MATHEMATICAL AND HEURISTIC SOLUTION APPROACHES FOR SHELF ASSIGNMENT PROBLEM IN MULTIPLE WAREHOUSES

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Keywords

Shelf Assignment, Warehouse Layout, Mathematical Model, Decision Support System

Abstract

One of the most important elements of the supply chain is the warehouses. Effective warehouse layout reduces delivery time to the customer and the cost of storage. In this study, warehouse layout problem in a ceramic factory with multiple warehouses and heterogeneous raw materials is discussed. For the solution of the problem, a multi-objective mixed integer mathematical model is proposed. The first aim of the model is to assign the raw materials to the shelves considering the raw material priority coefficients by minimizing the transportation distance between two warehouses and four factories and the second one is minimizing amount of shelf used in these warehouses. As the problem is classified as NP-Hard, in addition to the mathematical model, a heuristic algorithm has been also developed to solve large-scale problems. Based on this heuristic, a decision support system (DSS) with a user-friendly interface has been proposed for the engineers in the factory. By the help of proposed DSS, more efficient use of warehouses and systematic storage of items have been provided. In this manner, total transportation cost is decreased approximately 61% in the factory.

ÇOKLU DEPOLARDA RAF ATAMA PROBLEMİ İÇİN MATEMATİKSEL VE SEZGİSEL ÇÖZÜM YAKLAŞIMLARI

Anahtar Kelimeler

Raf Atama, Depo Yerleşimi, Matematiksel Model, Karar Destek Sistemi

Öz

Tedarik zincirinin en önemli unsurlarından biri depolardır. Etkili depo düzeni, müşteriye teslimat süresini ve depolama maliyetini azaltır. Bu çalışmada, birden fazla depo ve heterojen hammadde içeren seramik fabrikasında depo yerleşim problemi tartışılmıştır. Sorunun çözümü için çok amaçlı bir karma tamsayılı matematiksel model önerilmiştir. Modelin ilk amacı, hammadde öncelik katsayılarını göz önünde bulundurarak hammaddeleri raflara atayarak, iki depo ve dört fabrika arasındaki taşıma mesafesini en aza indirmek; ikincisi ise bu depolarda kullanılan raf miktarını en aza indirmektir. Problem NP-Zor olarak sınıflandırıldığı için, matematiksel modele ek olarak, büyük ölçekli problemleri çözmek için de bir sezgisel algoritma geliştirilmiştir. Bu sezgisel çözüm algoritmasını temel alan, kullanıcı dostu arayüze sahip bir karar destek sistemi (KDS) önerilmiştir. Önerilen KDS' nin yardımıyla, depoların daha verimli kullanılması ve hammaddelerin sistematik olarak depolanması sağlanmıştır. Bu şekilde, toplam nakliye maliyeti fabrikada yaklaşık % 61 oranında azaltılmıştır.

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1. Introduction

An effective inventory management is very crucial for consumer services to increase their customer satisfaction. For this reason, it is very important that the raw materials are on the right shelf in the right warehouse at the right time to deliver the final product to the customer on time. So, raw materials and associated warehouse layout becomes an important area of inventory management.

Warehouse layout problem is one of the key issues of warehousing. Therefore, it is one of the most popular subjects in the literature. Zhang, Xue and Lai (2002) unlike the warehouse layout problem (WLP), they investigated the multiple-level warehouse layout problem (MLWLP). MLWLP has a horizontal movement from the cell to the elevator and a vertical move in the elevator to the ground. The horizontal and vertical unit transportation cost is item type-dependent in MLWLP. An integer programming formulation of MLWLP is proposed. The objective of problem is to minimize the total vertical and horizontal cost. To solve the problem, genetic-algorithm (GA) based heuristics are introduced and some improved techniques are presented. Yang and Feng (2006) tried to place different items into the warehouse effectively for reducing total transportation cost for storage. A mathematical model and a tabu search algorithm are developed to solve the problem. Baray and Cakmak (2014) introduced the multi-level warehouse layout problem with different z-axis storage spaces in their study. The multi-level warehouse layout methodology is proposed to minimize the total material handling costs. For this purpose, a mathematical model and PSO algorithm are proposed. Wutthisirisart, Sir, and Noble (2015) handled the material location selection problem that allocates materials to two different warehouses. The objective of the proposed model is to minimize the total storage and transportation costs. Four material location models/policies with different decision restrictions are introduced to solve the problem from different material handling perspectives. The four models are analyzed and compared with each other based on data derived from a real industrial scenario. Roodbergen, Vis and Taylor (2015) investigated how to improve warehouse performance by deriving an effective design method for the simultaneous determination of warehouse layout and the warehouse's control policies. Simulation was utilized to determine the performance of the various resulting scenarios. Also, the issues of strategic concern (a type of warehouse and overall material storage/handling decisions), issues of tactical concern (establishing the layout and storage assignment) and issues of operational concern were investigated. Results show that the proposed method in this study can be applied in many alternative warehousing settings. With the use of this study with a company in the Netherlands, they have shown that savings in an average travel distance of 84,67 m per order (53%). Gul et al. (2016) addressed the problem of an automotive supplier with limited storage space in response to the quantity of stock the main industry wants. It was aimed to calculate the areas that will be allocated in the warehouse according to the frame types and volumes, providing maximum storage space and volume in the warehouse against changing customer demands. Three mathematical models have been developed for this purpose. In the first mathematical model, the optimum number of settlements of the frames is taken into consideration by considering the warehouse-shelf dimensions. In the second model, it was aimed to create minimum customer diversity in each corridor. Using the placement results in the second model, the total number of product types of each shelf in each corridor was tried to be minimized. Because of the complexity of problem, a heuristic algorithm was developed for the problem. Zhang and Nishi (2017) developed an integrated strategy that combines a dedicated storage location assignment with the capacitated lot-sizing problem into a single mathematical model that minimizes the total cost of travel, reserved storage space, handling, production, inventory holding, and setup costs. Fan and Wang (2018) investigated a new single item dynamic lot-sizing problem which a firm rents warehouse space to store the product in a flexible way. They presented a dynamic programming algorithm.

Warehouse design and operation research domain in the study of Rimiene (2008) observed on the basis of design problems at a strategic, tactical and operational level as well as focused on the importance of decisions intersection at different stages of operation, including resources scheduling and policies embracement. The study of Guerriero, Musmanno, Pisacane, and Rende (2013) investigated production allocation problem for multi-level warehouse. The main purpose of this work is to solve the products allocation problem in a multi layers warehouse with compatibility constraints among the classes. The objective is reducing delivery times, costs and inventory as much as possible. In this research, a linear model was developed to represent the problem mathematically. Their model complexity increases as the number of product classes and the dimension of the warehouse. The mathematical model failed to give a solution. Because of that they also created a heuristic approach. The model was implemented in Java. The study made by Rakesh and Adil (2015) developed an algorithm that determines lane depth, the number of storage levels, lateral depth, and width of a three-dimensional order picking warehouse minimizing space and material handling costs. The paper presents a mathematical model and algorithm to decide four of the most important decisions in designing a warehouse racking system, lane depth, number of storage levels, lateral depth and width.

In the study of Zhou, Piramuthu and Chu (2017) a system that uses RFID along with shelves has been proposed. The paper examines the space and capacity constraints. The stochastic Markovian method was used to make decisions to the location. Bartoszewicz and Latosinski (2019) introduced a new method for a class of discrete time inventory management system with multiple suppliers. Goods are delivered to a single warehouse with limited capacity. Also, suppliers don't accept a small quantity order in this problem. It makes the problem more complicated. This study investigates discreet time sliding mode control, inventory management with bounded shipment size. Under those topics, a lot of constraint and variables were defined. It has been proven that the proposed inventory management strategy guarantees 100% satisfaction of consumers demands without too small or large orders.

In addition to warehouse layout studies, there are studies in the literature to determine the importance and classification of inventory items in the warehouse. There are some Analytical Hierarchy Process (AHP) and optimization integrated inventory optimization studies in the literature. Ramanathan (2006) proposed a weighted linear optimization model and illustrate in this study for classifying inventory items in the presence of multiple criteria by using AHP. Cakir and Canbolat (2008) also proposed an inventory classification system based on the fuzzy AHP, a commonly used tool for multicriteria decision making problems. They integrated fuzzy concepts with real inventory data and design a decision support system assisting a sensible multi-criteria inventory classification. Kırış (2013) compared fuzzy analytic network process (ANP) approach and traditional ABC analysis in a construction firm that applied an ABC classification. The fuzzy ANP approach was applied to recover the uncertainness of ANP method and it provides to make a more flexible decision in vagueness environments.

In this study, where a real problem was addressed, it was planned to obtain the most suitable warehouse layout by assigning items to warehouses and shelves to minimize transportations from warehouses to factories. As seen from the literature, multiple warehouses have not been discussed much in the literature. In addition, as in many real-life problems, the problem has a multi objective structure. Minimization of total costs and the transportation distances are very common objectives. In this study, beside the total distance, the amount of shelf used in the warehouse is also considered to be minimized. As a result, the problem of raw material shelf assignment in multiple depots with multi-objective structure is not yet a much-studied problem in the literature. For this reason, the proposed model here is a new model for the literature.

The remainder of this paper is organized as follows. In the next section, the detailed description of the considered problem is presented. The mathematical formulation of problem is also provided in Section 2. Proposed heuristic algorithm that is used to solve large size problems is given in the Section 3. Finally, conclusions and future research are contained in Section 4.

2. Material and Method

In this study, the shelf assignment problem approach is used to assign the raw materials, required for production, to the appropriate shelves in the warehouses. The problem examined differs from the studies in the literature in terms of the constraints that multiple warehouses serve multiple factories and the placement of raw material pallets on shelves.

2.1. Problem Description

In the ceramic factory, there are currently two raw material warehouses. Raw materials are stocked as stacking because there is no shelf system in the warehouses. The warehouses W1 and W2 cannot be used efficiently, because there is no space in the warehouses for some raw materials and these are stocked outside of warehouses. The place and location of the raw materials in the warehouses are uncertain and it's hard to track them. To place and track the raw materials are time consuming. Because of these reasons the factory is planning to design a shelf system in order to keep the stocks of the raw materials systematically in W1 and W2.

The shelf system planned to be used in the warehouses will be the shuttle shelf system. Based on the dimensions of the warehouses, maximum 4-storeyed shelves can be placed and the available number of shelves for W1 and W2 are 180 and 284, respectively. There are 252 different raw materials that need to be stored. These raw materials are kept in different dimensional pallets, and totally 3844 raw material-pallets must be stored in W1 and W2. And obviously, one type of pallet is used for multiple raw materials. The 27 types of pallets, their total usages and the number of raw materials using these pallets are given in Table 1. For clarification, the 100X100 dimensional pallet is used by 10 different raw materials and this palette is used a total of 168 units.

Table 1
Pallets' Information

No	Pallet Type Dimensions (cm. x cm.)	Total Pallet Usage	Total Raw Material Variety	No	Pallet Type Dimensions (cm. x cm.)	Total Pallet Usage	Total Raw Material Variety
1	100X100	168	10	15	120X150	18	2
2	100X120	719	58	16	120X160	78	6
3	100X130	21	2	17	120X180	24	1
4	105X130	21	3	18	120X190	114	15
5	105X140	65	6	19	120X210	21	3
6	110X110	775	117	20	125X140	109	13
7	110X130	11	2	21	125X190	27	1
8	110X140	109	17	22	80X120	1048	114
9	110X150	28	3	23	80X160	21	2
10	110X170	20	2	24	90X120	17	4
11	110X190	11	1	25	90X140	42	3
12	115X115	7	1	26	90X190	3	1
13	115X190	87	11	27	93X120	239	16
14	120X115	41	1				

Shelf system that will be used in warehouses is a shuttle shelf system. Therefore, the input-output order of the items in stocks is based on the LIFO (Last In First Out) principle, that is, the final raw material-pallet that put on the shelf is taken first. Adhering to this principle, placing only one kind of raw material pallet on each shelf will provide efficient operations. The visual form of the shelf assignment is given in Figure-1. As seen from the Figure 1, the shelves are as like the container type. So, only one kind of raw material-pallet must be assigned to each shelf.

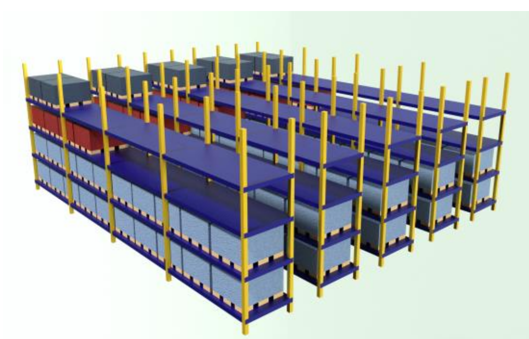

Figure 1. The Proposed Shelf Assignment System

The company wishes to make a shelf investment for its warehouses for two purposes. The first one is to minimize the total distance that raw materials are transported to the factories, and the second is to minimize the number of shelves used. Since the company will make a shelf investment once, the number of pallets to be assigned to the shelves within the tolerance determined by the firm has been determined based on the data of the last three years.

2.2. Data Collection and Analysis

The raw materials are loaded to pallets, and these pallets, called raw material-pallets, will be stored on the shelves. The annual consumption of raw materials, the number of raw material-pallets stored in the warehouses, the raw material-pallet information, the warehouse and shelf criteria are gathered. Using these data, firstly ABC Analysis was performed to obtain the priorities of raw materials. Then, some of the other collected data used as parameters to develop the mathematical model.

2.2.1. ABC Analysis

The ABC classification method developed by the General Electric Company in the 1950s, which is quite valid in recent years, helps in the inventory management of the enterprises that are in the decision-making situation between the different options (Kılıç, Aygün, Aydın Keskin and Baynal, 2014).

In this study, three-year data were collected for the raw materials and ABC analysis was developed based on cumulative data at the request of the factory. As a result of ABC analysis, 252 different raw materials are classified as A, B and C groups. A group has 48 raw materials, B group has 73 raw materials and C group has 131 raw materials. Priority coefficients are determined as 0.80, 0.15 and 0.05 for A, B and C group raw materials, respectively. The obtained priority coefficients will be used as priority parameter in the proposed mathematical model to provide storage of pallets with high priority coefficient to nearest shelves.

The raw materials and their obtained priorities are given in Table-2.

Table 2
Raw Materials' Priorities

Raw material no	Priority Coefficient
01.02.01.01.00004	0.8
01.02.01.01.00009	0.15
01.03.01.01.00012	0.8
01.03.01.01.00019	0.15
01.03.01.01.00039	0.8
01.05.00.00.00002	0.8
...	...
03.04.01.02.00011	0.15
03.04.01.02.00026	0.15
03.06.01.00.00007	0.8
03.09.01.00.00028	0.05
03.09.04.00.00008	0.05

Following ABC analysis, classes of pallet types used for raw materials are also determined as given in Table 3. The resulting palette classes will give the corresponding priorities in Table 2. Thus, in the developed mathematical model, the priority of each raw material-pallet pair was obtained automatically.

Table 3
Class of the Pallets

No	Pallet Type Dimensions (cm.xcm.)	Total raw material variety	Class Information	No	Pallet Type Dimensions (cm.xcm.)	Total raw material variety	Class Information
1	100X100	10	A-B-C	15	120X150	2	B-C
2	100X120	58	A-B-C	16	120X160	6	B-C
3	100X130	2	C	17	120X180	1	A
4	105X130	3	B-C	18	120X190	15	A-B-C
5	105X140	6	B-C	19	120X210	3	B-C
6	110X110	117	A-B-C	20	125X140	13	B-C
7	110X130	2	A-C	21	125X190	1	A
8	110X140	17	B-C	22	80X120	114	A-B-C
9	110X150	3	B-C	23	80X160	2	C
10	110X170	2	B-C	24	90X120	4	C
11	110X190	1	A	25	90X140	3	C
12	115X115	1	A	26	90X190	1	C
13	115X190	11	A-B-C	27	93X120	16	A-B-C
14	120X115	1	A				

According to the Table 3, it can be seen that, the 10 kinds of raw materials carried by the 100x100 dimensional pallet are also raw materials of three classes. The 90x120 dimensional pallet is used by 4 different raw materials and all of them are classified to just one class.

2.2.2. Trend Analysis

The collected data was also analyzed to check if there is a seasonal effect or not and thus the past data can be calculated with the demands of the coming years. As it's known, trend analysis is a technique used in technical analysis that attempts to predict the future product stock movements based on recently observed trend data.

The analysis was conducted for 38 raw materials from group A. The trend analysis graph of a raw material is given in Figure 2. It was observed that there is neither trend nor seasonality. Therefore, forecasting could not be performed by using trend analysis. The study of Özdemir and Özdemir (2006) showed that the trend analysis in the ceramics industry has not yielded any significant results when forecasting the demand. As a result of this situation, 25% tolerance for usage values was added with the decision of the company.

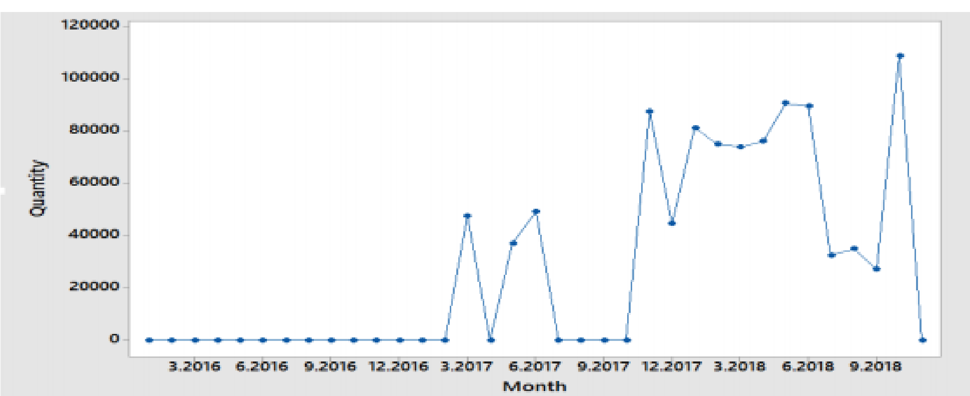

Figure 2. Trend Analysis for a Selected Raw Material

2.3. Multi-objective Mixed Integer Mathematical Model for Shelf Assignment Problem

In terms of the simplicity of the model, the problem of raw material-warehouse-shelf assignment has been determined with a single index k by specifying which shelf is in which warehouse by numbering the shelves from 1 to r. Therefore, the model developed to solve the problem has been turned into a raw material-pallet-shelf assignment problem.

The first objective of the problem is minimizing the total transportation distance of raw material-pallets from shelves to the entrance door (I/O) of the warehouses. This objective function is one of the common objectives of the warehouse layout problems. In this study, the second objective is to minimize the total number of shelves used. As mentioned in the problem definition, the shelf system is not used in the current system. When switching to the shelf system, considering the costs, the number of shelves to be used is aimed to be as small as possible.

When assigning raw material-pallets to the shelves, it is important to have as minimum left space as possible for efficiency. Because, as mentioned before, only one type of raw material-pallet will be placed on each shelf. Therefore, if the raw material-pallets are placed so that the shortest edges do not extend beyond the width of the shelf, more raw material-pallets are placed in a shelf than the long edge of the corresponding pallet.

Based on given specific characteristics of problem, a mathematical model for the shelf assignment problem is proposed. The sets, indices, parameters and decision variables associated with mathematical model are given below.

Sets:

I = {*1, 2,…, n*} pallet sets

K ={*1, 2,…, r*} shelves sets

Indices:

i:number of raw material-pallet, $i \in I$

k:number of shelves , $k \in K$

Parameters:

d_k: I/O distance of k^{th} shelf

w_i: priority coefficient of i^{th} raw material-pallet

e_i: the smallest edge of i^{th} raw material-pallet

l_i: total number of i^{th} raw material-pallet pair

a: the distance from I/O to furthest shelf

b: total number of shelves

sl: length of a shelf (1217 cm.)

Decision variables:

$x_{ik} = \begin{cases} 1, & if\ i^{th} \text{ raw material-pallet pair is assigned to } k^{th} \text{ shelf} \\ 0, & otherwise \end{cases}$

u_{ik}:number of i^{th} raw material-pallet pair assigned to k^{th} shelf

S_i : number of shelves used by i^{th} raw materail-pallet pair

Constraints:

$$\sum_{i=1}^{t}\sum_{k=1}^{r} x_{ik} \le \sum_{i=1}^{t} S_i \qquad (1)$$

$$\sum_{i=1}^{t} x_{ik} \le 1 \qquad \forall(k) \qquad (2)$$

$$\sum_{i=1}^{t} u_{ik} * e_i \le sl \qquad \forall(k) \qquad (3)$$

$$\sum_{k=1}^{r} u_{ik} = l_i \qquad \forall(i) \qquad (4)$$

$$u_{i,k} \le \ l_i * x_{ik} \qquad \forall(i,k) \qquad (5)$$

$$x_{ik} \in \{0,1\} \qquad \forall(i,k) \qquad (6)$$

$$u_{ik}, S_i \ge 0 \qquad \forall(i,k) \qquad (7)$$

Objective function:

$$min\ Z = \sum_{i=1}^{t} \sum_{k=1}^{r} (l_i * w_i * d_k * x_{ik})/a + \sum_{i=1}^{t} S_i /b \quad (8)$$

Constraint (1) group ensures that the number of assigned shelves for each raw material-pallet can be at most the number of shelves used by i^{th} raw material-pallet pair (S_i). This constraint also guarantees minimization of number of used shelves for all raw material-pallets in the objective function (Eq. 8). Based on LIFO principle, it is assumed that only one type of raw material-pallet can be assigned to each shelf to provide efficient operations. Constraint group (2) guarantees that there should be at most one raw material-pallet pair type on each shelf. Different raw materials use different size of pallets. However, the length of each shelf is same (1217 cm). So, according to the shelf capacity, there can be different number of pallets in each shelf. The number of pallets in a shelf has maximum amount if these are placed by holding their shortest edge. Constraint group (3) ensures that the total length of assigned pallets to a shelf cannot exceed shelf length. Constraint group (4) indicates that each pallet type should be assigned to any shelf in a warehouse. Constraint group (5) provides the relationship between the decision variables. Constraints group (6) gives the binary decision variables. Constraint group (7) are the sign constraints of decision variables.

The multi-objective function of problem is given in Equation (8). First part of objective function is to minimize transportation distance between warehouses and factories. The raw material-pallet pairs are assigned to the shelves considering the raw-material priority coefficients (w_i) and total number of raw material-pallet pair i (l_i). As expected, the raw materials that have high priority and maximum amount will be placed to as possible as the nearest shelves. Second objective is to minimize the number of shelves used in the warehouses to use the capacity investment costs more efficiently. The objective function should be normalized because of the fact that each objective has different units as meters for distance and amount for selves. The distance from I/O to furthest shelf (a) and total number of shelves (b) are used for normalization of bi-objective function.

The proposed mathematical model for shelf assignment problem has (nr) binary variables, ($n + nr$) positive variables and ($nr + 2r + n + 1$) constraints. So, implementation version of this model to ceramic factory consists of 1,783,616 binary variables, 1,787,460 positive variables and 1,788,389 constraints.

The mathematical model for shelf assignment problem has been solved by using GAMS optimization package program. The objective function value is found as 1,019.62 in 116 seconds.

3. Proposed Decision Support System

The running time of mathematical model in GAMS does not exceed the reasonable time limits. However, high investment cost optimization software like GAMS is not preferred in enterprises. In addition to this, the problem being addressed is a real-life problem confirms that the system contains dynamic and variable parameters. When raw material variety and raw material quantity increase in the future, GAMS may not provide optimal results due to NP-hard nature of problem. As a result, a heuristic algorithm has been developed to solve this problem. This heuristic algorithm was developed in MS Excel VBA and detailed information for the heuristic algorithm is given in Section 3.1. The solution approach proposed in this section is actually a decision support system (DSS). The developed heuristic algorithm forms the model base of DSS. The interfaces of DSS are explained in detail in the next subsection.

3.1. Heuristic Algorithm

The aim of the shelf assignment problem in this study is to assign the raw material-pallets to the shelves taking into consideration the raw material priority coefficients by minimizing the transportation distance and the amount of shelf used in the warehouse. As expected, assignment of pallets with high priority coefficient to nearest shelves helps the minimization of first objective function. Assignments to the shelves considering fully loading provides the minimization of the number of shelves used in the warehouses. This means that, a shelf will not be assigned to the next shelf until the pallet shelf is fully loaded as far as possible.

Based on heuristic rules that are given above, the pseudocode of heuristic algorithm is given as follows:

Pseudocode:

```
Initialize
For each raw material
  Sort raw materials according to the raw material priority from large to small
Next
If raw material_priority=0,8 then
  Sort raw materials according to the raw material amount from large to small
End if
If raw material_priority=0,15 then
  Sort raw materials according to the raw material amount from large to small
End if
If raw material_priority=0,05 then
  Sort raw materials according to the raw material amount from large to small
End if
For each shelf
  Sort each shelf according to shelf distance from small to large
Next
For each raw material
  For each shelf
    If raw material length is smaller than the shelf length
      Assign the raw material to the shelf
        If raw material amount>0
          If there is not enough space on the shelf
            Assign the raw material to next shelf
          End if
        Else
          Assign the next raw material to next shelf
      End if
    End if
  Next
Next
End sub
```

According to results of heuristic algorithm, a total of 3283 raw material-pallet consisting of 252 different raw materials are assigned to 450 out of 464 shelves. The total raw material transport distance in the warehouses is approximately 83676.61 meters. As a result of this study, the total transportation distance of the raw materials decreased to 31929,81 meters. In this manner, the factory decreased the cost of approximately 61%. When this result is compared with the optimum result found by mathematical model, the normalized first objective value is obtained as 1030. The value of the second objective function was the same value in the exact and heuristic solution (450 shelves). From this point of view, the gap of the heuristic algorithm to the optimum solution is around 0.01. Therefore, when the problem size increases, companies can use this heuristic solution approach efficiently.

3.2. Data Stores and User Interfaces

The user interface is the space where human-machine interactions take place. The other key element of a DSS is user interface. The DSS is developed in Ms Excel VBA because the company and also most of the companies are very familiar to the Ms Excel. In this way, an easy-to-understand, user-friendly interface is designed. With the help of the interface, the users do not have to have any knowledge about the heuristic algorithm. They will just enter and/or modify the related data and then run the algorithm.

When the program is first opened, the screen in Figure 2 is displayed. The first 4 columns as Product Code, Priority, Product length (shortest length of the pallet) and the amount are parameters that are entered by the users. In short, they form the data store of the DSS.

When the program is run, it gives that the shelves in the warehouse where the raw materials are assigned, the amounts to be assigned to the shelves, the priority coefficients of the raw materials, the size of the raw material pallets to be placed on the shelves and the shelves left empty. As an example, in Figure 2, all 11 numbers of raw material 01.05.00.00.00002 is assigned to shelf 181 in W2 (warehouse 2). All 4 raw material 01.03.01.01.00012 is assigned to shelf 121 in W1. When all raw materials assigned to the shelves, the shelves 116, 176, and the rest in figure in W1 left empty. The left empty shelves after the solution are given in the last two columns of the screen.

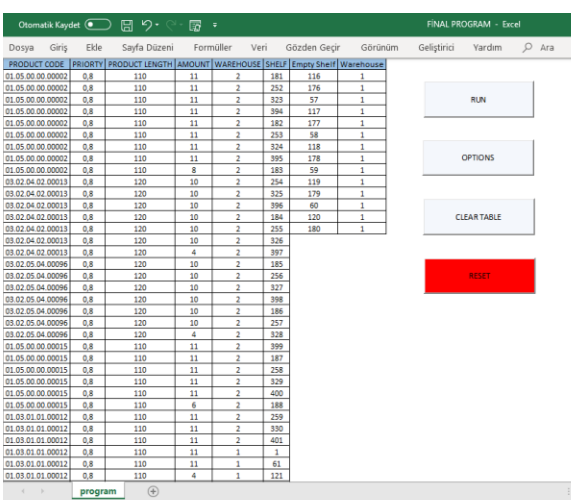

Figure 2. User Interface

The raw materials currently used by the factory are in the program's data set. The user can see which raw materials is assigned to which shelf and how many amounts of these raw materials with the "reset" button. This button is only for assigning the raw materials that in main data. The "run" button is used for changes made by using the option button. For example, if quantity of a raw material in the current system increase or a new kind of raw material enters the system, the heuristic algorithm will examine again. However, previous assignment of current raw materials does not change and new raw material will be assigned to available shelves.

As shown in Figure 3, the user can add, delete, find and change raw material information with the "options" button. The user can add a new raw material with using the "add" button. Also, if the user wants to reach the raw material information, can use the "find" button by writing raw material code. If a raw material is not used anymore, it can be deleted by using the "delete" button and the shelves which these raw materials assigned will be displayed as an empty shelf. In addition, user can make change the priority coefficient, quantity, or pallet size of raw materials with use "change" button. If user want to delete all the outputs of the program, can use the "clear table" button and repeat the process.

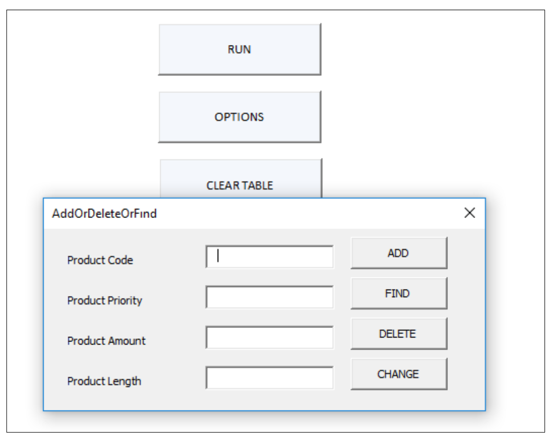

Figure 3. Option Button's Function

4. Conclusion

In recent years, globalization has changed the industrial landscape in many countries and regions. Today, sectors are in competition. Companies have to keep up with these changing conditions and a competitive environment. In order to continue their activities in a competitive environment, firms should give importance to entrepreneurship and innovation issues. The aim of this study is to design the warehouse system which will be used effectively by establishing a shelf system.

A multi-objective model is proposed to assign the raw material-pallet pairs to the shelves. The objective of the model is to minimize transportation distance between warehouses and factories considering the raw material priority coefficients and minimize number of used shelves in the warehouses. The proposed mathematical model is implemented in GAMS. Since GAMS is required high investment cost and it could not provide a good solution or even feasible solution when raw material variety and raw material quantity increase in the future, a decision support system based on a heuristic algorithm has been developed. This system has an easy-to-understand, user-friendly interface and it has been developed by using Ms Excel VBA.

The new shelf system will enable the warehouse to be used effectively. With the shortening of material collection times, productivity is expected to increase. As the labor force is used more effectively, time losses will decrease and the safety and satisfaction of the employees will increase. Due to the decrease in collection and distribution times, customer satisfaction will be the increase. All these activities mean earnings for the enterprise and are high priority activities in the area of sustainability. The new shelf system also brought to the warehouses creates a safer working environment and reduce the damage to the environment. In the existing system, pallets are stored in warehouses by stacking method. Because of stacking, there have been many accidents in the warehouse due to the fall of the pallets. Proposed shelf system for the warehouses will prevent these accidents. With this study, employee safety will greatly increase. With the shelf system, the warehouses will be more regular and more systematic, so the decreasing travel distance of labors, fatigue factor will decrease and it will create a healthier working area for employees. In the current system, some materials are expired because the materials unknown where are stored. With the innovations that brought to the warehouses, the environmental damage will reduce by using fewer chemicals because of the lack of such a problem. In addition to this, due to a decreasing number of movements with the raw material shelf assignments so that the energy used will also decrease.

Conflict of Interest

No conflict of interest was declared by the authors.

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