International Journal of Advanced Smart Convergence Vol.12 No.3 233-243 (2023)
http://dx.doi.org/10.7236/IJASC.2023.12.3.233

IJASC 23-9-27

The Validation Test process and CTE Suitability Evaluation based on IEC-61508 for Improving Safety and Reliability on Unmanned ICT Parcel Storage

Myung Sung Kim*, Young Min Kim**

** M.S. Candidate, Department of Systems Engineering, Ajou University, 206, World cup-ro, Yeongtong-gu, Suwon-si, Gyeonggi-do, Korea*
audtjddl200@ajou.ac.kr
*** Associate professor, Department of Systems Engineering, Ajou University, 206, World cup-ro, Yeongtong-gu, Suwon-si, Gyeonggi-do, Korea*
pretty0m@ajou.ac.kr

Abstract

In modern society, since the expansion of the e-commerce market and the spread of the pandemic, face-to-face business are gradually changing to non-face-to-face. In the logistics industry, the demand for unmanned courier storage is increasing due to lack of loading space from urbanization and courier theft accidents. As the demand for unmanned parcel lockers increases, improved functions such as food storage and efficient space loading are required. This study develops an integrated model-based evaluation procedure of product based on performance factors according to the IEC 61508 standard for newly unmanned parcel storage devices with active loading technology, and derive Critical Technology Element based on the product's core functions and performance goals. As proposing these research , We expect improve the safety and reliability of development targets by identifying and evaluating elements.

Key words: *Functional Safety, IEC-61508, CTE, Validation Test, Unmanned Parcel Storage*

1. Introduction

1.1 Background

Recently, domestic parcel delivery volume has been rapidly increasing, especially in the metropolitan area. Due to massive urbanization, 50.2% of Korea's total population lives in the metropolitan area. It makes a lot of courier orders [1]. Small-volume, frequent deliveries of small households due to the increase in e-commerce and the expansion of single-person households appear to had a significant impact on the volume of parcel delivery in the domestic metropolitan area. Figure 1 shows the sales trend of CJ Korea Express, one of the largest companies in the domestic delivery industry market. Looking at this graph, you can see that sales have increased by about 2.5 times the current courier sales in 2012 [2].

Manuscript Received: August. 22, 2023 / Revised: September. 2, 2023 / Accepted: September. 10, 2023
Corresponding Author: pretty0m@ajou.ac.kr(Young Min Kim)
Tel: +82-31-219-3949, Fax: +82-31-219-2334
Associate professor, Department of Systems Engineering, Ajou University, Korea

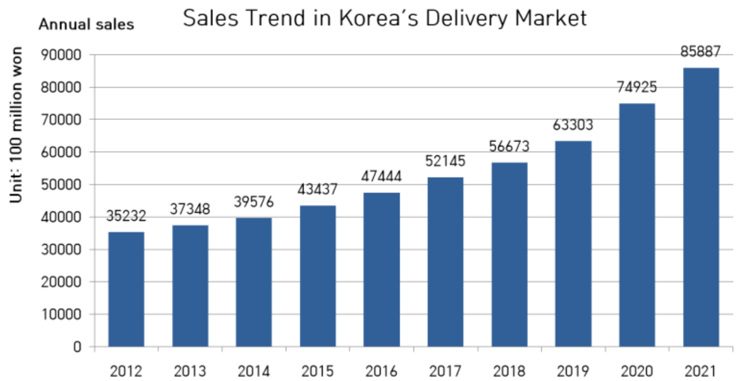


Figure 1. Sales trend in the domestic parcel delivery market [Unit: KRW 100 million]

As the volume of parcel delivery increases, many problems are occurring one after another. The lack of residential space due to massive urbanization, storage space for parcels is becoming scarce, which raises the risk of exposure to parcel theft [3]. In addition, as food delivery increases, problems such as spoilage of refrigeration required food and reduced usability have occurred due to development that does not consider user requirements, it is leading to a demand for unmanned parcel lockers and innovative functions. To solve these problems, researchers in Korea, developing a " unmanned parcel storage device with active loading technology based on ICT and cold chain" that enables refrigerated storage and efficient loading. The unmanned ICT-based parcel storage device with active technology which is properly classifies goods according to size and shape and uses an internal transfer device to enable the loading of delivery goods using space efficiently. In addition, it is equipped a refrigeration storage function. so it can be used to store food that requires refrigeration. But this parcel storage devices that apply new concepts are likely to cause errors and malfunctions, functional failures. Because different from the malfunctions that can occur in existing automatic storage boxes. Therefore, to improve the safety/reliability and efficient development of unmanned parcel storage devices and remote-control integrated control systems, appropriate verification and evaluation are necessary for each development life cycle.

1.2 Related works

Kim & Kim conducted a study on parcel box recognition using AI's deep learning technology for develop the ICT unmanned parcel storage. Box detection and location estimation studies were conducted using the YOLOv5 model for parcel recognition, these four models were compared and analyzed to perform an experiment showing the optimal parcel box recognition performance. Therefore, it seems that the basis for building an intelligent parcel storage system, which shows optimal efficiency in real time using the YOLOv5 large model. In this study, the operating concept and configuration devices were described in detail for the development of the ICT unmanned parcel storage. [4]. Kim identified the core technologies that must be secured for weapon system development at the component level based on the work breakdown structure of the weapon system. Kim specifically proposed a technology research and analysis methodology based on a work breakdown structure that prevents blank technologies at the point of research and development. The effectiveness analysis of the proposed methodology was applied on the 'A' missile weapon system. As a result of this study, element technologies were derived through ROC analysis of the target weapon system and ROC gap analysis of the current technology and the target weapon system, and technologies requiring core technology planning were identified. It was also derived as a critical technology element CTE of A weapon system [5]. Kim & Kim tried to explain the composition of the standard and the safety life cycle to help understand IEC 61508, as the explanation of the judgment and application of IEC 61508, which can be considered the parent standard of functional safety, was somewhat ambiguous. The safety life cycle is about the company-wide life cycle of safety-related E/E/PE systems and is explained step by step from the concept stage to the disposal and disassembly stage, and an overview of SIL(Safety Integrity Level) judgment criteria and formulas are also specified. In addition, a case study was conducted to quantitatively evaluate the hardware SIL of a gas detector, a safety control system, by applying FMEDA. As a result of this study, the hardware SIL of the gas detector according to the probabilistic measure was SIL 3, but the maximum allowable SIL according to the structural measure was determined to be SIL 2, and was evaluated as the final SIL 2. Through this study, the application and problems of IEC-61508 were identified [6].

Through previous studies conducted, it has been confirmed that research is underway to evaluate technology maturity and apply IEC-61508 to develop new systems safely and efficiently. In particular, Due to the description of IEC 61508's judgment and application is somewhat ambiguous, it was confirmed that many studies proposing new techniques are being conducted in the field of risk analysis and safety integrity judgment.

1.3 Problem definition

When developing a new system, safe and reliable development must be performed by considering the development schedule, cost, satisfaction of requirements, etc., and the system life cycle as a whole so that the system can be developed systematically and efficiently. In order to develop a systematic and efficient system, in terms of project management, technical maturity evaluation is conducted to serve as a standard for operations such as cost and schedule. Regarding system life cycle and safety, systems can be developed efficiently through standards such as IEC-61508. Accordingly, technology maturity evaluation and safe system design research according to IEC-61508 are in progress, but the application standards of IEC-61508 are ambiguous and new techniques are continuously being proposed to build a safe system.

Therefore, in this study, in order to set appropriate evaluation procedures and standards, we developed an evaluation procedure based on an integrated model of product performance factors based on the IEC 61508 standard for ICT-based parcel storage devices with active loading technology under development. and We also propose research to improve the safety and reliability of development targets by identifying CTEs based on the product's core functions and performance goals.

1.4 Composition of the paper

This paper is structured as follows. Chapter 1 explains the research background and related previous research, and Chapter 2 explains the Unmanned ICT parcel storage device and the proposed test model and verification scenario based on IEC-61508. Finally, the procedures for assessing TRL technological maturity and deriving CTE are explained. Chapter 3 explain the results of test case and verification scenario analysis by applying the proposed process model to the Unmanned ICT parcel storage device, and finally shows the results of CTE. Chapter 4 explains the conclusion.

2. Unmanned ICT parcel Storage System and Proposed Methodology

2.1 Unmanned ICT parcel Storage

The Unmanned ICT parcel storage system explained in this paper measures the height and weight of the cargo through sensing when cargo is placed on the shelf located at the cargo inlet, and loads the cargo based on the measurement information and loading box information. In addition, it is a newly improved parcel storage device equipped with a refrigeration storage function so that it can be used to store food that requires refrigeration. Shelves containing cargo can be placed in the many slots of the loading space, this is used to minimize empty space for loading automatically. This device development aims to build a system platform that integrates and manages comprehensive information about delivery items through a separate remote control server. This devices are installed inside or outside the station, and are also installed in the external environment of shared residences such as apartments. It can perform functions that allow various users to send and receive goods, and users can operate it through the display screen of the parcel storage device and a smartphone app. Figure 2 shows the Unmanned ICT parcel storage device and sub-component devices.

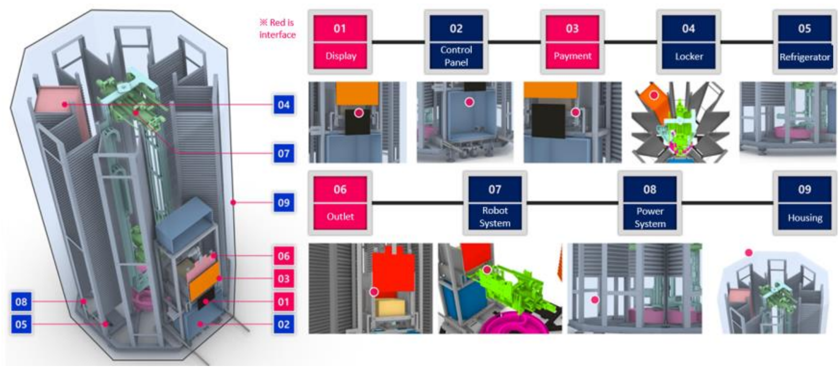


Figure 2. Sub-assemblies in the ICT-based parcel storage device with active technology

2.2 Securing safety/reliability of the system through compliance and application of IEC-61508

IEC-61508 is called standard of Functional safety of electrical/electronic/programmable electronic safety-related systems. This is the parent standard for functional safety and provides functional safety technical requirements related to overall industrial safety. International safety certification standard that determines the safety integrity level It is a general functional safety standard that can be applied to all types of safety systems if the safety system has elements based on electrical, electronic or programmable electronic technology. Normally, the safety life cycle of IEC 61508 is based on application to new safety control systems that have not yet been developed [6-7].

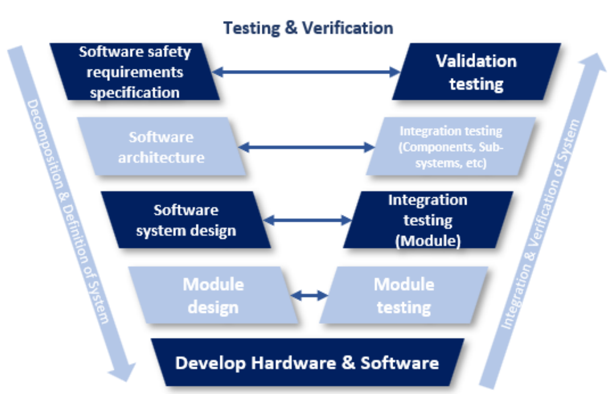


Figure 3. V-Model for Functional safety in IEC-61508

Figure 3 shows the V model presented in IEC-61508 to perform appropriate verification and evaluation for each development life cycle. The left side of the V model can be seen as the definition and decomposition stage. As you move down from the requirements definition and conceptual design above, detailed design progresses. The right side shows the verification and verification test procedures, such as requirements and whether the system has been designed correctly, relative to the left side. These steps are performed on the left and right sides of the same layer of the V model, which shows that appropriate evaluation procedures and standards for the design stage are important.

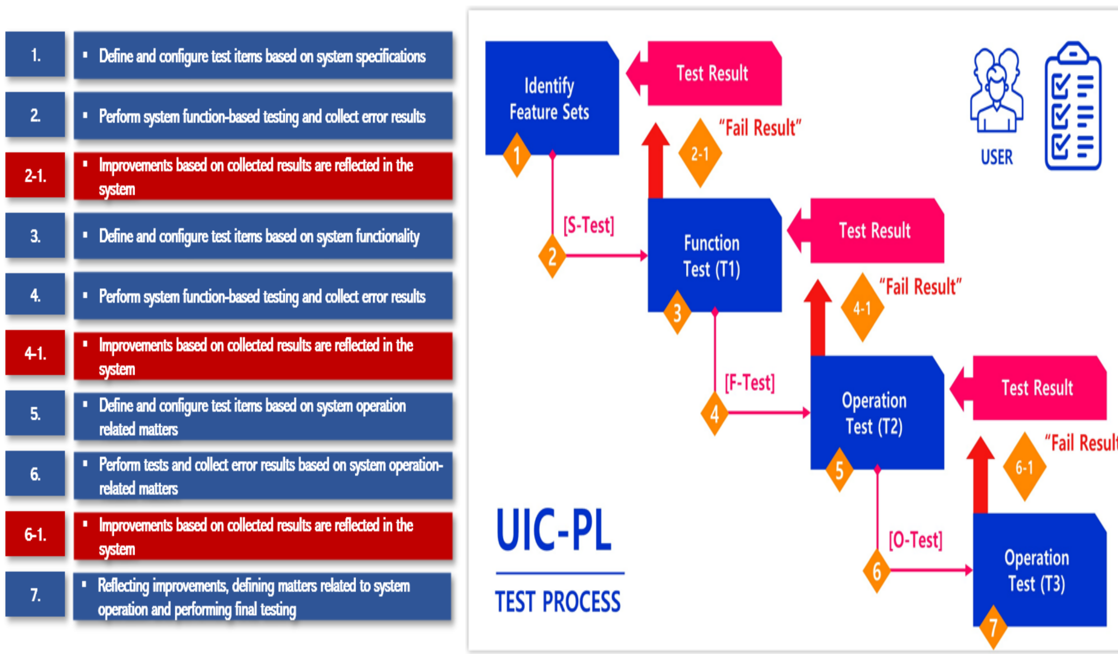


Figure 4. Proposed Test Process based on IEC-61508

Figure 4 shows the model-based evaluation criteria and procedure results generated by selecting an appropriate Model-based Testing technique by developing an integrated model-based evaluation procedure of product performance elements based on IEC- 61508 in developing the Unmanned ICT parcel storage device. Tests are performed based on the system's specifications, functions, and operation-related matters, and finally, all improvements are applied to perform final testing, and the results of each test are reflected in the system.

Once the design with system improvements is implemented through the proposed test process, As an analysis to ensure the safety/reliability of the parcel storage device, factors that may affect the operation of the system must be defined by analyzing and deriving results for each step through derived the SIL (Safety Integrity Level) of IEC-61508. Factors that may affect the operation of the system are defined by analyzing and deriving results for each stage through SIL, and the standards for this grade consist of severity, exposure, and controllability. Once each step and probability are defined, the SIL grade is defined as shown in Table 1. The SIL level is composed of the following: QM (Quality Management), which has little hazardous impact on the system, can be managed as an area of quality management. Grade A is the lowest risk, Grade B is the low grade, Grade C is the dangerous grade, and Grade D is the most dangerous. As a result of the analysis, in the case of parcel storage devices, most of the derivations were defined as QM, and the analysis results showed that this was because most causes related to risk were located inside the device.

Table 1. SIL(Safety Integrity Level) based on IEC-61508

SIL(Safety Integrity Level)					Risk parameter	level	Description
Severity	Exposure	Controllability			Severity	S0	Usually controllable
		C1	C2	C3		S1	Easy controllable
S1	E1	QM	QM	QM		S2	Normal controllable
	E2	QM	QM	QM		S3	Hard controllable or impossible
	E3	QM	QM	A	Exposure	E1	Rarely
	E4	QM	A	B		E2	Possible
S2	E1	QM	QM	QM		E3	Likely
	E2	QM	QM	A		E4	Very high
	E3	QM	A	B	Controllability	C0	Usually controllable
	E4	A	B	C		C1	Easy controllable
S3	E1	QM	QM	A		C2	Normal controllable
	E2	QM	A	B		C3	Hard controllable or impossible
	E3	A	B	C			
	E4	B	C	D			

2.3. CTE Identification and TRL Process

The Korea Defense Acquisition Program Administration defines CTE in the TRA work guidelines as follows. “CTE (Critical Technology Elements) are technically important elements for completing the project in the category of individual weapon system research and development projects. It refers to a technology that has a decisive impact on meeting business goals (performance, cost, schedule) or has new development content, development method, demonstration environment, and design conditions compared to existing technologies[8].” CTE derivation makes it possible to evaluate TRL (Technology Readiness Level), a quantified measurement indicator to evaluate the maturity or implementation stage of a developed technology, so that the level of preparation is possible until the technology is actually used[9]. Identification of Critical Technology Elements is a process of determining the value of the technology to be adopted, and includes cases where it has a significant impact on satisfying operational requirements, cost reduction, and schedule reduction.

Figure 5 expresses the subprocess for CTE selection. In confirmation and evaluation, the evaluation team confirms and evaluates the data presented by the development agency for the confirmed CTE, and the development agency cooperates with all evaluation-related matters, including the evaluation team's on-site inspection. In order to determine the technology maturity level TRL for each CTE, a standard checklist for each technology maturity level TRL is used to check the development output and supporting data performed to date compared to the development goal. Finally, the evaluation team leader checks the development agency's self-assessment results, field inspection results, and related supporting materials, and then evaluates the technology level at each stage to evaluate the progress and supplementation of each stage and the inability to proceed with the research process.

Figure 5. CTE derivation process and checklist

3. Application example of ICT parcel storage device

3.1 System test case procedure construction results

In this section, the proposed IEC-61508-based test model procedure was performed to ensure the safety/reliability of the unmanned ICT unmanned parcel goods storage device. The results of system analysis and safety analysis based on process and operation scenarios are derived to enable confirmation of risk sources and results expected to occur during system use.

Table 2. Sample of SIL level of Unmanned ICT Pacel storage system

Process step	Potential Failure Mode	Severity	Potential Causes	Exposure	Current Process Controls	Controllability	SIL
2. User access recognition	Approach sensor failure	S0	Part general failure	E1	Check for access sensor failure in the control unit	C0	-
3.Start screen display	Display failure	S1	Part breakage	E3	Check display failure in control unit	C2	QM
3.Start screen display	Display error	S2	Part general error	E2	Check display error in control unit	C1	QM
3.Start screen display	Display failure	S1	Part general failure	E3	Check display failure in control unit	C1	QM
4B-1. Using App	Communication device failure	S1	Part general failure	E2	Check communication device module failure in the control unit	C1	QM
6. Reservation information recognition	Communication device error	S0	Part general error	E3	Check communication device module error in the control unit	C0	-
7B-2. Cargo slot open	Cargo slot failure	S3	Part general failure	E1	Check cargo slot failure in control unit	C2	QM
7B-2. Cargo slot open	Cargo slot error	S2	Part general error	E2	Check cargo slot error in control unit	C2	QM
7B-3. Cargo information recognition	Weight sensor failure	S0	Part general failure	E1	Check weight sensor failure in control unit	C0	-

Table 2 shows the results of defining factors that can affect the operation of the system by applying the safety integrity level of IEC-61508. Failure situations that may occur during each operation process were set, failure modes and effects were defined in each failure situation, and a SIL grade was determined according to the failure impact, potential, and control, and the system was tested.

By applying the SIL grade results derived from each failure situation, a test procedure was established considering relatively fatal failure situations. Table 3 shows the sample of results proposed by establishing a systematic testing procedure for applying safety technology to the parcel storage system. The proposed test procedure consisted of the stages of functional testing based on requirements and specifications and operational process based on operational processes. The errors derived from each test result were reflected in the system so that it could be developed into a safety-secured system. In addition, necessary response measures were proposed through definitions based on analysis results, and relevant matters were defined to enable quick and stable processing when problems and errors occur.

Table 3. Sample of test case result

System	Test list	Check List	Recommended
Display	Is it possible to control the device and store and receive items through a touch screen?	Repair	Ex) Display repair
	Is it possible to display cargo information and manipulate each process through a touch screen?	Inspection	Ex) State inspection
Control panel	Is the device passed by Panel controllable?	Repair	Ex) Control panel repair
	Is it possible to maintain and manage the condition for stable operation and operation of the device?	Inspection	Ex) State inspection
Payment	Is it possible to handle the costs incurred by using the device?	Replacement	Ex) Replacement payment device
	Is it possible to print receipt and waybill information after payment?	Repair	Ex) Repair print device
Locker	Is it possible to store the goods?	Inspection	Ex) State inspection
Refrigerator	Is refrigeration possible for food?	Replacement	Ex) Replacement refrigerator device
Outlet	Does the outlet function work?	Repair	Ex) Repair outlet device
Robot system	Is it possible to move the slot to a designated location for storage and transportation of cargo?	Repair	Ex) Repair robot arm device
	Does the magnetic gripper that holds the slot work?	Inspection	Ex) State inspection
Power system	Is it possible to receive and control power?	Repair	Ex) Repair power supply device
Housing	Is it possible to protect the device from the external environment and physical shock?	Replacement	Ex) Replacement housing panel
Frame	Is it possible to maintain the basic structure of the device without breaking it?	Inspection	Ex) State inspection

3.2 System Validation scenario analysis results

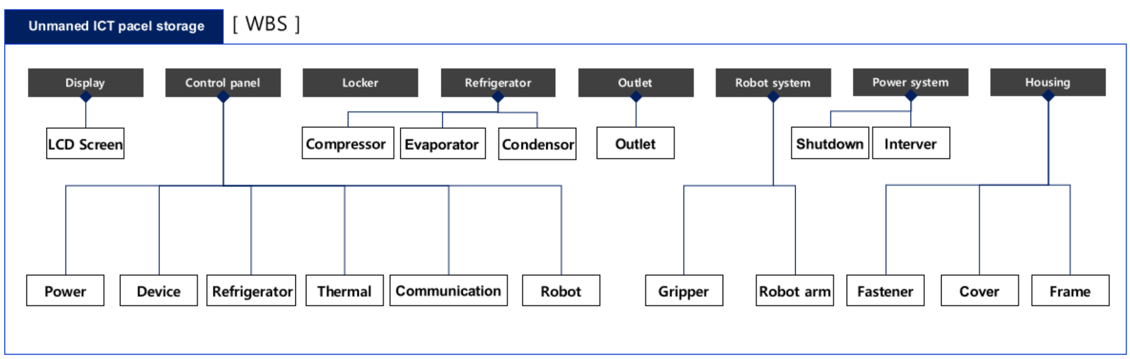
Table 4 shows a sample of the results verified and constructed based on the operating scenario to perform a safety/reliability evaluation of the parcel storage device based on these test results. The Validation scenario was built based on a user- and device-centered process with reference to the operating process. The details of each operation for using the device or for the device to respond to the user's request were defined, including the evaluation of each step, details of the event or error, expected results, actual results, and occurrence situations. As with testing, necessary response measures were proposed through definitions based on analysis results, and relevant matters were defined to enable quick and stable processing when problems and errors occur.

Table 4. Sample of validation based on scenario result

Purpose	Test case design to check operation of parcel storage device		
Reference	User & Device Process: in & out		
Step	Details	Expected/Actual Results	Type
1	Device inoperable	Device unavailable	Suspended
2	No user recognition	Decreased device usability	Fail
3	display malfunction	Device unavailable	Not Executed
4-1	display malfunction	Device unavailable	Not Executed
4-2	Communication equipment failure	Device unavailable through app	Fail
6	Communication equipment failure	Reservation information not available	Fail
7A-3	Robot inoperable	Device unavailable	Not Executed
7A-4	Gripper failure, transfer not possible	Cargo transfer not possible	Not Executed

7A-5	Outlet inoperable	Cargo storage and pickup not possible	Not Executed
8B-2	Cargo slot location recognition error	Improper cargo storage and transportation	Not Executed
7A-6	Outlet inoperable	Device internal exposure	Fail
10	Payment device inoperable	Payment impossible and termination impossible	Fail
11	Communication device inoperable	Unable to send text message	Fail
11	Print device inoperable	Receipts and invoices cannot be printed	Fail

3.3 Derived Critical Technology Elements



Display	▪ **User interface for operating the delivery goods storage device and screen display device component for displaying information**
Control panel	▪ Control unit that controls the operation of the device to achieve the functional goals of the delivery goods storage device
Locker	▪ A storage unit that stores cargo placed inside the delivery goods storage device.
Refrigerator	▪ A refrigeration unit to maintain the condition of refrigerated cargo stored in a delivery goods storage device.
Outlet	▪ An entrance that serves as a passage through which cargo is moved in and out of the delivery goods storage device.
Robot system	▪ The robot unit that performs the role of moving delivery goods from inside the delivery goods storage device to the storage area.
Power system	▪ Power unit that provides and controls power for the operation of the delivery goods storage device
Housing	▪ The exterior part blocks and protects the interior of the delivery goods storage device from the external environment and supports the structure of the device.

Figure 6. Work Breakdown Structure based on Technology classification

The CTE selection method consists of three steps: identifying CTE review targets, determining CTE candidates, and confirming CTE. In the first stage, risk factors that could have a decisive and significant impact on the target performance of the system were derived through required performance analysis and related function analysis based on the WBS(Work Breakdown Structure) based on the technology classification system, and potential CTE review targets were identified. In the second stage, detailed element technologies were added to each WBS to derive the core development technology elements of the project among the CTE review targets identified in the first stage. In addition, each element technology was added to the middle classification corresponding to the WBS classification system, and the component level was created. Figure 6 shows the WBS and detailed element descriptions derived in this way. The upper part of Figure 6 shows the WBS of the technology classification system derived in step 1, and the lower part explains the detailed element technologies of the candidate CTE specified in step 2. Finally, in the third step, CTE is created through candidate CTE. Each CTE checklist in figure 5 was used in the added element technology to generate CTE for the corresponding part, and the identified CTE was decided through an expert meeting. Table 5 shows the derived CTE.

Table 5. Derived CTE on Unmanned ICT Parcel storage

Sub-system	Function	Specification
Locker	Active storage function	Active technology must be applied to enable loading according to the height of the goods.
	Slot configuration function	Shelves for storing goods must be provided at a certain level or higher to store all goods.
	Slot storage function	A shelf storage function should be applied to enable storage of unused shelves.
Refrigerator	Temperature control function	It must be possible to control the temperature of the refrigerated section for storing low-temperature products.
	Humidity control function	Humidity control in the refrigerated section for storing low-temperature products must be possible.
Robot system	Vertical movement function	A vertical movement function must be applied for vertical transport of goods.
	Horizontal transfer function	The horizontal movement function for horizontal transport of goods must be applied.
	rotation function	A rotation function must be applied for transport of goods.
Housing	protection function	The internal components of the equipment and equipment installed inside must be protected from the external environment.
	vibration resistant function	Vibration resistant performance that can withstand vibrations from the external environment must be secured.
	Maintenance function	Opening and closing functions for maintenance and repair of the device must be applied.
Control Panel	Temperature control function	It must be possible to control the temperature of the refrigerated section for storing low-temperature products.
	Cargo status check function	It must be possible to stamp the condition of general goods to check their condition.
	Waybill Information transmission function	It must be possible to send and receive information about invoices generated for the storage of goods.

4. Conclusion

As the demand for courier services has rapidly increased in the logistics industry, various problems such as space shortage and courier theft accidents have emerged due to massive urbanization. To solve these problems, researchers in Korea are developing a “ Unmanned parcel storage device with active loading technology based on ICT and cold chain” that enables refrigerated storage and efficient loading. Unmanned ICT parcel storage devices equipped with new technologies such as automatic loading function and refrigerated storage are likely to cause errors and malfunctions, that is, functional failures, that are different from the malfunctions that can occur in existing automatic storage boxes. Therefore, in order to improve the safety/reliability and efficient development of unmanned parcel devices and remote control integrated control systems, appropriate verification and evaluation are necessary for each development life cycle.

This study developed an integrated model-based evaluation procedure for product performance factors based on the IEC 61508 standard. In addition, the CTE identification and evaluation process based on the product's core functions and performance goals was explained. Lastly, we applied this to an ICT-based parcel storage device with active loading technology under development to derive system test cases, verification scenarios, and core element technologies. It is expected that this research will become the basis for efficient system design and improvement of safety and reliability of the development target.

5. Acknowledgement

This work was supported by a grant from R&D program of the Korea Evaluation Institute of Industrial Technology (20014664).

References(SAMPLE)

[1] Statistics Korea, Population by Administrative District (Si/Gun/Gu) and Gender. *https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1B040A3.*

[2] S. L. Ju, H. J. Kang and S. H. Oh, “Correlation analysis between COVID-19 cases and emergency alerts service,” *The Journal of The Institute of Internet, Broadcasting and Communication (IIBC)*, Vol. 21, No. 5, pp.1-9, Oct 2021. DOI : 10.7236/JIIBC.2021.21.5.1

[3] S.W. Pyo, T.M. Park, H.C. Shin, M.H. Jang, H.J. Kim, J.H. Lee and H.C. Yu, "Arduino-based Courier Storage System Development for One-person Households," in Ploc. 41th the Korean Association of Computer Education Conference, pp. 125-128, Jan.18-20, 2018.

[4] M.R. Kim and Y.M. Kim,” Parcel Classification and Positioning of Intelligent Parcel Storage System Based on YOLOv5,” *Applied Sciences*, Vol. 13, No. 1, pp.437, Dec 2022. DOI : 10.3390/app13010437

[5] M.S. Kim, "Effect Analysis of WBS-Based Technology Research and Analysis Methodology for Defense Technology Planning: With ‘A’ Missile System," *Journal of Korea Academia-Industrial cooperation Society (JKAIS),* Vol. 21, No. 12, pp. 211-217, Dec 2020. DOI : 10.5762/KAIS.2020.21.12.211

[6] S.K. Kim and Y.S. Kim, "A Study on a Safety Life Cycle of IEC 61508 for Functional Safety," *Journal of Applied Reliability*, Vol. 14, No. 1, pp. 81-91, Mar 2014. UCI : G704-SER000010073.2014.14.1.008

[7] IEC, *61508-1 Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements*, 2010. Reference number IEC 61508-1:1998(E)

[8] Defense Acquisition Program Administration, Technology Readiness Level (TRA) Work Guidelines. *https://www.law.go.kr/admRulLsInfoP.do?admRulSeq=2100000196829&vSct=*

[9] H.S. Lee, C.J. Shin and S.J. Kang, "A Study on the Evaluation Method of Defense Technology Valuation Using the Readability Level Assessment of Core National Defense Technology," *Journal of the Korea Institute of Information and Communication Engineering (JKIICE)*, Vol. 23, No. 12, pp. 1710-1719, Dec 2019. DOI : 10.6109/jkiice.2019.23.12.1710

[10] H.C. Woo., On an Improved Method for the Generation of Critical Technology Elements in Carrying out Technology Readiness Assessment, M.S. Thesis. Ajou University, Suwon, Gyeonggi-do, Republic of Korea., 2012. http://www.riss.kr/link?id=T12859078