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PREDICTION OF REFRIGERATED VEHICLE ENVIRONMENT FOR OPTIMIZATION OF COLD-CHAIN LOGISTICS

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Abstract. *With the recent rise of the 4th industrial revolution, the era of 'logistics 4.0' based on crucial element technologies such as artificial intelligence (AI), Internet of Things (IoT), and big data is coming. In addition, as the global logistics competition environment develops, the need for developing a logistics advancement system is increasing. In the current logistics system, a new business model is emerging with the development of information and communication technologies (ICT), and it is necessary to innovate the logistics system to respond to this. Logistics system innovation is ineffective if it stops at the development of a simple business model, and demands the integration of logistics-related IT, H/W, and S/W technologies. This paper proposes a data analysis system design to extract and utilize meaningful information by collecting and analyzing the logistics data collected in the cold-chain distribution environment based on AI. The proposed AI-based data analysis system first defined the data on items currently managed within the logistics and developed a learning model suitable for low-temperature logistics vehicle control based on the collected data. The proposed logistics data analysis system can be utilized to develop optimal handling technology for low-temperature logistics products and predict logistics conditions. This study is expected to lead to energy savings in refrigerated vehicles and innovation in the smart logistics industry.*

Keywords: Cold-chain, Refrigerated vehicle, AI, IoT, Logistics 4.0

1. **Introduction.** Recently, the fresh food market has been rapidly developing due to changes in consumer perception and industry trends. There is a need to improve the logistics system of fresh food to meet customers' demand for high-quality products. In order to adapt to the unexpected environment, it is necessary to convert the existing cold-chain logistics and control system to a more integrated logistics system, which also requires a competitive management system. In the meantime, various studies have been conducted on the logistics of transporting dry cargos, and various companies have introduced the latest facilities such as the Internet of Things (IoT), big data, and location-based technologies [1-3]. However, low-temperature logistics lacks interest in its importance and operation. Unlike dry cargo logistics, low-temperature logistics are logistics that must ensure product quality and safety through appropriate temperature management. Such low-temperature logistics must maintain the temperature throughout the entire logistics process. In order to provide low-temperature logistics service, not only refrigerated logistics centers but also all networks, including vehicles, must be operated in a cold-chain. Differentiated research is required because of the many essential characteristics [4].

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Until now, research on cold-chain distribution focuses on data utilization through the follow-up of existing logistics information or the application of IoT technology. In addition, it can be said that it was carried out in the direction of strengthening the cold-chain focusing on the storage and delivery functions [5,6]. In this study, data that can be extracted from low-temperature vehicles and data generated during product distribution are collected and analyzed based on the connection with the IoT platform that is collected in real time in cold-chain logistics. Furthermore, we propose a data analysis system design plan to extract and utilize meaningful information. In particular, for the effective operation of the cold-chain, it is essential to develop a method for rapid extraction and utilization of meaningful data collected in real time. The proposed process data analysis system is expected to maximize the use of field information, such as developing optimal handling technology for cold-chain products and predicting logistics conditions.

The paper is structured as follows. Section 2 presents literature review on cold-chain and smart logistics. Section 3 proposes the structure of a cold-chain integrated management system as well as the framework of a control system. Section 4 describes AI-based prediction in cold-chain product environment with a case study. Finally, Section 5 concludes the paper.

2. **Literature Review.**

2.1. **Cold-chain.** Cold-chain refers to the production, storage, transportation, sale, delivery, and consumption of temperature-sensitive products such as agricultural, livestock, and marine products, food products, flowers, pharmaceuticals, and processed foods. It refers to a low-temperature distribution system that ensures the quality and safety of goods by controlling the appropriate temperature.

In the case of Korea, there is a lack of systems or technical systems that manage in real time the entire cycle of production – packaging – storage (warehousing) – transportation – wholesale/retail – consumer and loading and unloading stages required for each stage, which are the main stages of the cold-chain [7]. Only a few companies or fields such as pharmaceuticals apply the tracking management system to manage the entire life cycle. In addition, in the case of cold-chain products, including food, unlike general products, there is mainly an expiration date, and there is a problem in that the product's value disappears entirely after a certain period. Due to the characteristics of the cold-chain, various studies have been conducted on the current status of cold-chain logistics and improvement methods [8,9]. Differentiated research is needed because low-temperature logistics has several important characteristics, such as maintaining temperature and humidity, compared to room-temperature logistics [10,11]. In particular, there is a need for a method to quickly extract and utilize meaningful data collected in real time [12].

Most small refrigeration tower vehicles operate by connecting the refrigeration unit to the vehicle's engine because the logistics control temperature range is relatively small. Medium and large logistics vehicles use a refrigeration unit driven by a separate engine. This is because a wide range of temperature control can ensure the freshness of logistics. A refrigeration tower vehicle with a refrigeration unit maintains the freshness of the food and refrigerated/frozen products inside the vehicle by maintaining a constant temperature. In this study, data that can be extracted within the logistics center and generated during product distribution are collected and analyzed based on the connection with the IoT platform that is collected in real time at the cold-chain logistics site. AI-based cold-chain environment prediction technology to extract and utilize meaningful information will be developed through this. In addition, we would like to propose a smart cold-chain management system that can utilize it. It is expected that the proposed data analysis system will maximize the utilization of field information, such as developing optimal handling technology for cold-chain products and predicting logistics conditions.

2.2. **Smart logistics.** Today, with the expansion of trade and the rapid growth of home shopping, Internet, and mobile shopping, the logistics industry is showing explosive growth. In addition, new business models based on the new technologies of the 4th industrial revolution are being created or the existing business areas are rapidly expanding. The 4th industrial revolution utilizes ICT such as AI, big data, IoT, block chain, and robots to secure connectivity between various objects and maximize value creation through interactions between them [13]. Through this, various devices that are used to be operated independently interact through cutting-edge ICT, and it enables the optimized operation of the entire supply chain through advanced information transmission and analysis between devices. In the logistics 4.0 system, transformation is underway from a consumer-centric to a system in which the entire supply chain is digitally connected, sharing information and making decisions in real time [14]. In order to implement and operate the core logistics technology in the logistics 4.0 era, several detailed technologies must be developed and comprehensively operated.

IoT-based cold-chain management technology is based on terminal recognition equipment (sensor) technology that can collect, store, and analyze cargo information in the supply chain and transmit it to the management system. The collected data is analyzed and used for supply chain operation [15]. Stakeholders in the supply chain should be able to understand the transport and storage status of goods easily and should be able to influence the operation of the supply chain based on the information obtained. Differentiated research is needed because cold-chain logistics lacks interest in its importance and operation and has several essential characteristics compared to room temperature logistics. In particular, there is a need for a method for extracting and utilizing data collected in real time.

3. Design of Data Analysis System for Cold-Chain Logistics.

3.1. **Cold-chain integrated management system structure.** A cold-chain refers to a distribution system that maintains the proper temperature from production to consumption as the object to be preserved at low temperature, as shown in Figure 1. Primarily, it is necessary to provide value-added services as a distribution center that integrates various functions such as packaging, assembly, processing, sales, exhibition, and marketing and

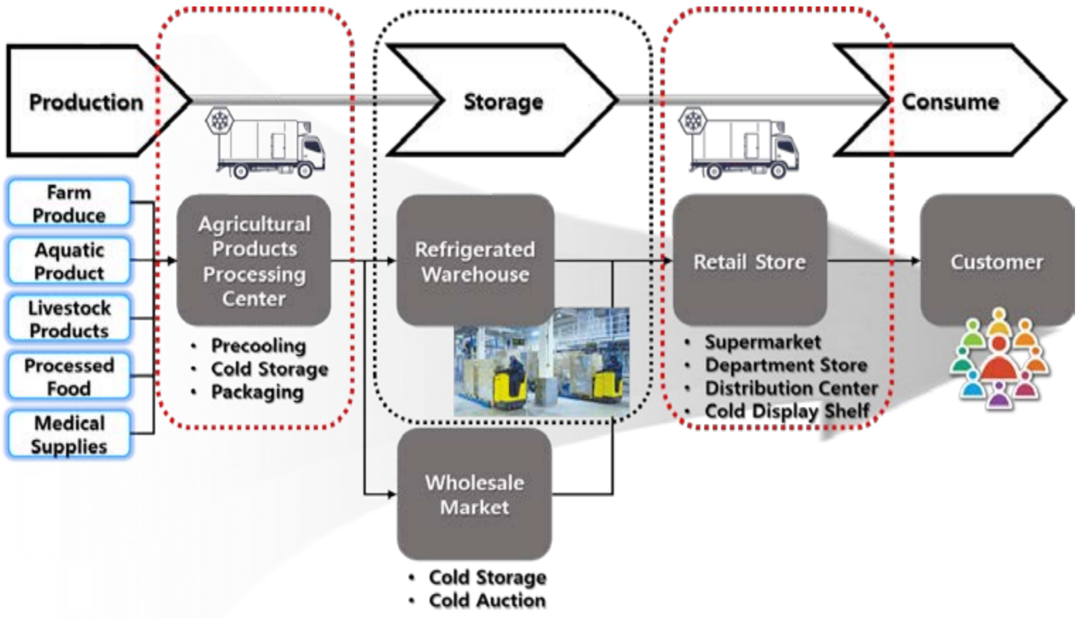

FIGURE 1. Cold-chain system structure

storage only. This means systems must be redesigned to accommodate these new services. This study aims to develop a new management system in a refrigerated vehicle, as shown in Figure 1.

The proposed system first selects representative products by characteristics of products handled within the cold-chain logistics network and acquires data through IoT sensors for the additional data collection on handling/rehandling in the current logistics center and distribution process needs this. Among the AI technologies, the detailed technology capable of optimal analysis of cold-chain products is selected and the production environment in the cold-chain is predicted through learning models such as deep learning. After that, it is possible to compare the logistics status, simulation results, and warehousing plans grasped in real time for all stages of the cold-chain. In addition, it is possible to reduce the loss of time and resources by providing the information desired by workers and managers through real-time monitoring. Furthermore, through the control of storage facilities and transport equipment, effects such as improvement of operational efficiency and establishment of an optimal operation plan based on the simulation results can be expected, and the predicted results can be immediately reviewed on-site by applying the changed facility control to the simulation.

3.2. **A framework of a cold-chain logistics control system.** In order to utilize artificial intelligence and Internet of Things technology for optimal management and distribution of products handled in cold-chain logistics, the cold-chain logistics control system framework was defined as shown in Figure 2. The cold-chain logistics control system framework proposed in this study means a real-time control and management system for the entire main cycle of the cold-chain, including the refrigerated container.

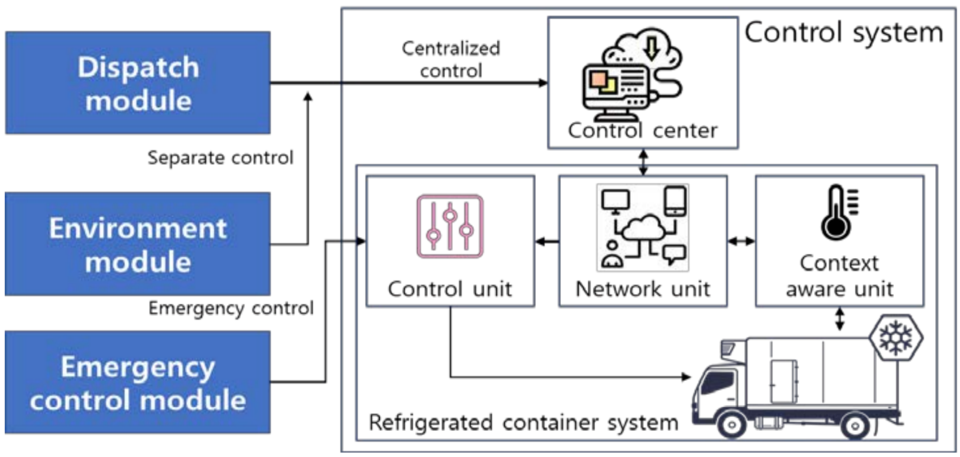

FIGURE 2. Cold-chain logistics control system framework

The proposed framework can be divided into three modules in chronological order. First, the dispatch module is responsible for generating a rough scheduling strategy for refrigerated containers. Second, the environment module could tune scheduling strategies based on real-time environmental information. Finally, in order to deal with networking failures, the refrigerated container must also be equipped with emergency control modules, to ensure the stability of the internal temperature of the container even control signals cannot be transmitted.

3.3. **Distribution quality management based on statistical analysis.** Cold-chain products are susceptible to freshness and spoilage. Cold-chain products are delivered to customers through various cold-chain environments such as warehouse, delivery, and store display. Changes in the environment that occur in the process can greatly impact product quality. For example, in the case of milk and dairy products, the temperature should

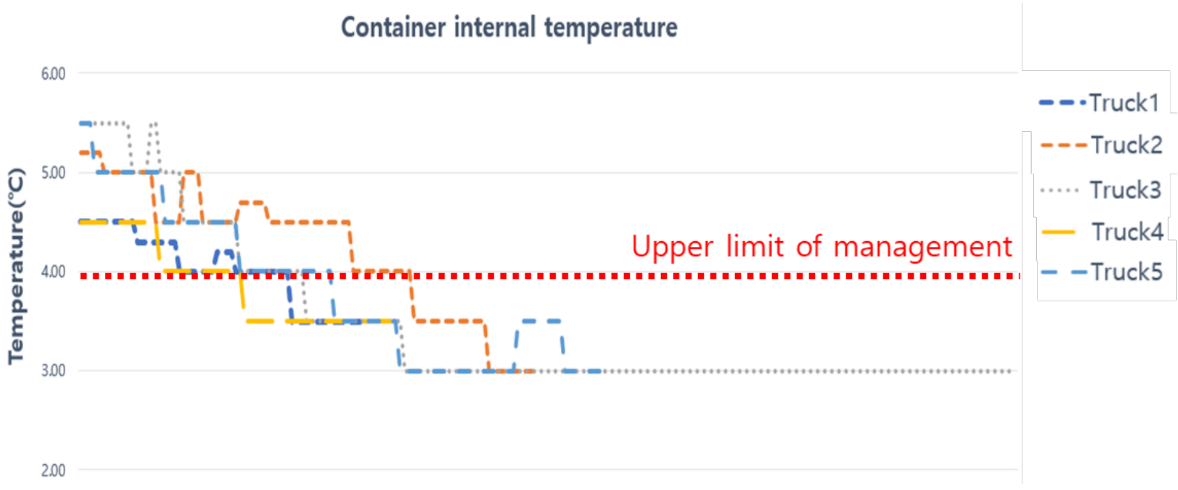

Figure 3. Temperature distribution during dairy management [16]

always be kept below 4°C, but the actual delivery or store display situation and the temperature between processes are shown in Figure 3. That is, most are distributed at 3°C to 4°C or less, but many are also observed between 4°C and 6°C. This problem can cause corruption and a bad risk of cold-chain products. Therefore, if it is possible to analyze and predict changes in the production environment on the cold-chain, it is possible to maintain the quality of cold-chain products delivered to customers and improve customer satisfaction.

Environmental factors to be considered in the cold-chain include the temperature, humidity, loading and unloading time between processes, surrounding climate, etc. If sufficient data is available, it is possible to support decision-making on shelf life selection, delivery rules, and storage volume, as well as change in logistics methods based on cold-chain product environment prediction using artificial neural networks, meta-heuristics, and machine learning methodologies.

4. AI-Based Prediction in Cold-Chain Product Environment.

4.1. **Energy management modeling.** From the perspective of the cold-chain management, the aim of the optimal control of the container temperature is to effectively schedule the output power of the container refrigerator so that the operating costs of the container business can be minimized and a good level of refrigeration within the refrigerated container can be maintained. Therefore, the objective function is made up of the parts: the cost of the electricity, utilization, and maintenance of the compression refrigerator used in the container, as shown in Equation (1), where α_m is the electricity price at time m, P_m denotes the refrigerator's power consumption, and γ marks the refrigerator maintenance cost per unit of power consumption.

$$Y = \min \sum_{m=0}^{M} \alpha_m P_m + \gamma P_m \tag{1}$$

4.2. **A case study.** In this study, the AI-based product environment prediction process, method, and result for dairy products is presented as a case study. First, the experimental environment for the case study is defined as follows.

- Limited to dairy delivery environments, assume a total of 5 delivery vehicles.
- Each delivery vehicle acquires temperature and humidity data inside the vehicle and outside the vehicle with a sensor every 5 minutes.
- Generate simulation data using the actual acquired internal temperature data.

- Utilizing 539 pieces of data acquired in 5 minute increments from 2,695 minutes, the total delivery time of all delivery vehicles.

The most important environmental factor to be managed in the cold-chain delivery of dairy products is the internal temperature, and the internal temperature during the cold-chain delivery of dairy products must be maintained uniformly below 4°C. In this case study, we try to optimize the internal temperature of the delivery vehicle by considering the environmental information (external temperature, external humidity) and time generated during the dairy distribution process. Therefore, multiple correlation analysis was used to analyze the correlation between multiple independent variables, and the Pearson correlation coefficient was used for the correlation coefficient. In addition, multiple regression analysis was performed using MLP to predict internal temperature by learning data of highly correlated variables. In addition, an internal temperature control scenario was constructed to keep the internal temperature predicted by the multiple regression model below the upper management limit. Correlation analysis and learning models were developed in a Python environment. In this case study, MLP was used to predict the actual internal temperature according to time and external temperature and humidity, and a multiple regression analysis was performed. Table 1 is a table summarizing the coefficient of determination (R^2), which is a good fit with the multiple regression model. According to the results of the correlation analysis, time, external humidity, and external temperature were all considered, and time and external humidity only were compared. As shown in Table 1, delivery vehicles 1, 2, 4, and 5 were not significantly affected by the external temperature, but in the case of delivery vehicle 3, the coefficient of determination was significantly different depending on whether or not external temperature was considered. The model with the highest degree of fit was the case of delivery vehicle 2, and delivery vehicle 3 was slightly lower. Therefore, it seems that correlation analysis from various perspectives is needed additionally, such as correlation analysis by section of the delivery time for each delivery vehicle.

Table 1. Summary of multiple regression result

Category	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
R^2 (Time, Hum, TempO)	0.8959	0.9441	0.8932	0.9246	0.9102
R^2 (Time, Hum)	0.8865	0.9376	0.6249	0.8795	0.8980

When using the model that considers the external temperature of delivery vehicle 3, the internal temperature is predicted to be 4.46°C when 30 minutes have elapsed, the external temperature is 25°C, and the external humidity is 70%. This cannot satisfy the target value to be maintained below 4°C, so it is necessary to establish decision-making and strategy to lower the internal temperature. Using the extracted multiple regression analysis formula, the internal temperature of the delivery vehicle can be predicted, and an efficient delivery vehicle environment setting and logistics operation strategy can be derived using this.

5. **Conclusions.** In order to enhance the competitiveness and efficient operation of cold-chain logistics, it is required to develop a data analysis system to collect and analyze data throughout the entire cold-chain to extract and utilize meaningful information. In addition, due to the characteristics of cold-chain products that are sensitive to temperature, distribution quality management technology, and product environment prediction technology according to real-time environmental changes are required. However, the current low-temperature logistics in Korea continue to waste time and resources due to the lack of

data linkage. This study proposed a cold-chain logistics control system framework, and a method for extracting and utilizing data collected in real time was presented. In addition, the study is meaningful in that it can predict the cold-chain vehicle environment through data learning and confirm the possibility of application. In the future, it is expected that it will be possible to expand into research that can configure a constant temperature logistics environment through AI-based prediction and reduce the energy consumption of cold-chain vehicles.

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