Designing Chilled Warehouse Layouts by Data-Driven Approach

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(Received: August 3, 2023; Revised: December 19, 2023; Accepted: December 25, 2023)

Abstract

This paper aims to understand the current storing practices in a chilled warehouse and proposes a new warehouse layout using a data-driven approach. The products, temperature, and humidity data were collected to explore the warehouse's current practices and environment. The authors used ABC analysis and the postharvest management technique to design the layouts by determining the product's essential characteristics and requirements. The author collected the data from one of Thailand's cold chain warehouse providers from January to April 2022. However, the authors discovered that there is limited research relating to cold chain warehouse layout design. It is difficult to determine the correct layout design due to the dynamic range of products in this warehouse type. The authors found that the current storage practice could be improved in many ways. Redesigning the warehouse layout is one improvement that will create new standard procedures in the depositing and withdrawing process. It could improve the warehouse's operation by reducing the operation time and ensuring a smoother flow of tasks within a tight timeline. Also, keeping the inappropriate product nearby could affect the product quality. Some products are sensitive to ethylene, which could directly affect product appearance and quality. It could result in faster product spoilage than the usual shelf life. Another finding is that each case study chilled warehouse room area has a different temperature and humidity. In the case of not storing the product in an appropriate area that matches the product's characteristics, those factors could directly affect the product's quality and appearance. In the end, the author has suggested two layouts that take into account the characteristics and requirements of the most active product this company has deposited and withdrawn as a primary factor.

Keywords: 1) Chilled Warehouse 2) Layout Design 3) Postharvest Management 4) Data-Driven Warehouse

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Financial Support from College of Arts, Media and Technology to Grerg Suriyamanee is acknowledge.

Introduction

The warehouse is one of the essential components of the supply chain. It closes the gap between goods production and consumption by allowing products to be securely stored and distributed to reach their destination. The essential operation within the warehouse includes receiving goods, processing orders, dispatching the goods, and replenishment them (Richards, 2017, p. 22). Many different warehouses operate in the supply chain today, from the raw material storage facility to the fulfillment center. Some warehouses are customized to suit the goods that are stored inside. For example, the warehouse is designed to be a temperature-controlled storage facility in cold chain logistics. This type of warehouse is called cold storage or refrigerated warehouse. Cold storage or refrigerated warehouse are designed for perishable products or goods requiring a temperature-controlled environment. Fast-moving goods like pharmaceuticals, meat, fruits, and vegetables are required to use this type of warehouse to control the quality and prevent it from spoiling (Dong, Xu and Miller, 2020, p. 8).

The cold chain market is expanding, leading to the rising consumer demand in agricultural transportation and fresh food franchise businesses. It is also needed in the medical and healthcare sectors. Reports from the Global Cold Chain Alliance have shown that the capacity of cold chain warehouses across the globe in 2020 was 719 million cubic meters. The capacity is more significant than 16.7 percent when compared to 2018. Approximately 61 percent of the total capacity is held by only three countries, two of which are located in the Asia-Pacific region. India, China, and Japan are the top 3 countries with the most cold chain warehouse capacity, which accounts for 320 million cubic meters (Salin, 2020, p. 11).

On the other hand, Thailand's cold chain business also has significant growth, using value as a factor. The business value of Thailand's cold chain business is approximately 34 billion baht, with an annual growth of 5% in the total logistics market in 2021. It is expected to grow at least 8% by 2022 (JWD InfoLogistics Public Company Limited, 2021; Janglom, 2019). Warehouse operations needed to be focused on to manage the warehouse smoothly. Many practices have been implemented to improve the efficiency of the operation. The well-known practices include standardizing vendor operations, designing picking and storing procedures, making popular products easy to reach, and optimizing warehouse layout (Richards, 2017, p. 200).

With the advance of technology in each decade, businesses have implemented the latest technology to improve their business performance. The research from Kumar, Narkhede and Jain (2019, p. 15) mentioned that during the 1990s, warehouse businesses focused on cost-effectiveness. However, finding the right tools and techniques to optimize the warehouse was difficult. During 2001-2010, the warehouse gets more attention as the inventory holding point. The business focused on improving inventory optimization, operational efficiency, and customer service. Some of the ICTs are implemented, and shifting the warehouse into semi-automated. Therefore, warehouse management systems were implemented in the last decade to manage the warehouse and inventory level. However, with the rapid growth of the e-Commerce market. It creates difficulties for the warehouse with the VUCA environment- which is unpredictable, uncertain, and complex. Some warehouses are starting to implement the latest technology such as robotics, internet of things devices, cloud computing, and AGV system.

In order to implement the latest technology, the business has to invest a lot of money. For this reason, it could create a financial barrier for most of Thailand's businesses, categorized as micro, small, and medium enterprises (SMEs). However, the business can use the data-driven approach to design and transform its business processes. Designing the appropriate warehouse layout could directly impact the warehouse's operation and efficiency, such as improving access in the picking and storing process to be more accessible. With limited research during 2019–2022 on cold chain warehouses in the context of designing the appropriate layout, this study aims to understand the current practice of storing processes in a chilled warehouse and use temperature and humidity data to propose new warehouse layout designs based on product characteristics and postharvest management theories. The authors expect that this paper could provide an improvement idea for the warehouse manager by integrating academic theories with a real-world case study. Using the ABC analysis and historical product data would provide insights into product trends and warehouse storage capacity. With the dynamic of the chilled warehouse scenario, many products are coming in and out of the warehouse. Each product has its own requirements and characteristics. Postharvest management could provide the guidelines for an appropriate product requirement, and the warehouse operator could follow those instructions to store the product more appropriately. It could reduce the chance of a drop in product quality or appearance. For example, some products are sensitive to the fast-changing temperature. If the operator stores them in the wrong place, it could result in lower product quality, affect the product's appearance, and have a shorter shelf life than the normal condition.

The papers are divided into four sections: a literature review, research methodology, findings, and conclusion and discussion. In the literature review, the authors explore the concepts of ABC analysis, postharvest management techniques, and case study research. These concepts will be used in categorizing the products into groups, leading to a new warehouse layout. The authors have described the process of selecting products, categorizing products into groups, and using postharvest management techniques in the research methodology section. Finally, the authors show the original warehouse layout and the current practices the case study warehouse uses to operate. The dynamic range of products that are stored in the warehouse has also been discovered, along with the findings on temperature and humidity factors in the warehouse environment. Then, the author analyzes the theory to propose the new warehouse layout.

The conclusion and discussion sections also suggest some technologies and ideas that could help improve warehouse performance, operation, and efficiency.

Literature Review

One of the organization's ultimate goals is to ensure it runs smoothly and increases efficiency. Since the fourth industrial revolution, many companies have adopted the ideas and moved forward to transform their organizations. The fourth industrial revolution, or Industrial 4.0, has the characteristic of adopting more smart devices, transforming tasks into more autonomous ones, and even using data to drive the organization. Using data to drive the organization could provide better insights and make better decisions. However, there are many approaches to data-driven solutions, ranging from digital transformation, data analytics, decision support systems, and artificial intelligence automation (Hupperz, et al., 2021, p. 5). Some of the approaches mentioned need massive investment in order to be implemented.

For this reason, it could create financial barriers for small and medium-sized businesses (SMEs). Also, after investing a huge amount of money and implementing the approaches, it could lead to another problem if the selected approach does not suit the characteristics or operation of the organization. So, the authors selected the data analytics approach to explore the historical data of the case study warehouse, resulting in warehouse layout optimization. After exploring the data, the author found that the total amount of each product is entirely different. For example, in the same month, A product is counted at 60,000 kilograms, and B product is counted at only 1,500 kilograms. ABC analysis theory is also considered the fundamental theory used to create the classification and grouping of the product. So, the authors chose ABC analysis theory to handle the product classification and have an overview of which product to prioritize in inventory management.

1. ABC Analysis

Increasing business operations' efficiency is one of the goals, among other objectives. Inventory management is one of the activities that can be optimized in order to increase efficiency. ABC analysis is one of the theories that have been proposed. ABC analysis is a method for prioritizing inventory management. Alternatively, the theory is commonly known as the Pareto Principle or the 80/20 rule. The concept uses the relationship between wealth and population to indicate that 80 percent of the outcomes originate from 20 percent of the factors. Typically, it is applied in many areas, such as management and manufacturing (Ziyadin, et al., 2020, p. 4).

However, in the ABC analysis, inventories are classified into three types: A, B, and C. The items classified into A classes will then receive the most attention, followed by B classes and C classes. Originally, the ABC analysis focused on the dollar volume, which defined that the A class accounted for the most considerable dollar volume and highest demand among the inventories. Nevertheless, the items classified as C-class have the lowest value and demand (Ravinder and Misra, 2014, p.257).

Many researchers also use ABC analysis as a methodology for optimizing the warehouse. The research from Aksütoğlu, et al. (2020, p. 919) uses ABC analysis and Value Stream Mapping as tools in the research to improve warehouse operation by determining the necessary processes and designing the operation procedures' future state. The author also suggested that implementing the RFID and Lighting systems for picking and storing could improve warehouse efficiency. Therefore, Sreekeaw, Sukpanya and Khaengkhan (2019, p. 252) also uses the ABC analysis to classify products in the radish business warehouse. Errors often occur because the radish business warehouse does not have systems to store and distribute the products. The visual control concept was implemented along, which supported the picking and storing process. Another research by Hamali, et al. (2019, p. 352) aims to improve and optimize the catering service warehouse layout. The authors use ABC analysis in categorizing the products and use that information to redesign the layout with linear programming. The study leads to allocating products in the warehouse and the rack placement. However, the study also found that products such as coconut milk require higher storage temperature than others and must be placed at the back of the room. The research from Hamali, et al. (2019, p. 355) can increase the space for inventory by 20 percent.

2. Postharvest Management

Almost every set of activities includes pre-production, production, and post-production. Postharvest management refers to a part of activities categorized as post-production agriculture practices. The activity starts with harvesting, cleaning, washing, and packing until storage. These activities are categorized as postharvest practices to remove undesirable elements and enhance product appearance with quality standards. Postharvest management aims to maximize the added value of products such as fruits and vegetables. Another aim of postharvest management is to reduce the losses of the product, which uses temperature management and packing to control it (El-Ramady, et al., 2014, p. 68).

Many factors can cause product losses or create quality reductions. Postharvest management also focuses on this area in order to reduce those losses. It focuses on the environment, including temperature, humidity, ethylene production, ethylene sensitivity, and even postharvest injuries caused by temperature. El-Ramady, et al. (2014, p. 128) said that all fruits and vegetables would likely have a chilling injury if the temperature were below five degrees celsius and the humidity was between 90 and 95%. However, there is limited research on applying postharvest management to practical warehouses. Therefore, the research implemented on postharvest management in the warehouse only focuses on the product. Many of them focus on the adoption of ICT in warehouse management.

3. Case Study Research

A case study is a method of research used to develop an in-depth, multi-faceted understanding of a complicated topic in its real-life setting (Yin, 2017, p. 35). The information may then be utilized to make decisions about the issue the organization or individual is facing.

According to Crowe, et al. (2011, p. 1), The case study method is especially beneficial when it is necessary to gain an in-depth understanding of an issue or phenomenon of interest in its natural real-life setting. The case studies can be defined in numerous ways. In Yin (2017, p. 247) research, it was mentioned that case studies are methods that can be utilized to explain, describe, or investigate occurrences or phenomena in the typical settings in which they take place. The case study research consists of six general processes which includes planning, designing, preparing, collecting, analyzing, and sharing (Yin, 2017, p. 31). However, Crowe, et al. (2011, p. 5) only focus on the processes that include case defining, case selection, data collecting and analyzing, data interpreting, and finding reports.

Research Methodology

The authors collected product data from January 2022 to April 2022 to explore the chilled warehouse's current practices. According to the case study warehouse, the warehouse capacity is considered to be in high demand. In other words, it is a peak season for the warehouse. So, the authors used that timeframe to represent the trending product during the peak season. Then, the product data was categorized into groups using Python to remove the duplicates, standardize the product names, and create usable data. The library called Openpyxl has been installed to handle the Excel files, which are the data from the case study warehouse. Then, the authors used the Pandas library for the processes of cleaning and transforming data, as mentioned earlier. During that time, the temperature and humidity data were also collected by data loggers (Testo H175/177, Germany), which created an overview of the environment in each warehouse area.

The authors select the products with the most active movement in depositing and withdrawing during that time. Then the product data are used in this stage in designing the first warehouse layout. The first layout used the ABC analysis calculation and classified the product into three classes: A, B, and C. It is also based on the Pareto Principle, which states that 20% of the stock accounts for 80% of the value. The A class is counted for 20% of the stocks and has 80% of the value. The B class accounted for 30% of the stocks and 25% of the value. Lastly, the items classified in the C class accounted for 50% of the stocks, which have 5% of the total value.

The second model used product data based on ABC analysis calculation and postharvest management techniques. The postharvest management techniques provide a guideline on product characteristics and the required environment, such as optimum temperature and humidity. The temperature and humidity data that have been collected are used in this stage. It helps create the storing zoning for the products which will suit the postharvest management required environment factors.

Result

According to the case study research theory, this work is currently on the finding report process. This section will illustrate the result of this study in which the authors choose one of the cold chain warehouse providers in the Northern Region of Thailand as the case study warehouse. The warehouse has both chilled and frozen rooms. However, the authors selected chilled room 1 as the case study. The chilled room controls the temperature not to exceed 6°C and not less than 0°C. In dimension, the room is 12 x 24 meters and has a height of 6 meters. The room can hold 55 slots of shelves that can store goods. Each self has four levels, creating a total of 220 slots for storing goods. The original warehouse layouts are displayed in Figure 1-3.

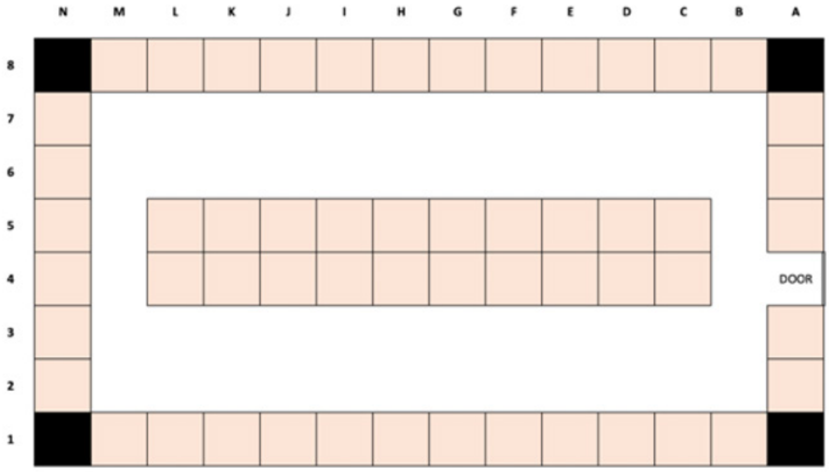

Figure 1 Original Warehouse Layout Design (Top Down View)

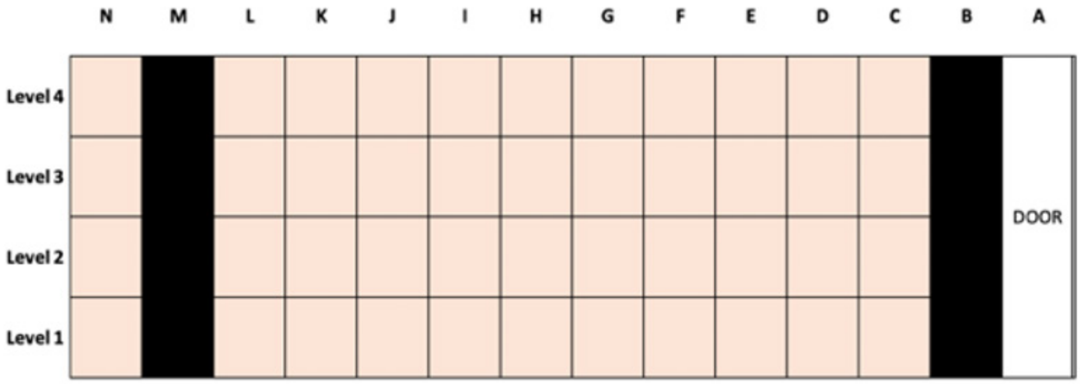

Figure 2 Original Warehouse Layout Design (Side View from Row 1)

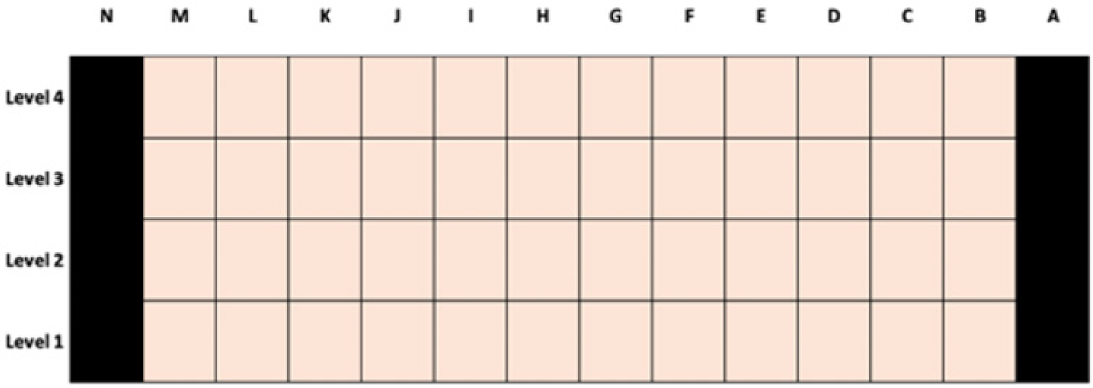

Figure 3 Original Warehouse Layout Design (Side View from Row 4)

Currently, the case study chilled warehouse does not have the guidelines or practices in storing process. The history of product data was not used to improve and redesign the warehouse layout. The product will be put into the storage rack by determining the type of customer rental criteria and the available space. The temperature and humidity differences in each room area can create post-harvest injury to the product especially fresh produce if the storing location does not match the characteristic of product requirements.

Regarding the standard procedure and temperature setting in the cold chain warehouse announced by the Ministry of public health of Thailand, the temperature required for the chilled warehouse should not exceed 5°C for fresh meat products and egg products and not exceed 10°C for fruits and vegetables. The authors used 5 data loggers to record the temperature and humidity data every 30 minutes for two weeks in the case study chilled warehouse environment. The data loggers were placed in five different areas, as shown in Figure 4, which create an overview of the temperature and humidity data in each area of the room.

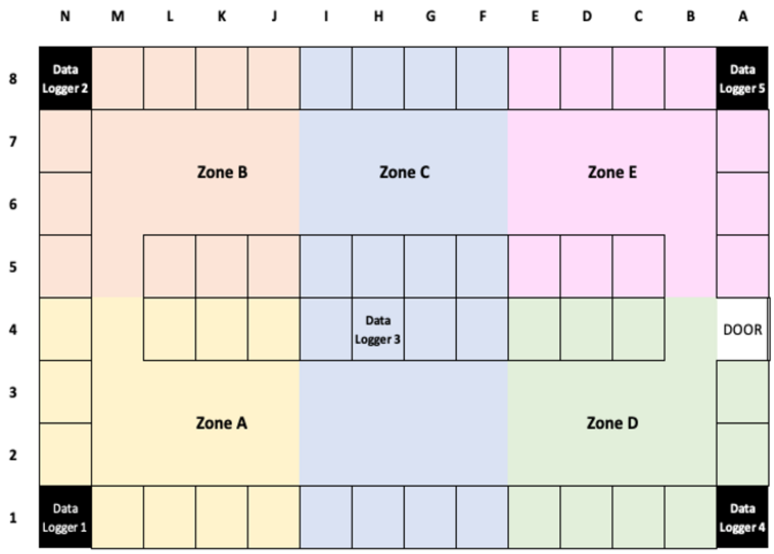

Figure 4 Data Loggers Placing Area

From Figure 4, the author has placed data loggers in the position of N1 for zone A, N8 for zone B, H4 for zone C, A1 for zone D, and A8 for zone E, which then categorizes zone A and zone B as the backend area, zone C as the middle area, and zone D and zone E as the front area. The author also found that in zone A, the maximum temperature is 7.8°C, the average temperature is 4.74°C, and the minimum temperature is 2.7°C. The humidity in this area ranges from 71.30% to 98.80% and averages 87.01%. There are 11 days out of 14 days of the data that the temperature difference is more than 3°C. However, in the zone B, the maximum temperature rises to 9.8°C; the minimum temperature is the same as zone A and averages 5.01°C. The humidity ranges from 73.20% to 99.90% and averages 87.01%. The front area, which includes zones D and E, is close to the door. Zone D temperature ranges from 3.10°C to 9.10°C with an average of 4.93°C. The humidity ranges from 74.20% to 99.90% and averages 92.14%.

Table 1 shows the summary data of temperature and humidity in each zone of the room.

Zone	Temperature (°C)			Humidity (%rH)		
	Max	Min	Avg.	Max	Min	Avg.
A	7.80	2.70	4.74	98.80	71.30	87.01
B	9.80	2.40	5.01	99.90	73.20	87.90
C	13.10	3.40	5.75	99.90	78.20	98.34
D	9.10	3.10	5.25	99.90	71.70	89.70
E	8.70	3.50	4.93	99.90	74.20	92.14

Moreover, in the middle area or zone C, the maximum temperature rises to 13.10°C and the minimum of 3.40°C. The average temperature in this zone is 5.75°C, which is higher than in other zones. The humidity ranges from 78.20% to 99.90% and averages 98.34%. The temperature and humidity data were summarized in Table 1. On product data, the authors collect the data from January 2022 - April 2022. They were then cleaned and analyzed as mentioned in the research methodology. At first, the product data comes in an unusable form. For example, the A product data comes in A (Customer A) and product A (Grade A). So, the authors transform and then categorize it into a usable form using python language. The authors also found that the products stored in the chilled warehouse are very dynamic. There were over 179 products ranging from vegetables, fruits, dairy products, flowers, and meat. For this reason, the authors select the product based on the criteria that the products appear in depositing and withdrawing every month. The data show that 16 products have movement as the criteria. It includes green onion, romaine lettuce, bell pepper (green, red, yellow), squash, eggplant, daikon, radish, carrot, iceberg lettuce, beets, green oak, baby cos lettuce, green bean, cucumber, cabbage, and red oak. According to postharvest management, each product has its own environment, such as temperature and humidity factors. So, the authors used the references of temperature and humidity requirements from the University of California's postharvest center and summarized the factors and environment needed for products mentioned earlier in Table 2.

The authors have designed and proposed two alternative warehouse layouts. The first layout is based on ABC analysis calculation, and the second layout is designed based on the postharvest management technique.

Table 2 shows the summary data of product optimum environment.

Product	Optimum Temp. (°C)	Optimum Humidity (%rH)	Recommend Shelf life (Days)
Green Onion	0	98% +	up to 32
Romaine Lettuce	0	95% +	up to 21
Bell Pepper	7.5	95% +	21 - 35
Squash	5.0	95% +	up to 14
Eggplant	10.0 - 12.0	90% +	up to 14
Daikon	0	95% +	7 - 14
Radish	0	95% +	7 - 14
Carrot	0	98% +	28 - 42
Iceberg Lettuce	0	95% +	21 - 28
Beets	0	90% +	10 - 14
Green Oak	0	95% +	up to 21
Baby Cos Lettuce	0	95% +	up to 21
Green Bean	5.0 - 7.5	95% +	8 - 12
Cucumber	10.0 - 12.5	95% +	up to 14
Cabbage	-0.5 - 0	95% +	21 - 42
Red Oak	0	95% +	up to 21

Layout based on ABC Analysis

After using the ABC analysis calculation, the author transforms the value into the percentage of each product stored in the warehouse, as shown in Table 3. However, the products that have a frequency of less than ten each month are categorized as "others" which account for nearly 38% of the warehouse storage capacity. The author also proposes the new warehouse layout based on ABC analysis in Figure 5.

Table 3 shows the product value based on ABC Analysis.

Product	ABC Class	Frequency (Times)	Value (%)	Accum. (%)
Green Onion	A	610	14.83	14.83
Romaine Lettuce	A	223	5.42	20.25
Bell Pepper	B	377	9.16	29.41
Squash	B	177	4.30	33.71

Product	ABC Class	Frequency (Times)	Value (%)	Accum. (%)
Eggplant	B	236	5.74	39.45
Daikon	B	135	3.28	42.73
Radish	B	149	3.62	46.35
Carrot	B	69	1.68	48.03
Iceberg Lettuce	C	73	1.77	49.80
Beets	C	66	1.60	51.40
Green Oak	C	63	1.53	52.93
Baby Cos Lettuce	C	71	1.73	54.66
Red Oak	C	77	1.87	56.53
Cabbage	C	64	1.56	58.09
Green Bean	C	78	1.90	59.99
Cucumber	C	95	2.31	62.30
Others	C	-	37.70	100.00

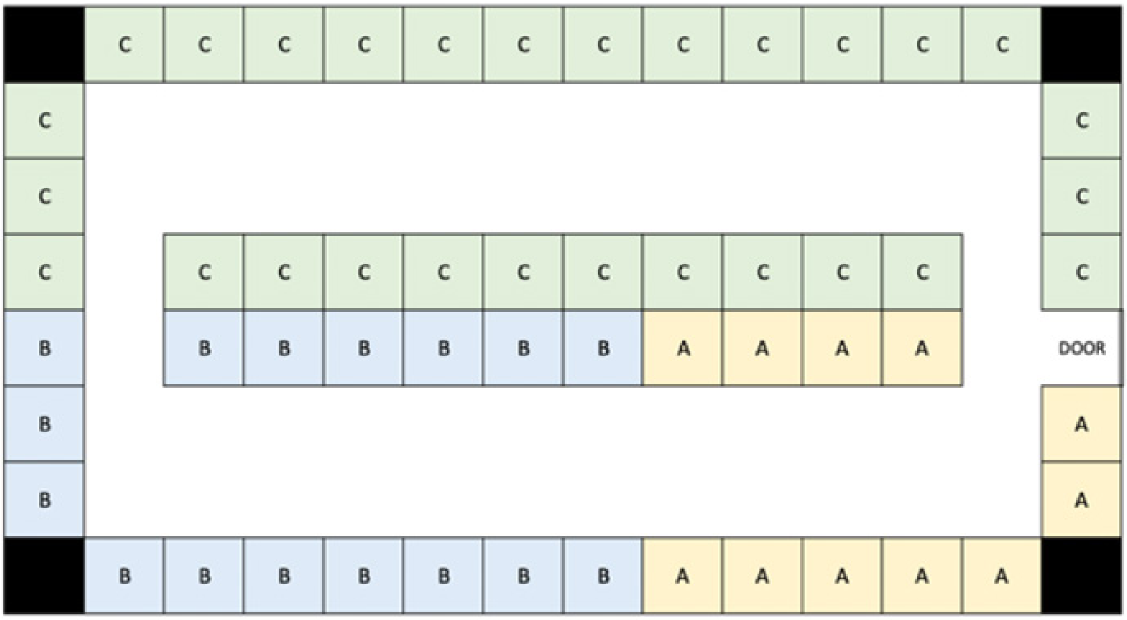

Figure 5 Warehouse Layout Design (ABC Analysis)

Layout based on Postharvest Management

The authors designed and proposed the second layout based on ABC Analysis in the first layout and the postharvest management technique in Figure 6. Each zone's temperature and humidity data are used to determine the appropriate storing area for each product characteristic and environmental factor.

Figure 6 Warehouse Layout Design (ABC Analysis with Postharvest Management)

Conclusion and Discussion

Warehouses are one of the essential components in the supply chain. Designing the appropriate warehouse layout could improve efficiency in the storing and picking processes. Also, the operation procedures will be smoother. However, another factor that needs to be considered is the product's quality when stored inside. Environments such as temperature and humidity can cause product quality reductions such as weight loss, chilling injuries, and internal disorders.

From the data, the authors have found that the products that were stored inside the case study chilled warehouse are very dynamic. Many types of products are stored in the same warehouse room. However, some products can cause other products to have quality and appearance issues. For example, one product's spoilage could lead to a faster rate of spoilage for another product. Also, some of the products are sensitive to environmental factors, such as the temperature factor for green onions, which the product is highly perishable. For example, if the temperature of the chilled warehouse rises above 10°C, green onions' shelf life can be reduced by up to 20 days from the standard shelf life.

This study designed and proposed the warehouse layouts based on the selected 16 products, as mentioned earlier. However, more than 100 products are not selected due to the low frequency of deposits and storage in the warehouse. This paper still has a limitation regarding implementing the proposed warehouse layouts. For future research, research regarding the implementation of the proposed warehouse layout and performance evaluation of the proposed warehouse layout should be conducted. With the dynamic factors in the real-world setting, it could lead to other results and raise other research questions. However, it could also show a significant improvement in performance and operation regarding routing and retaining product quality. Therefore, designing the layout may require considering all the products that will be deposited and stored inside. The latest technology, such as artificial intelligence, could be used to develop central management tools to help with product storage processes. The system may need a function that suggests the most appropriate storage area according to the environment required by each product. This function needs to ensure that the new product stored next to the others will not cause or affect quality or injury. As mentioned, temperature and humidity are among the essential factors that will affect the product's appearance and quality. The system design may need to consider connecting every function to central management tools. The systems may need to connect to the sensors in the warehouse and cooling management module, which will automatically adjust the temperature and humidity, even the airflow, in case they exceed the settings. It would help the business increase operation efficiency and real-time monitoring, realize significant changes on short notice, and reduce product quality and appearance issues. The warehouse and project managers could initiate using the data-driven approach for the first step by analyzing and interpreting the data that the company is collecting, such as product data, environmental factors, and even customer data. For example, based on customer and product data, this could create insight into the demand for warehouse storage that is needed and which timeframe is considered a peak season for their product. With this, the warehouse manager can foresee warehouse capacity planning and ensure that there is a place available for this customer to meet their demand. Also, the mentioned factors could help create more essential insights that lead to better decision-making and better operation management.

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