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On the Derivation of Safety Requirements and Specifications based Integrated System Operation Scenario for the Development of Unmanned Courier Storage Device Platform in Urban Areas

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Abstract

In modern society, digital lifestyles are spreading to minimize contact with people and to receive contactless information. The spread trend has established an unmanned distribution system in which transactions through contactless technologies such as kiosks and chatbots are activated in face-to-face transactions with sellers and consumers. In order to streamline logistics supply worldwide, digital new deal based joint logistics hubs, unmanned courier storage platforms, and fresh logistics based last mile services have been developed into unmanned logistics systems, focusing on the intelligent logistics system automation process. Unmanned courier storage system installed in urban areas and home to daily logistics where volume is concentrated are provided with fresh logistics services through cold chain and receiving freights in contactless environments. Development is also underway to minimize safety accidents caused by courier services, such as managing various information based on the integrated control system. This paper defines the concept of integrated operation for the development of a platform for contactless unmanned courier storage device developed into next-generation logistics system. In addition, we intend to develop systems engineering-based output for deriving safety requirements and specifications by identifying risk sources that may occur in the operational scenario. Therefore, the goal is to establish a foundation for safety and reliability between interfaces of logistics systems to be installed in apartment and subway station environments that want to provide unmanned logistics services to various consumers.

Keywords: *Unmanned Courier Storage device, Cold Chain System, Courier Information System, Contactless Logistics Safety Requirements.*

1. Introduction

The urban unmanned courier storage device is a contactless next generation logistics platform developed by pandemic trends such as COVID 19. The device has a storage box installed in apartment or subway platform to solve social issues such as infection, loss of courier, minimization of crime rate related to courier service, increase of freight volume of fresh food concentrated in urban areas [1]. The past storage device was a simple storage device that temporarily stores freight for unmanned delivery and receives the information of the courier service after confirming the information on the screen. In order to increase usability, cold chain-based technology is being developed to maintain the condition of freight to the customer's receipt based on the

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convenience of device operation for contactless delivery of various items such as fresh food [2]. The core technology starts with the requirement to prevent overwork of courier delivery person and to simplify the logistics process. This technology refers to the fusion between technologies such as loading, shipping, storing, receiving functions of storage devices and artificial intelligence, loading and unloading robot control, product recognition, fresh logistics, and remote product information management [3]. However, there are environmental variables that are usually installed and operated outdoors. Therefore, it is necessary to develop requirements based on the durability structure suitable for various storage transportation environments and the safety and reliability of devices that are not affected by the surrounding environment [4]. To this end, the concept of integrated operation and scenario and core functions should be defined to improve usability of unmanned courier storage devices to be installed in urban areas. This paper includes the defined operational concept for deriving safety requirements and the hazard identification process that can occur in scenarios. In addition, the present invention proposes a development specification for designing a safety requirement-base, and aims to build a foundation for improving reliability of an unmanned courier storage device.

2. The Definition of the Problems

2.1 Unmanned Storage Device's Operational Technologies' Problems based on Last Mile

The unmanned courier storage device is a logistics equipment that stores and manages freight in urban areas with high market accessibility and traffic efficiency, such as Figure 1. The device is developed based on safety tracking technology, ICT, logistics robot application technology, and product monitoring technology [5]. Existing commercialized storage devices have disadvantages in usability due to inconvenience in operating exterior interfaces. In addition, limited technologies such as authentication identification to remove security related courier accidents such as theft and loss, and attachment of alarm devices to prevent theft are applied [6]. In order to expand the usability of devices and efficient operation, it is improving base technologies such as last mile suitable for outdoor regions such as apartments and subways [7]. Last mile is equipped with a food safety tracking process for fresh logistics, reduction in lead time for contactless logistics delivery, and cold chain that minimizes chemical changes in temperature sensitive foods and medicines [8], [9]. Therefore, it is important to design the concept based on safety requirements such as frozen container operation, cold chain quality prediction, and state monitoring technology for fresh products in order to be developed as cold chain storage device [10]. In addition, it is important to establish safety concept for separate storage, loading efficiency, product status recognition, robot control, and comprehensive control of general and fresh products [11]. It is necessary to develop operational concepts, scenarios, hazard analysis, and safety function-based requirements to improve reliability based on safety design of the device.

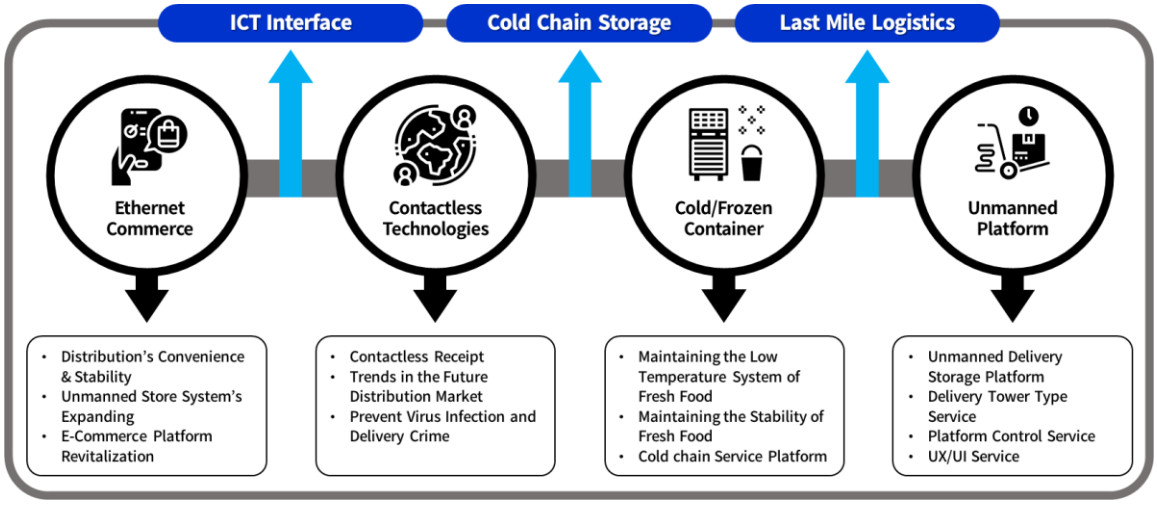

Figure 1. Status of Prior Research Related to Unmanned Storage Platform

2.2 The Importance of Unmanned Courier Storage Device's Development

For efficient operation of freight volume concentrated in urban areas, unmanned courier storage device should maintain freshness of food through cold chain technology, robot technology for active loading of large volume of couriers, and unmanned device with monitoring technology for managing products at last mile stage are needed [12]. It is also necessary to analyze the requirements for improving the convenience of devices that store products, deliver and receive customer products smoothly in urban areas with high freight volume. Therefore, it is necessary to check the status of the products and the recipient, to manage the automation of the products through remote control, to automatically detect the size of the atypical release freight, and the weight. In addition, an integrated management system is also required to transmit and receive the status and location information of the couriers to SMS in conjunction with remote control server to prevent defects in the unmanned service. The device needs to design a reliable safety-related concept for storage and transportation environments such as storage, packaging, loading, classification, transportation, step by step hazard analysis, and system engineering-based research such as safety requirements to prevent virus infection through contactless delivery and prevent courier safety accidents. For the safety design of the device, the operational concept and scenario that integrate information management functions such as storage, robot-based loading of freights, and delivery should be defined. In order to prevent malfunction and defects of the device, hazard analysis, safety requirements, and specifications should be derived. All design processes should be applied with safety concepts to be developed as safe logistics devices based on international standard systems engineering activities.

2.3 Research of Scope and Procedure

This paper develops concept, scenario, functional design, hazard analysis, safety requirements and specifications based on storage system operation technology, cold chain operation technology and remote product information monitoring technology for the development of unmanned courier storage device. The final specification designs basic specifications for prototype development of device and includes holistic research process from the systems engineering perspective to build safety and reliability based on technology linked to device. The research procedure defines the integrated concept as shown in Figure 2, and develops specifications suitable for the subway platform and apartments that require unmanned services to derive safety requirements based on system operation scenarios. The safety requirement step identifies the hazard which can occur in the whole system. The analysis technique establishing the safety measure of the SSHA(Subsystem Hazard Analysis) base architecture design product is applied. To verify the safety requirements, safety specification patterns of basic pattern, fault detection pattern, and fault reaction pattern are utilized.

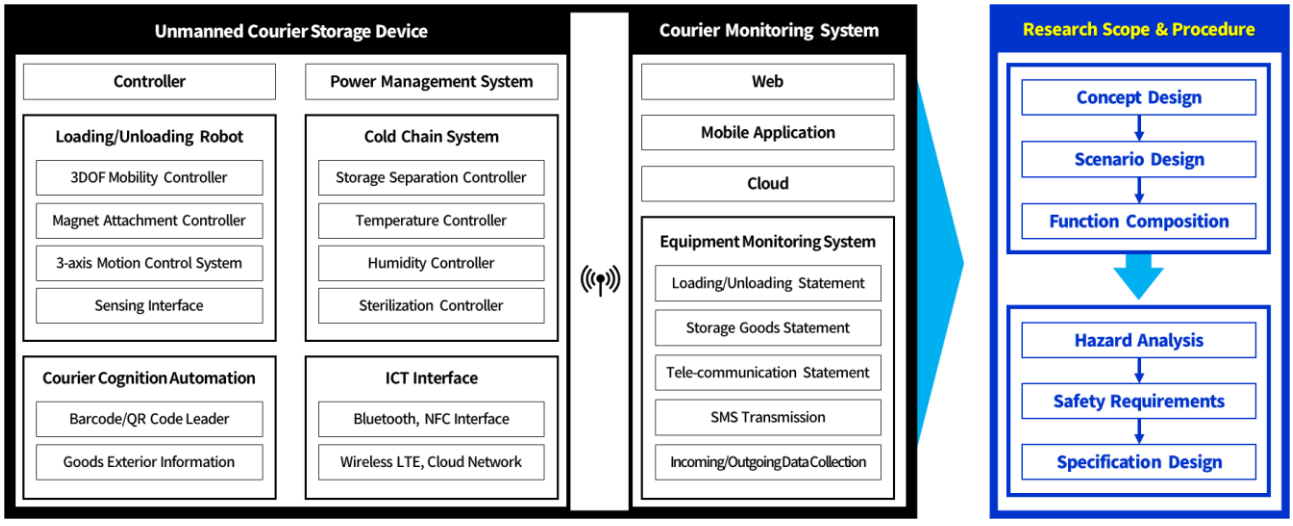

Figure 2. Research Scope and Procedure

3. Development of Unmanned Courier Storage Device Platform in Urban Areas

3.1 Development of Unmanned Courier Storage Device's Operating Concept

The intended purpose of the unmanned courier storage device is a logistics integrated management platform that combines cold chain technology and active freight loading technology. It mainly uses technology to prevent courier crime in contactless environments and to provide fresh logistics services through cold chain refrigeration function. The device is designed as octagonal pickup tower devices that enhances the loading efficiency in apartment and subway platform, and the concept of integrated management of processes and information is applied through remote logistics server. As shown in Figure 3, the device's system consists of an installation environment(apartment, subway platform), users(courier delivery person, silver courier delivery person, subway passenger, apartment resident), and mobile apps linked to the device. The inside of the device consists of general, storage function of refrigerated freight, loading and unloading robot control function of freight, user interface, power part etc. The device is monitored through remote control server, and provides necessary information to couriers and customers using the device. In particular, customers receive integrated information such as product information, fresh storage status, and product receipt process through SMS. All processes are managed through the Courier Storage Information Integrated Control System.

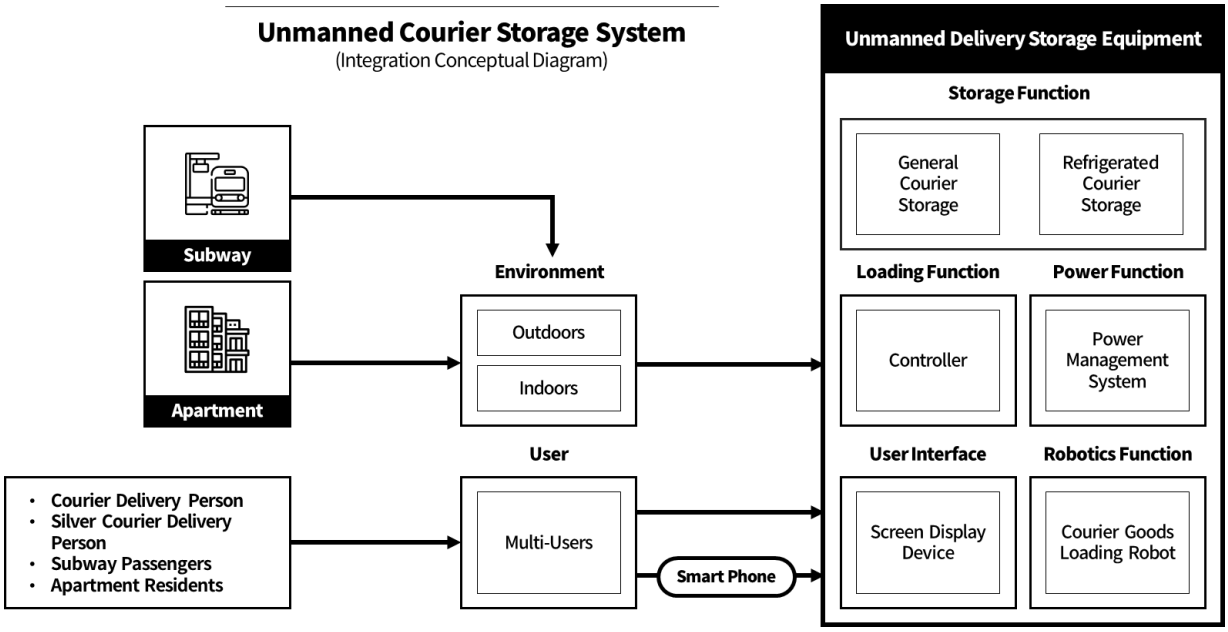

Figure 3. Unmanned Courier Storage Device's Concept

3.2 Development of Unmanned Courier Storage Device's Operating Scenario

Unmanned courier storage device is possessively varied the freight loading function to the pickup tower of the ICT interface base. The general and refrigerated freights are divided based on cold chain. It gives an order through robot module with the size of freight and it transfers to storage. Information is delivered through the display unit, the user app, and the control server to confirm the state of the kept freight. The scenario for the customer who uses the unmanned courier storage device can receive freight stored through time of 5 seconds of general product and 7 seconds of cold chain product based on operation concept of figure 3. In addition, kiosk panel and mobile app of the device can check product information operation, device operation, and freight receipt process. User is provided freight information, fresh keeping state, and monitored situation of logistics process through the remote control server to SMS. The device manager transmits the freight and device position to courier delivery person through courier storage information integrated control system and guides storage device to perform loading, delivery, and storage behavior.

3.3 Development of Unmanned Courier Storage Device's Structure and Function

The unmanned courier storage device is detailed in the whole system as 8 subsystems, 11 components and part, as shown in Figure 4. The device is configured to perform normal operation with a safe design of a subsystem, component, and part linked to the system. Therefore, as shown in Table 1, it consists of display, control, storage, refrigeration, courier entrance, robot, power, exterior. Each subsystems have complex design unit, and performs potentially generated hazard analysis between interfaces. In addition, the safety requirements are specified based on results of hazard analysis, and this is included in the final specification.

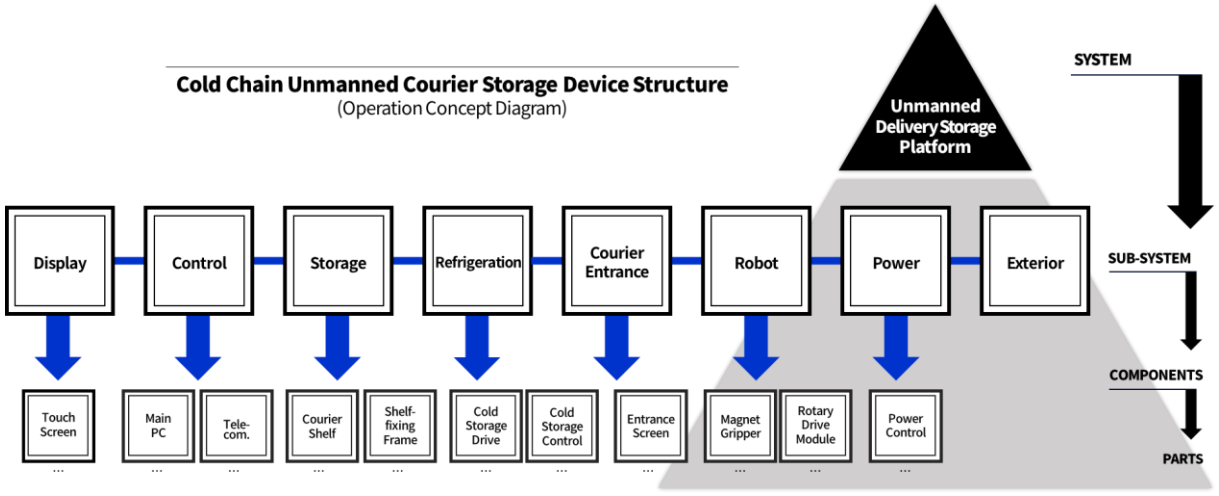

Figure 4. Unmanned Courier Storage Platform's Structure Analysis

Table 1. Unmanned Delivery Storage Platform's Function

No	Subsystem	Function
1	Display	User Interface(Kiosk, Touch Screen) for Displaying Information
2	Control	Delivery Courier Storage Equipment Operation Control
3	Storage	Courier Storage Inside the Delivery System
4	Refrigeration	Maintaining the Condition of the Refrigerated Courier Storage
5	Courier Entrance	The Entrance and Exit of the Unmanned Delivery Storage Platform
6	Robot	Moving Courier to the Storage through Robot Control
7	Power	Providing and Controlling Power for Equipment Operation
8	Exterior	Blocking the Impact of Indoors and Outdoors Support the Structure

4. Development of Unmanned Courier Storage Device's Safety Requirements and Specification in Urban Areas

4.1 Hazard Identification of Unmanned Courier Storage Device in Urban Areas

Hazard analysis was performed to develop safety requirements for concept, scenario, structure and functional design of the device. In order to develop safety measures for each function of subsystems that perform major functions, SSHA(Subsystem Hazard Analysis) technique was used. In addition, the hazard analysis was performed by identifying part of subsystem to which the safety path is applied. The range of identification was display, control, storage, refrigeration, and robot, which derived the hazardous factors of the subsystem level for deriving safety requirements as shown in the following table 2.

Table 2. Unmanned Delivery Storage Platform's SSHA

No	Subsystem	Function
1	Display	The minimum temperature display unit to be displayed on the touch screen and the interlocking app is 0.01 °C, and the temperature display size can't comply with the height of 2.4mm or more, which may reduce the usability of senior users. Electrostatic electricity is induced to the touch screen adoption in which the ESD (Electrostatic Discharge) isn't designed and the malfunction of indicator can be caused.
2	Control	The power source of the apparatus can be quarantined to the malfunction of the power divider for control including the robot control, the keeping, the refrigeration function etc. The product inside temperature management function can be quarantined to the temperature and humidity sensor malfunction for the separation control of the cold chain and general freight. Overload can be caused to the height measurement malfunction of the loading robot part.
3	Storage	The tray information of the storage supporting the weight of freight is misidentified and the freight kept in tray can be damaged. The tray information in which the loading is completed is misidentified and the operation of the robotic section for the freight transfer can be quarantined between tray.
4	Refrigeration	The information of cold chain temperature indicator is incorrectly identified, or product can be damaged to temperature and humidity sensor malfunction for thermo-hygrostat of the fresh food in which disinfection, and sterilization are necessary. The freight information classified into the cold chain is identified as the general freight and the state of freight can be degenerated.
6	Robot	The fine adjustment function of the loading for the tray fixing of 50kg and unloading magnet gripper malfunction and freight can be damaged in the inside of device to the falling of freight. The device may malfunction due to overloading of freights outside the tray load range. The information of general and refrigerated freights loaded in the robotic section is misidentified and freight state kept in tray can be damaged.

4.2 Derivation of Unmanned Courier Storage Device's Safety Requirements in Urban Areas

Safety requirements were derived by applying to 6 subsystems with features of fault detection, safe state transition, and degraded mode operation. First, based on the SSHA analysis results, we developed safety requirements with basic pattern, fault detection pattern, and fault reaction pattern. In addition, safety requirements are specified as shown in Table 3 for the development of final specification's safety design. In particular, the safety requirements of display, control, storage, refrigeration, and robot were designed as items such as usability, convenience of operation, electrical safety, sensitivity to temperature and humidity, efficiency of loading, durable material adoption, and information integration management system construction. The following technologies should be applied for the safety design of the device based on the requirements.

Unmanned courier storage device should be designed with octagonal optimization structure to increase the

loading efficiency of general and refrigerated freights. It should consist of 525 loadable storage trays to store 49 items with a height of 410 mm per tray. Cold chain storage part, which is sensitive to temperature and humidity and condition to maintain temperature and humidity, should be composed of 151 of the total trays. The 525 total trays are grouped into 75 split trays per tower, as components of 7 pickup towers. The freight weighing 600kg per tower should be able to be loaded. The robot technology of the magnet gripper type is applied for loading and unloading of the loaded freight.

Table 3. Unmanned Delivery Storage Platform's Safety Requirements

No	Subsystem	Safety Pattern	Safety Requirements
1	Display	Basic Pattern	Considering various users, the minimum temperature display unit to be displayed on the touch screen and the app is 0.01 °C and the temperature display size is designed to be 2.4mm or higher.
		Fault Detection Pattern	The touch screen in which the durable ESD(Electrostatic Discharge) function is applied to is reflected to the device and malfunction is prevented from the static electricity.
2	Control	Fault Detection Pattern	The OVP(Over Voltage Protection) control circuit for the excess current prevention including the robot control, storage, refrigeration function, etc. is designed. The emergency power supply is equipped addition and the malfunction of power divider is prevented.
		Basic Pattern	Close Loop based design is applied for the device inside temperature and humidity control and administration.
		Fault Reaction Pattern	The laser sensor is equipped for the exact height measurement of loading robot part and height of 49 freight of 410mm per tray is accurately calculated.
3	Storage	Basic Pattern	The durable material for enduring weight of freight is adopted the storage space use related data management system is built the freight's storage tray information is managed.
4	Refrigeration	Basic Pattern	The temperature monitoring function is added in the integration control server for managing the information(refrigeration > +1°C, freezing -20°C~-40°C) of cold chain temperature indicator and constant temperature state is kept. In order to control the storage movement of refrigerated and the general freight putting into the device, article and status information monitoring function are added to the integration control server. In order that the cold chain storage efficiency of device is enhanced, the freight status information monitoring function is added to the integration control server.
6	Robot	Fault Reaction Pattern	The transporting robot module capable of loading, and the fine adjustment function of the unloading magnet gripper the secession of freight is prevented is added.

4.3 Development of Specifications based on Safety Requirements for Unmanned Courier Storage Device in Urban Areas

Unmanned courier storage devices installed in apartment and subway history are analyzed to require suitable cold chain storage conditions(refrigeration > +1°C, freezing -20°C~-40°C) that aren't affected by external environmental variables. Cold chain functions to control temperature and humidity conditions defined specifications for separating and storing general and refrigerated freights. Since up to 315,000 kg of freight must be loaded on 7 pickup towers consisting of 525 trays, the specifications of magnet gripper type loading and unloading robot control technology are also defined. As a result, the development specifications for 4 core-functions of exterior, storage, and user interface were derived as shown in Table 4 for development of unmanned courier storage devices based on electrical mechanical safety and reliability.

Table 4. Unmanned Delivery Storage Platform's Specification

No	Part	Factor	Specification
1	Exterior	Equipment Size	2,160mm x 2,160mm x 4,000mm
		Total Number of Storage(Trays)	525EA(75EA/Trays)
		Tray Size	500mm x 410mm x 16mm
		International Protection Marking	IP55(IEC 60529)
2	Storage	Storage Size and Weight Limitation	41*31*28 = 100cm / 50kg
		Number of Courier Storage	7EA Courier Stored/line(410mm-High)
			Total 49EA Courier Stored
		Cold chain Maintenance Temperature	-10℃~10℃(Minimum)
		Number of Cold chain Storage	Total 141EA(23EA/Tower)
		Tower Support Weight Limitation	600kg/Tower
		Storage, Reception Time	General 5sec, Refrigeration 7sec
3	User Interface	External Communication Interface	Wireless (LTE or 5G, etc.)
		KIOSK Interface	Minimum Temperature Display Unit is 0.01°C.
			Temperature Display Size is 2.4mm or Higher
		Mobile Application	Android 4.3, iOS 8.0

5. Conclusion

In this paper, we identify storage systems, cold chain operation technologies, remote freight information monitoring technologies necessary for unmanned courier storage device design and analyze the structure of the device by defining the operational concept, scenario, and function. In addition, safety requirements were derived through hazard analysis of subsystem level and applied to the final specification. As a result of safety requirement analysis, it was confirmed that safety design for cold chain(split storage technology by product temperature), ICT(freight's delivery status monitoring through remote control), automatic detection of unstructured freight's weight and size and magnet gripper type robot technologies(controlling the loading and unloading of freights through rotary and vertical moving robots) through freight information recognition are important. For the commercialization of unmanned delivery courier storage device, it is necessary to develop detailed service scenarios for each concept of operation, to identify detailed safety requirements based on scenarios, and research to safety design based on systems engineering standards. This paper doesn't include SSHA technique and other hazard analysis processes. To develop detailed safety measures and specify safety requirements for devices, follow-up researchers and follow-up analysis of various risk analysis such as PHA(preliminary hazard analysis), FHA(functional hazard analysis), SHA(system hazard analysis), IHA(interface hazard analysis), O&SHA(operation and support hazard analysis).

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References

[1] J.M. Park, J.W. Won, K.D. Sung, Y.M. Kim, "On derivation the System Analysis and Evaluation Indicators of Blockchain-based Smart Electronic Transport Waybill Platform for Improvement of Logistics Service Operation Efficiency and Personal Information Security," Korea Safety Management & Science, Vol. 22, No. 4, pp. 75-86, December 2020.
DOI : https://doi.org/10.12812/ksms.2020.22.4.075

[2] Atanu Chaudhuri, Iskra Dukovska-Popovska, Nachiappan Subramanian, Hing Kai Chan, Ruibin Bai, "Decision-Making in Cold Chain Logistics using Data Analytics: a Literature Review," The International Journal of Logistics Management, Vol. 29 No. 3, pp.839-861, 2018.
DOI : https://doi.org/10.1108/IJLM-03-2017-0059

[3] S.H. Moon, "Analysis of Artificial Intelligence Applied Industry and Development Direction," The Journal of the Institute of Internet, Broadcasting and Communication(JIIBC), Vol.5 No.1, pp.77-82, 2019.
DOI : http://doi.org/10.18006/JCCT.2019.5.1.77

[4] Imran Ali, Sev Nagalingam, Bruce Gurd, "A resilience model for cold chain logistics of perishable products," The International Journal of Logistics Management, Vol. 29 No. 3, pp.922-941, 2018.
DOI : https://doi.org/10.1108/IJLM-06-2017-0147

[5] S.M. Lee, D. Lee, ""Untact": a New Customer Service Strategy in the Digital Age," Serv Bus 14, 1–22, 2020.
DOI : https://doi.org/10.1007/s11628-019-00408-2

[6] Matthias Klumpp, "Automation and Artificial Intelligence in Business Logistics Systems: Human Reactions and Collaboration Requirements," International Journal of Logistics Research and Applications, Vol.21, Issue 3, pp.224-242, 2016
DOI : https://doi.org/10.1080/13675567.2017.1384451

[7] B.J. Jeon, "Creating Shared Value in Senior Parcel Delivery : The Case of "CJ korea express"," Korea Business Review, Vol.19, No.4, pp.105-128, 2015
DOI : http://doi.org/ 10.17287/kbr.2015.19.4.105

[8] David T. Goomas, "Immediate Feedback on Accuracy and Performance: The Effects of Wireless Technology on Food Safety Tracking at a Distribution Center," International Journal of Logistics Research and Applications, Vol.32, Issue 4, pp.320-328, 2012
DOI : https://doi.org/10.1080/01608061.2012.729391

[9] Y.H. Choi, "A Study on the Freshness of Agricultural Products Distribution," The Journal of the Institute of Internet, Broadcasting and Communication(JIIBC), Vol.6, No.3, pp.377, 2020.
DOI : http://doi.org/10.18391/JCCT.2020.6.3.377

[10] Jia Wei Han, Min Zuo, Wen Ying Zhu, Jin Hua Zuo, En Li Lü, Xin-Ting Yang, "A Comprehensive Review of Cold Chain Logistics for Fresh Agricultural Products: Current Status, Challenges, and Future Trends," Trends in Food Science & Technology, Vol.109, pp.536-551, 2021.
DOI : https://doi.org/10.1016/j.tifs.2021.01.066.

[11] Li Huang, Udo Piontek, "Improving Performance of Cold-Chain Insulated Container with Phase Change Material: An Experimental Investigation." MDPI Journals, Appl. Sci. 2017, 7(12), 1288, 2017.
DOI : https://doi.org/10.3390/app7121288

[12] Szczepanik Tomasz, Skowron-Grabowska Beata, Nowakowska-Grunt Joanna, Brzozowska Anna, "The Application of Computer Systems Used in Logistics Centres by Courier Companies," Fakulteta za Management, Vol.12, Issue.2, pp.145-153, 2017.
DOI : http://doi.org/10.26493/1854-4231.12.145-153