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On the Integrated Operation Concept and Development Requirements of Robotics Loading System for Increasing Logistics Efficiency of Sub-Terminal

Sang Min Lee*, Joo Uk Kim**, Young Min Kim***†

** Ph. D. Candidate, Department of Systems Engineering, Ajou University, Korea*
*** Senior Researcher, Korea Railroad Research Institute*
**** Associate professor, Department of Systems Engineering, Ajou University, Korea*

lsm@ajou.ac.kr, jookim@krri@re.kr, pretty0m@ajou.ac.kr

Abstract

Recently, consumers who prefer contactless consumption are increasing due to pandemic trends such as Corona 19. This is the driving force for developing the last mile-based logistics ecosystem centered on the online e-commerce market. Lastmile led to the continued development of the logistics industry, but increased the amount of cargo in urban area, and caused social problems such as overcrowding of logistics. The courier service in the logistics base area utilizes the process of visiting the delivery site directly because the courier must precede the loading work of the cargo in the truck for the delivery of the ordered product. Currently, it's carried out as automated logistics equipment such as conveyor belt in unloading or classification stage, but the automation system isn't applied, so the work efficiency is decreasing and the intensity of the courier worker's labor is increased. In particular, small-scale courier workers belonging to the sub-terminal unload at night at underdeveloped facilities outside the city center. Therefore, the productivity of the work is lowered and the risk of safety accidents is exposed, so robot-based loading technology is needed. In this paper, we have derived the top-level concept and requirements of robot-based loading system to increase the flexibility of logistics processing and to ensure the safety of courier drivers. We defined algorithms and motion concepts to increase the cargo loading efficiency of logistics sub-terminals through the requirements of end effector technology, which is important among concepts.Finally, the control technique was proposed to determine and position the load for design input development of the automatic conveyor system.

Keywords: *Robotics Loading System, End Effector Platform, Loading Decision System, Cargo Information Automatic Cognition, Loading Management System.*

1. Introduction

In modern society, the spread of digital life people who want to minimize contact with people and receive contactless information has led to the development of unmanned distribution systems such as kiosks and chatbots in face-to-face transactions with sellers and consumers [1]. In order to streamline logistics supply in accordance with the unmanned system, a contactless logistics industry ecosystem was created centered on the digital New Deal-based joint logistics hub, unmanned courier goods storage device, and cold-chain-based lastmile service [2]. The contactless logistics industry is becoming a driving force for the growth of the courier market by increasing the volume of courier goods nationwide along with the growth of the online market [3].

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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

For delivery of ordered goods, couriers advance the loading of cargo on trucks and utilize the process of visiting the destination directly [4]. The task of loading the cargo to be shipped to a 2.5-ton truck should ensure the safety of handling the irregular release cargo, and there is a disadvantage that the labor load is high due to repeated work performance [5]. In addition, problems are created that reduce work efficiency and increase social costs due to reduced productivity, such as causing safety accidents of workers during cargo processing [6]. Therefore, it is necessary to have an intelligent robot technology-based loading system [7], such as improving loading efficiency based on loading automation technology and protecting human resources by reducing work intensity and risk sources [8].

In this paper, we conducted to derive the concept and requirements of robot-based loading automation system suitable for small and medium-sized sub-terminals that increase the efficiency of delivery cargo and the work productivity of courier drivers due to the growth of the logistics industry. Based on the loading system including semi-autonomous cargo compartment entry and direction adjustment function, end effector technology and image-based loading algorithm which enhance the loading efficiency of the release cargo, the logistics automation base necessary for improving the working environment of small and medium sub terminal is presented. The present invention is to increase the safety and reliability of a logistics system by flexibly performing cargo processing through a robot-based loading system, increasing the volume of cargo in a logistics center, and minimizing the labor intensity and safety accidents of workers through robot collaboration and automation technology.

The composition of this paper is as follows.

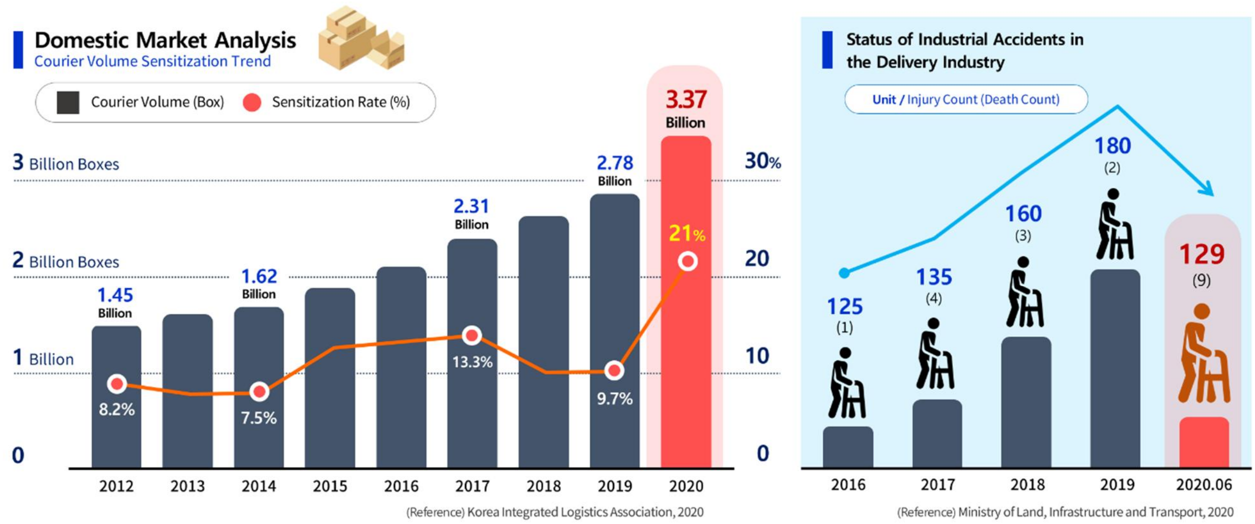
First, the introduction conducted a study on the background and necessity. In section 2, the study aims to draw problems based on the current status of the delivery service and the precedent cases of the system for automation of the delivery service. In section 3, design inputs were developed through analysis of operational concepts and requirements, and the results of the study were derived. In the last section 4, the results of the paper were summarized.

2. The Definition of the Problems

2.1 Analysis of Problems in the Delivery Loading Process

The delivery cargo delivered to the customer is classified by destination through the automation equipment and is loaded into the truck by the courier [9]. Before the delivery, the worker transfers the cargo to the truck and performs the reloading of the cargo in accordance with the delivery order in the loading box interior space. The average loading time (the state where all things are aligned) is about 30 minutes, and the loading process for delivery is all performed through the labor force of the courier [10]. Since the number of cargoes that couriers have to ship per day is increasing every year, they are doing excessive work due to the loading before the delivery begins.

The couriers are working until night time for the day delivery, and the physical burden of the long-term operation and the walking transfer for delivery is also increasing [11]. Figure 1 (a) and Figure 1 (b) show the results published in 2020 by Korea Integrated Logistics Association, Ministry of Land, Infrastructure and Transport, respectively. Figure 1 (a) shows the trend of courier volume and sensitization rate in the domestic courier market. Delivery volume shows an increasing trend every year. Figure 1 (b) shows the state of industrial accidents in the delivery industry by year. Accidents tend to increase every year, in the first half of 2020, 9 deaths and 129 injured people were reported during delivery of courier services.



(a) (b)

Figure 1. Logistics accidents statistics in Korea, 2020

(a) Korea Integrated Logistics Association, 2020, (b) Ministry of Land, Infrastructure and Transport, 2020

To solve this problem, the change of the laws and regulations related to classification personnel and early morning delivery (probably announced on January 1, 2022) limits the working hours of courier workers from 10:00 to 22:00, and the introduction of a system prohibiting early morning delivery after 22:00 to reduce the work intensity is being discussed. In the case of the study for delivery workers, it is not a fundamental solution to the social problems of the delivery industry because it is focused on improving the work efficiency and the competitiveness of the delivery service. Test beds related to automation equipment are being operated to efficiently handle courier cargo [12]. However, there is little infrastructure to install automation equipment at small logistics sub-terminals with vehicles over 20 cargo trucks. Therefore, it is not a realistic alternative to minimize the work intensity of the worker to be put into the loading work.

2.2 Prior Case Study on the Robotics Loading System

Prior research on automation equipment is being conducted to effectively handle courier cargoes. In the case of a large Hub courier terminal, the task is carried out using a telescopic conveyor, an automation device for loading cargo [13]. This can reduce the labor burden of workers, but it lacks universality in that it is applied only to large trucks and that workers should handle cargo directly. The related patented technology 'Autonomic truck loader and unloader' is linked to the conveyor. The technology is being developed in advance of the technology of loading cargo using robotic arm inside the truck. The cargo information recognition and the loading environment information are not considered, and it has a limit that it is difficult to operate in a limited space.

In 'Robotics system with automated package registration mechanism and methods of operating the same', it is in associated with conveyor. The technology that performs the loading of the cargo reflecting the location using various sensors inside the truck was applied. The present technology is disadvantageous to the performance of the direction control function optimized for the loading box of the truck and has a low utilization in the working environment. The ‘Automated truck unloader for unloading/unpacking product from trailers and containers’ technology overcomes this and performs position adjustment using various sensors in the truck loading box. However, there is a limitation of the use of the mechanism for delivering the loading environment information.

Since the prior cases related to the automatic loading equipment are concentrated on loading cargo in trucks, it is necessary to apply cargo recognition technology and loading environment recognition technology to reduce the labor consumption of workers [14]. In order to improve the loading efficiency of automation devices, consideration of operating environment is essential [15].

2.3 Research of Scope and Procedure

In this paper, we develop the integrated operation concept and optimized requirements of robotics loading automation system for the loading efficiency of courier cargo developed in the rapid growth of contactless online market. The development direction proposes a loading automation system targeting sub-terminals and small trucks that can operate independently of last mile and retail technology. Also, the operational concept and requirements applying environmental characteristics are derived.

Especially, in the case of a robotics loading system, it is composed of an automation device that doesn't utilize the labor force of a courier. And we develop device design inputs by applying systems engineering techniques and holistic viewpoints-based development processes. Finally, the integrated concept design is carried out to attribute the cargo recognition applying the robot-based automation concept and the artificial intelligence-based image recognition concept and the cognitive function of the loading space to the robotics loading system. Figure 2 shows the goal, scope, and procedure of this paper.

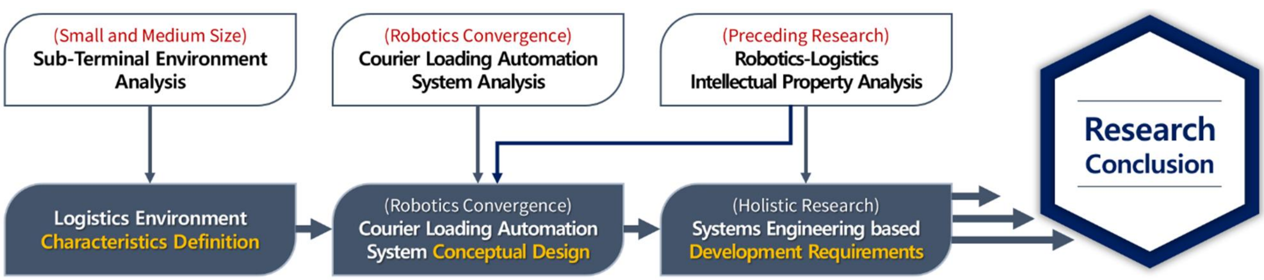


Figure 2. Research goal, scope and procedure

3. Development of the Integrated Operation Concept and Requirements for Robotics Loading System

3.1 Design of Integrated Operation Concept for Robotics Loading System

The robotics loading automation system applies the design reflecting the property of the loading environment for the delivery cargo loading efficiency. In the sub-terminal, the process of classifying the cargo transported from the hub terminal as an automation equipment and loading it in the cargo truck by delivery destination is executed. In this process, automation function should be applied to reduce the labor load of couriers and to increase the efficiency of loading work. Therefore, the robotics loading system should be composed of a new conveyor for transferring cargo such as Figure 3, an end effector for loading, an image recognition device for checking loading space and loading state, a distributor for cargo order and loading management, an image-based recognizer for checking cargo status and tag information, and a sensor for detecting cargo engagement.

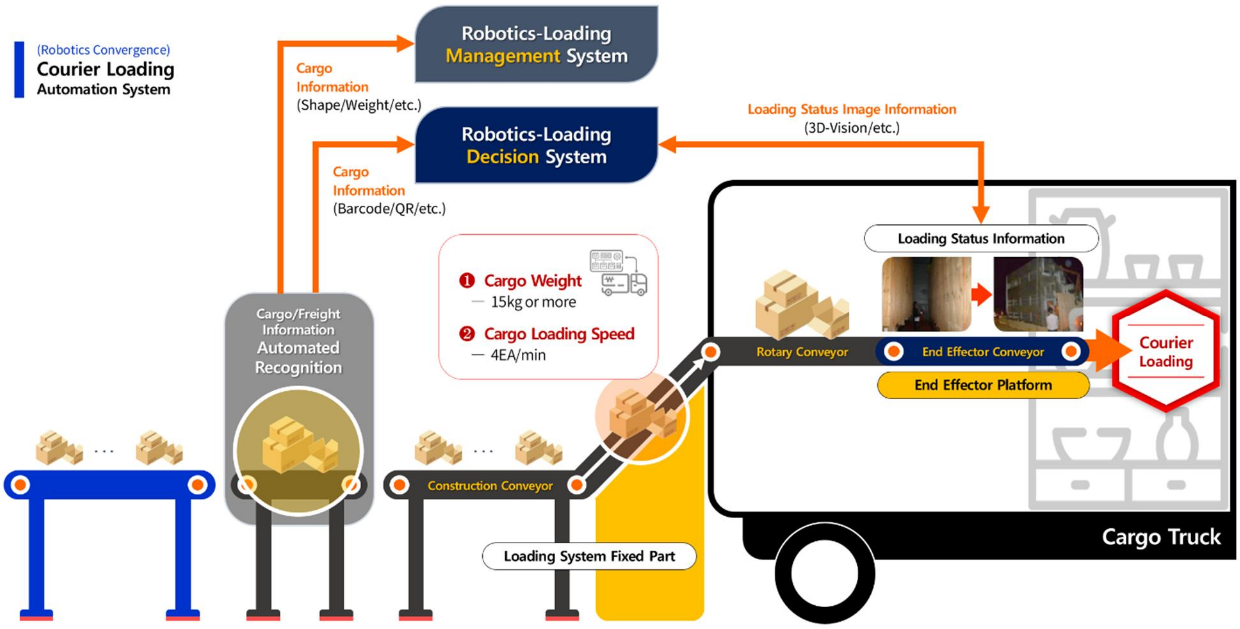


Figure 3. Robotics loading system's integrated operation conceptual design

In addition, artificial intelligence-based loading software including loading order and loading information recognition algorithm for loading operation management and loading decision making should be subordinated. In the robotics loading system, the shape and weight of the loaded cargo should be recognized, and the cargo should be loaded according to the information determined by the loading order decision to the end effector. For this purpose, structural point of view end effector, conveyor, and cargo information recognition system should be built in the concept of operation to be developed, such as Table 1.

Table 1 defines functions for end effectors, rotary conveyors, and expansion and contraction conveyors for normal operation of the robot loading system. In addition, algorithm-based cognitive systems, path division algorithms, and functions of control units were defined for load control. In order to check the condition of the loaded product and the condition of the loading operation, sensors and forecasting technologies that can predict risk sources and failure conditions were defined. In the case of control functions of loading systems such as semi-autonomous, autonomous, and manual, and risk sensors and failure sensors for risk source analysis of cargo and parts, data-based predictive maintenance functions can be added and managed.

Table 1. Robotics loading system's function list based Integrated operation concept

No	Robotics Loading Sub-System		Integrated Concept and Function
1	**End Effector**	End Effector	End effector for loading the transferred courier cargo in a designated position Structure Application for Loading of Various Types of Cargo
		End Effector Conveyor	Final conveyor for delivering to the end effector It comprises with the rotation type for the exact loading Gravity compensation function offer
		Loading State Confirmation Imaging Device	The device for on a real time basis confirming the information of the cargo loaded in the vehicles

2	**Rotary Conveyor**		Conveyor connected to the end effector Configure to rotation form for correct location selection
3	**Construction Conveyor**		According to the vehicle depth and height, it comprises with the vertical height control form in order to control height
4	**Loading System Fixed Part**		Fixing unit for fixing the construction conveyor, the rotary conveyor, and the end effector
5	**Cargo Recognition system**	Image-based Recognition Device	Cargo information recognition based on image (barcode and image) Ordering for Destructive Cargo and Load Optimization
		Construction Conveyor	Freight transfer conveyor for the image-based cargo information recognizer application Margin adjustments for recognition and loading planning
		Cargo Distributor	Ordering for Damage or Optimization after Passing an Image-based Cargo Information Recognition Machine
6	**Sequential/Path Divider**		Loading order control based on the weight, delivery distance, and shape of the stored cargo for optimization of cargo loading
7	**Loading System Controller**		Semi-autonomous based loading System Location Control Control of the operating mode of the loading system such as autonomous/passive
8	**Hazard Detection Sensor**		Risk detection such as cargo engagement, impact occurrence, and worker stenosis
9	**Fault Detection Sensor**		Checking the failure of major parts
10	**Predictive Maintenance**		Manage parts production and use history Maintenance history management of parts

3.2 Loading Environment Recognition Concept Design

In order to load cargo, the recognition technology for cargo and loading environments to be put into the device should be applied. Therefore, the loading decision system with the cargo shape recognition and loading space arrangement algorithm specified in Table 2 and the loading work management system for the monitoring of cargo information, dispatch information, and loading system should be implemented. In particular, the loading decision-making system needs the function of recognizing the cargo information-based phase order, batch decision and loading cargo information. For spatial recognition, a loading algorithm considering the size of cargo is applied based on the depth camera sensor.

As shown in Table 2, in the loading decision-making system, technology to determine cargo to be handled through cargo information recognition, damage recognition through cargo images, optimal cargo loading placement, and loading decision-making is applied. In the management system that manages tasks under loading conditions, cargo information inquiry, allocation information inquiry, and loading system monitoring are configured to instruct accurate loading tasks.

Table 2. Robotics loading system's recognition algorithm and operation system

No	Robotics Loading Sub-System		Integrated Concept and Function
1	**Loading Decision Making System**	Cargo Information Recognition	Query cargo information associated with barcode, QR code-based cargo information confirmation and a phase-off task management system
		Recognition of Damage through Cargo Image	AI-based cargo damage recognition algorithm
		Loading State Image Analysis	Algorithm for loading state analysis based on AI
		Cargo Loading Optimal Arrangement	AI-based optimization loading layout algorithm
		Loading Decision Making	Identification of cargo loading based on image information and loading status Cargo processing in conjunction with an end effector and a cargo dispenser based on identification information
2	**Loading Management System**	Cargo Information Inquiry	Inquiry of information-based cargo information acquired through a cargo information recognizer Providing planning-based information for optimal arrangement of cargo loading, such as cargo delivery location, weight, etc.
		Allocation Information Inquiry	Provide vehicle allocation cargo and cargo delivery location information
		Loading system Monitoring	Monitoring the progress of vehicle allocation cargo Loading system state monitoring Loading system control for hazard and fault detection

The loading algorithm is derived from the simulation results based on the weight, volume, state and movement distance of the cargo, and calculates the optimal loading zone based on the dispatch vehicle and local information. The Way Point for the cargo loading is drawn through the result calculating. In the loading work management system, the role of processing after the cargo information confirmation and faulty cargo recognition is proceed. For the design of the cargo loading algorithm structure of the robotics loading system, the recognition algorithm is equipped with sensors (risk and fault detection sensors) that identify unintended failure and risk sources that may occur during load operations.

3.3 Development of Requirements for Robotics Loading System

The robotics loading system, designed based on the environment of the sub-terminal, is designed to be optimized for small trucks of 2.5 tons or less, such as Figure 4, based on the functions defined in Table 1 and Table 2. The robotics loading system should be configured to recognize cargo and loading space based on image recognition algorithms and to increase optimal cargo loading efficiency. Because the loading order is determined by reflecting the characteristics of the cargo, a part should be formed to wait for the subordinated cargo.

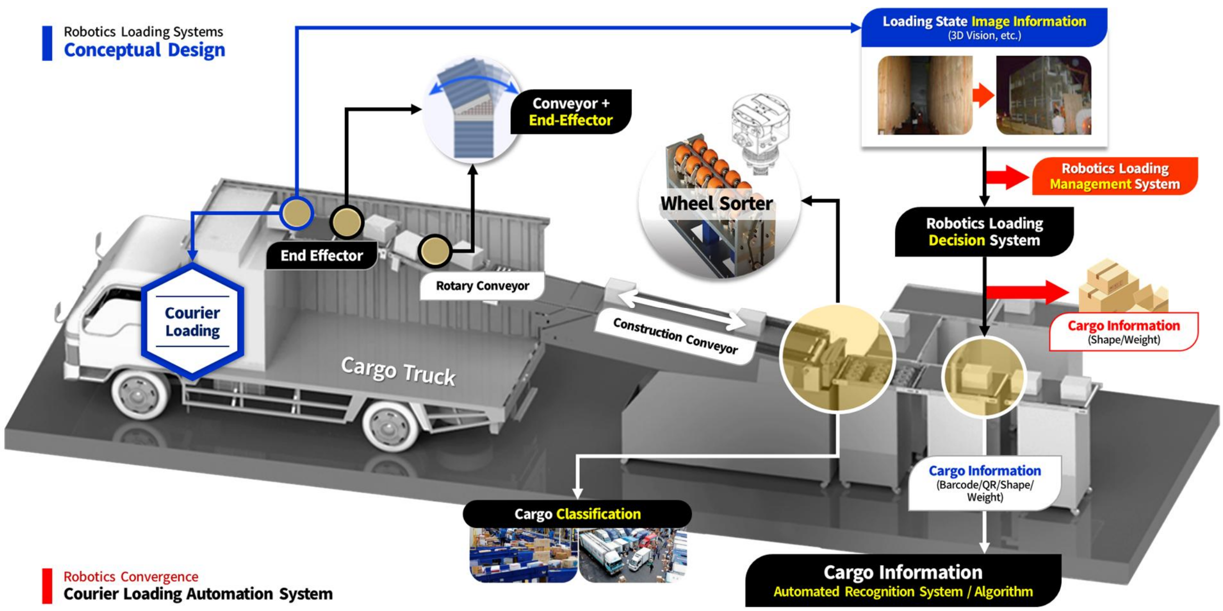


Figure 4. Robotics loading system's integrated operation conceptual design

In case of the cargo in which the loading order is delayed, it is transferred to the standby part conveyor through the pivot wheel sorter and it waits until the loading order is appointed. If the loading order pitches, it puts into the robotics loading system internal device and the loading is completed through the end effector. The system is also provided with an energy-reducing conveyor device to increase energy efficiency and to prevent damage to the loaded cargo through the collision prevention device and the recognition sensor. To this end, requirements for optimized loading system design such as Table 3 should be defined.

The design requirements and techniques that are important in Table 3 are as follows. It allocates subsystems to maintain a stable loading process through efficient multi-formal cargo loading, real-time cargo recognition and status check, incorrect cargo collection and loading order control, cargo loading and loading positioning, transportation vehicles, cargo management and scheduling, and AI-based object recognition algorithm.

Table 3. Robotics loading system's design requirements

No	Sub-System	Design Requirements
1	End-Effector + Conveyor	Efficient multi-type atypical cargo loading
2	Cargo Information Autonomous Recognition Device	Realtime cargo recognition and status check
3	Large Classification Sorter Module	Faulty cargo collection and loading order control
4	Loading Decision Making System	Cargo loading and loading location determination
5	Loading Management System	Dispatch vehicle, cargo management and scheduling
6	AI-based Object Recognition Algorithm	Image-based loading and loading space recognition

4. Conclusion

In this paper, we designed the integrated operation concept and requirements of robotics loading system for collaboration and unmanned cargo loading work performed by existing couriers. The system recognizes the information and location of cargo through image recognition-based algorithm and proposes a loading algorithm to enable optimal cargo loading by spatial recognition through depth camera sensor. The recognized results are configured to be interlocked through each loading automation module, and the optimized operation of the cargo loaded into the device is guaranteed. Through this research, we have developed concepts and requirements to minimize the labor consumption of couriers who are put into robot-based loading automation work, to prevent safety accidents during cargo processing, and to establish a work base that can concentrate on delivery. And the focus was on flexibly operating the cargo volume that can be handled at the logistics terminal by increasing the cargo processing speed through automation equipment. We have proposed a requirement that can be constructed from a modified cargo self-loading system through the collaboration structure of workers and robots based on concepts and requirements. In this paper, it is necessary to carry out follow-up research to improve the safety and reliability of the system automation system through the application of safety analysis techniques based on systems engineering activities such as step-by-step risk analysis and safety requirement-based specifications that may occur when operating the system.

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