Storage and Order Picking Process Design for Perishable Foods in a Cold Warehouse

Bensu Güntez, Gizem İşgüzerer(✉), Çağla Güşeç, Merve Özen, Mert Paldrak, and Banu Yetkin Ekren

Industrial Engineering Department, Yaşar University, Bornova, Turkey
{mert.paldrak,banu.ekren}@yasar.edu.tr

Abstract. This study searches a suitable storage and retrieval policy resulting with efficient performance metrics in a cold warehouse located in Izmir. Due to the fact that the cold warehouse involves perishable food products, the policy that is searched by this work aims a storage and retrieval policy resulting with decreased process time in the system. Not only process time is aimed to be decreased, but also, we aim to decrease food waste in the warehouse. We define the storage and retrieval algorithms and simulate them to compare their performances. Furthermore, warm up periods and confidence intervals has been defined for the average cycle time by using Output Analyzer tool of ARENA 16.0 commercial simulation software. Also, a sensitivity analysis is performed to analyse the trade-off between product arrivals and demand distribution of product types. Finally, a user-friendly decision support system is developed using Excel-VBA interface by embedding the proposed simulation models.

Keywords: Perishable foods · Cold warehouse · Storage · Retrieval · Due date · Simulation

1 Introduction

Warehouses play a significant role in the continuous implementation of a series of activities from material supply to product shipment. Therefore, the warehouse is an important link between vendor and consumer. It is not just a place where to put products for later use or shipment, but also has an important place in achieving the desired level of customer service at the lowest cost from a logistics point of view. Warehouses can be single, multi-storey, or multi-depth, with handling, loading/unloading, protection, transfer places and equipment, as well as administrative unit areas. In these warehouses, vertical and horizontal carriers such as elevators and shuttles are used. Effective warehouse management is achieved by performing efficient storage and retrieval operations which would help in reaching those supply chain responsiveness and cost effectiveness targets. In the case where products kept in warehouses are perishable products, management of cold warehouses subject emerges. It is more complex to operate such cold warehouses than non-cold ones, this is because it requires faster process times due to its nature of high energy consumption in the facility and risk of rapid deterioration of products.

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N. M. Durakbasa and M. G. Gençyılmaz (Eds.): *Digitizing Production Systems*, LNME, pp. 800–811, 2022.
https://doi.org/10.1007/978-3-030-90421-0_68

In this study, based on the warehouse layout and the utilized racking system, we develop storage and retrieval policies so that the average process time is decreased and food freshness in the warehouse is increased. We aim to develop different storage and retrieval policies by using what-if analyses and then compare their performances to select the best one.

2 System analysis

In this study, we consider a cold warehouse which stores perishable foods in Kemalpaşa/İzmir. This cold warehouse consists of three rooms and each storage area is divided into two sides as left and right. In each of the three rooms in the warehouse, there are three forklifts and workers using them. Also, this cold warehouse consists of deep lane storage racks having single feeding entrance points for loading and unloading the food products. There are 15 racks on the right, and each consists of 21 bays. On the left, there are 17 racks, and each consists of 13 bays. Besides, both sides are comprised of 4 tiers (See Fig. 1). According to these data, there is an area of 6432 pallets, but the total shelf capacity used is 5400 pallets. Due to the fact that the shelves are in front of the cooler causes space loss, we cannot use our cold warehouse efficiently. This situation causes an approximately 17% loss in the cold storage area and this may cause some problems. The warehouse provides service according to all temperatures, mainly between -25 °C and -18 °C. Room temperature and humidity values can be kept digitally and manually, stored, and shared with customers instantly.

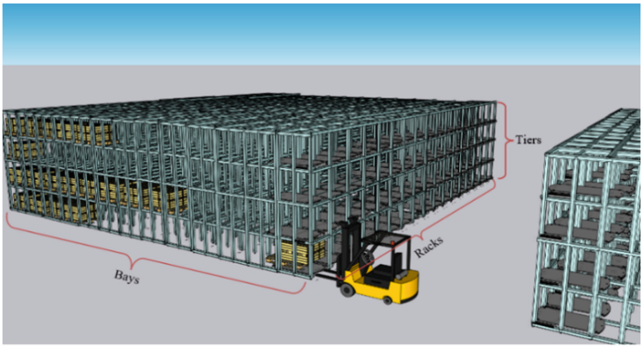

Fig. 1. 3D view of the warehouse

In this cold warehouse, different types and amounts of products arrive every day. For these products, the main processes are storage and retrieval processes. In the storage process, first product arrives at the Input/Output (I/O) point and the forklift is seized at the I/O point, which is considered the reference point. Then, the forklift picks up the product at the I/O point and brings it at the appropriate storage address. After lifting up the load at the correct tier, the forklift drops off the load at the entrance point of the rack. Then, shuttle carries the load at the rearmost available bay. In the retrieval process, the forklift first travels to the address of the product to be retrieved. Then, it travels to the

I/O point with the load to release at the I/O point. At the end of each day, the remaining shelf life of products is reduced by one day and updated. Products are carried out by two different vehicles which are reach trucks and shuttle. It moves vertically with the reach truck and places on the relevant rack. The shuttle moves the products horizontally and places them at the relevant bay. Shuttle automatically places the products at the rearmost available bay. Several time delays occur in the storage and retrieval processes due to the forklift and shuttle movements. These time delays are time delay between two adjacent racks, tiers, and bays.

3 Problem Definition

The facility mentioned in this study is a cold warehouse located in Kemalpaşa/İzmir. The main problem about this cold warehouse, due to that single loading/unloading entrance points the product that comes first is places at the back of the rack. If the storage of these products is not done according to a specific system, then forklift have to unload the products in front of them when it needs to reach the product with the closest remaining shelf life, and this causes a great waste of time. This waste of time can be examined in two stages. Firstly, products to be loaded according to the order received from the customer are searched by the employees with forklifts since a specific system is not applied. This may lead to waste of time as it requires a wandering search for each product. Secondly, in the case of delivery or shipment of products stacked at the back, it causes labour and time losses due to the removal and rectification of products again. Due to the fact that there is no specific addressing and product placement model in the cold warehouse, the delivery processes in the cold warehouse are prolonged. The literature research focuses on storage and retrieval strategies to solve these problems and make improvements for reducing food waste in the cold warehouse. According to these researches, the studies try to obtain the best scenario for the cold warehouse by combining different storage and retrieval strategies.

4 Literature review

In this study, a research has been done from various sources to examine the information, results on the topics and subheadings discussed. The literature review began with the investigation of cold storage and retrieval policies for perishable foods. Examples of storage policies that reviewed are as follows; random storage, class-based storage, dedicated storage, and correlated storage. After applying the combinations of these storage policies with different retrieval policies, the results obtained were analysed. By comparing the results, the most appropriate strategies for cold storage were tried to be determined. While determining these strategies, this study focused on the remaining days of our products by decreasing the time and movement amount required for shipment. In addition, while searching the literature, we had the opportunity to examine the warehouses operating in general areas other than cold storage for perishable foods.

The most critical factor is choosing the right storage strategy, for the cold warehouse and all other warehouses. While doing research, various storage policies have emerged. In addition to these storage policies, it can be seen other operational decision variables.

Riccardo Manzini (2009) [1] worked on storage strategies such as random storage, dedicated storage, class-based storage, and correlated storage. For these strategies, the total material transport distance was examined. Among these strategies, random storage is in a worse position than other strategies, resulting in more material transport distance. Moreover, Riccardo Manzini examined several operational decision variables. One of the most important of these is positioning rules which are zig-zag rule and parametric stripes rule. Other important aspects of storage strategies are specifying how much the product will be stored and deciding the location of the products to be stored. Another research belongs to Riccardo Accorsi, Riccardo Manzini and Marco Bortolini (2012) [2], they have focused on two main issues which are how much of each SKU (Stock Keeping Unit) to store and where the most suitable locations are to store each SKU. They have aimed to present a systematic hierarchical top-down procedure that allows the combining of sequential decision steps concerned with allocation and assignment issues. They have worked on assignment rules which are CB (Cluster-Based), COI (Cube per Order Index), OC (Order Closing), P (Popularity), T (Turn Rule). According to results, COI and P assignment rules manage to reduce total traveling. In addition, the best performance is obtained through a combination of the COI assignment rule and the EQS (Equal Space Strategy) allocation strategy.

Anil Akpunar et. al (2017) [3] studied on warehouse design in terms of number of aisles, bays, and tiers as well as number of AVs as decision variables for energy reduction in the AVS/RS. In this article, different design systems were planned by comparing different simulation studies by using autonomous vehicles. Another research belongs to Sunderesh S. Heragu et. al. (2010) [4] stated that specifying a near-optimal,AVS/RS-based, warehouse design shape, measuring the effects of various pre-defined design parameters on the key performance measures by using simulation gives important outputs. In this article, the aspects including dwell point policy, scheduling rule, input/output (I/O) locations and interleaving rule are considered in the DOE. Moreover, In Gino Marchetass (2011) [5] study is another example for the storage using with AVS/RS. The article shows that the tier captive configurations offer better performances, and it were more expensive due to the higher number of vehicles for made an AVS/RS therefore, another storage have been made on "tier to tier" as an alternative.

5 Modeling and Solution Methodology

Most of the systems encountered in real life have a complex structure. In this case, it is not possible to solve the models of these systems by mathematical methods. Analysis and solution of such systems are done by simulation model. In the simulation study, the data collected from the real system (if available) are used to estimate the input parameters required to run the model of the system. The notations, warm-up periods and developed policies of the proposed simulation model for the studied cold warehouse are presented in this section. The parameters, variables and equations of the proposed simulation model are listed below.

Parameters

TR: Forklift travel time delay between two adjacent racks.

TS: Shuttle travel time delay between two adjacent bays.
TT: Forklift travel time delay between two adjacent tiers (lifting up/down).

Variables

TN: Tier no
BN: Bay no
RN: Rack no
PA: Product amount to store relevant rack
TTR: Forklift travel time delay for the rack
TTBS: Shuttle travel time delay for storage
TTBR: Shuttle travel time delay for retrieval
TTT: Forklift travel time delay for the tier
TTTOTS: Total travel time for storage
TTTOTR: Total travel time for retrieval
RDA: Remaining Days A (Total due date value of A products in the warehouse)
RDB: Remaining Days B (Total due date value of B products in the warehouse)
RDC: Remaining Days C (Total due date value of C products in the warehouse)
TA: Total number of A products in the warehouse
TB: Total number of B products in the warehouse
TC: Total number of C products in the warehouse
FA: A Freshness (Average Freshness for A products)
FB: B Freshness (Average Freshness for B products)
FC: C Freshness (Average Freshness for C products)
TFABC: Average Freshness for all products
CT: Cycle Time
AVGCT: Average cycle time (from TNOW function)
AVGWT: Average waiting time (from seize forklift queue)

$$TT_R = T_R \times 2 \times R_N \times P_A \tag{1}$$

$$TT_{BS} = B_N \times T_S \times P_A \tag{2}$$

$$TT_{BR} = (B_N - 1) \times T_S \times P_A \tag{3}$$

$$TT_T = P_A \times 2 \times T_T \times (T_N - 1) \tag{4}$$

$$TT_{TOTS} = TT_R + TT_{BS} + TT_T \tag{5}$$

$$TT_{TOTR} = TT_R + TT_{BR} + TT_T \tag{6}$$

$$F_A = RD_A / T_A \tag{7}$$

$$F_B = RD_B / T_B \tag{8}$$

$$F_C = RD_C/T_C \quad (9)$$

$$TF_{ABC} = (RD_A + RD_B + RD_C)/(T_A + T_B + T_C) \quad (10)$$

$$CT = AVG_{CT} - AVG_{WT} \quad (11)$$

Equation (1) is used to calculate the time elapsed between the forklifts movement between racks. Equation (2) is used to calculate the time elapsed in the movement between bays for the shuttles storage process. Equation (3) is used to calculate the time it takes for shuttle to move between bays for its retrieval process. Equation (4) is used to calculate the time elapsed in the movement between tiers while the forklift is placing products. Equation (5) provides the calculation of the total time for the storage process by collecting the calculation that includes the time of the movements in the previously calculated rack, shuttle, and tier. Equation (6) provides the calculation of the total time for the retrieval process by collecting the calculation that includes the time of the movements performed in the previously calculated rack, shuttle, and tier. The next three Eqs. (7, 8, 9) add up the due dates according to the type of products and divide them by the number of products. In this way, the average freshness of the products is calculated. Equation (10) gives the total average freshness rate in the warehouse. In this section, due dates of all products in the warehouse are collected and divided by the total number of products in the warehouse. Equation (11) allows to calculate the average cycle time. The waiting time of the forklift in the queue is subtracted from the TNOW value kept at the top of the system.

As a modelling methodology, we focus on Random Storage Policy which is used when products do not have any specific location in the warehouse. In this policy, products are located randomly, and it closely represents to the real system. The only difference is the product reaching the warehouse is stored in the nearest suitable location. For the most suitable location, products are stored firstly on the first tier and then on the other tiers. This strategy is particularly useful in warehouses with a high variety of products. Due to this diversity, there is no need to allocate a specific place for any product coming to the warehouse. This storage policy has the following advantages: excellent space utilization, flexibility, and easy to expand-understand. The most important benefit is that it requires less space to store all products compared to a dedicated storage policy. The biggest disadvantage is that it requires detailed record tracking and discipline. Workers should be well informed about where products are stored, especially as the locations of the stored products vary. In Fig. 2, random policy rack design is shown for each type of product, and this represents a smaller version of the cold warehouse. Since Random policy is closer to the real system, we based this policy when validating our model.

In the simulation of the problem, it is assumed that: there are three types of products which are Type A, B and C, product types arrive randomly, demands are distributed Uniformly, due dates (shelf lives) are distributed Triangular, 60 products arrive each day to the warehouse, there are several time delays which are time delays between two adjacent racks (4 s), bays (5 s) and tiers (5 s), there are three forklifts and workers using it, there is a single Input/Output (I/O) point which is a reference point, there is a single room in the warehouse and the exact size (number of racks, bays, and tiers) of the

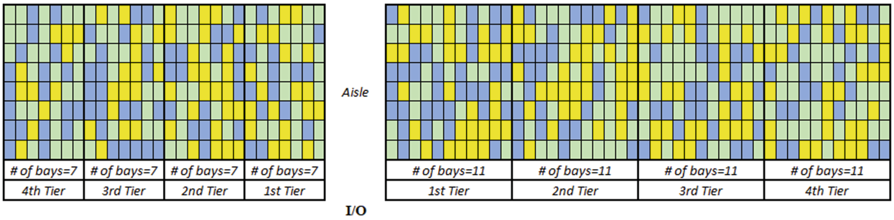

Fig. 2. Design of the random storage policy

warehouse is used. When the warehouse is examined, it is concluded that the layout of the warehouse cannot be changed. Therefore, the aim of the project is designing storage and retrieval operations resulting with minimum waste of time and perishable products for the warehouse. Most of the simulation models start empty and idle. In almost every case, these conditions are different from the steady-state condition. Due to this, it takes time for the simulation model to reach the steady-state. During this time, the model is in a transient state. In addition, observations collected during this time can affect the accuracy of performance measure estimates if the transient state persists for a long period of time. Thus, the simulation model needs to run for a period of time called the "warm-up period". In this case the warehouse assumed to start empty and idle, the performance metric is average cycle time and models are run for 200 days.

In order to determine the warm-up periods in the simulation models of the policies, a time persistent type of statistic was created on ARENA 16.0 and an output file was obtained. Plots were created using the Output Analyzer with the obtained file. When these plots are examined, the steady-state condition is determined (considering the part of the warehouse after it is full) and the comparison of the models provides a more accurate result. In addition, when determining the steady-state condition, five replications were used instead of a single replication to consider the variations that may occur and increase the accuracy. In the Random Policy, the warm-up period is determined as 128 days (11.000.000 s).

As a solution methodology, first we focus on dedicated storage policy. Dedicated (or Fixed Slot) Storage policy is based on the principle that every product has its dedicated location. Every SKU (Stock Keeping Unit) is assigned to a particular location within the warehouse. This strategy is more applicable for small or larger warehouses. The total capacity of the slots assigned to each SKU must be equal to the storage space corresponding to the maximum on-hand inventory of each individual SKU. Dedicated (or Fixed Slot) Storage policy has some advantages which are ease of use, comfortable installation, and familiarity with product locations for the employee. However, it has some disadvantages which are poor space utilization, difficulty to make changes in product fields. Whereas Class-based storage policy refers to divide products into classes and assign to products for a dedicated area of the warehouse. Thus, storage is occurred according to its class. The significant benefit of this policy is to reduce travel time. In our model, we have implemented the horizontal class-based storage policy for both sides (right and left) of our cold warehouse. We assumed that we have three different types of products in this policy which are product A, B and C. According to this policy, we placed product A on the first tier, product B on the second tier, and product C on the third and fourth tier. One of the reasons for the layout shown in Fig. 3 is that the due date of product C is longer, and it arrives more than other products in our cold warehouse. In addition, this layout represents a smaller version of our cold warehouse. In the first and second solution methodologies which are Horizontal Class-Based Policy and Vertical Class-Based Policy, the warm-up period is determined as 128 days (11.000.000 s) for Horizontal Class-Based Policy. The warm-up period for the Vertical Class-Based Policy is determined as 93 days (8.000.000 s).

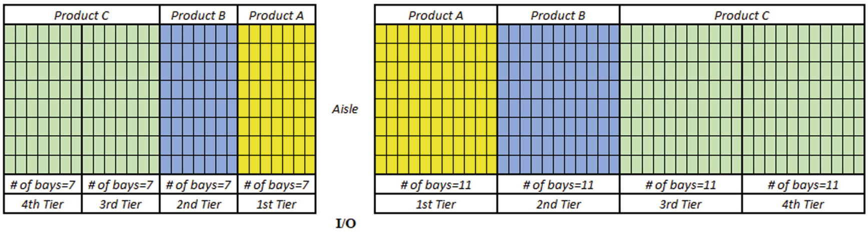

Fig. 3. Design of the horizontal class-based storage policy

As another solution method, we focus on another type of dedicated storage policy which is vertical class-based storage policy. This policy is very similar to horizontal class-based storage policy, but the only difference is that the three types of products mentioned are located on each tier (See Fig. 4). Thus, it is aimed to minimize the time that the forklift will lose during its movement between tiers. Since the products in the warehouse are perishable products, it is aimed to reduce the waste of these products. For this reason, the retrieval operation of all policies mentioned is designed according to minimum due dates.

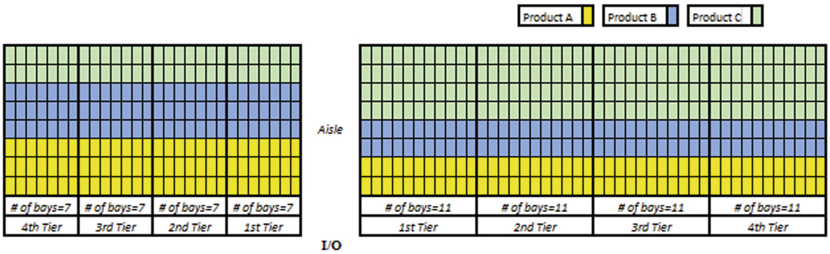

Fig. 4. Design of the vertical class-based storage policy

6 Computational Results and Decision Support System

A. *Verification*

The aim of this section is to verify the proposed simulation model. Verification is used to ensure model behaviour makes sense, assets are moving in the direction they should be, and process steps are performing as expected. In this case, the effect on total storage and retrieval times in the change of the number of product arrivals has been observed using animation. While verifying the policies, two different scenarios were created for each policy. For both scenarios model has run for thirty days, and the simulation time unit was determined as seconds. In the first scenario, fifty products arrive at warehouse per day, the demand distribution for product type A and B was determined as UNIF(8,9) and for product type C as UNIF(7,8). Whereas, in the second scenario, sixty products arrive at warehouse per day, the demand distribution for product types A and B were determined as UNIF(10,12) and for product type C as UNIF(8,9). Total storage time was expected to increase with the increase in the amount of product arrivals, and total retrieval time was expected to increase with the increased of demand, and it was observed that they increased as expected. Figure 5 represents the change in total storage and retrieval times for the Random Policy, respectively.

B. *Validation and Improvements*

In simulation, confidence intervals are frequently used as a quantitative method of validation. There are several approaches used in comparing the behaviour of the simulation model which are the use of confidence intervals and hypothesis tests to make an objective decision. Therefore, confidence intervals can be used as the range of accuracy of a model for model validation. In order to determine the confidence intervals in the simulation models of the policies, an output type of statistic was created on the ARENA 16.0. The comparative confidence intervals of the three policies were obtained using the output files of the models with five replications and warm-up periods. By the comparison of the three policies, there is not a significant difference between Horizontal Class-Based and Vertical Class-Based Policy but there is a significant difference between both policies and the Random Policy at 95% confidence level between means according to average cycle time, which is one of our performance metrics (See Fig. 6). The policy with the least average cycle time was determined as Vertical Class-Based Policy, then Horizontal Class-Based Policy and Random Policy.

Another method that can be used to make an objective decision is hypothesis testing. Students T-Test is one of the techniques for testing a hypothesis on the basis of a difference between sample means. By using this method, it is aimed to determine a probability that two populations are the same with respect to the variable tested. Mean values used represent average cycle time in Eq. 1 and 2, $\mu 0$ is for the real system and $\mu 1$ is for the simulation model.

$$\mathrm{H}_0 : \mu_0 = \mu_1 \tag{12}$$

$$\mathrm{H}_1 : \mu_0 \neq \mu_1 \tag{13}$$

It was mentioned that Random Policy is the closest to the real system. For this reason, validation of the proposed simulation model was based on Random Policy. In the real system, average cycle time is 3.29 min. When Table 1 in sensitivity analysis section is examined, maximum average cycle time is 3.29 min in the Random Policy which is same as the real system. Hence, it is observed that there is enough evidence to reject H1. So, the proposed simulation model accurately represents the real system.

C. *Sensitivity Analysis*

The uncertainty in models where the values for the inputs used in the model will differ is the focus of sensitivity analysis. In the proposed models, sensitivity analysis was applied according to two different inputs. The first input was determined as fifty product arrivals daily, demand distribution for product type A and B as UNIF(8,9), and for product type C as UNIF(7,8). The other input was determined as sixty product arrivals daily, demand distribution for product type A and B as UNIF(10,12), and for product type C as UNIF(8,9). As it is seen from the Table 1, there are two different performance metrics which are average cycle time (min) and average freshness. By the comparison of the three policies studied, maximum average freshness was observed in Random Policy and the minimum average cycle time was observed in Vertical Class-Based Policy (See Table 1).

Table 1. Comparison of performance metrics of all policies

Policy	Daily Storage Arrivals	Demand Distribution of Product Types: *Product Type A*	*Product Type B*	*Product Type C*	Forklift Utilization	Performance Metrics: Average Cycle Time (min/product)	Average Freshness (total remaining days until expiration/total number of product)
Horizontal	50	UNIF(8,9)	UNIF(8,9)	UNIF(7,8)	0.26	2.04	12.66
	60	UNIF(10,12)	UNIF(10,12)	UNIF(8,9)	0.32	2.12	12.65
Vertical	50	UNIF(8,9)	UNIF(8,9)	UNIF(7,8)	0.37	2.03	12.67
	60	UNIF(10,12)	UNIF(10,12)	UNIF(8,9)	0.38	1.93	12.44
Random	50	UNIF(8,9)	UNIF(8,9)	UNIF(7,8)	0.40	3.26	12.69
	60	UNIF(10,12)	UNIF(10,12)	UNIF(8,9)	0.48	3.29	12.69

D. *Decision Support System*

Furthermore, the proposed simulation model is implemented in an Excel-VBA interface to increase the ease of use and comprehensibility of the established work (See Fig. 7). In the interface, the user is asked which policy to run from three policies: Random Storage Policy, Horizontal Class-Based Storage Policy, and Vertical Class-Based Storage Policy. Inputs requested by the user are first the replication length, then the number of replications and the warm-up period. Time units are required for replication length and warm-up period, these units consist of days, hours, minutes, and seconds. Then the user enters the average amount of daily demand for three products in the cold warehouse. Another important input is travel time inputs for the forklift. In this section, the user is expected to enter the time in unit of seconds how long the forklift in the warehouse will travel between adjacent rack, bay, and tier. The user then clicks the "Run Model" button and runs the desired model with the information entered. All these inputs are read by the "ReadWrite" module of the ARENA 16.0. In the output part of the decision support system, when user clicks the "Show Chart" button then, relevant graphs (average freshness, total storage time, and total retrieval time) are created of the three policies according to the inputs entered by the user (See Fig. 8).

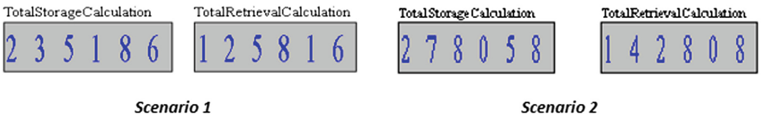

Fig. 5. Change in total storage and retrieval times for random policy

Fig. 6. Comparison of average cycle times confidence intervals for all policies at confidence level of 95%

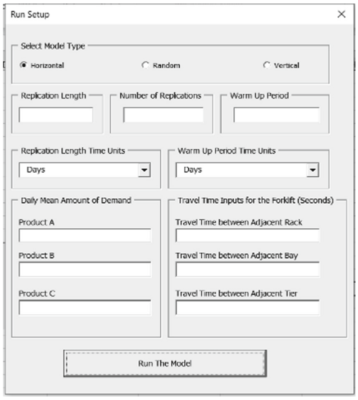

Fig. 7. User-friendly interface of the arena models

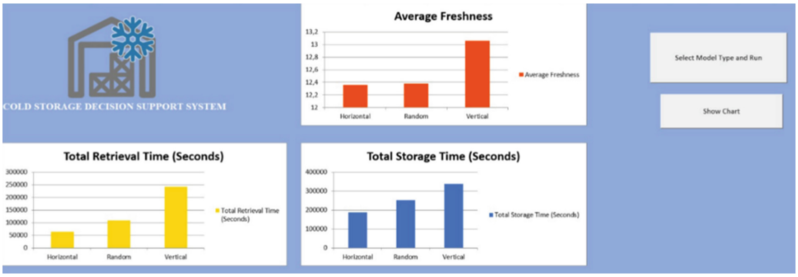

Fig. 8. Output of the Decision Support System

7 Conclusion

In cases where the layout of the warehouse cannot be changed, the design of the processes that take place in the warehouse is important for efficiency. In this project, different storage policies and appropriate retrieval policy have been determined over the existing layout of a cold warehouse containing perishable foods. Afterwards, these policies were simulated using ARENA 16.0 software and the policies developed in line with the performance criteria determined as average cycle time and freshness were compared. The outputs of these scenarios are presented to the user by providing data flow between ARENA 16.0 and Excel-VBA interface. It is aimed to find the policy that gives the best results in line with the outputs obtained from the policies created. As a result, it is possible to choose between policies developed with a minimum average cycle time or a maximum average freshness. More different storage and retrieval policies can be researched as future works.

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