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On the Needs of Vertical and Horizontal Transportation Machines for Freight Transportation Standard Containers to Derive Design Requirements Optimized for the Urban Railway Platform Environment

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Abstract

Recently, the number of consumers using digital online distribution platforms is increasing. This caused the rapid growth of the e-commerce market and increased delivery volume in urban areas. The logistics system, designed ar006Fund the city center to handle the delivery volume, operates a delivery system from the outskirts of the city to the urban area using cargo trucks. This maintains an ecosystem of high-cost and inefficient structures that increase social costs such as road traffic congestion and environmental problems. To solve this problem, research is being conducted worldwide to establish a high-efficiency urban joint logistics system using urban railway facilities and underground space infrastructure existing in existing cities. The joint logistics system begins with linking unmanned delivery automation services that link terminal delivery such as cargo classification and stacking, infrastructure construction that performs cargo transfer function by separating from passengers such as using cargo platform. To this end, it is necessary to apply the device to the vertical and horizontal transportation machine supporting the vertical transfer in the flat space of the joint logistics terminal, which is the base technology for transporting cargo using the transfer robot to the destination designated as a freight-only urban railway vehicle. Therefore, this paper aims to derive holistic viewpoints needs for design requirements for vertical and vertical transportation machines and freight transportation standard containers, which are underground railway logistics transport devices to be constructed by urban logistics ecosystem changes.

Keywords: *Urban Railway Logistics, Vertical Transportation Machine, Horizontal Transportation Machine, Freight Transportation Standard Containers, Automated Guided Vehicle.*

1. Introduction

Underground logistics technology in urban areas is approached by logistics infrastructure construction technology that performs freight function separated from passengers by analyzing freight platforms and idle spaces of platforms of railway platforms [1]. The main technologies are classified into the construction of last mile-linked services such as freight classification and loading, and the technology of transporting freight to railway vehicles using underground railway platforms [2]. In the case of transportation technology, horizontal transportation machine for flat transfer of underground space, vertical transportation machine supporting vertical transfer in the vertical direction, low-floor design technique for transportation and

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loading efficiency, and freight transportation standard container controlling flexible freight volume are being developed [3]. The optimized freight transport method in the limited underground railway platform is to utilize intelligent transport devices with unmanned transport robot technology such as AGV [4]. Therefore, it is necessary to apply standard container for freight transportation to ensure the maximum loading amount of freight and to lighten the size of transfer device. Urban logistics-based technologies such as vertical transportation machine, which develops horizontal transportation machine with low-floor design and AGV operation concept, and shares freight elevation platform installed in existing underground space, should be reinforced. In this paper, we design optimization model of logistics transportation system by verifying the needs analysis and validity of holistic viewpoints to derive requirements of vertical and horizontal transportation machines suitable for underground railway platforms.

2. The Definition of the Problems

2.1 Problems of the Operation Structure of Urban Logistics System

The consumption structure of last mile logistics is being advanced online from offline worldwide [5]. This resulted in overcrowding of logistics, which increased the volume of road transport delivery freights from the outskirts to the urban areas [6]. To solve this problem, joint logistics system using urban railway facilities, common spaces and underground space infrastructure is being created to distribute the traffic volume centered on roads [7]. The system is designed based on research on the feasibility of freight transport functions such as freight classification, loading, last mile and logistics efficiency by separating the urban railway platform from passengers [8]. Therefore, it is necessary to develop infrastructure and logistics transport equipment based on needs to convert freight demand such as urban courier from vehicles to railways.

The railway logistics infrastructure is constructed as joint logistics terminal, urban railway vehicle for freight transportation, and logistics space for last mile for freight collection, classification and transportation as shown in Figure 1. In order to transfer the freight loaded in the railway vehicle to destination location, space and platform is utilized. Among them, the method for increasing efficiency of transfer utilizes horizontal transportation machine for loading freight through freight transportation standard container and flat transfer of a container, and vertical transportation machine to be installed on freight platform. The devices are basis of joint logistics operating system that shares logistics information to a number of carriers, consignees and various logistics personnel in railway vehicle base [9]. In order to separate passenger functions and freight transportation functions, and to establish safe railway freight operation system, it is necessary to derive the needs of vertical and horizontal transportation machines based on conveyor technology and AGV technology [10].

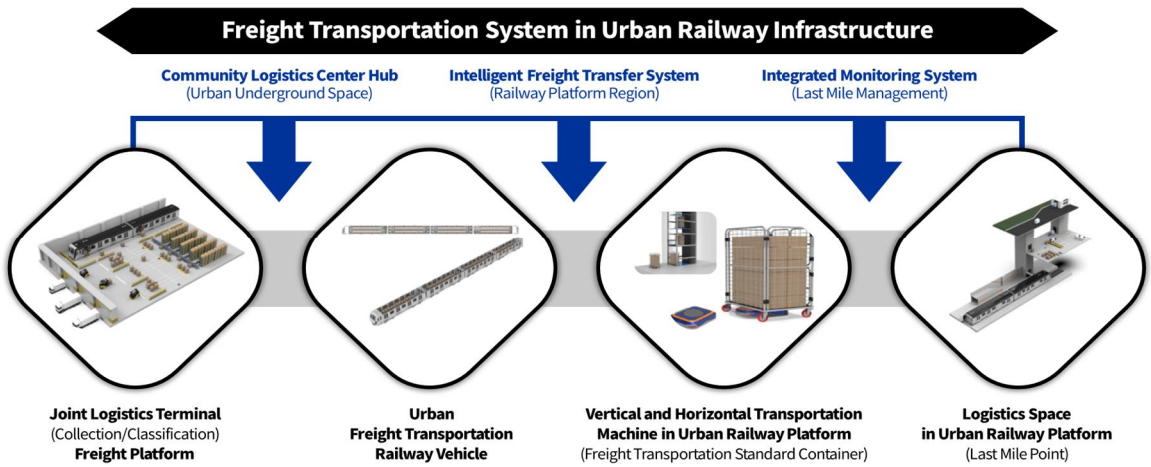

Figure 1. Freight Transportation System's Operation Status

2.2 The Importance of Vertical and Horizontal Transportation Machine's Development using Underground Railway Platform

The underground joint logistics system starts from the concept of converting road transport demand into railways. The vertical and horizontal transportation machine used in the underground space is analyzed as improved equipment for efficiency and optimization of freight transport based on AGV, intelligent logistics transport robot, and vertical platforms installed in platform [11]. This device's unmanned logistics device installed in limited space of railway platform, which performs last mile to logistics space in platform, unlike vertical conveyors, lifts, and AGV equipment used in the logistics center. In addition, it is applied to infrastructure in operation after design and construction are completed and has the advantage of being able to transport combined components in connection with various devices.

First, the commercialized vertical transportation machine is general elevation platform that performs one-way, two-way transport through drive motors and chains around vertical conveyors, vertical lifts, and multi-layered transport devices [12]. The horizontal transportation machine is AGV that horizontally transfers the dedicated rolltainer through optical tapes, QR codes, barcodes, and LiDAR-based recognition to drive the path installed on the floor [13]. On the other hand, the proposed device is optimized for the urban railway platform and there is conceptual difference in the combination of the plane and vertical transfer of freight loaded in the freight transportation standard container in limited common logistics space. For the safe design of vertical and horizontal transportation machines, it is necessary to research the needs from holistic viewpoints on the limit load of freight transportation standard containers that guarantee the maximum loading capacity, the height of device coupled with the container, the speed of device, and the coupling operation with multiple devices.

2.3 Research of Scope and Procedure

In this paper, we analyze the current status of underground logistics system and conduct concept design necessary for development of effective vertical and horizontal transportation machines. In addition, the needs analysis of vertical and horizontal transportation machines is conducted to derive design requirements optimized for underground railway platform environment. The scope and procedure of the research derive functional, technical, and environmental Needs based on the features of operational concepts and functions of vertical and horizontal transportation machines, as shown in Figure 2. Based on needs, we identify the core functions to be composed of integrated systems and develop design requirements. The device design model suitable for the underground railway platform is presented through the analysis and verification process of the needs which is applied the holistic viewpoints to the derived requirements.

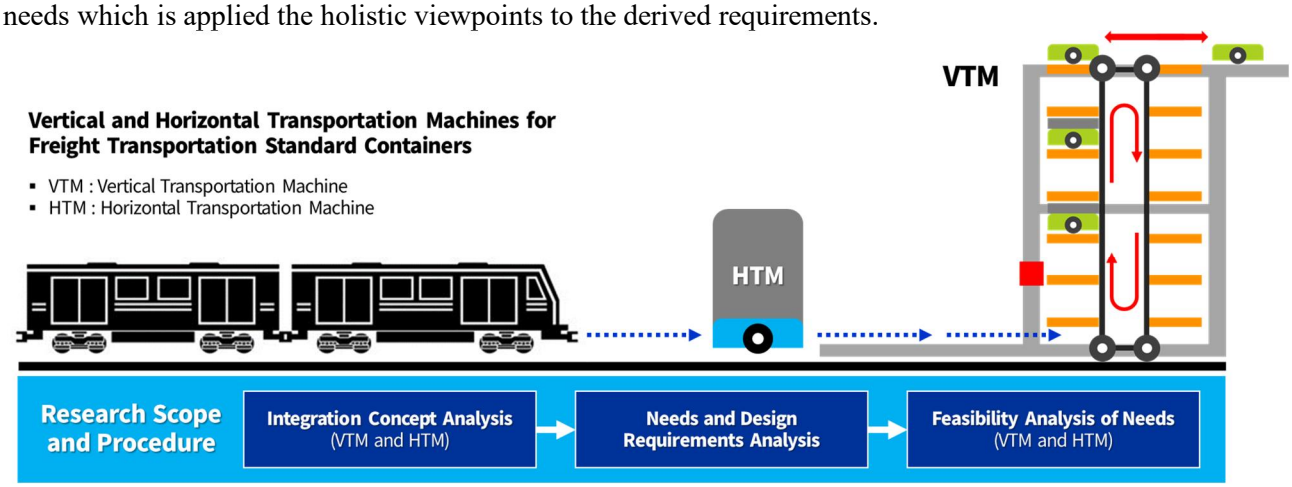

Figure 2. Research Scope and Procedure

3. Analysis of Vertical and Horizontal Transportation Machine's Operation Concept

3.1 Analysis of Integration Operation Concept

The vertical and horizontal transportation machine is used in logistics spaces, common areas and logistics terminal in urban railway platform, and is logistics device combined with freight transportation standard container, AGV, and vertical conveyor technology having the function of vertical transfer in the vertical direction and freight transfer in the flat space in freight platform. The device performs last mile by connecting plurality of devices for transporting freight loaded on railway vehicle in logistics space, urban railway infrastructure, as shown in figure 3. First, the horizontal transportation machine coupled with the freight transportation standard container arrives at the platform while being on board the railway vehicle. The device is grouped and transported along path configured in the dummy platform while maintaining constant distance, and is fixed to transfer plate of vertical transportation machine for multi-layered transport. In order to arrive in the physical distribution space which is determined after canceling the horizontal transportation machine and tightening when arriving at the determined destination location the vertical transportation machine supports transfer. All processes of the last mile step connected to railway vehicle, horizontal transportation machine, and vertical transportation machine are configured to be controlled in the integrated control system.

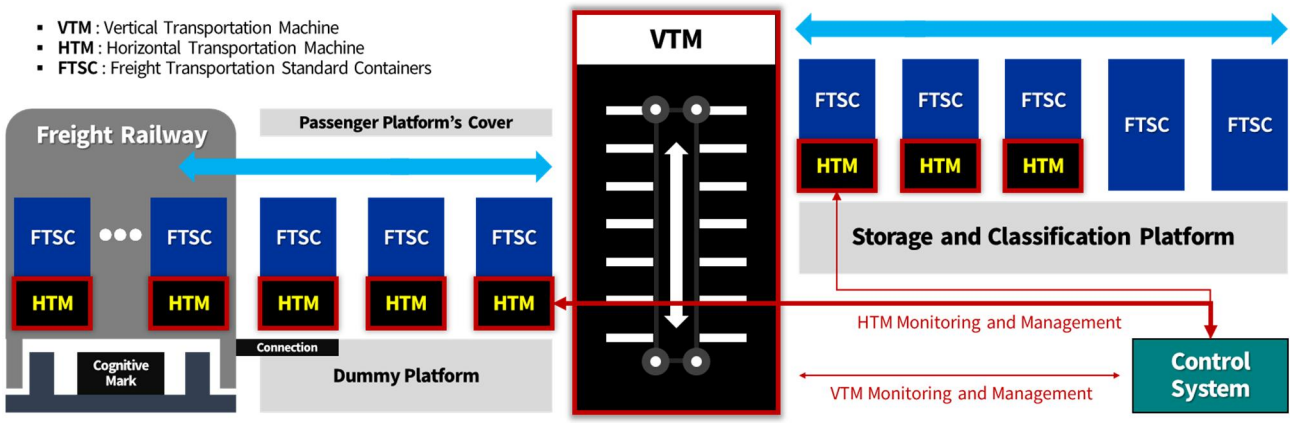

Figure 3. Integration Model's Concept Design

3.2 Analysis of Vertical Transportation Machine(VTM)'s Operation Concept

The vertical transportation machine is fixed type equipment installed vertically in urban railway platform and transferring the horizontal transportation machine loaded with freight arriving at the platform through the freight train to upper floor of logistics space in platform. The device is installed in underground space and railway dummy platform, and maintains standby conditions to load freight of the horizontal transportation machine. The operation preparation state for fixing is activated in the vertical transportation machine performing top and bottom through the rotary type transfer plate and inter-layer transfer the freight loaded in the 2 trains like figure 4 is the flat transfer with freight transportation standard container fixed and coupled with the horizontal transportation machine. Thereafter, rising and falling are performed based on vertical conveyor, vertical lift, and multi-layered transfer technology to the destination layer. All processes are controlled by the integrated control system to separate from passengers and perform safe freight transport functions independently.

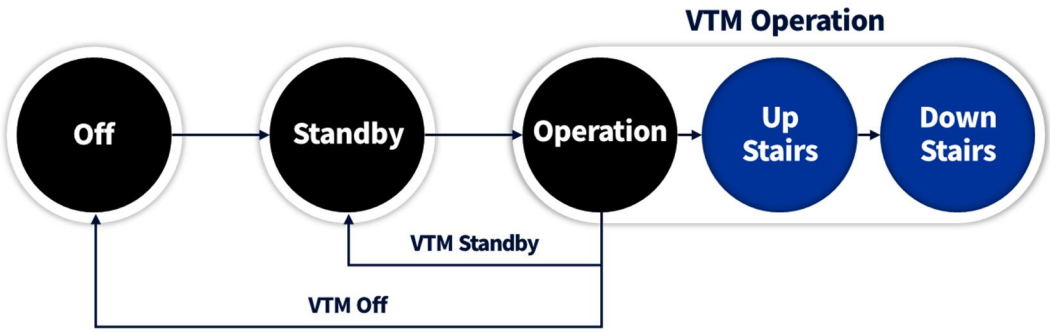

Figure 4. Vertical Transportation Machine's Operation Concept

3.3 Analysis of Horizontal Transportation Machine(HTM)'s Operation Concept

The horizontal transportation machine is AGV-based unmanned transfer device that transports freight loaded in the freight transportation standard container in urban railway infrastructure to designated target destination. The device is applied to transport freight in conjunction with freight trains and vertical transportation machines on the dummy platform of underground space and railway platform. In order to recognize the transfer, storing, and the handling location information as the state fixed with rolltainer or the freight transportation standard container, the horizontal transportation machine uses QR code method and transfer path is decided. In addition, the device applies the concept of low-floor design with minimum height to increase the loading efficiency of the freight transportation standard container. As shown in Figure 5, the safety concept of stopping operation and entering the standby state is also included in the state of not being fixed with device and freight transportation standard container. In the platform performing the passenger function, the standby state mode performs a function of monitoring malfunction of horizontal transportation machine. The operation state is monitored by the integrated control system to remove safety accidents such as collisions between the devices when plurality of horizontal transportation machines are transported.

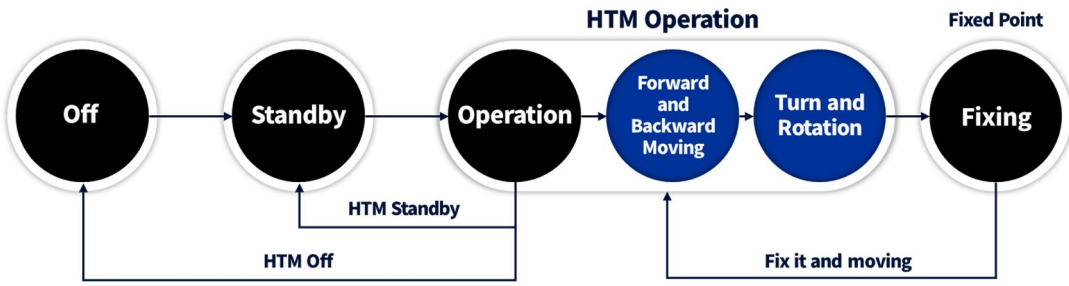

Figure 5. Horizontal Transportation Machine's Operation Concept

4. Development of Vertical and Horizontal Transportation Machine's Design Requirements and Analysis of Needs Feasibility

4.1 Derivation of Functional, Technical, and Environmental Needs

The vertical transportation machine is installed and operated in urban railway infrastructure unlike the vertical conveyor, vertical elevator, vertical lift, multi-layered freight transfer equipment. Vertical transportation machine is complex logistics transfer system that can be combined with a plurality of logistics devices on operating urban railway platform. The device is installed vertically in the railway platform, and the horizontal transportation machine arriving at the railway platform is fixed to rotary vertical transport plate of the vertical transportation machine through flat driving. It transfers the horizontal transportation machine through the inter-layer transfer of the conveying plate to the physical distribution space and the vertical

transportation machine advances final step delivery to the destination location. Several freight transportation standard containers and horizontal transportation machines are mounted inside the device, so the design core factor is the maximum load capability of the vertical transportation machine. The maximum load is an indicator of the plate fixation capability to prevent freight departure from the conveying plate. Therefore, the device requires functional, technical, and environmental needs for safe transport of freight as shown in Table 1.

Table 1. Vertical Transportation Machine's Design Perspective's Needs

No	Functional Needs	Technical Needs	Environmental Needs
1	Up and down transport should be possible	Control and control of the ascending and descending transport of the device must be possible	Should be installed in a space within a limited station
2	Horizontal transportation machine must be able to be fixed during transportation	The boarding recognition and binding function of the horizontal transportation machine must be controlled	Should not be affected by vibrations generated by train transfers in stations
3	Freight transportation standard containers, and horizontal transportation machine must all be covered	It should be possible to control the device linked to the entry and boarding process of the horizontal transportation machine	It should be designed and installed to avoid structural burden on the installation environment
4	Number of horizontal transportation machine must be transferred in the upward or downward direction.	Information related to the location of the horizontal transportation machine must be transmitted and received	Noise and vibration should be minimized when transferring the horizontal transportation machine
5	Location recognition of the transferred horizontal transportation machine should be possible	Radio control and control should be possible through the control system	The impact from operating the device must be minimized

The horizontal transportation machine is AGV-based logistics equipment that transfers freight loaded in freight transportation standard container in urban railway infrastructure. Because the guideline of the floor is recognized as the QR code for the stacking, transfer, storage, and handling location, it is different from the general AGV and rolltainer transfer technology. First, the low-floor design technique is applied to increase the loading efficiency inside the container because the freight load changes according to the height of the device. In addition, durable structure is required to maintain fastening state to prevent the device from being separated from the vertical transportation machine and the freight vehicle. Several devices are driven on the platform, monitoring of swarm movement is also required. In order to monitoring the swarm movement of the device, the integrated control system controls the path and the transfer state for preventing the collision between the device in transfer. Therefore, the device requires functional, technical, and environmental needs for safe transport of freight as shown in Table 2.

Table 2. Horizontal Transportation Machine's Design Perspective's Needs

No	Functional Needs	Technical Needs	Environmental Needs
1	It must be transferable through a standard container for cargo transportation	Control and control of the operation of device and freight transfer must be possible	The operation in the space in the subway station should be considered
2	When transferring the container, it must be fastened through the fixing function	Information on freight contained in standard freight transportation containers must be delivered to control system	Consideration should be made not to interfere with the operation of the device when transferring through the vertical transportation machine
3	Low-floor design requires entry into the lower part of the rolltainer	It should be possible to recognize boarding to the vertical transportation machine and control the binding function	Environmental variables for boarding freight trains should be considered
4	Binding should be possible when transferring the vertical transportation machine	It must be possible to recognize boarding of freight trains and control binding functions	
5	It must be able to bind when transporting freight trains	The location-related information of horizontal transportation machine must be transmitted and received to control system	

4.2 Design Requirement Development

The vertical transportation machine is composed of elevation platform installed for multilayer transfer of urban railway platform. The horizontal transportation machine is operated to the state that isn't installed the PSD(Platform Screen Door) for the railway dummy platform and freight. The horizontal transportation machine fixed to the rotary type conveying plate is in associated with for freight with the integration control system. The device requires design inputs such as vertical transfer, freight transfer, power control, load support, equipment control, information transmission and reception for vertical direction rise and fall. In addition, it is necessary to perform functions such as fixed function to prevent the separation of freight and a rotation sequence to control the entry and exit order of the device. Therefore, it is necessary to design maximum speed of 1.0m/s and maximum loading capacity of 3ton, and safety rate considering the dynamic impact generated during high weight freight transfer.

According to the horizontal transportation machine is the height of the devices, amount of the freight loaded in the freight transportation standard container is determined. Therefore, AGV technology based on low-floor design of 150mm or less is needed considering the efficiency of transportation. In addition, the integrated control system is fixed to the freight train and the vertical transportation machine to prevent the departure of the freight and to control the total process of the destination transfer. Therefore, the device requires design inputs such as position recognition unit, driving motor and wheel, sensor unit, transportation container fixing unit, battery unit, information transmission and reception unit, control unit, state display unit, train binding unit, emergency stop button, and state display panel. The maximum speed of 1.2m/s and maximum capacity of 400kg(100kg of equipment, 300kg of cargo), 50mm of emergency stop distance, 4-degree of climbing ability, and 4 hours of battery charging time are also applied. Since the horizontal transportation machine has characteristics of the swarm movement, hazard analysis and safety measures for the swarm technology should be designed.

4.3 Needs Feasibility Analysis

The results of analyzing the needs of the vertical transportation machine are as follows. It is analyzed that the one-way transfer method combining the freight interlayer transfer using wheel conveyor and elevator method, docking transfer technology of horizontal transfer device loaded with freight transportation standard container, and integrated control technology for freight location recognition is reasonable. The results of analyzing the needs of the horizontal transfer device are as follows. Low-floor design and unmanned transport functions including freight transportation standard containers are analyzed as core needs. The range of battery performance for charging and discharging is important for freight vehicle and vertical transportation machine, freight transport technology through fixing with freight transport standard container, movement path according to work instructions and swarm control technology. The device is transferred directly from the arrival of the train to the destination, so integrated control is required. Also, since the transfer efficiency is determined according to the platform, the 4-degree climbing ability and docking method with the vertical transfer plate are important design requirements. In conclusion, it can be applied as needs of the improvement model of the joint logistics transportation system through the expansion of the use of urban railway facilities like Figure 6.

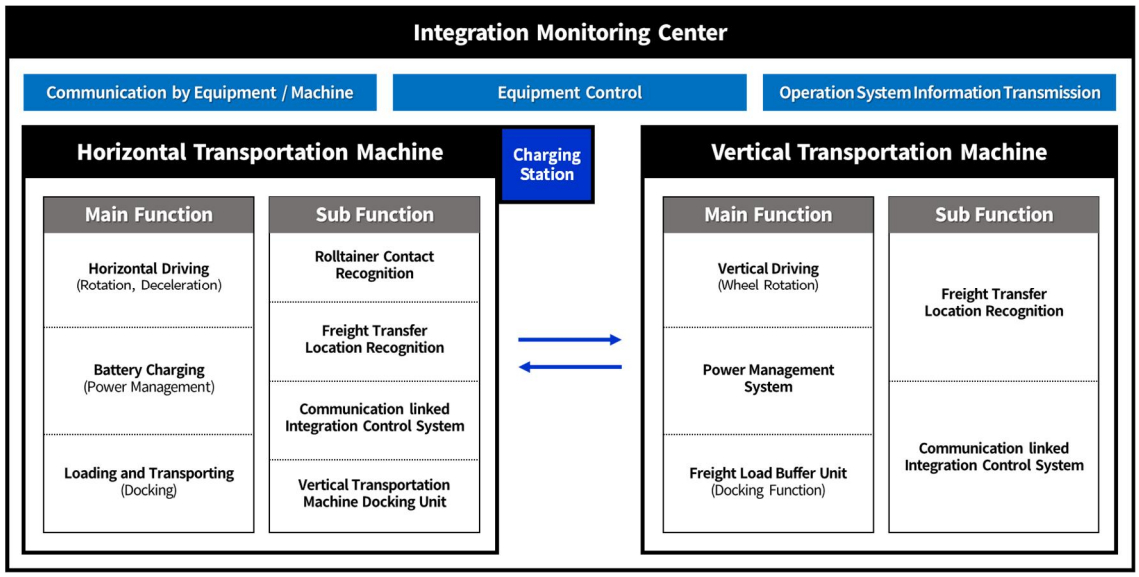

Figure 6. Vertical and Horizontal Transportation Machine's Function Diagram

5. Conclusion

In this paper, we conducted the derivation and validity verification of functional, technical, and environmental needs to derive design requirements optimized for the urban railway platform. In addition, the concept of operation of the AGV-based vertical and horizontal transportation machine and the freight elevation platform for performing vertical and horizontal transfer of the efficient loading method called the freight transportation standard container was designed. The vertical transportation machine needs an operational scenario-based safety design to model the transport efficiency of the device based on the maximum speed and maximum weight when rising and falling. It was confirmed that reliability factors such as vibration and shock resistance for load structure design according to the efficiency and load amount of one-way vertical transfer are also considered. The horizontal transport device needs to have specifications such as maximum capacity of loading standard containers required for low-floor design and maximum speed, maximum capacity, emergency stop distance, and climbing ability to secure reliability of swarm transfer considering the amount of transportation. Reliable structural design is needed to eliminate the risk caused by docking errors between the freight vehicle and the vertical transportation machine. In addition, integrated control system for monitoring the state of the total process of performing the fixing transfer between devices is also linked. Based on the technology, the vertical and horizontal transportation machine can convert the demand for freight transportation in urban areas where the freight volume is concentrated into underground railway platform. For

this purpose, it is necessary to provide additional safety measures using detailed scenario design and hazard analysis method for prototype device design, test bed demonstration, and simulation-based research.

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