Fig 1., which are named human performance (HP), management for improvement (MI), safety conscious working environment (SCWE), leadership & organizational control (L&OC), encompass multiple safety culture traits. The convergent and discriminant characteristics of this 4 dimension structure can also be verified by examining intercorrelations. Table 4 provides Pearson correlation coefficient calculated for all combinations of factors. The correlations among safety culture and four dimensions show strong support for their positive relation. Inter-factor correlations are all around recommended range and are lower than inter-class correlations which support the dimensional structure. It is noteworthy that the Cronbach's alpha values for the IAEA model are in the range of (0.83, 0.92) for each of the five dimension, while those of the US are in the range of (0.77, 0.96) [5, 6]. Therefore it can be interpreted that the four dimensional KINS model has much higher internal consistency compared to other models. Overall, it can be concluded that the discriminant and convergent validity of the KINS safety culture model is supported by survey result.

Table 4. Intercorrelations among 4 safety culture overall and 4 dimension, Cronbach's alpha.

	SC	HP	MI	SCWE	Cronbach's alpha	# of items
HP	.96	-			.94	19
MI	.95	.93	-		.97	15
SCWE	.95	.85	.86	-	.98	16
L&OC	.98	.94	.91	.91	.95	15

3.4. Within-Group reliability Analysis

Within-group reliability is necessary to justify the key underlying premise of safety culture that it is shared by individuals in organization. It is expected that individuals in different groups have certain degree of correspondence in the perception of safety culture. The degree to which respondents at the same organization had similar responses to items on the safety culture survey can be used to reveal the within-group reliability of the model. It would have been preferred if the survey was conducted in several NPPs so that the result of one site can be compared with those of other sites. In this study, survey answers are divided into four groups according to the respondent's work group. The mean scores of the overall safety culture factor of each group are compared. Table 5 provides the numbers of respondents, means, standard deviations for the overall measure of safety culture in four work groups. The F-value of the ANOVA analysis, which verifies the hypothesis of indifference of group means, is 1.479 with p-value =0.27. Therefore the survey data could not support the differences among working groups, which can be interpreted as the variance (errors) of answers is mainly caused by individual differences not by sub-group differences within an organization. This further can be interpreted as the within-group reliability of the model.

Table 5. Descriptive statistics for safety culture of 4 work groups

	n	Mean	SD	F-value
Work group 1	16	5.50	1.2	1.479
Work group 2	15	5.62	0.89	
Work group 3	15	5.39	0.77	
Work group 4	24	5.02	0.97	

4. Discussion

The NPP where the survey was conducted is in pre-operational phase that the site level safety culture characteristics can be different with operating organization. Therefore, it is desirable to do further comparative and confirmative research based on the data obtained from surveys at multiple operating NPPs. Another important criterion of new model, criterion related validity, needs also further research. Development and gathering of performance data which is related to actual "safety" of nuclear power plant are needed to identify the relationship between safety culture and safety performance. Authors consider this study as pilot which has a contribution on verifying the construct validity of the model and the effectiveness of survey based research. This is the first attempt that the validity of safety culture oversight model has been investigated with empirical data obtained from Korean nuclear power operating organization. Further study will

be conducted based on the results described in this paper.

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