A Study on the Methodology for Determining Safety Culture Focus Grades Based on a Multi-faceted Analysis

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1. Introduction

In the nuclear field, significant advancements in safety have been made concerning technological aspects. However, occasional incidents emphasize the need for a comprehensive approach to safety, including safety culture [1-2]. The International Atomic Energy Association (IAEA) consistently emphasizes the use of a graded approach in its safety principles and recommendations [3-4]. The IAEA Safety Glossary defines 'graded approach' as follows: "*For a system of control, such as a regulatory system or a safety system, a process or method in which the stringency of the control measures and conditions to be applied is commensurate, to the extent practicable, with the likelihood and possible consequences of, and the level of risk associated with, a loss of control*" [5].

A graded approach allows for valuable resources and attention to be focused on crucial activities. Also according to the safety principles of the IAEA, "Safety has to be achieved and maintained by means of an effective management system" [3]. It should be noted that management systems are both influenced by and also themselves influence the culture of an organization [6]. Thus, a holistic and systematic approach to safety culture is essential within management systems.

While numerous safety culture assessment methods primarily focus on evaluating the organization's safety culture maturity level [7-10], a systematic decision-making tool utilizing a graded approach is currently absent. To overcome this, this paper introduces the concept of a focusing grade, providing a sophisticated and practical framework to evaluate and enhance safety culture in organizations. This methodology utilizes a systematic approach to identify key areas that need immediate attention and resources, thus allowing the development of an optimized safety culture improvement strategy that can effectively boost organizational performance.

This methodology enables a multidimensional analysis, taking into account the *Frequency*, *Maturity*, and *Difficulty* of each safety culture element, as opposed to relying solely on risk contribution, to determine their relative importance. To exemplify the practical implementation of this methodology, a case study was undertaken utilizing data from the target period: 2011 to 2015.

2. Framework

The overall framework consists of three key stages [11]. The first stage involves the analysis of a single parameter, while the second stage integrates these results to determine the focusing grade. The final stage analyzes the focusing conformity for alignment verification, enabling the improvement of the balance in a safety culture plan. This methodology conducts a multi-faceted analysis, considering the *Frequency*, *Maturity*, and *Difficulty* of each safety culture factor, as opposed to relying on risk contribution, to determine their relative importance.

Table 1 Ten traits of Harmonized safety culture model [12]

#	Traits	
1	IR.	Individual Responsibility
2	QA.	Questioning Attitude
3	CO.	Communication
4	LR.	Leader Responsibility
5	DM.	Decision-Making
6	WE.	Respectful Work Environment
7	CL.	Continuous Learning
8	PI.	Problem Identification and Resolution
9	RC.	Raising Concerns
10	WP.	Work Planning

2.1 Stage 1 – Single Parameter Analysis

In the first stage, the frequency, difficulty, and maturity of safety culture factors are analyzed. *Frequency* represents how often a safety culture factor arises during a target period. *Difficulty* indicates the level of challenge in implementing, maintaining, and improving a particular aspect of an organization's safety culture [13]. *Maturity* represents the degree of development, understanding, and integration of a specific aspect of the safety culture within an organization.

Frequency is derived from the analysis of target periods or events. Difficulty is obtained by developing a hierarchical model through literature research and expert advice. Subsequently, experts perform an Analytic Hierarchy Process (AHP) to establish the weights for each difficulty contributor [14-16]. Lastly, the maturity grade of safety culture factors is determined, by identifying relevant items from safety culture assessment

reports and comparing their relative numbers. Maturity grade represents a relative level, not an absolute one.

The K-mean clustering algorithm is employed to ascertain the grade of a single parameter. K-means clustering is a type of unsupervised machine learning algorithm used to classify items into a pre-determined number of clusters or groups based on their characteristics. The optimal number of clusters was determined using the elbow method. Given that the optimal number of clusters was found to be three in the majority of the cases (approximately 92%), it was decided to categorize the grades for a single parameter into three groups.

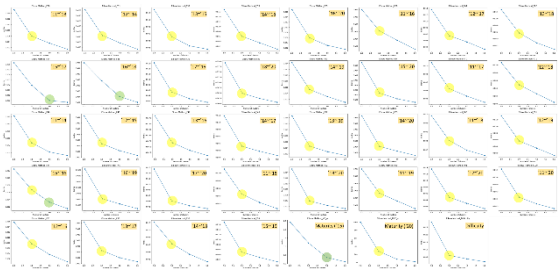

Fig. 1. Optimal cluster count per data set (highlighted in yellow for 3, and in green for 4)

2.2 Stage 2 – Focusing Grade Analysis

This stage is where the results from the previous stages are integrated to determine the focusing grade of safety culture factors. The *focusing grade (FG)* can be determined using a grading rule utilizing *the focusing index* as shown in Table 2, or by using a grading table as shown in Table 3. The grading table is a table that pre-calculates the focusing index for each cell and displays the focusing grade on the cell's color. The focusing grade is displayed in red for 'very high', orange for 'high', yellow for 'mid', green for 'low', and blue for 'distinctive'.

The focusing index is the sum of the indices of frequency or criticality, and maturity and difficulty. In the case of high frequency, high difficulty, and weak maturity, the index for each single parameter is 1 point, and for mid frequency, mid difficulty, and moderate maturity, it is 0.5 points. The single parameter index for low frequency, low difficulty, and strong maturity is 0 points. If the sum of these three scores (i.e., the focusing index, FI) is 2.5 or more, the focusing grade becomes 'very high', and if it is 2 or more but less than 2.5, it becomes 'high'. If the FI is 1 or more but less than 2, the FG is 'mid', and if it is less than 1, it is 'low'. When frequency is used as a parameter, if frequency and maturity show contradictory results (i.e., high frequency and strong maturity, or low frequency and weak maturity), the focusing grade is determined as 'distinctive'. This is because one would generally expect that safety culture traits indicating a high frequency would have relatively low maturity (or many areas needing improvement). Therefore, for traits determined to have a distinctive focusing grade, an appropriate focusing grade should be assigned through additional analysis.

Table 2 Focusing grading rules.

Focusing Grade (FG)	Rule	Combination
Very High	$FI \geq 2.5$	HHH, HHM
High	$2 \leq FI < 2.5$	HHL, HMM
Mid	$1 \leq FI < 2$	HML, HLL, MMM, MML
Low	$FI < 1$	MLL, LLL
Distinctive	When F and M are opposite	F, M = HL

* It is noted that 'H' for maturity grade stands for weak maturity here.

Table 3 Focusing grading table for a target period.

F \ M	Weak				Moderate				Strong			
High	D	H	M	L	D	H	M	L	D	H	M	L
	FG	VH	VH	H	FG	VH	H	M	FG	D	D	D
Mid	D	H	M	L	D	H	M	L	D	H	M	L
	FG	VH	H	M	FG	H	M	M	FG	M	M	L
Low	D	H	M	L	D	H	M	L	D	H	M	L
	FG	D	D	D	FG	M	M	L	FG	M	L	L

2.3 Stage 3 – Focusing Conformity Analysis

The concept of *Focusing Conformity (FG)* provides a method to assess the alignment of an organization's safety culture improvement efforts with the identified areas of importance (as per the *Focusing Grade*). This helps ensure that resources and efforts are being adequately and appropriately directed towards the most critical areas of safety culture.

In the first step, the direct impact of the safety management plan on safety culture factors is estimated. This impact estimation provides a starting point for the analysis of the safety culture but may not fully reflect the overall effectiveness of the safety management plan. The degree of influence, *estimated impact (EI)* is evaluated as very high, high, medium, low, and none.

The results of the focusing conformity analysis can be categorized into three grades: 'favorable', 'excessive', and 'insufficient'. If the focusing grade and estimated impact for a given safety culture factor are identical, it can be said that the safety culture plan has a favorable focusing conformity for that element. If the estimated impact is greater than the focusing grade, the focusing conformity is considered excessive. Conversely, if the estimated impact is less than the focusing grade, the

focusing conformity is deemed insufficient. This allows for the verification of the appropriateness of the overall allocation of safety culture plans across the entire safety culture model.

The focusing conformity of the plan for safety culture trait i is:

$$focusing\ conformity_i = \begin{cases} favorable & FG_i = EI_i \\ excessive & FG_i < EI_i \\ insufficient & FG_i > EI_i \end{cases}$$

Based on the evaluation results of focusing conformity, the safety culture plan can be revised, and the focusing conformity of the revised plan can be re-evaluated through an iterative process. This iterative refinement helps to improve the balance of the safety culture plan. If the conformity is excessive, overrepresented traits can be trimmed by pruning or eliminating some of the associated strategic initiatives, typically discarding those perceived to be of lower priority or less consequential. If the conformity is insufficient, new strategic initiatives specifically targeting these traits should be conceptualized and incorporated to add initiatives for underrepresented traits. After adjustments, another round of alignment verification is conducted to evaluate the congruence of the revised set of strategic initiatives with the focusing grades. If the alignment is still found lacking, the adjustment process is reiterated.

3. Case Study

In the case study, the focusing grade will be derived from a total of 27 events that occurred from 2011 to 2015. An example is proposed to evaluate the focusing conformity of the safety culture enhancement plan announced by the domestic nuclear power plant operator in 2016, comparing it with the focusing grade, and to improve that plan.

3.1 Stage 1 – Single Parameter Analysis

This stage involves quantifying and grading the frequency, maturity, and difficulty of safety culture traits. The frequency of safety culture factors is derived by analyzing 27 reported operating events in domestic nuclear power plants over the period from 2011 to 2015. The event investigation reports, which were used as the data source, were obtained from the OPIS website [17]. Safety culture traits are derived by analyzing the events and then converted to frequency. As for maturity, as previously explained, the number of related items for each safety culture trait was counted by analyzing the areas for improvement items derived from the special safety culture inspection of domestic nuclear power plants. It was assumed that fields with many items requiring improvement were relatively weak. The results of the special safety culture inspection conducted on the Korean nuclear operating organization, KHNP, in 2014 and 2015 were used for this analysis. Table 4 summarizes results of the single parameter analysis.

Table 4 Single parameter analysis

Traits	Quantification result			Single parameter grade		
	F (`11~`15)	M (2015)	D	F	M	D
IR	0.0207	1.00	0.4708	H	M	L
QA	0.0144	0.25	0.5920	M	S	M
CO	0.0063	0.75	0.5538	L	M	M
LR	0.0232	3.25	0.6095	H	W	M
DM	0.0173	1.00	0.6655	M	M	H
WE	0.0053	0.00	0.4593	L	S	L
CL	0.0195	4.25	0.7284	H	W	H
PI	0.0160	3.00	0.7127	M	W	H
RC	0.0000	1.50	0.4112	L	M	L
WP	0.0249	1.00	0.7238	H	M	H

3.2 Stage 2 – Focusing Grade Analysis

The focusing grade can be determined using a grading rule utilizing the focusing index (Table 5). The grading table is a table in which the focusing index has been precalculated for each cell, and the focusing grade is indicated by the cell's color (Table 6). If the focusing grade is very high, it is indicated in red; if high, in orange; if mid, in yellow; if low, in green; and if distinctive, in blue.

Table 5 Determination of focusing grade by focusing index.

Traits	**IR**	**QA**	**CO**	**LR**	**DM**	**WE**	**CL**	**PI**	**RC**	**WP**
F grade	H	M	L	H	M	L	H	M	L	H
M grade	M	S	M	W	M	S	W	W	M	M
D grade	L	M	M	M	H	L	H	H	L	H
Focusing Index (FI)	1.5	1.0	1.0	2.5	2.0	0	3.0	2.5	0.5	2.5
Focusing Grade (FG)	M	M	M	VH	H	L	VH	VH	L	VH

Table 6 Determination of focusing grade by the grading table.

F \ M	Weak				Moderate				Strong			
High	D	H	M	L	D	H	M	L	D	H	M	L
	FG	CL	LR		FG	WP		IR	FG			
Mid	D	H	M	L	D	H	M	L	D	H	M	L
	FG	PI			FG	DM			FG		QA	
Low	D	H	M	L	D	H	M	L	D	H	M	L
	FG				FG		CO	RC	FG			WE

3.3 Stage 3 – Focusing Conformity Analysis

This stage involves the alignment verification of the safety culture enhancement plan. It compares the estimated impact of the safety culture enhancement plan

with the focusing grade derived from the previous stage. In Case 1, the plan for analyzing focusing conformity was presented at the 'Nuclear Safety & Security Information Conference' in 2016 (Fig. 2.). The distribution level of the Overall Plan was estimated by counting and grading the number of strategic items associated with each trait (See Table 7). The following step is to determine focusing conformity by comparing the estimated impact level and focusing grade. Table 7 also presents the focusing conformity evaluation results.

Fig. 2. KHNP's safety culture management plan presentation data [18]

Table 7 Result of focusing conformity analysis.

Traits	IR	QA	CO	LR	DM	WE	CL	PI	RC	WP
Focusing grade	M	M	M	VH	H	L	VH	VH	L	VH
Estimated Impact	M	L	M	H	M	L	VH	H	M	M
Focusing Conformity	Fav.	Ins.	Fav.	Ins.	Ins.	Fav.	Fav.	Ins.	Exc.	Ins.

It should be noted that the reference plan utilized in this case study is based on the content listed in publicly available presentation materials. This is merely an example to demonstrate the feasibility of the methodology and does not evaluate an actual applied plan (which could potentially have more specific and numerous items).

4. Discussion

In this section, the frequency is tracked over the next 5 years period. Table 8 represents the change from the frequency of 2011-2015 to that of 2016-2020. Most of the factors evaluated as *Favorable* in terms of focusing conformity showed a negative Δ Frequency, meaning the frequency decreased. Despite the favorable focusing conformity of CL, the frequency increased, which seems to be influenced by the high difficulty of this factor. In other words, high difficulty implies that it is also difficult to improve, so even though both the focusing grade and estimated impact were rated as very high, it may not have been sufficient. However, from the perspective of efficiently allocating limited resources, it is impossible to indefinitely increase the related strategies for factors already evaluated as favorable. It is necessary to ponder on how to enhance the effectiveness of the already established plan.

Interestingly, factors that were evaluated as insufficient in terms of focusing conformity mostly showed an increase in frequency (*Leader Responsibility* (LR), *Decision-making* (DM), *Problem Identification and Resolution* (PI), and *Work Planning* (WP)), with *Questioning Attitude* (QA) being the only one to show a decrease despite its insufficient conformity. DM, PI, WP belong to the group with high difficulty, and QA belongs to the group with medium difficulty, which is relatively lower than LR. It can be speculated that the relatively low difficulty influenced these results.

Nevertheless, the analysis covered in this case study does not handle all actual safety culture management strategies and adopts a simplistic approach, so more detailed analysis would be necessary to ensure the reliability of such interpretations.

Table 8 Focusing conformity and change in frequency.

Traits	Focusing Conformity	Frequency		Δ Frequency
		`11~`15	`16~`20	
IR	Fav.	0.0207	0.0148	-5.83E-02
QA	Ins.	0.0144	0.0131	-1.25E-02
CO	Fav.	0.0063	0.0043	-2.00E-02
LR	Ins.	0.0232	0.0235	3.50E-03
DM	Ins.	0.0173	0.0199	2.65E-02
WE	Fav.	0.0053	0.0052	-7.00E-04
CL	Fav.	0.0195	0.0230	3.53E-02
PI	Ins.	0.0160	0.0188	2.81E-02
RC	Exc.	0.0000	0.0000	0.00E+00
WP	Ins.	0.0249	0.0275	2.58E-02

5. Conclusion

In conclusion, the proposed methodology, by introducing the concept of a focusing grade, provides a sophisticated and practical framework to evaluate and enhance safety culture in organizations, especially those in high-risk industries such as the nuclear sector. The methodology offers a much-needed alternative perspective on the difficult task of assessing the risk contributions of different organizational factors. It utilizes a systematic approach to identify key areas that need immediate attention and resources, thus allowing the development of an optimized safety culture improvement strategy that can effectively boost organizational performance.

Notably, the common elements assessed with high focusing grades from the case studies were *Continuous Learning*, *Work Planning*, *Leader Responsibility*, and *Problem Identification and Resolution*. It is important to bear in mind, however, that the focusing grade does not suggest that traits with lower grades can be neglected. Rather, it indicates the areas that may require more immediate attention and resources.

Regarding future work, several key areas could be further developed to enhance the framework. These include reevaluating the assumptions of equal weighting of parameters, increasing data collection efforts to ensure robust and representative results, developing a more comprehensive methodology for estimating the impact of the overall plan, and improving the resolution of safety culture factors analysis. Although this study proposes a clear and simple grading rule, expert review and consensus on the suggested grading rule will likely be required in the future. Additionally, it is necessary to validate the effectiveness and robustness of the proposed method across different settings through empirical studies. By addressing these areas, future research could significantly enhance the effectiveness and applicability of the graded approach to safety culture management.

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