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A SURVEY ON THE SAFETY SYSTEM MATURITY LEVELS OF ELECTRONICS MANUFACTURERS IN SOUTH KOREA

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The main objective is to identify the level of advancement of safety systems in various levels of smart factories. Smart level verification systems are being implemented in Korea, but safety systems are not paying much attention to smart factory level checks. Using a checklist, nine Korean electronics manufacturing enterprises checked their level of safety system. The checklist consists of 142 items, which were divided into four dimensions (laws and certifications, safety designs and configurations at the facilities, safety devices and guards, and maintenance and training). As a result, a high-ranked enterprise in smart factory level showed excellence in the safety system maturity level as well. Compared to the level of the company's smart factory, the level of advancement of safety systems has been confirmed to be lower.

Key words: electronic manufacturing enterprise, smart factory, safety system assessment checklist, safety system maturity

INTRODUCTION

Globally, more than two thirds of enterprises either operate smart factories at present or plan to construct a smart factory [1]. This is because intelligent manufacturing systems such as Smart Factory generate a lot of profits (increase productivity, reduce costs, etc) for companies [2]. In addition, a plan was announced in South Korea to institute a "Public-Private Joint Smart Factory Promotion Team" and build about 30,000 smart factories, merging ICT (Information communication technology) with the manufacturing and production processes of Small and Medium-sized Enterprise by 2025 [3]. Various maturity models have been developed to systematically evaluate the state of the company in its transition to smart factory. A maturity model is a tool for conceptualizing and measuring the maturity of an organization or process with respect to a particular target state [4]. The maturity assessment aims to identify the current state in the process of reaching the target stage of the entity. There are models to evaluate readiness or maturity associated with Industry 4.0.

In Germany, the "Readiness Model" (RM) evaluates the Industry 4.0 maturity of enterprises in six dimensions, one of which is titled, "smart factory" [5]. The RM helps identify the level of smart factory maturity, however it is not suitable for assessing the advanced safety system of enterprises because safety is not a primary concern with the RM. In addition, there are various models [4, 6, 7, 8], but there are no detailed items about the safety system. It is necessary to include safety systems in the maturity assessment. This is because if industrial 4.0 related technologies are used for safety, this will lead to improvement of process safety [9]. Furthermore, smart factory is characterized by new types of processes,

technologies, or organizational change. Such system changes bring about new and emerging risk factors, and it is essential to identify and prevent these risks [10, 11]. Also, system changes affect other subsystems and processes. It means that advanced safety system should not be carried out separately because it interacts with other systems [9]. Besides, the transition to smart factory may require different strategies depending on the size of the enterprise. Some studies [3, 12] show that safety management of different approaches is needed depending on the size of the enterprise.

In South Korea, the "Smart Factory Level Verification System" (SFLVS) has been in effect since 2019 [13]. The system classifies the level of an enterprise's smart factories with 44 items, but there are only two items regarding safety. Obviously, it is insufficient to evaluate the advanced safety system.

In addition, other studies [14-16] concerning smart factory risk management, do not provide safety system details sufficiently. As mentioned above, the current models were to examine, with minimal attention paid to the safety system, the different levels of smart factory.

The present study aims to check the advanced safety system in smart factories through a checklist and to identify that the same level of safety systems are established. As the first step, advanced safety system was defined based on smart factory evaluation models. Afterwards, the checklist was made based on laws and standards related to prior research and existing smart factories. Finally, the checklist was applied to nine electronic manufacturing workplaces to evaluate and compare their smart factory level and degree of advanced safety system.

Table 1: Comparison definitions of safety system maturity and smart factory level verification system

	Checklist (Safety 'n')	Smart Factory Level Verification System (Levels) [17]
Safety IV (Level 4-5)	Component failures, exchange cycle prediction and proactive protection measures through big data and AI technology, autonomous safety checks of CPS (self-compatibility declaration)	Autonomous operation from monitoring to control to optimization (Level 5) Simulate to optimize proactive response and decision making (Level 4)
Safety III (Level 3)	Facility/automatic control through abnormal condition monitoring, history management, and facility life predictions	Analyze and control the collected information (Level 3)
Safety II (Level 2)	Monitoring the safety of machinery and equipment (including module facilities) and workers	Enables real-time monitoring of production information (Level 2)
Safety I (Level 0-1)	Safety standards for machinery and equipment (including module facilities) in both domestic and foreign cases	Partial standardization and performance information management (Level 1) Unrecognized and ICT not applied

METHODS

Safety system maturity levels

In this study, the word "safety system maturity" is used to describe the "advanced safety system". Previous models such as RM, SFLVS, are not suitable for the assessment of safety system maturity levels because their primary concern is to measure smart factory maturity, not safety. To check on safety system maturity, four levels were considered in this study. Table 1 shows the safety systems maturity levels in this study.

Safety I (=basic), the lowest level of safety system maturity, refers to the absence of ICT or compliance with safety standards. Note the three representative models above. They have a common feature of ICT; 1) the RM classifies six stages based on the three criteria (the degree of information technology, strategy, investment in Industry 4.0), 2) RAMI 4.0 indicates the importance of information exchanges and decision-making between layered production system structures [18], 3) SFLVS classifies enterprises with respect to ICT utilization in such a way that non-ICT applied enterprises are assigned into the lowest stages.

The Safety II to IV ranges are based on the SFLVS in Korea. Safety II (=intermediate 1) is associated with simple monitoring and data collection, and Safety III (=intermediate 2) with control and data analysis through monitoring. Safety IV (=advanced) includes proactive responses through simulations, real-time safety control through AI, capability of component life predictions using big data, and the autonomous safety verification of module facilities using cyber-physical systems.

In addition to ICT, continuous modularization and flexibility in manufacturing process is one of the key concepts of Industry 4.0. During modular facilities installations, problems are often observed at the interfaces between different modules [19]. Therefore, it is necessary to consider possible risk factors such as "facility modularization" or "module facility coupling." To ensure the safety

of flexible production systems is also one of key parts in the safety system.

Procedure for proposing the checklist

The procedure for the checklist construction is as follows. First, the checklist presented in earlier research [20], was reviewed and rearranged. It was then verified by experts working in the areas of IT and industrial machinery (e.g., automated guided vehicles, safety sensors, and circuits) for any missing items. Second, safety standards applied to key devices among smart factory construction facilities were reviewed. Those are on industrial robots, cooperative robots, conveyors, and automated guided vehicles. Then, the above items related to the safety system maturity were added to the checklist. Third, maintenance of facilities and safety education items were inserted to the checklist. Despite the significance of the safety management aspects, those were not contained in the previous study [20]. Relevant items were extracted from the KOSHA Guide [21]. Fourth, the checklist was finally reclassified as "Items via interviews and document verification" and "Items for on-site facility installation and status" for convenience of workplace survey. Finally, the final checklist consists of 142 items.

Checklist configuration

The dimensions and details of the safety system maturity level assessment checklist are shown in Table 2. The 142 items in the checklist are largely divided into four dimensions: 1) laws and certifications, 2) safety designs and configurations at the facilities, 3) safety devices and guards, and 4) maintenance and training. Again, the four dimensions can be subdivided into 21 subcategories. All the items belong to one of the four levels designated by Safety I, Safety II, Safety III and Safety IV, and each level has 90, 17, 20 and 15 items, respectively. From now on, we will refer to the four levels as "Safety n."

Table 2: Categories and detailed items of the safety system evaluation checklist

Dimension	Detailed item	References
Laws and certifications	Mechanical equipment	Occupational Safety and Health Act Article 34 (Safety Certification), Article 34-2 (Indication, etc. of Safety Certification), Article 35 (Reporting on Voluntary Safety Verification), Article 35-2 (Indication, etc. of Voluntary Safety Verification), Article 36 (Safety Inspections), Article 36-2 (Safety Inspections under Self-Inspection Program)
	Safety Control System	
Safety designs and configurations at the facilities	Information Operations Technology and Communications Network	Enforcement Decree of The Occupational Safety and Health Act Article 28-5 (Machinery, Tools, etc., subject to Voluntary Safety Confirmation), Article 28-6 (Harmful or Dangerous Machinery Subject to a Safety Inspection)
	Cooperative work safety	
	Modular Equipment	
	Control device (portable)	
	Safety guard	
Safety devices and guards	Safety device (sensor)	Enforcement Rules of the Occupational Safety and Health Act Article 124 (Application for Safety Inspection), Article 126 (Period of safety inspection and the method of acceptance and indication)
	Compliance with working regulations	
Maintenance and Training	No-manipulation indication	Notice on the procedure of safety certification and autonomous safety confirmation reports Safety Inspection Notice ISO 10218-1, ISO 10218-2, ISO TS 15066, ISO 13849-1 IEC 61508, IEC 60204 DIN EN 1525 DGUV 209-074 Industrieroboter Technical Standard for Driverless Industrial Trucks (S3-M-13)
	Safety monitoring	
	Energy release	
	Operation documents in the right place	
	Establishing maintenance regulations	
	Operation result record management	
	Establishment of Safety Education	
	Training Execution	
	Training Management	

Criteria for determining safety system maturity level

A criterion is required to assign the safety system maturity level to an enterprise. For each level, the safety system scores are calculated based on how many items in each level are satisfied. If the number of positive answers exceeds 60% of the total “Safety n” items, the “Safety n” are considered “satisfied” as expressed by Eqn. (1). In addition, if some of items are “cannot be answered” for some reasons, such as unknown information or the absence of a facility, those are excluded when scoring the safety system maturity level. If the answer is “partly satisfied”, the corresponding score for the item is multiplied by a weight of 0.5. Here, a borderline for the criterion of 60 was referenced from a previous study [20].

$$\text{Safety } n \text{ score} = \frac{(\text{Number of satisfied items}) + 0.5(\text{Number of partly satisfied items})}{(\text{Total number of safety } n \text{ items}) - (\text{Number of items that cannot be answered})} \times 100 \geq 60 \tag{1}$$

For example, if an enterprise gives 70 and 3 positive answers from 90 and 17 items in “Safety I” and “Safety II”, that means to a pass in “Safety I” and a fail in “Safety II” resulting in “Safety I” finally.

Application of evaluation checklist by safety system maturity level

The checklist was applied to nine enterprises, which are four large, three mid-sized, and two small-medium-sized enterprises. Details on the enterprises are summarized in Table 3. The nine enterprises chosen were either in smart factory operation or in preparation. By business type, these were two display manufacturers, one mobile phone manufacturer, one logistics enterprise, and two electronic component assembly enterprises. Notwithstanding small discrepancies in size and business type, the enterprises have several points in common: similar processes or equipment.

Table 3: Information on enterprises considered in this study

Name	Type of Enterprise	Size of Enterprise	Main Facilities
S1	Display manufacturing	Large	Industrial robot, conveyer
S2	Cellular phone manufacturing	Large	Industrial robot, conveyer, AGV, cooperative robot
S3	Manufacture of auto parts	Small	Injection molding machine, annealing machine, vibration melting machine
S4	PCB manufacturing	Small	Conveyer
S5	Manufacture of automated device protection	Small	Screen printer, chipmountor, reflow
L1	Display manufacturing	Large	Industrial robot, conveyer, AGV
L2	Logistics (loading)	Large	Conveyer
D1	Electronic component assembly	Medium	Industrial robot, conveyer, AGV,
D2	Electronic component assembly	Medium	Cooperative robot conveyer, AGV

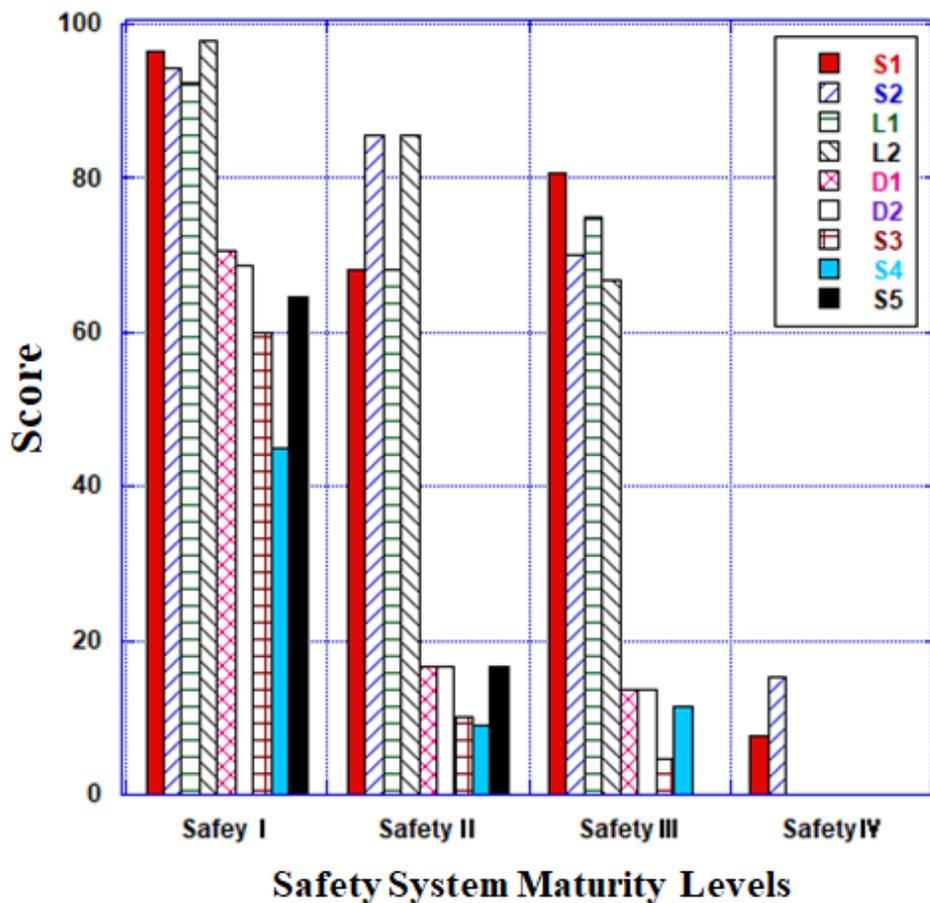


Figure 1: Safety system maturity level by workplace

Most of the items could be answered by research staff, however, some items required person-to-person interviews. For the items on devices and processes, some of all machinery and process were sampled and used to evaluate the safety system maturity level.

RESULTS AND DISCUSSION

Analysis of safety system maturity by sized of enterprise

The safety system maturity assessment results for the nine enterprises are shown in Figure 1.

Large enterprises (S1, S2, L1, L2) in this study passed the conditions of Safety I to III. The four enterprises have scores greater than 90 for “Safety I”, and the Safety II

scores of S2 and L2 are 15% greater than those of L1 and S1. The difference is because some safety circuits at S1 and L1 could not be checked and the job processes were not fully monitored. In addition, there was no separate safety network, which is related to a safety system including emergency stop function. To ensure the emergency stop function, redundant wiring or sensors are required. However, as complicated wiring for redundancy can cause a communication problem of emergency shutdown malfunctions, separate safety network should be equipped to prevent the problem [22]. In Safety III conditions, S1 received the highest score of 81. The superiority of S1 to the other large enterprises is found from data management. For example, S1 records and monitors the open-close histories of safety doors as well as persons entering and leaving dangerous zones. None of the enterprises have passed the condition of Safety IV yet, although, S1 and S2 seem to have Safety IV safety system maturity capabilities more than the other large enterprises.

All the medium-sized enterprises passed the Safety I. However, "Safety n score" in Safety I was approximately 20% lower than those of the large enterprises. The reasons are as follows; 1) it is not clear whether safety function-related circuits are configured, 2) safety certification components are not used, and 3) safety documents related to machines are not maintained. Moreover, all the medium-sized ones could not satisfy Safety II and III. Compared to the large enterprises, their deficiencies in Safety II and Safety III are: 1) safety function operation monitored, 2) safety system access management, 3)

safety data collected and utilized. Monitoring functions enable to detect abnormal signals from equipment/instruments and control via remote monitoring functions. Thus, these functions are important because it can prevent accidents in advance and enable more desirable safety management activities.

Among the three small enterprises, S3 and S5 satisfied Safety I conditions, but S4 did not. The low Safety I score of S4 is due to insufficient safeguards and a paucity of safety documentation at some facilities. Undoubtedly, any enterprises other than large enterprises could not reach this borderline of Safety II and Safety III. This result is attributed to limited ICT infrastructure facilities, more specifically, for safety functions (e.g., using a computerization system, limited monitoring). Since a majority of small businesses are in the beginning stage of ICT, that led to low safety system maturity level on the businesses.

Comparison levels of smart factory and safety system maturity

Figure 2 shows a comparison between the levels of smart factory and the safety system of the enterprises. The abscissa and ordinate represent the safety system maturity level and the smart factory level, respectively. It can be easily understood that the level of the safety system maturity of one enterprise is proportional to the corresponding smart factory level, however, the former appears somewhat less than the latter. It can be reasoned that safety systems are not considered as important as productivity.

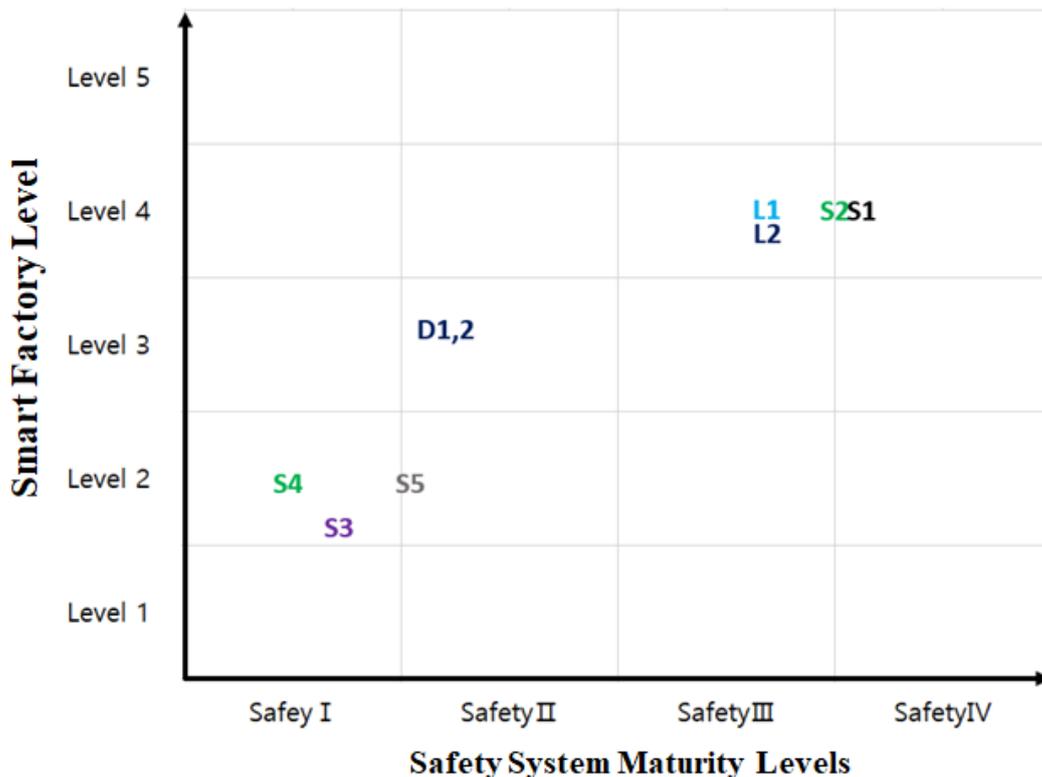


Figure 2: Comparison of levels between smart factory and safety system maturity

Large enterprises were positioned at level 4 in terms of smart factory and at Safety III in terms of safety systems. Small and medium enterprises were at basic levels (levels 1 and 2) in terms of smart factory, and their safety system maturity level was Safety I or less.

CONCLUSION AND RECOMMENDATIONS

Motivated by insufficient safety aspects in previously developed "smart factory level verification system (SFLVS)", this study confirmed the safety system maturity in South Korea's smart factories through a checklist. The checklist is made up of 142 items so as to evaluate key devices safety requirements as well as safety management in a smart factory. After constructing the checklist, it was applied to nine domestic businesses via staff interviews. This is the first attempt to compare smart factory levels with safety system levels for Korean electronic manufacturing enterprises, this showed that both are related to the enterprise size. From the result, it is revealed that the larger size and more advanced smart factory level, the higher safety system maturity level. This relation comes from ICT utilization, which is fundamental to both the smart factory level and safety system maturity. However, ICT utilization of safety systems is lower than the company's technology level. This is believed to be because safety systems are not considered in evaluating smart factory maturity. In the introduction of high-tech technologies, it is necessary to consider safety systems together to reduce the use of technology and errors. Through the developed checklist along with SFLVS, what needs to be done can be identified for enhancing smart factory level and safety system level. In this study, the maturity of the safety system has been confirmed for a small number of South Korea's smart factories, and a follow-up study on how to establish an effective safety system in smart factories is needed.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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