A Simulation Modeling Approach Method Focused on the Refrigerated Warehouses Using Design of Experiment

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Abstract. For performance optimization of Refrigerated Warehouses, design parameters are selected based on the physical parameters such as number of equipment and aisles, speeds of forklift for ease of modification. This paper provides a comprehensive framework approach for the system design of Refrigerated Warehouses. We propose a modeling approach which aims at the simulation optimization so as to meet required design specifications using the Design of Experiment (DOE) and analyze a simulation model using integrated aspect-oriented modeling approach (i-AOMA). As a result, this suggested method can evaluate the performance of a variety of Refrigerated Warehouses operations.

1. Introduction
There has been growing interest in improving the operating efficiency of warehouses, which is one of the key facilities used in the logistics sector. Such interest reflects the intention of the sector in increasing its competitive edge, reducing costs, and improving services as a way to bolster the competitiveness of logistics companies [1]. Warehouses are core facilities for undertaking integrated logistics operations comprising the storage, loading, and unloading of goods, and operations of information systems. They are used to increase added value through expanding the function and role of storage facilities and to ensure flexibility in supply. In particular, refrigerated warehouses (i.e., insulated warehouses with refrigerating systems) have become more important owing to the changes in and expansion of the nation’s food consumption practices. Although cold-storage warehouses have been investigated from various perspectives, studies on the systems needed for the conversion of these warehouses into refrigerated distribution centers are still limited. Based on the comparison of the costs mobilized for building a non-refrigerated warehouse against the costs for a refrigerated warehouse, and the comparison of procurement and operating costs for a non-refrigerated vehicle and a refrigerated vehicle, the study analyzed the factors contributing toward the high-cost structure of refrigerated logistics systems [2]. Previous studies have addressed ways to bring about advancements in the cold chain systems and accordingly presented simulation models [3-4]. However, there should be more suggestions on how to build a simulation model that takes into consideration the characteristics of refrigerated warehouses. Moreover, there should be more proposals on how to increase the efficiency of the operating system needed for converting the warehouses into refrigerated distribution centers [5]. This study aimed to analyze the operating system so the cold-storage warehouses can be converted into refrigerated distribution centers. The purpose of the study was to propose a standard platform for the analysis of refrigerated distribution centers methodology, based on applied test planning methods, and the operation of such distribution centers.
2. Current status of refrigerated warehousing in Korea

An investigation into the present status of refrigerated warehouses in South Korea reveals the existence of 804 such facilities that are being operated by 120 businesses across the country, of which about 15% warehouses are located in Busan that handle more than 50% of the nation’s refrigerated capacity [1]. The figure indicates that the city has large-scale cold storage facilities and they play an important role. This is because, in general, the closer the facilities are to import hubs of marine products, the greater is the efficiency they can offer to those implementing the distribution processes. Therefore, the greatest number of refrigerated warehouses are located and currently under operation in Busan. However, the city’s cold storage facilities are also being operated with an emphasis on storage function, as previously mentioned. Of the 120 cold-storage operators in South Korea, 32 companies (or 27%) have completed at least 31 years of operation, thus having advanced in age. Thus, it is necessary for the local refrigerated distribution processes to revitalize the operations of cold storage logistics completely to ensure improvement. Until now, only a very small number of studies have been conducted on the conversion of cold storage warehouses into refrigerated distribution centers. The results show that the South Gyeongsang Province ranks the highest with its 178 cold-storage companies, followed by Busan, Seoul and Gyeonggi Province, and South Jeolla Province with 120, 102, and 93 cold storages, respectively; additionally, 14 new refrigerated warehousing companies have entered the market in South Jeolla Province alone in the past year, followed by 4 in the Incheon area, 3 in the Daegu and South Gyeongsang Province, respectively, and 1 in the South Chungcheong Province. Busan is the only city showing a net reduction of one.

3. Operation of Cold Chain Systems

As illustrated in figure 1, a cold chain system refers to a temperature-controlled distribution system designed to ensure the quality and safety of products throughout the process of producing, storing, transporting, marketing, and consuming temperature-susceptible items, such as agricultural, livestock, marine products, foods, flowers and plants, and medicines. The cargo refrigeration system aims at achieving extended shelf life for retaining the freshness and value of products by preserving them at an appropriate temperature(s). A cold chain system is divided into the main part (including precooling, packaging, transporting, storage, and low-temperature facilities near consumers) and supplementary part (other functions) [2].

This study proposed a platform for an operating system for refrigerated distribution centers that are integrated with a cold chain system.

4. Analysis of refrigerated distribution center design

This study first implemented a crosscutting concern analysis of the refrigerated distribution center’s operating system design by transmitting each piece of information for each class and executing the
feedback. When it comes to building a simulation model, an object-oriented model is implemented vertically, thereby facilitating an efficient representation of the simulated design and model construction [6]. The downside of object-oriented simulation designs and models is that the exclusive consideration of vertical elements might lead to a failure in modularizing the crosscutting concern existing between the modules because the sole emphasis is being placed on vertical elements. Based on the previous theories, this study (a) built a simulation model that modularizes common areas by utilizing the i-AOMA and (b) achieved redundancy elimination, modification of the established model, and an increased efficiency during reuse in figure 2 [7].

Figure 2. Concept of the i-AOAM.

The task of refrigerated warehouse simulation modeling was divided into two parts: modeling the operating equipment system and warehouse operating system. The division was followed by the implementation of inheritance-class creation and inheritance within the operating equipment system, which was materialized by the object-orientation technique. Furthermore, many output variables are available for the simulation model while designing refrigerated distribution centers based on design parameters obtained through the i-AOMA. However, the most important among them is the operating efficiency of the refrigerated distribution centers. Hence, the distribution centers’ storage rate was selected as the output parameter for determining the optimum way to operate. Concerning the determination of the values of input parameters for obtaining the best output parameters through simulation, a significant amount of time and cost is required as the number of input parameter combinations increases, which leads to a significant increase in the number of areas to be explored. Thus, an efficient test plan was implemented as a solution. This study chose to apply the Taguchi methodology to reduce the number of simulation tests to be performed and to estimate the optimal input parameters. The most prominent features of the methodology include the test planning based on the use of orthogonal arrays and determination of optimal condition based on the analysis of SN ratio [8-9]. For designing a refrigerated distribution center, this study utilized the ‘A Center’ located in the Busan area as the focal point of investigation. The automated cold-storage warehouse of the A Center is integrated with an automated storage and retrieval system (AS/RS) and a cold chain system.

Table 1 shows seven input/output parameters established for the refrigerated distribution center. Table 2 summarizes the test values that were used for simulations of the distribution center.

| Table 1. Input/output parameters for the refrigerated distribution centers. |
|---------------------------------|------------------|
| Input parameters               | Range of parameter values |
| Speed at which forklifts drive within the warehouse premise | 20 km/h–40 km/h |
| Speed at which forklifts drive within the warehouse premise | 20 km/h–40 km/h |
Table 2. Simulation level-values of refrigerated distribution centers.

| Control Factor | Details of Control Factor | Level (Level Values) |
|----------------|---------------------------|----------------------|
| A              | Refrigerating capacity    | Level 6 (10, 12, 14, 16, 18, 20) |
| B              | Number of forklifts within the premise of the warehouse | Level 3 (1, 2, 3) |
| C              | Speed at which the forklifts run within the premise of warehouse | Level 3 (20, 30, 40) |
| D              | Speed at which the forklifts run within the premise of the loading dock | Level 3 (1, 2, 3) |
| E              | Speed at which the forklifts run within the premise of the loading dock | Level 3 (20, 30, 40) |
| F              | Number of transportation systems/equipment | Level 3 (1, 2, 3) |

The refrigerated distribution center’s storage ratio has a larger-the-better property, with the signal-to-noise (SN) ratio computed in Equation (1) as follows:

\[
SN_i = -10 \log \left( \frac{1}{n} \sum_{j=1}^{n} \frac{1}{y_{ij}} \right) \quad (1)
\]

The orthogonal array in line with this study is \( L_{12}(4^3 \times 3^6) \). Using this array will require only 12 tests to be conducted. In the \( L_{12}(4^3 \times 3^6) \) array, A (Level-4 factor) was placed in Row 1, while the remaining Level-3 factors (B through G) were placed in Rows 2 through 7, respectively. Under the 12 actual test conditions, the storage rate is computed to be the ratio between (a) the actual storage volume in the refrigerator throughout the simulation process, to (b) the refrigeration capacity of the cold-storage cargo, as shown in Equation (2) below:

\[
\text{Storage rate} = \frac{\text{Actual storage volume}}{\text{refrigeration capacity}} \quad (2)
\]

The model built to calculate the storage rate was subjected to a simulation that lasted 365 days, with each day comprising 8 hours. After 2 weeks (or 80 hours) of simulation, the system was found to have stabilized. The main effect diagram showed that the total refrigeration capacity of the warehouse increased as the rack-specific storage capacity increased from 20 to 40, causing the within-warehouse storage rate to decrease. The results also showed that an increase in the number of forklifts from 3 to 6 within the premise of warehouse led to a decrease in the storage rate due to the interference between the forklifts. Contrarily, an increase in the number of forklifts operating inside the loading dock was found to have led to an increase in storage rate. Concerning the number of transportation systems, three systems enjoyed greater storage rate than two systems; however, four systems showed an opposite trend. Furthermore, the analysis showed that no significant effects were exerted on the storage rate by either the speed of forklifts operating inside the warehouse or the ones inside the loading dock. Analysis of Variance (ANOVA) was performed to determine the statistical significance.
of the control factors. Tables 3 and 4 summarize the results of ANOVA and the optimal conditions for control factors, respectively.

### Table 3. ANOVA for SN ratio.

| Source | DF | SS   | MS   | F     | P     |
|--------|----|------|------|-------|-------|
| B      | 4  | 5.66264 | 2.31194 | 156.36** | 0     |
| C      | 3  | 0.34235 | 0.09993 | 14.85*  | 0.009 |
| D      | 2  | 0.29837 | 0.08182 | 11.21*  | 0.031 |
| G      | 3  | 0.15235 | 0.0573  | 5.28*   | 0.1   |
| Error  | 3  | 0.05592 | 0.0083  |        |       |
| Total  | 15 | 6.51163 |        |        |       |

### Table 4. Optimal conditions for control factors.

| Control Factor                                      | Level Value |
|-----------------------------------------------------|-------------|
| Storage capacity (B)                                | 30          |
| Speed at which the transportation equipment moves within the premise of warehouse (C) | 45          |
| The number of RGVs inside the automated refrigerated warehouse (D) | 4           |
| The number of transportation equipment (G)          | 3           |

Based on the results, the design control factors for the refrigerated distribution center were applied to a cold-storage distribution center located in the Busan area. The center, a 7-storied building (1-storey in basement and 6-storey above the ground), has a storage capacity of approximately 31,000 pallets, gross floor area of 24,380 m2, and operates facilities such as freight elevators, passenger elevators, and emergency power generators. The center has a nominal capacity of 90,000 tons. It is equipped with eight vertical conveyors that move the cargo between the loading dock located on the first floor and the automated freezers and refrigerators in the cold storage areas in the upper floors. Such system design allows the handling of 2,000 pallets, per day. Compared to the data from other refrigeration systems, it was found that this center’s storage capacity decreased by 50%, but its processing time increased by 50%.

### 5. Conclusion

This study aimed to propose an efficient way of designing refrigerated warehouses, considering the diverse operating and storage methods of automated cold-storage warehouses and based on the characteristics of the cargo to be refrigerated. The Taguchi methodology was utilized for designing such a system to construct and analyze the refrigerated warehouse simulation model. Specifically, the study aimed to propose a way to revitalize the operations of refrigerated warehouses in the Busan area. As the first step toward achieving this goal, the operating process to be applied within the warehouse was examined and the results were used for designing a simulation model. This application was followed by the performance of simulation analysis, based on the results obtained by using the Taguchi methodology, and the optimal plans for operating the warehouses were established. The results also revealed that the areas storing mostly multiple accounts of an identical product had a greater average process volume compared to that of other areas with dissimilar qualities. These areas also had an extremely high transportation equipment operation rate inside the warehouse. Based on the aforementioned, additional investments for new warehouses and new warehouse construction were not
found to be essential. However, effective mobilization of transportation equipment inside the warehouse was found crucial. The investigative approach considered by this study can offer advantages, such as reduced time in not only designing and operating refrigerated warehouses but also undertaking the redesign. In terms of simulation implementing techniques, this study carried out an examination of interfaces between the modules by using object-oriented techniques based on the re-utilization of the integration-oriented modules developed here. The examination allowed the study to design and materialize an operating model that took into consideration the operating characteristics of refrigerators dealing with a wide range of cold-storage cargo. The results were obtained from the establishment of additional systems, facility expansion, and the resulting changes in input data. The results were also obtained through the easy establishment of a simulation model when the system was subjected to reconfiguration. Future studies could use the response surface methodology (RSM) to estimate the optimal combination(s) of various implementation conditions that are needed for building and operating a simulation model. The combination(s) estimated might be utilized when investigating a way to operate the facilities actively, given an increase in the level of practical challenges.

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