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Safety Culture, A New Challenge to Human Factors Engineering for 21st Century

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Objective: This paper discusses the recent challenges to human factors engineering due to the safety culture.

Background: As incidents occurring in specific fields such as logistics, plant, energy and medical sectors in Korea, as well as in the public sectors including railway, road, aviation and shipping, are recently raised as social issues from the disaster dimension, those incidents are dealt with as man-made disasters in many cases. The trend regarding all accidents as man-made disasters has been expanded in the active perspective that the controllability of all incidents should be ensured in technology development, due to change from a fatal point of view regarding disasters as random occurrence of uncertainties in the past.

Method: Man-made disasters are concluded as human errors, and safety culture stands out as a cause of human errors or a new cause item recently. Because safety culture, however, is a very comprehensive term, of which true nature is obscure, although many definitions of safety culture have been presented, the safety culture may make avoid the true nature and responsibility of an incident, or make the main player and subject obscure. Raising safety culture as a cause without presenting a specific countermeasure will be just a wisdom of hindsight.

Results and Conclusion: This study reviews the fundamental discussions on "Is safety culture a task of human factors engineering?" and the existing approach carried out from various perspectives in order to seek an effective approach on the new task of safety culture in the human factors engineering field. This study discusses an engineering approach to meet a precondition that safety culture is not just an added factor through a review of the approaches in the proactive fields such as nuclear power and aviation, and the traditional approaches of human factors engineering.

Application: This study especially defines the perspective of socio-technological system that has expanded the existing man-machine system, and discusses a systemic approach embracing various interactions, and several overriding tasks.

Keywords: Safety culture, Human factors engineering, Human error, Human error 3.0, Systemic approach, Socio-technological system, Disaster

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1. Human Factors Engineering in 21st Century

In embracing the ICT (information and communications technology) era facing with the shock of AlphaGo, the human-centered concept with a clear principle of ultimately enhancing human value regarding the concern on unlimited development of technology rapidly becomes common. Human factors engineering started with core

technologies innovatively enhancing the system effectiveness of entire industrial production through Mayo's Experiments, Time and Motion Study and THERBLIG Analysis according to specialization. Simultaneously, human factors engineering has steadily made contributions through the most effective perspective of "human-centered" in grasping and solving various problems that humans face, such as failures and accidents in an engineering way in the process of achieving system effectiveness, according to rapid technological change (Lee, 2009, 2011a, 2015; Lee and Lee 2009).

However, the following trend of today's technological society changes so that human factors engineering cannot easily make contributions and exert solving capabilities. Complexity increases fast, according to the increase in the size of system, information volume and information processing capabilities. At the same time, mutual dependability is rapidly going up, due to increase in mutual association relations and impacts with the outside of a system, as well as the inside of a system. Although complexity is hardly perceived, while each player is felt like independent in normal state, complexity is revealed suddenly through dependent areas in emergency or abnormal state, which works as a rapid burden and barrier. Also, a technical problem functions as a shocking form. Consequently, the spreading size and scope of the problems in a specific technical area are infinitely expanded enough to hugely affect the entire society, not to mention other adjacent fields. Therefore, the problems of a specific technology have stood out as social responsible problems, in addition to being simply limited to the field concerned. The Perrow's concept of normal accident or the Beck's paradigm of the risk society have been proposed in that the risk of the modern technological society intertwined with complex association relations is unavoidable (Perrow, 1984 recited by Lee, 2015).

Since humans are ultimately responsible for all accidents and problems, human factors engineering is burdened by scientific research on and engineering solution to human-centered problems in the 21st century. However, the examination of a specific cause and responsibility becomes impossible, or it becomes difficult to devise realistic countermeasures and solutions, due to such new characteristics. It is difficult to identify a cause and devise a countermeasure in most incidents, because of huge gap between cause and countermeasure, as well as the gap between problems and causes. Although lots of efforts are made to identify clear cause and responsibility of a given problem, responsibility avoidance, as well as desire to identify a cause, is an instinctive tendency. Therefore, the efforts to identify causes become root making it difficult to identify accurate incident causes and establish an effective countermeasure.

In such a situation, discussions on most incidents recently occurring mentioned safety culture as a main cause. Such a trend to point out safety culture as a root cause of all the problems is bolstered, due to several reasons: First, there is no additional burden in the examination of factual relationship, since it is clear that safety culture affects anyhow in terms of comprehensive meaning as the background of all accidents or incidents. Second, safety culture is effective as termination criterion finalizing the unlimitedly continuing causes' segmentation and complex causal relationship discussion, since safety culture is a factor not specified and segmented yet. Third, safety culture has no additional burden according to a problem raising the result of safety culture, arising from no execution item or obscurity in relation with countermeasures, due to no definition of specific players and subjects, and no examined influence relationship. In this regard, the rapid standing out of the safety culture problem is not a just new task, and thus prudent tackling is urgent through a specific approach and human factors engineering technology development on safety culture.

2. Understandings of Safety Culture

2.1 Human error 3.0 and safety culture

To review the fundamental concept on whether safety culture is a task of human factors engineering, this study reviewed the history of change of human factors engineering that has solved various problems occurring in various fields from the human effort perspective, and tried to discover a good starting point from human factors engineering's conceptual development. Human

error means that a human conducts an action different from his/her intention. Therefore, a human error has been identified as human action's important characteristic, regardless of good or bad result, and human factors engineering has been dealt with from the three dimensions (adopted from Lee, 2015).

First, studies on human factors engineering's human errors have been actively carried out in making an effort not to cause physical damage (injury) in human's behavioral process. Those studies have contributed to analyzing and improving work so that humans performing work in the manual work-centered society are not damaged. Human error is a core technical area that has continued from the beginning period of human factors engineering, and this is called human error 1.0 for convenience' sake. The main focus of human error 1.0 was to analyze human's action or job characteristics, improve work or train repetitively, and coordinate so that variability and uncertainty in job cannot be a problem (Lee, 2015). Human error 1.0 also checks the status of being in line with worker's characteristics and physical burden, or measures relevant skillfulness and manages career through anthropometry, biomechanics and work physiology (Kim et al., 2006, 2008; Lee and Yoon, 2012).

Second, as machines rapidly develop, human's function faced with complex demand, compared to manual work situation. Because humans cannot be satisfied with just no physical damage in the action process, an era that needs to cope with all human actions causing failure in a system began. To differentiate the era, it can be called a system error or human error 2.0 for convenience' sake (Hollnagel and Fujita, 2013; Reason, 1997 recited by Lee, 2006, 2015). The focus of human error 2.0 was to analyze and improve the surrounding environment (setup including the given interface) that causes an error, because failure is caused by human factors, although there is no problem in human him/herself. Because, human error 2.0 cannot identify with only human's action, and cannot solve with only the change of human action, an analysis, design and setup should change and solve mainly from the entire system. Most human factors engineering with a motto of "Fitting the Task (System) to the Human" since the middle of the 20th century can be the area of human error 2.0.

Third, a failure or an accident may be caused in the entire system, although humans who are included in the inside of a system did not make a mistake or reveal a problem recently. Such a failure can be seen as a problem that humans should be responsible (that is, man-made disasters), and therefore there is a perspective discussing such a failure by including it into human error (Lee, 2011a, 2015). Such a human error has different character from previous human errors, and it can be differentiated as human error 3.0 for convenience' sake. In human error 3.0, extensive factors can be involved in the system failure, and a human error can be an accident/a failure without fault to a worker in the inside of a system. What is important is that examination of the cause of the inside of a system on error is not appropriate, and an effort to analyze root causes including external factors beyond system's usual limitation, or to identify countermeasures rather than cause is effective (Lee, 2015).

Although the discussion of safety culture is unavoidable as the background cause of human error 3.0, concrete examination and countermeasure are not easy. In view of the definition of culture, "safety culture is not a factor of a system, but the system itself", (IAEA, 2012, 2016), the background issue such as safety culture needs to be grasped and analyzed as entire system, not just additional factor deciding the safety of the system. Safety culture should not be limited to the traditional corporate culture perspective that regards safety culture as part of organizational culture.

An approach and concrete technology become different according to where the core of safety culture should lie (Choi, 2008; Lee, 2011a, 2016; KHNP, 2012; Lee, 2014; Jang et al., 2012, 2015; Jung et al., 2016). In the case focusing on safety, engineering actions on safety have been concretized to quite degree from the safety management perspective in which those actions have steadily been developed and practiced. For example, safety improvement effects have been acquired by adopting a safety management program, such as safety management system (SMS), a long time ago in the high-reliability fields including process plant, nuclear power and aviation. In the occupational safety field, various onsite safety improvement programs are implemented. However, a practical management system and specific method that can tackle recent safety culture issues including human error 3.0 in the

existing safety management field can hardly be found.

2.2 Perspectives and approaches of safety culture

Safety culture was formalized, as safety culture was pointed out as a cause of Chernobyl Nuclear Power Plant, the popular development of technology culture in the 20th century, which caused an unimaginable disaster in the former USSR in 1986 by IAEA INSAG-1. The definition of safety culture proposed from the Chernobyl accident is given by IAEA INSAG-4 as follows (IAEA, 1991, 1998).

> The assembly of character and attitudes in organizations and individuals which establishes that, as an overriding priority, safety issues receive the attention warranted by their significance.

In the analysis of many large scale accidents including space shuttle explosion, offshore crude oil leakage, airplane crash and sinking of a cruise, comprehensive root cause meaning complex background problem beyond the existing technical scope was started to be raised without a concrete assessment method, and a clear concept. This is a common phenomenon to the recent Fukushima Nuclear Power Plant accident as well, irrelevant of fields and domestic and international accidents (IAEA, 2012, 2015, 2016). Safety culture is raised as a frequent cause in the discussion of the recent accidents including Asiana airliners' crash at SF Airport, Sinking of Sewol Ferry, hydrofluoric acid leakage, KTX collision and great fire, as well as incidents in the nuclear field, such as loss of off-site power failure/concealment and forgery and modification of parts of Kori unit # 1 in Korea.

However, there can be various definitions and approaches according to the perspectives viewing the core of safety culture (Choi, 2008; Lee, 2016; IAEA, 2016; Jang et al., 2015; Lee, 2011b, 2016). Perspectives looking at the core of safety culture as safety or culture according to topic are different, and also the perspectives are different depending on the players of viewing safety culture, such as society, organization, company, worker and individual. Therefore, the seeking of an effective approach is difficult.

In safety management, there are many cases to point out safety culture as a core cause of safety problem without specific criteria, concept or perspective, and to request safety culture improvement as a solution means as a panacea. Safety culture is also used as a comprehensive meaning complementing concrete measurement and assessment criteria's biases, such as safety performance according to the level of safety performance. Various perspectives and definitions on safety culture are possible depending on discipline field, and very conflicting approaches are also possible by technical field.

2.2.1 Safety culture as a culture

Viewing safety culture regarding culture as core, comprehensive definitions are possible, such as "a society's total life style" (Linton, R), "complex whole of all abilities and habits including the knowledge, belief, arts, values, norms, technologies and means for food, clothing and shelter acquired as a member" (Tyler, E.B.) However, it is difficult to construct or select a concrete approach, due to a cultural relativism perspective asserting that there is nothing like good or bad in culture, and that a concrete fixed perspective should not apply. Although safety culture from the cultural perspective is abstract, the following (see Table 1) basic characteristics items and relevant functions of culture can be referred to in constructing and selecting individual safety culture approach on the basis of culture's peculiarity and diversity (Lee, 2014).

The true nature of safety culture can be identified diversely as custom, tradition, civilization, climate/atmosphere, manner, style and pattern/code. As seen in the safety culture pyramid model of E. Schein (see Figure 1), the intangible part is core, and the model regards that the intangible decide the tangible. Therefore, the point of view that specific intervention and sufficient identification

of safety culture are difficult fundamentally in the cultural perspective approach is dominant. Although the intangible can be identified with some comparative culture (Hofstede, 1991 recited by Cha and Na) information, it is the general opinion that such a thing is limited to humanities study. What is negative to safety culture's intervention possibility from the cultural perspective functioned as a root cause by which safety culture-related R&D and active actions were delayed.

Table 1. Conceptual attributes and functional descriptions of 'culture' term (adopted from Lee, 2015)

Category	Characteristics	Functions
Sharing attribute	Common things of behaviors and the way of thinking commonly revealed to the members	Since people share culture for organizational life, cultural intervention can be predicted though others.
Learnability	Grow as a member through learning, because members acquire, rather than getting biologically and innately	Individuals accept culture through learning, a society socializes culture to individuals, and order can be maintained. Therefore, learning structure is essential.
Accumulation	Culture continues to be handed down through human's language and letter use abilities	Tradition is made through addition of a new type to existing culture, and cultural content becomes more abundant.
Wholeness	A society's culture consists the whole with close correlation of each factor	Dynamic composition is needed, because the change of a cultural factor brings about the change in other areas serially
Variability	Culture continuously changes, not fixed, and cultural change occurs in the process to effectively cope with	Linkage with external change, since culture helps adaptation to environmental change, and contributes to cultural accumulation

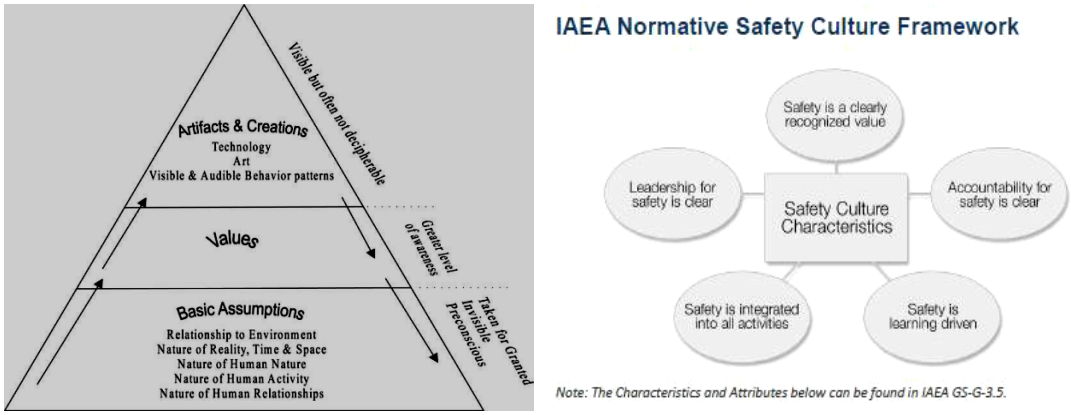


Figure 1. A typical model of safety culture (left), a typical set of safety culture attributes (IAEA, 2012)

Although the seriousness of safety culture stood out early even in the nuclear field, specific requirements were presented just recently. IAEA, NRC and INPO presented cultural attributes or traits of safety culture, rather than definition of it, and utilized them as criteria or requirements. For culture-centered approach to safety culture, the segmentation of items through attributes, traits and principles is required to make the definition in line with relevant fields concrete. This seems to be effective to just voluntary goal, rather than an objective discussion. Many companies segment attributes to be in lie with their companies, and apply them to self-assessment (IAEA, 2012; Kim et al., 2013; Lee et al., 2012; Lee, 2016).

2.2.2 Safety culture focused on safety

If safety culture is seen though the topic of safety, steady and realistic efforts are found from the relatively practical perspective. In the occupational safety field, safety culture was regarded as a critical factor to ensure safety, and as a goal to ultimately achieve. As seen in the definition of culture, safety culture starts from a concept and consciousness and is manifested as concrete behaviors. In practical work, however, the promotion of concept maturity and consciousness growth can be carried out putting priority on the identifiable and invention—possible areas like behaviors. Safety culture can be established successfully by continuously utilizing the association relationship between consciousness and behavior (see Figure 2). After planning culture's practicing factor, namely concrete activity, it is to associate various activities with goals organically, establish plans by position and individual, and execute those plans. If it continues, and make humans be skilled with each activity, they can sympathize with each activity's effectiveness and perceive value. An activity that began with the sense of obligation is perceived as a need, and then perceived as value as time goes on. Finally, a long-term perspective, through which all those become a culture, is offered. Although safety culture's maturity stage is classified into rule, performance and continuous stages, they can be segmented differently by level according to goal.

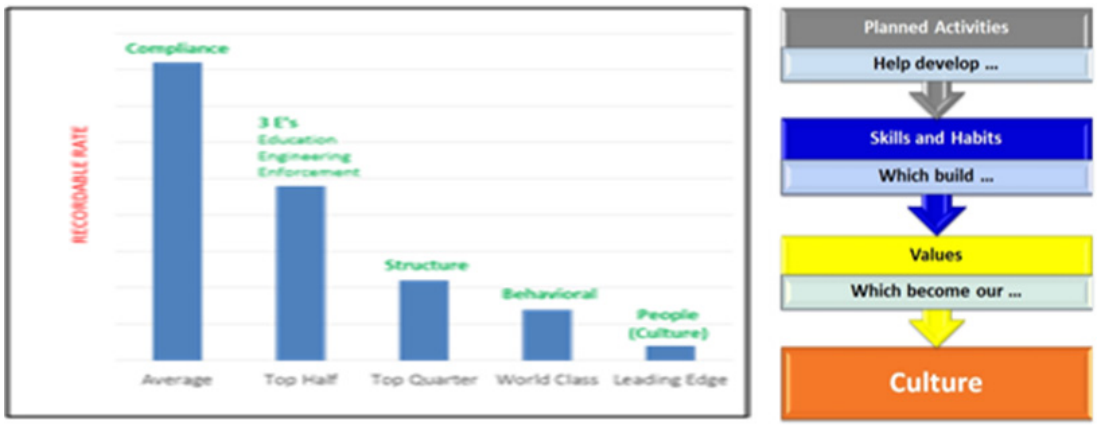


Figure 2. Stages and steps for maturing a safety culture in a company

The details of safety culture activity and technology applied in the safety management field are greatly diversified. However, concrete safety culture activity types are limited to slogan/motto, poster, campaign, wake up training and moral education, or practicing techniques do not go beyond peer inspection, safety sign method and case diffusion. An approach to safety culture from the safety management aspect is active in the aviation field, and seems to be successful. Human resource management aiming at pilots' teamwork improvement has developed to a so-called 7th generation TEM, and is reported to improve the safety activities of all aviation workers including controllers and mechanics. Above all, the collection and utilization system of safety experiences managed voluntarily is a representative system, and it approaches overall safety in an integrated manner by establishing a systematic manpower system-based system encompassing voluntary report of trivial human errors, which is called KAIRS in Korea (Lee, 2011a, 2014).

The contents of safety culture that have been put into practice in the safety management field are diversified and concrete, and seem to have generated huge effectiveness for formation of safety climate and safety conscious working environment (SCWE). The safety-centered safety approaches developed thus far have mainly aimed at worker protection and injury prevention, irrelevant of individual traits, and they have been absorbed in total safety management scale and management mode. Although they are

still safety culture-related activities and techniques, the application results' causal relationship with the changes and phenomena related with concrete safety culture is not clear, and therefore motive as a safety culture approach is weak. Since additional burden is unavoidable in applying all activities and practicing techniques, a concern that intangible core-based belief can be threatened, due to distrust on the safety culture approaches, in the case that results are not concrete enough to induce and maintain voluntary motive of the relevant people, is simultaneously involved.

2.2.3 Safety culture from corporate perspective

When viewing safety culture from the player's and subject's perspective, many very concrete study cases and business administration methodologies have been presented. The detailed methodologies of safety and health management defined early emerged as a common task together with quality and environmental management that were actively conducted from the 1980s. Since then, seeking safety culture combined with ethics and sustainability perspectives according to a more expanded corporate culture concept has been active (ISO18000/23000). From the corporate essential core factor perspective, safety culture's concrete factors and procedures are defined, and practical assessment and intervention methods are presented. For example, the 7S model or Ser-M model is corporate culture model, and there are cases that presented a model composing corporate practical model and detailed scale dealing with safety culture, based on those models.

Although most companies include safety culture as part of the environmental safety and health policy and principle as shown on the right of Figure 3, there are not many companies combining safety culture with operating systems. Although the principle, "All accidents are preventable" is believed, how to implement the principle in the practical procedure of management system is important. Even though safety culture is emphasized, and if people do not implement it in actual management system, the principle and declaration are meaningless, and belief collapses momentarily. Therefore safety culture will be effective no longer. Safety culture exists on the basis of a belief that workers not only believe they can achieve safety, but also that they can implement it in reality. Although company officials cannot face with safety culture with the same concept and values, the safety culture needs to be implemented as the true nature of a concrete management system, not inevitable content of management goal. Safety culture from the corporate perspective is accepted as one of the goal to steadily achieve, but it is difficult to find a case, in which safety culture is embedded in the inside of a company in line with concrete requirements as yet. Actually, such a safety culture is demonstrated, limited to independent management information, production or individual practicing task at production site, which are comprehensively and cyclically assessed, as necessary.

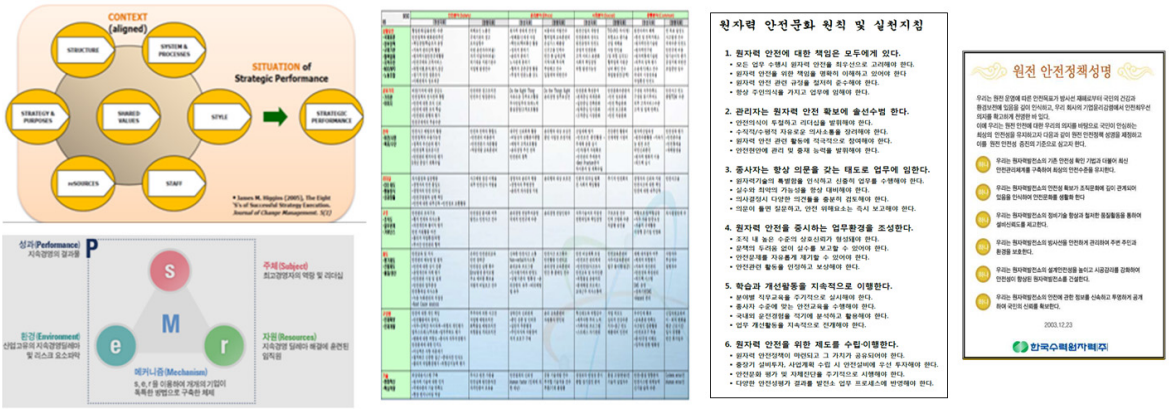


Figure 3. A set of safety culture criteria based on 7S and Ser-M model (adopted from Lee, 2015)

2.2.4 Safety culture approaches focused to human

When safety culture considers a human, who is the main player and subject of safety culture, various discussions are related with safety culture in the sociology psychology, organizational administration and human factors engineering fields. Since sociology and psychology fields offer active meanings on ethics and philosophy starting from human nature and personal value system, a fundamental improvement possibility of safety culture can be offered, when concrete conclusion is drawn. For example, safety culture research continues in the organizational administration or sociology field. However, those researches do not deal with various tangible factors like a total system including allocation of responsibilities and rights, procedural rules and methodology in practical work beyond humanities approach on the setup of fundamental principle/norm of safety culture. Although there are many studies on individual case on technical tasks and issues, the development of practical work methodology lacks.

Because errors can be classified as slip, lapse, mistake and violation according to the intention of action and cognitive level, the approach to safety culture should vary depending on the violation type (Reason, 1997; Lee, 2006). Especially, violation errors such as avoidance and sabotage have importance in priority; however, the basic study on violation phenomena and influence factors, as well as concrete technology development to cope with, is rare and rough as Figure 4 (Kang et al., 2016). The research on the issue of troublesomeness or mannerism standing out due to cultural change, or the flaws of group thinking like being unbeaten with many people or distribution of responsibility need to be urgently conducted as core topics of safety culture.

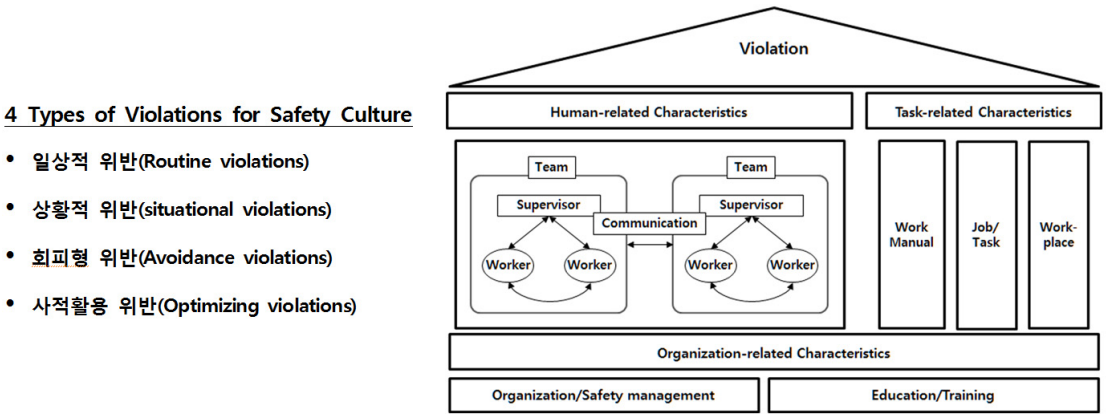


Figure 4. 4 types of violations and their house model for safety culture (adopted from Kang et al., 2016)

Studies on safety communication, as well as basic studies on risk perception and responses for safety culture in the sociology and psychology fields, are actively performed recently in Korean Psychological Association. The in-depth analysis on various human error issues, and many suggestions and analysis results that can be recommended in relation with training/education can be found, in addition to examination of fundamental response traits on given risks as 3F (flee, freeze and fight). However, a safety culture approach focused on humans is a study on very comprehensive tendency, or is concentrated on individual phenomenon and pre/post discussion of an accident. Therefore, it is difficult to expect a safety culture technique that can be applied to practical work process. The safety culture cases occurring recently are rare cases having peculiarity in each field, and therefore they are limited to basic discipline results, despite in-depth study. Or they do not seem to go beyond the limitations of general safety management means and technologies that are already utilized in occupational safety field, in spite of result-based deductions.

2.3 Safety culture approaches in practice

In the nuclear and aviation fields, where safety culture issues were raised through the experience of large scale accidents, a variety of onsite actions and approaches on safety culture have been conducted to establish safety and health culture. Although very diverse approaches are carried out, they can be classified into the following three, centered on practical works in the aviation and nuclear fields:

- Assessment-focused approach: Comparative assessment on the inside of an individual organization or industry or relative level and characteristics
- Model and requirement-centered approach: Seeking desirable safety culture model and legal requirements
- Issue-centered approach: Pre or post approach to safety culture issues that already occurred or that has a concern to occur

(a) A safety climate measuring software tool

			전혀 그렇지 않다	대체로 그렇지 않다	그저 보통이다	대체로 그렇다	매우 그렇다
44.	항공기가 충분히 정비되어 있어서 안전운항에 문제가 없을 것이라고 확신한다		①	②	③	④	⑤
45.	우리회사에서는 조종사가 조종업무를 안전하게 수행하는데 문제가 없을 만큼 충분한 훈련이 이루어지고 있다		①	②	③	④	⑤
46.	경영진은 사고가 발생하지 않는 한 안전에 많은 관심을 기울이지 않는다		①	②	③	④	⑤
47.	우리 회사는 안전보다는 돈을 버는데 관심이 더 많다		①	②	③	④	⑤

(b) A questionnaire of safety culture self-assessment (sample/part)

Figure 5. Software and worksheet for safety culture self-assessment (adopted from Lee, 2015)

To cope with safety culture issues, the activities and relevant R&D assessing airlines and nuclear power plants' safety culture were activated. Most assessment methods are interview or questionnaire-based, or a mode for indexing according to a specific scale and assessment logic. The following Figure 5 shows an example of representative questionnaire applied to safety culture assessment, and a fair safety culture monitoring system. In view of safety culture's traits, independence was emphasized, but self-assessment was frequently carried out from the aspect of preferential problem identification and autonomous measures to cope with, as a pressing issue occurs.

To grasp the true nature of safety culture, studies on the role of organizational factors in the actual accidents have been actively performed. As a result of drawing the hazards from the different perspectives of causes by re-analyzing nuclear power plant's sudden failure cases, several safety culture factors have been identified (Lee and Lee, 2009; Lee, 2011c). The U.S. NRC re-analyzed human error traits in the nuclear power plant accidents to investigate the situation of nuclear power plants from the safety culture perspective. As a result, most accidents occurred due to four or more of defects. The initial stage risk that the errors at the time of nuclear power plant construction in the 1960s and 1970s with 81% of potential errors was latent, and it could be revealed as a risk by safety culture traits in the operations of the 1980s was raised (Kim et al., 2014).

Second, activities setting up the factors and traits (attributes) of safety culture in each field and organization are active in the requirements-centered studies. Rather than examining as specific factors or comprehensive problems, the organizational safety perspective was raised to see as the movement itself determining many relevant factors' combinations and risks. This is in the same context as the approach from the organizational error perspective proposed by Reason. The safety culture's model and requirements-centered approach was sought, due to large scale accidents in the aviation and nuclear fields led by international organizations. In the aviation field, the SMS system was developed mainly by ICAO, and an information exchange system was built jointly and internationally.

Concerning individual airline and country, the FAA human factors management program of the U.S., and D company's unique CRM program can be representative safety culture cases. In the nuclear field, making requirements for an international agreement was conducted led by IAEA, OECD/NEA, after the Chernobyl accident. In the periodic safety review (PSR), open safety culture assessment was set up as a detailed requirement through assessment on overall operations including operation experience, organization and administration, (job) procedure and human factors. Recently, safety culture's basic attributes and detailed attributes have been presented, and they were to be utilized as question item-based guidelines for self-assessment (see Figure 6 and Table

	Unplanned scrams		NRC allegations		Total ROP inspects		Human perf. area		Problem ID & Res. area		Total SCCIs		ROP action matrix oversight		Chemistry perf. index		Human perf. error rate		Forced loss rate		ISA rate	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
SAFETY CULTURE	-.37**	-.27*	-.21	-.36**	-.39**	-.20	-.28*	-.12	-.37**	-.27*	-.23	-.26*	-.23	-.30*	-.27*	-.45**	-.36**	-.22	-.11	-.31*	.01	-.25
1. Management commitment	-.34**	-.25	-.24	-.38**	-.44**	-.21	-.30*	-.11	-.40**	-.30*	-.28*	-.27*	-.20	-.29*	-.27*	-.45**	-.38**	-.19	-.11	-.28*	-.01	-.23
2. Willingness to raise concerns	-.29*	-.31*	-.16	-.38**	-.21	-.10	-.16	-.03	-.24	-.18	-.10	-.18	-.31*	-.24	-.22	-.36**	-.37**	-.16	-.08	-.23	-.04	-.21
3. Decision-making	-.33**	-.30*	-.17	-.33**	-.37**	-.21	-.25*	-.13	-.35**	-.29*	-.21	-.32*	-.27*	-.32*	-.28*	-.40**	-.36**	-.20	-.08	-.33**	.05	-.28*
4. Supervisor responsibility	-.26*	-.26*	-.15	-.20	-.28*	-.17	-.27*	-.12	-.24	-.20	-.14	-.18	-.27*	-.30*	-.14	-.38**	-.40**	-.27*	-.06	-.26*	.01	-.23
5. Questioning attitude	-.29*	-.30*	-.41**	-.48**	-.47**	-.19	-.40**	-.15	-.37**	-.19	-.38**	-.23	-.17	-.26*	-.26*	-.45**	-.28*	-.19	-.19	-.29*	-.11	-.33**
6. Safety communication	-.35**	-.24	-.12	-.28*	-.31*	-.18	-.20	-.14	-.32*	-.20	-.14	-.21	-.19	-.29*	-.28*	-.44**	-.39**	-.23	-.14	-.33**	.00	-.23
7. Personal responsibility	-.24	-.07	.17	-.08	.04	-.06	.05	-.05	.00	-.06	.13	-.10	-.28*	-.05	-.27*	-.26*	-.21	-.20	-.06	-.25*	-.11	-.14
8. Prioritizing safety	-.23	-.21	-.09	-.21	-.28*	-.21	-.18	-.14	-.30*	-.25*	-.11	-.20	-.11	-.27*	-.21*	-.31*	-.25*	-.22	-.03	-.22	.10	-.16
9. Training quality	-.46**	-.09	.04	-.07	-.22	-.11	-.14	-.06	-.25*	-.15	-.10	-.20	-.23	-.23	-.30*	-.37**	-.19	-.25*	-.13	-.44**	.07	-.10

* $p < .05$.
** $p < .01$.

Figure 6. Correlations of safety culture and performance factors in nuclear power plants (adopted from Lee, 2015)

Table 2. A set of safety culture measures for rail-road (adopted from Lee, et al., a study on the development of the safety culture inspection process in Korean railway, 2012)

Railway safety culture index	Details
1. Safety policy and safety leadership	• Visibility of management's safety management • Safety culture propriety of safety policy approved by the management • Shaping management's safety mindset and climate within workplace
2. Communication among stakeholders	• Status of employee's participation in safety discussion • Accessibility to management on employee's safety culture • Trust culture within workplace • Safety information delivery system • Understanding level of safety information • Recording, investigating and easing procedure of safety concerns • Internal reporting system on safety concerns
3. Change management and self-diagnosis	• Employee's participation in change management • Employee training on change management • Employee motivation on change management and active response to feedback
4. Learning culture	• Accident investigation system • Blame allocation process and punishment process according to accident • Feedback system on accident causes
5. Safety responsibility mindset	• Safety culture/climate monitoring system • Safety-preferential behavior • Priority assessment of performance vs. safety management • Safety responsibility consciousness upon exceptional situation occurrence

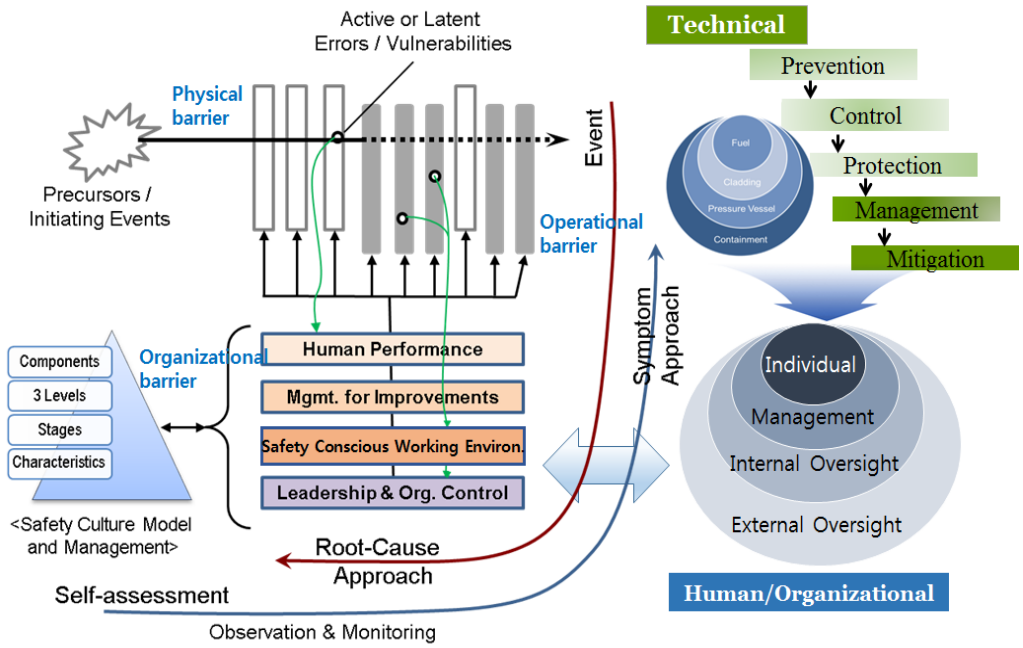


Figure 7. Concept and approach for safety culture oversight model development (adopted from Jung et al., 2016)

2). Unavoidably, an important direction in seeking practical work of safety culture in the nuclear field was set up, despite a general safety culture model and requirements.

Each country's regulatory body responsible for nuclear power plant's safety develops ideal safety culture models and work systems from the regulation aspect. The U.S. NRC that did not admit the need for active intervention on safety culture, immediately after the Chernobyl accident actually declared an active safety culture intervention policy through review of safety culture approach, after the nuclear vessel head degradation accident of Millstone Nuclear Power Station. The SCPS (Safety Culture Policy Statement) made nine trait requirements, and recommended active activities on 12 items. A Korean regulatory body presented the following conceptual diagram as shown in the Figure 7 below to build systematic safety culture practical work meeting the safety culture requirements similar to those of the U.S. NRC (IAEA, 2016; Jung et al., 2016).

3. Human Factors Engineering Approach to Safety Culture

3.1 An add-on to human factors engineering for safety culture

The human factors engineering field has presented concrete technologies and techniques, as well as active R&D including safety, to system effectiveness traditionally. Time and motion study, and work analysis active in the specialization and manual work period provided the foundation or practicing technologies of safety culture, and played a leading role. Since then, the man-machine paradigm became active for effective facility manipulation due to rapid advancement of engineering technology, and it contributed to the effective development of various engineering systems. The human factors engineering activities and technologies carried up until nowadays can be categorized into the following four categories (Lee, 2011c, 2015):

- Management support: Drawing and utilization of safety culture information through safety culture information and performance collection and analysis
- Job improvement and support: Offering accident prevention and support tools such as warning and information, or change of job description/method and allocation
- Site improvement: Working (mainly physical) environment improvement
- Consciousness improvement: Campaign, slogan/motto and poster

However, mostly those dealt with safety and performance required from the worker's personal perspective, and therefore the techniques handling the group aspect such as safety culture were relatively poor. Techniques on worker's health and wellbeing were left to occupational safety, and only the offering of managerial techniques such as relevant information's analysis and statistical processing was carried out. In Korea, especially, the organization and industrial psychology field, which is one field of human factors engineering, was relatively poor. Although job improvement and support activities were active, their correlation with safety culture was insufficient. Therefore, the introduction of a new concept or expansion to traditional human factors engineering is needed.

Above all, shift from the paradigm of traditional man-machine system to socio-technological system (see Figure 8) including new considerations is urgent (Lee and Lee, 2009; Lee, 2011c, 2013). The topics of human resource management domain including qualification, training and work plan, in addition to organization, allocation and schedule management, needs to be added by expanding personal job and workers-related human factors. Here, strategies and policies concerned with safety are included (especially, in the case of large system with high reliability), and the system domain should be expanded a lot to encompass social requirement factors.

In the socio-technological system, such tasks as teamwork, leadership, cooperation, communication, discord, ease of conflicts and expert ethics stand out as the main points of safety culture through addition to existing human factors engineering issues. These

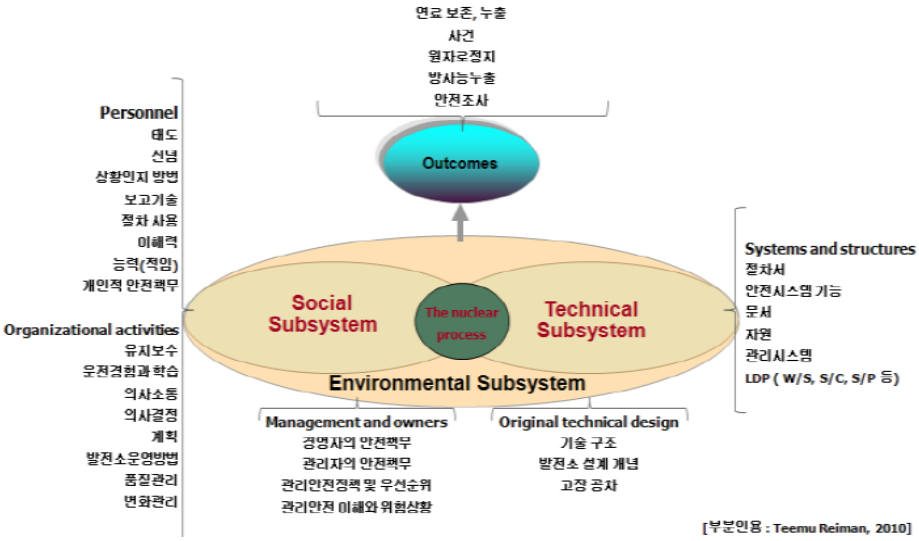


Figure 8. A conceptual scheme of a socio-technological system (Lee and Lee, 2009)

issues need to be handled with management factors, such as human/physical resources management and management basis and policy, and a so-called participatory ergonomics concept was discussed, centered on Europe on those issues early. Through the paradigms of MTO (Halden), HOF (OECD/NEA) and ITO/HTO (IAEA) under the expanded human factors engineering concepts, coping with in the human factors engineering way is sought in the nuclear field (IAEA, 2014, 2016). The key point is that the core of paradigm shift is that (safety) culture is not a newly introduced independent factor to a system (see Figure 9). Because safety culture is demonstrated as the behavior structure of socio-technological system, it is essential to consider system's various interactions sufficiently. Although it is included in the systemic approach constituting human factors engineering foundation, it is to present the systemic approach emphasizing the socio-technological system again (IAEA, 2016).

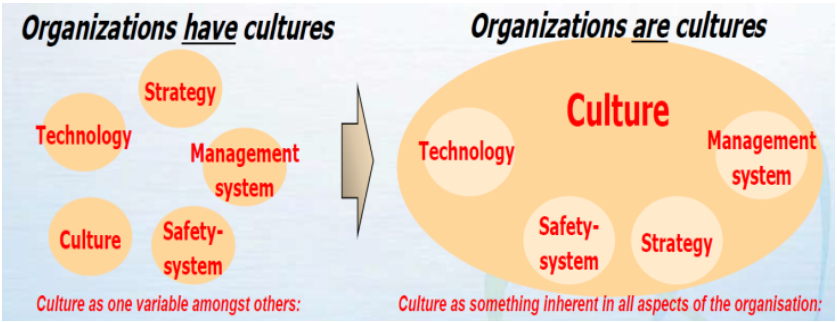


Figure 9. A start-line of a proposed approach to safety culture (IAEA, 2016)

Second, a close review on the detailed areas of expanding safety culture is needed from the human factors engineering aspect. The perception areas on risks can be divided into three areas: Known-knowns, known-unknowns and unknown-unknown from the human factors engineering perspective. The perception of each risk area is different, and also human factors engineering characteristics are different, and thus there is a need to differentiate human factors engineering approaches. As discussed in the

human error 1.0~3.0 concepts, R&D should be carried out by segmenting safety culture approaches from the personal, systematic and therapeutic perspectives, respectively. In addition, studies on fundamental surprise conditions in an unexpected situation as shown in the Fukushima Nuclear Power Plant accident are needed (see Figure 10). In an unexpected situation, intangible characteristics can work as a critical factor for safety culture's base hierarchy (IAEA, 2012, 2015, 2016).

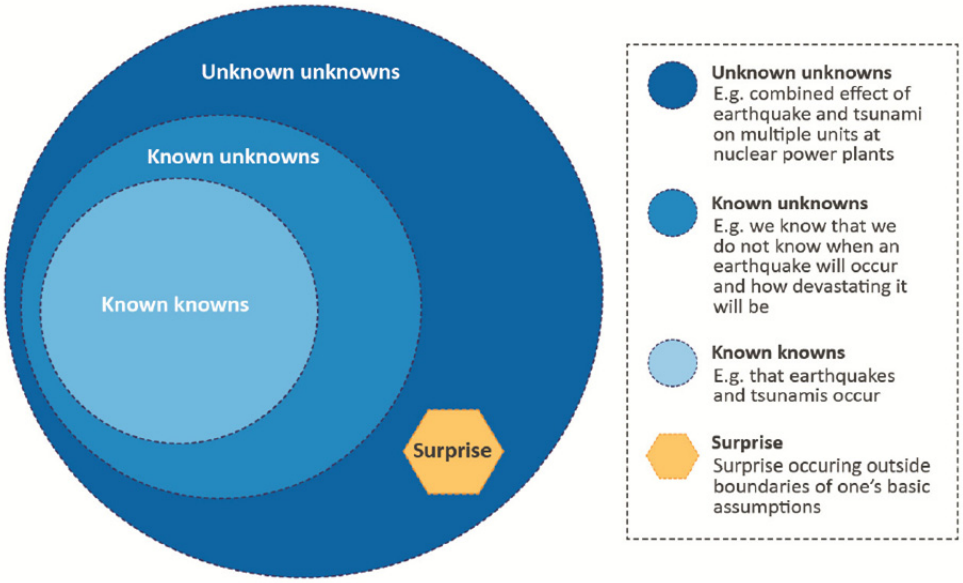


Figure 10. Known knowns, known unknowns, and unknown unknowns (adopted from Fig. 2.6-1 impact of unknown unknowns, Fukushima Di-ichi accident report, IAEA, 2015)

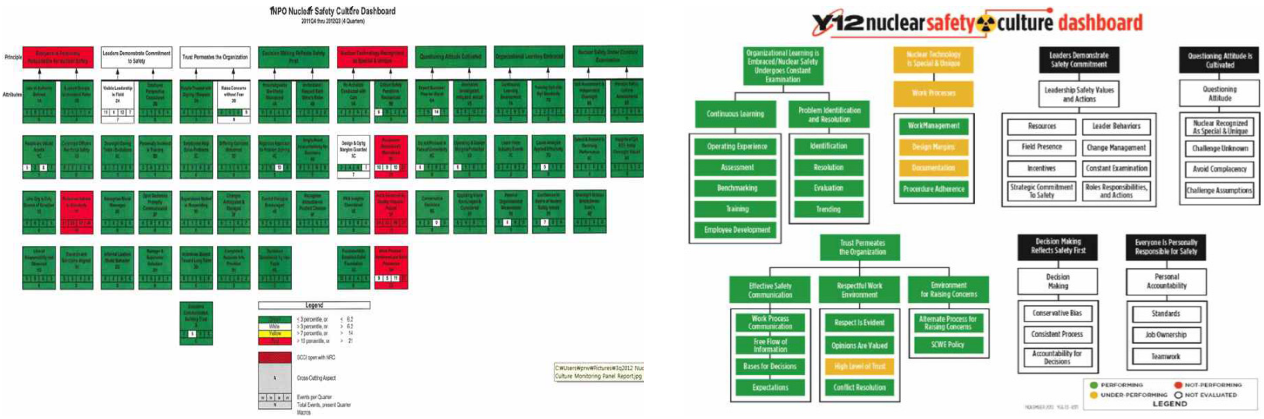
Lastly, safety culture should be approached in an integrated manner including cooperation with other fields in terms of problem identification and solution. The intangible aspect of base layer including belief and values cannot be identified, and problems are not easily revealed with just a study in a single field properly. Also, careful assumption and change need to be sought through cooperative efforts among disciplines in other fields. All actions and efforts to affect safety culture should be approached in combination with safety management, rather than separating them. Although the independent monitoring of safety culture is desirable, a technique using teamwork among the experts understanding technical background and psychological and behavioral science experts in the field concerned is essential upon an issue occurrence.

3.2 Two topics selected for human factors approach to safety culture

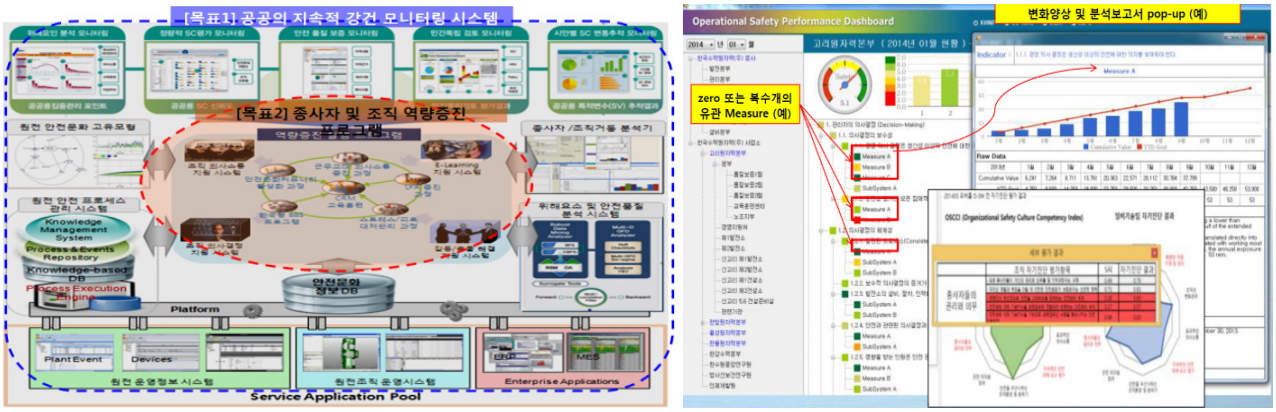
As for urgent tasks for a systemic approach to safety culture, the comprehensive information infrastructure providing entire approaches' foundation, a big data-based monitoring management and safety culture capability management program can be proposed (Lee, 2014, 2015). The existing technological status to promote discussions and the discussion points to be suggested for concrete technical things are as follows:

3.2.1 An infra system for safety culture information

Even though safety culture can be represented by safety performance data collection, analysis and arrangement in the safety management field, the information suitable for safety culture goal cannot be managed with only the current safety management



(a) Samples of Y-12 national security complex dashboard (example)



(b) A conceptual scheme of safety culture information system and a sample dashboard (proposed)

(c) A sample monitoring interface of safety culture indices

Figure 11. An information system and a sample dashboard for safety culture (adopted from Lee, 2015)

system data and function. Safety performance information including simple failure or injury can be utilized to reveal safety culture results, but it really lacks for the purpose of identifying the need for concrete intervention and engineering effect. Based on recently developed ICT technology, the modeling of company's production process and modeling of business (BPM: business process management) and computerized infrastructure (ERP: enterprise resource planning) establishment are diffused. On the basis of such a trend, the foundation for identification and intervention of safety culture is laid. In the nuclear field, the establishment of safety culture infrastructure is actively recommended mainly by IAEA through implementation of IMS (integrated management system). The following is an example of a recently developed safety culture management system. Figure 11 has illustrated the concept design similar to the management system developed in the nuclear filed with the U.S. Y-12's practical work screen.

The information of workers and stakeholders can be acquired using existing ERP/BPM-based technology as safety culture information infrastructure. By combining rapidly developing smart-phone and IoT technologies recently, infrastructure, through which safety culture information can be acquired from the behaviors of works and an organization, and monitoring and feedback can be conducted on the basis of various hypotheses, seems to be easily built.

Safety culture is not managed by single/simple scale value, but can be grasped through interpretation on various topics and perspectives on the acquired information. This is called *people analytics* by which big data-based humans' (group's) behaviors are assessed and predicted. It shows a rapid development as a future's core technology led by Google. In the R&D of safety culture, the monitoring process of acquiring and interpreting safety culture information, and various safety culture activity results can easily receive feedback (see Figure 12). Safety culture is not unified, and the perspectives required to manage it should be different. Therefore, a method to manage through dashboard for workers in various positions and fields needs to be developed. Contents and forms required for a variety of stakeholders (for example, relevant people under the ISO23000 standard) beyond the workers within an organization are also offered. As generally conducted in big data technology, a new development mode formed autonomously in a steadily complemented mode can be expected through onsite feedback, rather than through theoretical development in terms of the hypotheses and scale applied to the monitoring and management of safety culture.

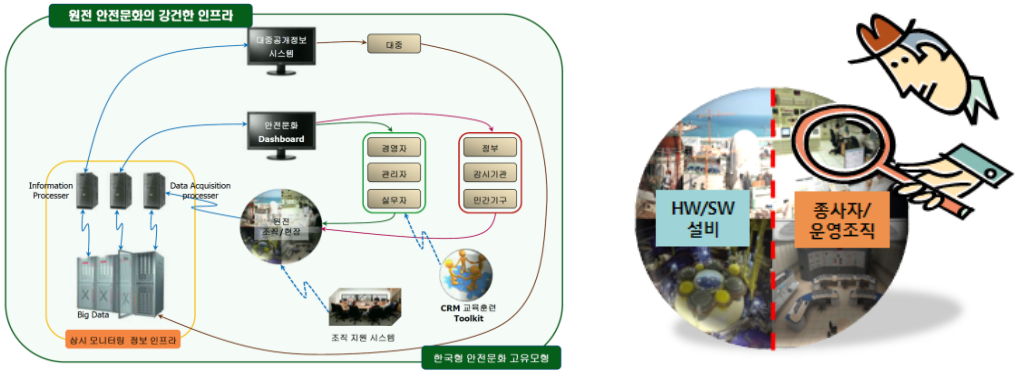


Figure 12. A conceptual scheme for safety culture monitoring and feedback (adopted from Lee, 2015)

3.3 Competence management for safety culture information

The urgent task in human factors engineering to solve the issues of safety culture is to secure concrete competence of relevant factors including individual, team and organization. Although the results and improvement methods at worker's personal level in relation with job and the job environment improvement in the safety management field have been continuously offered, a

method to build new comprehensive competence is needed at safety culture level. It is urgent to secure competence that can take managerial intervention at proper level in the actual work behaviors, such as teamwork, communication, safety decision making, leadership, and discord/conflict.

If safety culture information infrastructure is built, as mentioned in the previous section, not only the acquisition and analysis of a production system, but stakeholder's behaviors, are possible. Therefore, the information of competence improvement completing a safety culture work system is utilized. The following Figures 13 and 14 shows the monitoring and competence improving system for nuclear power plant's safety culture enhancement.

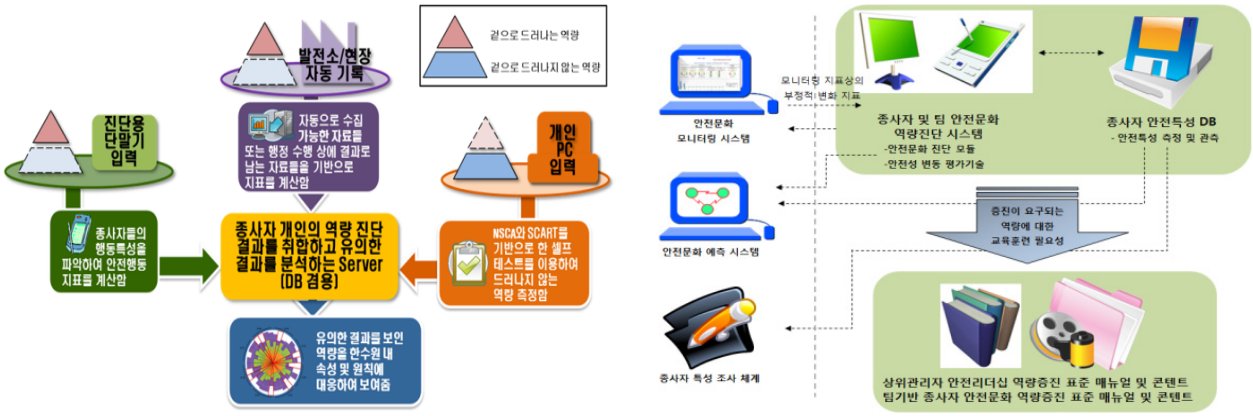


Figure 13. A Scheme for safety culture monitoring and competence management (adopted from Lee, 2015)

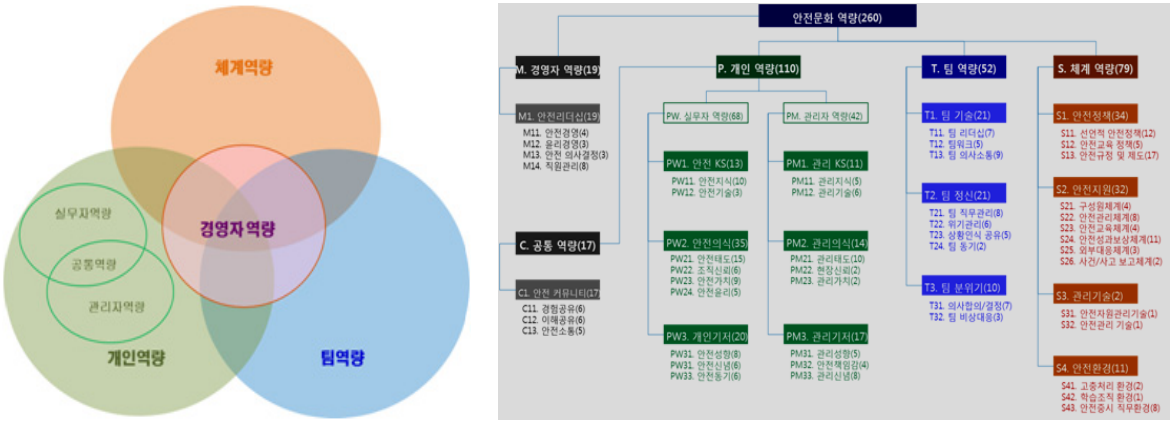


Figure 14. A scheme for safety culture competences (adopted from Lee, 2015)

Safety culture competence can be classified into individual, team and system competences, and the development of the monitoring logic and enhancement tool/program is urgent for each detailed item. The following figure shows a concrete example of safety culture competence items, and actually presents nuclear power plant workers' competence list (Jang et al., 2015). According to recent OECD recommendation, the NCS (National Competency Standard) is set up for overall occupational types of workers in Korea, and safety culture competence is in the same context.

4. Conclusion and Discussions

This study conducted a fundamental review on whether safety culture is a task of human factors engineering to seek an approach from the human factors engineering perspective on safety culture task, and review on various perspectives and approaches currently making up safety culture. This study actually discussed the concept and tasks of starting point to effectively deal with safety culture in human factors engineering solving safety issues from the given human factor perspective through a systemic approach. The man-machine system concept, the existing paradigm of human factors engineering, was expanded, and the definition of socio-technological system was adopted, and human factors engineering approaches on safety culture examining the expanded interactions were discussed in this study. This study presented the establishment of a safety culture information system for safety culture as a proposed topic, and development of detailed safety culture competence items, linkage of these and enhancement tasks.

As safety culture is frequently raised as a cause of an accident, the true nature of a problem is avoided, or actual countermeasures are delayed in many cases. The reason is that the concept of safety culture is still uncertain, and its true nature is ambiguous. However, if a concrete engineering method is acquired, disputes on uncertainties arising from safety culture can be solved. This can be referred to in overcoming a trend of using safety culture as a vague meaning thoroughly questioning worker's responsibility, as well as an existing situation in which inefficient dispute on comprehensive ethical demand, a concrete subject or result continues, due to a vague action.

Human factors engineering has built a practical methodology aiming at ensuring system effectiveness to increase human values according to technological development. To play such a role continuously in the 21st century, it should solve a new challenge of safety culture. A human factors engineering approach on safety culture needs to be materialized through many papers presenting the various trends, concrete tasks and R&D direction of safety culture.

Acknowledgements

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