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Development of KSCI Extended Index (KSCI-SMART) for Smart Safety Culture Diagnosis

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Abstract

As the integration of Smart Safety technology into industrial sites accelerates, driven by the Fourth Industrial Revolution and digital transformation, the safety management paradigm is shifting toward a data-driven intelligent framework. While these advancements contribute significantly to reducing critical disasters, they also introduce new cultural challenges, including technological dependency, digital fatigue, and privacy concerns. The existing human-centered Korean Safety Culture Index (KSCI) faces clear limitations in diagnosing these evolving characteristics of a smart safety culture. To address this gap, this study develops the "KSCI-SMART" (KSCI Extended Index), which aligns with government policy directions and comprehensively reflects technology-based characteristics. Through an extensive literature review, an integrated model was designed by adding the key variable of smart safety technology while maintaining the original KSCI structure. This model multi-dimensionally measures workers' attitudes toward technology acceptance, system trust, and the establishment of a Data-Based Ethics Culture. The findings suggest that the success of a smart safety culture depends more on workers' trust than on technical performance. Consequently, this study proposes institutionalizing the "Declaration of Non-Punitive Use of Data" as a prerequisite for KSCI certification and mandating Digital Literacy education for elderly workers. These measures are essential for fostering a sustainable and inclusive smart safety environment in the digital era.

Keywords: Smart Safety technology, KSCI-SMART, Data-Based Ethics Culture, Digital Literacy

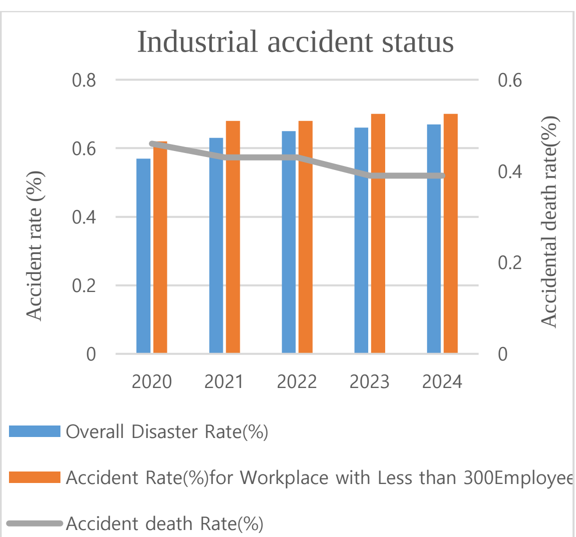
JEL Classification Code: J28, O33, M54

1. Introduction

1.1 Research Background

Recently, the introduction of smart safety technologies has been rapidly spreading in industrial sites due to the influence of the 4th industrial revolution and digital transformation. Advanced technologies such as IoT sensors, wearable devices, and Toolbox Meeting (TBM) platforms greatly contribute to detecting and preventing industrial accidents in advance, and are transforming the existing human-centered safety management method into a data-based technology-centered system. This technology-centered transition has both positive effects and causes new types of safety culture challenges. On-site workers are facing new cultural phenomena that have not been covered in existing safety culture, such as increased dependence on technology, digital fatigue from real-time data monitoring, and trust in system errors or malfunctions.

In order to respond to these changes and dramatically reduce industrial accidents, the government established a roadmap for reducing major disasters in 2022, setting a goal of lowering the industrial accident fatality rate per 10,000 workers to the OECD average level of 0.29 by 2026. Accordingly, the Occupational Safety and Health Agency is focusing on expanding the supply of smart safety devices and establishing a technology-based safety management system. In addition, KSCI (Korea Safety Culture Index) has been applied and distributed as a representative tool for objectively diagnosing the level of safety culture in the field



Source: https://www.index.go.kr/unify/idx-info.do?idxCd=5040

Figure 1: Industrial accident status

Table 1: Fatality Rate Statistics by year

article / year	Industrial accident fatality rate per 10,000 workers	Year-on-year increase/decrease in accident death rate
2020	0.46	0.0
2021	0.43	-6.5
2022	0.43	0.0
2023	0.39	-9.3
2024	0.39	0.0

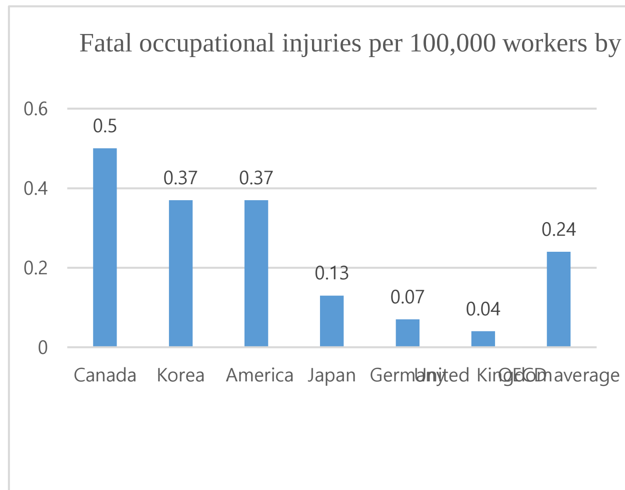


Figure 2: Fatal occupational injuries per 100,000 workers by economic activity

As shown in Table 1 and Fig. 2, the level of industrial accidents in Korea is still below the average of advanced OECD countries, and innovative technology-oriented safety management innovation and new safety culture diagnosis tools are essential to achieve the goal. Existing KSCI is a human-centered indicator designed around five key variables: safety leadership, safety behavior, safety support system, safety training, and safety communication.

1.2. Issues Raised

Amid changes in the technology-oriented industrial environment, the limitations of diagnosing the characteristics of smart safety culture are clear only with the five human-centered variables of the existing KSCI (safety leadership, safety behavior, safety support system, safety training, and safety communication).

In particular, the introduction of advanced technologies such as AI-based risk prediction systems, real-time monitoring of workers through wearable equipment, and smart construction robots has been accelerating since the 2020s in construction and manufacturing sites. Beyond simply reinforcing safety equipment, these smart safety technologies are fundamentally changing the safety management paradigm from 'post-response' to 'preemptive prevention and prediction'. Therefore, how much trust, active use, and participation in data-based decision-making have become key elements of safety culture, but existing KSCI has limitations in not covering new cultural challenges such as attitudes toward technology acceptance, system reliability, and digital fatigue. In conclusion, the development of KSCI Extended Index (KSCI-SMART), which conforms to the government's digital safety policy direction and can comprehensively diagnose technology-based safety culture characteristics is required.

1.3. The Purpose of Research

The purpose of this study is to supplement the limitations of the existing KSCI and present the direction of the extended indicator (KSCI-SMART) that can reflect the impact of smart safety technology on the safety culture of the organization.

First, it analyzes the factors that smart safety devices and systems affect workers' safety behaviors and organizational culture.

Second, we derive new variables and sub-items that expand the structure of the five variables of the existing KSCI (safety leadership, safety behavior, safety support system, safety training, and safety communication) by reflecting the characteristics of smart safety culture.

Third, by presenting a questionnaire (draft) that reflects the characteristics of smart safety culture, we intend to provide basic data that can be verified empirically in the future KSCI reorganization. By presenting a basic model for a smart safety culture diagnosis system that combines technology and culture, this study is expected to be used as basic data for future major accident reduction policies and smart safety dissemination policies of the Korea Occupational Safety and Health Agency(KOSHA).

2. Theoretical Background

2.1. Evolution of Safety Culture Evaluation Indicators

Safety culture is commonly defined as the shared values, beliefs, norms, and behavioral patterns regarding safety within an organization. Although definitions vary across studies, the underlying aim remains consistent: to promote positive changes in workers' safety behaviors through cultural and organizational influence.

The Korean government has long pursued initiatives to strengthen safety culture, one of the most representative being the Zero-Accident Certification Program. This system incentivized workplaces to achieve designated accident-free periods by offering benefits such as public procurement advantages and other institutional rewards. However, over time, unintended negative consequences emerged. Some workplaces began concealing or underreporting industrial accidents in order to maintain their certification status. Due to these serious side effects, the program was officially abolished on January 1, 2019.

Following its abolition, there was a strong societal and institutional demand for an alternative framework capable of objectively evaluating and promoting safety culture within organizations. In response, the Korea Occupational Safety and Health Agency (KOSHA) introduced the Safety Culture Certification System, designed to support workplaces in assessing their cultural strengths and weaknesses, while encouraging sustainable improvements. Despite various national efforts aimed at preventing industrial accidents, the recurrence of similar types of incidents highlighted the limits of technical countermeasures alone.

Recognizing this, the government shifted its focus toward fostering self-improving organizational safety cultures. This led to the development of the Korean Safety Culture Index (KSCI) in December 2023, which provides a standardized tool to evaluate safety culture by incorporating workers' participation, managerial practices, and the overall organizational environment. KSCI has since become an essential instrument for diagnosing cultural factors that influence accident prevention and overall safety performance in workplaces.

2.2. Structure of KSCI

The Korea Safety Culture Index (KSCI) is an index used and distributed by the Korea Occupational Safety and Health Agency (KOSHA). KSCI is used to objectively diagnose the level of safety culture within an organization by easily and simply measuring a company's safety culture and providing the results in the form of standardized reports. Ultimately, this indicator aims to prevent safety accidents and disasters through problem improvement. KSCI is designed to measure safety culture around the following five key variables:

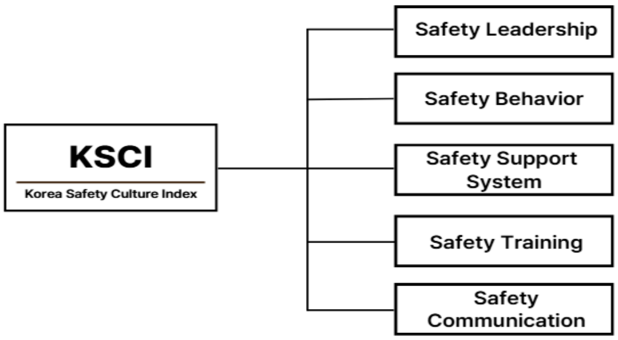


Figure 3: KSCI Five Variables Structure

Measurement questions consist of basic (18 questions) and extended (48 questions). KSCI's core goal is to standardize the components of safety culture that are commonly applicable to workplaces in all industries, and to provide diagnostic tools necessary for workplace members (managers, managers, workers, etc.) to check and improve the level of safety culture together.

2.3. The Impact of Smart Safety Technology on Organizational Culture

Smart safety technology encompasses AI-based predictive analysis, monitoring and warnings (including wearables), and risk zone control systems using robots. These technologies have brought about fundamental changes in the way industrial sites perceive risks. If existing safety management mainly relied on follow-up responses after accidents or worker experience information, smart safety technology enables objective data-based risk recognition and response in real time. These changes speed up the organization's risk response and convert the communication structure for safety from the existing hierarchical reporting system to a data-based horizontal warning and cooperation system. In this way, smart safety technology begins to form new safety norms, affecting the flow and authority of information within the organization.

Smart safety technology has several positive effects on safety behavior change. First, real-time data helps workers learn and settle safety behavior repeatedly by providing immediate feedback immediately after action. For example, if a wearable device immediately warns of an inappropriate posture or access to a dangerous area, the worker immediately corrects the inappropriate behavior. Second, smart safety technology lays the foundation for leadership by increasing the objectivity of safety management. Management can decide on safety investments and improve the system based on objective data rather than subjective reports or judgment of field managers. This can decisively contribute to solving the problem of insufficient safety management systems, which are often pointed out in KSCI diagnosis, and securing the execution power of the safety management system. Objective data clarifies where to take responsibility in the event of a safety problem and provides the logical basis for finding system improvements.

However, smart safety technology poses new ethical issues such as transparency, privacy, and surveillance. Wearable devices, etc., generate an ethical problem of personal privacy infringement by collecting workers' biometric data and location information in real time, which can lead to serious rejection and workers' resistance to technology. If smart safety technology data is used as a means of punishment or control for workers' deterioration of workability, failure to comply with safety instructions, workers intentionally avoid witnessing dangerous situations or reporting accidents in case of accidents, fearing that their biometric data or real-time location information will be recorded in the system. This consequently reduces the effectiveness of the safety system and leads to paralysis of the organization's risk perception ability. In addition, smart safety technology essentially requires the user's digital literacy. This can deepen the information gap for certain groups, such as elderly workers or workers at suppliers with low technology access and educational opportunities. If this gap is not resolved even if smart safety technology advances, safety information at the site is concentrated only on managers or skilled workers, and the vulnerable group becomes more vulnerable to safety information.

2.4. Smart Safety Culture and Technology-Based Safety Behavior Concepts

The spread of smart safety technology adds a new dimension of technology acceptability and data trust to the components of safety culture. Smart safety culture can be defined as the totality of the values, beliefs, and actions of members of the organization that occur in the process of using technology beyond simply introducing advanced equipment. This includes the area of technology-human interaction that the existing human-centered safety culture did not deal with. The smart safety culture encompasses two key concepts.

1) Technology Acceptance and Trust

In order to induce technology-based safety behavior, the technology acceptance attitude of members of the organization is essential. This is determined by the degree to which workers perceive smart devices as useful and easy to use (Davis, 1989's Technology Acceptance Model (TAM) applied mutatis mutandis). In particular, in the safety field, the level of system trust in the accuracy of wearable devices and ease of coping with errors determines whether or not to use technology. If trust is low, the effectiveness of safety technology is greatly reduced by ignoring the risk warnings or data-driven instructions presented by the technology.

2) Data Ethics and Transparency

The most important feature of smart safety culture is the formation of data-driven ethical norms. As mentioned in 2.3, smart safety technologies imply real-time surveillance possibilities. Therefore, workers trust the system and voluntarily provide data only when an organization complies with a clear commitment (Data Policy) to use data transparently only for safety promotion purposes, to thoroughly protect personal privacy, and not use collected data as a means of punishment. KSCI-SMART should contribute to minimizing the negative cultural impact of technology introduction by measuring the level of practice of this data ethics and transparency.

These new components of smart safety culture (technology acceptance, system trust, data ethics, and transparency) cannot be diagnosed with only five variables of the existing KSCI, so they serve as a key theoretical basis for the development of KSCI Extended Indicator (KSCI-SMART).

3. Research Methods

This study aims to supplement the limitations of existing KSCI and present the theoretical structure and measurement item (draft) of KSCI Extended Index (KSCI-SMART) that reflects the cultural impact of smart safety technology. Therefore, the methodology of this study focuses on the process of deriving theoretical variables through literature review and academic procedures to secure the importance of the derived variables and the validity of the measurement items.

3.1. Research Design and Procedures

This study consists of the following detailed procedures.

① Determining theoretical variables: By examining the structure of existing KSCI and prior research literature on smart safety technology, one key expansion variable (smart safety technology) to be added to KSCI-SMART is determined, and the conceptual definition of variables and sub-measurement areas are specified.

② Theoretical model presentation: As a variable related to KSCI's existing structure and newly added smart safety technology, the smart safety technology indicator structure is presented in the form of a hypothetical model.

③ Presenting the KSCI-SMART Final Indicator Structure: Present the structure of the final KSCI-SMART indicator reflecting the expansion variables and integrated questions, and derive the research results.

④ KSCI-SMART Score Measurement Detailed Step: Establish a score measurement criteria for the set survey and link the average score for each item according to the score to apply it to the Hudson Safety Culture Step 5 to determine the current location of the organization.

3.2. Derivation and Conceptual Definition of KSCI-SMART Extension Variables

3.2.1 On-site Implementation and Capacity Building

This sub-variable measures the degree to which workers recognize the usefulness of smart equipment, trust the accuracy of the system, and have the individual's digital capabilities necessary for the use of the equipment. This integrates the concept of usefulness and ease of use of the technology acceptance model (TAM) into the safety field and is an essential prerequisite for the successful settlement of technology introduction.

Table 2: Field implementation and capacity building measurement area

Subfactor	Measurement Areas
On-site implementation and Skill development	Rules of use of smart safety equipment and regular inspection/management
	Understanding and systematic use of smart safety data, strengthening organizational capabilities
	Fast and reasonable feedback, action, and continuous improvement system

3.2.2. Data Ethics

This sub-variable measures the level of ethical responsibility practice and the reliability of workers to resolve privacy violations, smart safety data monitoring concerns, and prohibition of use for punishment purposes that occur in a real-time data collection environment. This is the most important factor in determining the sustainability of the smart safety culture, and the compliance with the principle of non-punitive use of data is the key

Table 3: Data Ethics-Based Measurement Area

Subfactor	Measurement Areas
Based on data ethics	Declaring the principle that data shall not be used for personnel purposes such as monitoring or punishment
	Measure the level of perceived psychological stability based on the awareness that personal information and work efficiency are not monitored
	Measurement of the level of an ethical, horizontal, and open communication culture in which opinions can be freely exchanged and discussed regardless of position or age

3.3. KSCI-SMART Score Measurement Steps and Safety Culture Level Diagnosis Method

The score measurement step for the questionnaire answered is set to 1 to 5 points for each question on a 5-point Likert scale, and the score for each sub-factor is calculated for all questions on the basic/extended questionnaire. This score is the average of the item scores belonging to the factor. The measurement steps are shown below.

Step 1) Collect response and check scale

Respondents typically respond to a 5-point Likert scale for each question.

Step 2) Calculate the average score for each factor

To calculate the score for each subfactor, we use the factor score calculation formula:

$$\text{Factor Score} = \frac{\sum X_i}{n}$$

Where:

X_i = individual item score

n = number of items within the factor

This score represents the mean value of all items belonging to the corresponding factor.

Example:

If a factor consists of 13 safety leadership items and the total sum of the item scores is 52, the factor score is calculated as follows:

$$Safety\ Leadership\ Score = \frac{52}{13} = 4.0$$

Step 3) Derivation of safety culture level

The results obtained through the Likert 5-point scale-based questionnaire are applied to Hudson's safety culture 5-stage model to derive an average score for the variable

Table 4: Hudson Safety Culture Five-Step Model Average Score

The Evolution of Hudson's Safety Culture	Key Features	Score
1. Pathological	Who cares as long as we're not caught	1.0~2.0
2. Reactive	Safety is important, we do a lot every time we have an accident	2.1~3.0
3. Calculative	We have systems in place to manage all hazards	3.1~4.0
4. Proactive	We work on the problems that we still find	4.1~4.5
5. Generative	Safety is how we do business round here	4.6~5.0

Step 4) Setting Improvement Goals

Based on the scores measured on Hudson's safety culture five-stage model, we set specific goals for moving to the next stage.

Table 5: Hudson Targets for Step-by-Step Improvement

Stage	Improvement Goals (Next Stage)
1. Pathological	Avoiding the disregard for safety and providing a minimal framework for response and action in the event of an accident
2. Reactive	Clearly defining and documenting safety through rules and procedures
3. Calculative	Predicting potential hazards using safety data and implementing proactive measures
4. Proactive	Integrating safety into all decision-making processes and fostering a culture of continuous learning

Table 6: Hudson's Step-by-Step Improvement Challenges

Stage	Improvement Goals (Next Stage)
1. Pathological	Clarifying safety responsibilities and allocating resources for safety activities to ensure factor scores exceed 2.0
2. Reactive	Focusing on activities designed to elevate factor scores to 3.0 or higher

3. Calculative	Strengthening worker suggestion and feedback systems to ensure factor scores reach 4.0 or higher
4. Proactive	Internalizing safety throughout the organizational culture while maintaining all factor scores at 4.5 or higher

4. Development of KSCI-SMART

4.1. Derivation of the composition and measurement items of KSCI-SMART extension indicators

The KSCI Extended Indicator (KSCI-SMART) presented in this study maintains the structure of five key variables of the existing KSCI, but adopts an 'expansion and integration model' that adds one new variable specialized in the smart safety technology introduction environment.

① Variable expansion: One new variable of 'smart safety technology' derived from the theoretical background is added.

② Integrating existing variables: Expand the measurement range of existing indicators by integrating new measurement elements into variables closely related to smart technology among the five variables of existing KSCI.

Table 7: KSCI-SMART Components

Composition of KSCI-SMART Survey Indicators	Classification of Variables	Linkage with Existing KSCI Variables
The Five Core Variables of the Existing KSCI	Human - centered	Safety Leadership Safety behavior, Safety Support System Safety Training Safety Communication
An Additional Extended Variable	Technology Convergence and Data Ethics	Smart Safety technology

4.2. Basic Direction of KSCI-SMART Indicator Configuration

Present KSCI-SMART measurement item (draft)

The scale of the presented KSCI-SMART model uses a 5-point Likert scale (1: Not at all ~ 5: Very much so).

Table 8: Five-point Likert Scale

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
①	②	③	④	⑤

A. New Expansion Variables: Smart Safety Technology

Measures the attitude of workers to accept technology, trust in the system, and the capacity of individuals and organizations to utilize the technology following the introduction of smart safety technology

Table 9: Subvariable Field Implementation and Capacity Building Questionnaire

No.	Question
1	We always adhere to the usage rules and operating procedures for smart safety equipment.
2	Our company constantly inspects and manages smart safety equipment to ensure it functions properly
3	Our company's safety training is updated annually with essential content, based on the results of the previous year's safety performance analysis
4	Our company provides systematic training to all members, including contractors, on how to understand and utilize smart safety data
5	Our company provides separate, customized training on the use of smart safety equipment for elderly workers or those unfamiliar with the technology
6	I receive prompt and reasonable feedback and action from the company regarding improvement ideas for hazards detected by smart safety equipment and systems

Table 10: Subvariable data ethics-based questionnaire

No.	Question
1	Management clearly declares the principle that smart safety data will not be used for personnel purposes, such as worker surveillance or punishment
2	Managers maintain fairness when using smart safety data and apply technology-based feedback equally to all employees
3	Even when wearing smart safety equipment, I do not feel that the company is monitoring my personal information or work efficiency
4	I can report hazards detected by the system without fear that smart safety data will be used against me

5	Regardless of rank or age, we can freely exchange opinions and discuss the implementation and utilization of smart safety technology

5. Conclusions and suggestions

5.1. Research Summary and Academic Implications

This study presented the theoretical structure and measurement items of KSCI's extended index to capture changes in industrial sites that are accelerating technology introduction in the trend of the 4th industrial revolution, overcome the human-centered limitations of the existing KSCI (Korean Safety Culture Evaluation Index), and paid attention to both sides of the negative aspects of technology rejection due to privacy infringement, control measures, and data transparency violations.

The study focused on the ambivalence that the introduction of smart safety technology has a positive effect of improving objectivity and immediate feedback, while simultaneously causing serious ethical challenges such as monitoring concerns, data misuse, and technology rejection. To diagnose this problem, KSCI-SMART proposed an extended and integrated model that adds one key expansion variable called 'smart safety technology' in addition to the five variables of the existing KSCI. As sub-variables of the added variable, 'field implementation and capacity building' and 'data ethics base' can be added to derive opinions from management, managers, and workers on smart safety technology through survey items.

By presenting an extended and integrated model called KSCI-SMART that integrates the ethical and cultural aspects of technology introduction into the existing human-centered safety culture evaluation index (KSCI), it has laid the foundation for academic discussions on the paradigm shift in safety culture. It provided an in-depth understanding of the relationship between technology and safety by suggesting a new sub-variable of data ethics that can academically capture the objectivity/immediateness of the introduction of smart safety technology, privacy infringement, and technology rejection.

5.2. Policy Suggestions

KSCI-SMART presented in this study is a key policy tool for the successful implementation of the critical disaster reduction roadmap, and the following specific suggestions are presented.

First, in order to institutionalize data ethics policies and reflect KSCI, the government (Ministry of Employment and Labor, Occupational Safety and Health Agency) should specify 'declaration of data non-punitive use' as a prerequisite for KSCI certification for companies introducing smart safety technology. Furthermore, it is necessary to integrate KSCI-SMART's 'data-based ethical culture' item into the KSCI official indicator to quantitatively evaluate whether organizations that have introduced smart safety technology practice ethical responsibility.

Second, in order to solve the problem that smart safety technology deepens the digital divide, it is necessary to mandate safety training of digital literacy education. In particular, customized digital capacity building education for elderly workers and workers of partner companies should be strengthened as a key item of the 'safety training' variable.

Finally, support for data-driven safe communication systems should be expanded. Government support for building related software and platforms should be expanded to prevent smart safety data from simply being concentrated on managers and to be used as a tool for horizontal risk prediction and consultation between workers and managers.

5.3. Limitations of Research and Future Research Direction

This study is meaningful in that it presented the theoretical foundation and structure of KSCI-SMART through literature review, but has the following limitations.

First, because the concept of 'smart safety technology' develops very broadly and rapidly, certain sub-areas defined and measured in the study may not cover all the actual state and effects of smart technology introduction in the field.

Second, there may be limitations in generalizing KSCI-SMART indicators if there are subtle differences in special safety risk factors or organizational culture in industries or sites where KSCI-SMART is applied, or if the study subject does not represent the entire industrial site.

Third, in this study, the process of determining items through content validity, such as AHP analysis and CVR, was based on literature review and theoretical logic, so the reliability was low and was not a result of rigorous statistical verification.

In the future research direction, a statistical analysis is conducted based on the results of a survey of workers using smart safety equipment in the field after securing the validity of the content through experts and revising the index, and strictly verifying the structural validity and reliability of KSCI-SMART indicators. A follow-up study is needed to provide practical consulting and utilization models for improving safety culture in actual workplaces, such as guiding improvements and promoting safety activities, and to periodically update and expand measurement items to cover rapidly changing new smart safety technologies.

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