

A heuristic algorithm for the warehouse space assignment problem considering operational constraints: with application in a case study

Sanei, O., Nasiri, V., Marjani, M.R., Moattar Hussein, S.M.

Department of industrial and engineering

Amirkabir university of technology, Tehran, Iran

Abstract

An effective storage location assignment policy, in addition to its potential for optimal usage of warehouse space, reduces travel times related to storage, retrieval and order-picking activities. Moreover, helps to reduce congestions also enhances the balance among different warehouse activities. While previous research works exist regarding warehouse space allocation problem, considering modern concepts of logistics systems and also specific limitations for each case, further research in this respect is needed. This article deals with the problem of space assignment for the products in a warehouse considering various operational constraints. These constraints are mainly set to prevent decentralization of products in storage locations considering more explicit and more exquisite inventory control. A linear integer programming model and a heuristic algorithm based on the branch and bound method is proposed to solve the problem. Further, a software has been developed based on proposed algorithm for industrial usage. An experimental study, based on real data from an auto-industry shows the efficiency of the proposed algorithm achieving reasonable solutions.

Keywords: Warehouse storage allocation, Storage locations, Operational Constraints, Heuristic algorithm, Branch and bound algorithm.

1-Introduction:

According to the principles of supply chain management, leading companies try to achieve their intended targets in high volume production and distribution using minimum inventories throughout the chain and delivery of items delivered within short response times. Pacing in this direction has an important influence on warehouse management. It should be noted that warehouses are one of the key points of logistic processes which have a vital role in controlling and reducing logistics costs. The most important aspects of warehouse planning are inventory management and allocation of storage locations. An effective inventory management can bring down the storage costs by reducing inventory levels, while maintaining defined service levels. On the other hand, efficient allocation of storage locations will cause both reducing carrying time, retrieval and storage and order picking and reducing congestions of products and will also lead to a balance among different activities in warehouse.

This study is dealt with the problem of space allocation to products in a warehouse, considering real world restrictions. The specific layout of warehouse should be considered and the pallets of each product must be positioned in neighbor storage locations. Moreover high volume and high movement products should be closed to input and output gates of warehouse in order to minimum the total transportation while reducing logistic operations. The organization of paper is as follows; Section 2 is a brief Review of research in different ways of estimating warehouse space allocation. In Section 3 , The problem is defined and has been introduced as a linear integer mathematical model. In Section 4, a heuristic algorithm for solving this problem has been proposed. Results of recruitment of the proposed algorithm on the data storage logistic in an automobile manufacturing company are given in Section 5. Results have been abridged in Section 6 and in final section we observe references that we studied for our research.

2-Literature review:

One of the main aspects of warehouse planning is related to storage and layout of the stocks. So far, various issues and approaches regarding this issue are presented and various methods for solving have been proposed. Of course each of these studies, recruit special procedures for problem solving and improving warehouse layout. Order picking program, determining the storage and receiving levels of goods, has been considered.

According to literature three criterions has more favored in allocating goods to storage location. The first is the number of storage operations / recycling in a unit time. This method sort items based on these criteria, and then they are locating. The second criterion is the maximum inventory that defines as maximum space allocated to each class of goods. Spaces are allocating according to

calculation of the maximum space allocated for the items and ranking of them. The next criterion is COI (Cube Per Order Index) that defines as ratio of maximum occupied space to the number of storing operations / recycling in the unit of time (Kallina & Lynn 1976). Warehouse Layout design in various articles used different objective functions that can point to the minimizing average cost of making order picking, minimizing ordering time, maximizing use of space, maximizing access to goods and minimizing average transportations.

Ashayeri and Golders[7] worked on warehouse design and offered two ways to optimize design of the storage. Also Ashayeri presented a step design algorithm and design for warehouse. Also in literature a step method for the design of the warehouse and several solved examples, assumption for warehouse design, hierarchical design method were presented[5],[10,11]. Muppant 2007 [1] presented important factors for storage and proposed a Metaheuristic slow freezing algorithm that COI has been considered as a selected criterion for selecting the locations. Muppant 2007 [2] proposed an algorithm based on B&B in order to allocate places for storage. Semih Önüt, Umut R. Tuzkaya, Bilgehan Doğaç[8] considered a distribution-type warehouse that various type products were collected from different suppliers for storing in the warehouse for a determined period and for delivery to different customers. The aim of their study was to design a multiple-level warehouse shelf configuration which minimized the annual carrying costs. Since proposed mathematical model was shown to be NP-hard, a particle swarm optimization algorithm (PSO) as a novel heuristic was developed for determining the optimal layout. Jinxiang Gu, Marc Goetschalckx, Leon F. McGinnis[9] presented a detailed survey of the research on warehouse design, performance evaluation, practical case studies, and computational support tools. Jinxiang Gu, Marc Goetschalckx, Leon F. McGinnis[6] presented an extensive review on warehouse operation planning problems. The problems were classified according to the basic warehouse functions, i.e., receiving, storage, order picking, and shipping. Their purpose was to provide a bridge between academic researchers and warehouse practitioners, explaining what planning models and methods were currently available for warehouse operations, and what were the future research opportunities. René de Koster, Tho Le-Duc, Kees Jan Roodbergen[4] gave a literature overview on typical decision problems in design and control of manual order-picking processes. They focused on optimal (internal) layout design, storage assignment methods, routing methods, order batching and zoning. Peter Baker, Marco Canessa[3] explored the current literature on the overall methodology of warehouse design, together with the literature on tools and techniques used for specific areas of analysis. The general results from the literature had then been validated and refined with reference to warehouse design companies.

3- Decision model:

Traditionally the product assignment problem in a warehouse is defined as a transportation problem. In transportation problem, product assigning is based on a main principle which product with high transportation should be near to the I/O doors in order to minimize time of product transiting. Base of our work in this article is transportation problem and operational constrains add to it. In this problem we assume that quantity of storage and the requirement capacity of each product are known. The layout of studied warehouse is shown in figure 1. This warehouse has three storage locations in each row and the total number of locations is 24. It should be mentioned that we assume the number of locations in each row and number of rows as input parameters and they can be varied based on layout changing. The warehouse has just one I/O door located in the left of the warehouse. The related codes of storage locations are represented in figure1.

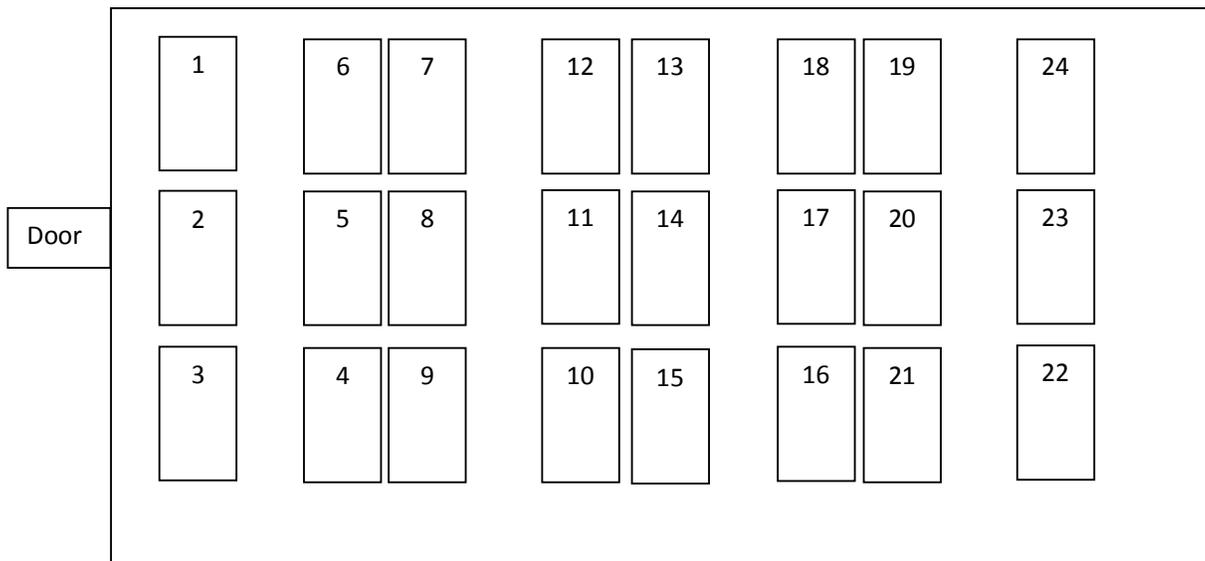


Figure1: warehouse layout with storage locations

Another attention is about operational constrains. As it mentioned before, these constrains are added to ensure that each type of product doesn't scatter and also to simplify the inventory management and the usage of transportation equipments. With studying in some warehouses, we realize that the priority of most warehouse managers is that if one product has to store in more locations it should be better firstly store in neighbor locations, secondly in opposite locations and then in backside locations and if none of these states occur, it can be positioned in non neighbor locations. For all of these states we propose a penalty cost and the object is to find

the best allocation of products, minimizing the summation of penalty costs and material handling costs. Different types of neighboring and their related penalty costs are shown in figure 2.

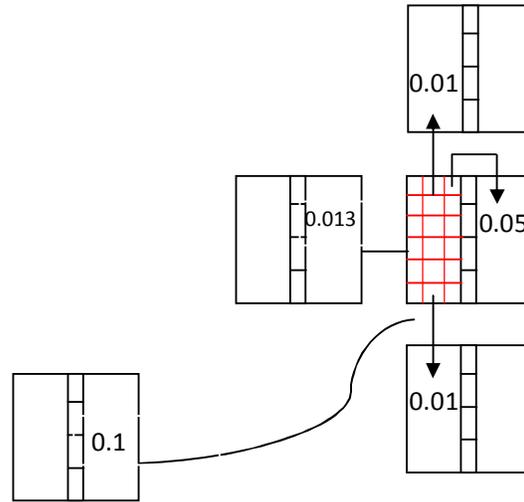


Figure 2 : Different types of neighboring and their related penalty costs

In this section we develop our model:

Parameters of model:

i : index of products $i = 1, 2, \dots, m$

j : index of locations $j = 1, 2, \dots, k$

T_1 : set of adjacent neighbor index $T_1 = \{1, 2, 4, 5, 7, 8, 10, 11, \dots\}$

T_2 : set of opposite neighbor index $T_2 = \{1, 2, 3, 7, 8, 9, 13, 14, 15, \dots\}$

T_3 : set of backside neighbor index $T_3 = \{4, 5, 6, 10, 11, 12, 16, 17, 18, \dots\}$

f_i : Quantity of product flow i in a day

t_j : Distance between storage location j to door

Cap_j : Area (capacity) of storage location j

s_i : Sum of capacity of pallets of product i

c_1 : Penalty cost of storing product in adjacent neighbor location

c_2 : Penalty cost of storing product in opposite neighbor location

c_3 : Penalty cost of storing product in backside neighbor location

c_4 : Penalty cost of storing product in non adjacent neighbor location

Decision variables:

$y_{i,j}$: Ratio of product i that located in location j

$$x_{i,j} = \begin{cases} 1 & \text{if any pallet from product } i \text{ locate in location } j \\ 0 & \text{otherwise} \end{cases}$$

$$p_{i,j}^1 = \begin{cases} 1 & \text{if product } i \text{ locate in adjacent location } j \\ 0 & \text{otherwise} \end{cases}$$

$$p_{i,j}^2 = \begin{cases} 1 & \text{if product } i \text{ locate in opposite location } j \\ 0 & \text{otherwise} \end{cases}$$

$$p_{i,j}^3 = \begin{cases} 1 & \text{if product } i \text{ locate in backside location } j \\ 0 & \text{otherwise} \end{cases}$$

$$p_{i,j}^4 = \begin{cases} 1 & \text{if product } i \text{ locate in non adjacent location } j \\ 0 & \text{otherwise} \end{cases}$$

$$p_{i,j}^5 = \begin{cases} 1 & \text{if product } i \text{ locate only in location } j \\ 0 & \text{otherwise} \end{cases}$$

Mathematical model:

$$\text{Min } Z = \text{Cost}_{\text{flow}} + \text{Cost}_{\text{penalty}} \quad (1)$$

$$\text{Cost}_{\text{flow}} = \sum_{j=1}^k t_j \sum_{i=1}^m f_i y_{i,j} \quad (2)$$

$$\text{Cost}_{\text{penalty}} = \sum_{j=1}^k \sum_{i=1}^m [c_1 p_{i,j}^1 + c_2 p_{i,j}^2 + c_3 p_{i,j}^3 + c_4 p_{i,j}^4] \quad (3)$$

St:

$$\sum_{j=1}^k y_{i,j} = 1 \quad \forall i = 1, 2, \dots, m \quad (4)$$

$$\sum_{i=1}^m s_i y_{i,j} \leq \text{Cap}_j \quad \forall j = 1, 2, \dots, k \quad (5)$$

$$y_{i,j} \leq x_{i,j} \leq M y_{i,j} \quad \forall i = 1, 2, \dots, m \ \& \ j = 1, 2, \dots, k \quad (6)$$

$$x_{i,j} + x_{i,j+1} = 1 + p_{i,j}^1 \quad \forall i = 1, 2, \dots, m \ \& \ j \in T_1 \quad (7)$$

$$x_{i,j} + x_{i,j+4} = 1 + p_{i,j}^2 \quad \forall i = 1, 2, \dots, m \ \& \ j \in T_2 \quad (8)$$

$$x_{i,j} + x_{i,j+4} = 1 + p_{i,j}^3 \quad \forall i = 1, 2, \dots, m \ \& \ j \in T_3 \quad (9)$$

$$\sum_{j=1}^k x_{i,j} \geq 2(1 - p_{i,j}^5) \quad \forall i = 1, 2, \dots, m \quad (10)$$

$$\sum_{j=1}^k x_{i,j} \leq 1 + M(1 - p_{i,j}^5) \quad \forall i = 1, 2, \dots, m \quad (11)$$

$$p_{i,j}^1 + p_{i,j}^2 + p_{i,j}^3 + p_{i,j}^4 + p_{i,j}^5 \geq 1 \quad \forall i = 1, 2, \dots, m \ \& \ j = 1, 2, \dots, k \quad (12)$$

$$x_{i,j} \in (0,1) \quad \forall i = 1, 2, \dots, m \ \& \ j = 1, 2, \dots, k \quad (13)$$

$$p_{i,j}^1, p_{i,j}^2, p_{i,j}^3, p_{i,j}^4, p_{i,j}^5 \in (0,1) \quad \forall i = 1, 2, \dots, m \ \& \ j = 1, 2, \dots, k \quad (14)$$

$$y_{i,j} \geq 0 \quad \forall i = 1, 2, \dots, m \ \& \ j = 1, 2, \dots, k \quad (15)$$

Objective function (1) minimizes the summation of transportation costs and penalty costs of product scatter in locations. Equation (4) indicates that all the pallets of each product allocate to a location. Equation (5) is the capacity constraint for each storage location. Equation (6) is for an accurate setting $x_{i,j}$. Equations of (7) to (11) are for setting decision variables that is related to type of neighboring. Equation (12) ensures that each product allocate to one location or at least one type of neighboring occurs.

4- Proposed algorithm:

Because of computational complexity of the studying problem, as the size of the problem that depends on the number of product type and the number of storage location is increased, exact methods are no longer applicable. Therefore we have to use metaheuristic or heuristic methods to solve this problem. In this article we present a heuristic algorithm based on Branch and Bound algorithm. General attitude of this algorithm is first achieving to a feasible solution and then is searching the solution space to find better solutions. In the first part we try to scoring locations and ranking products to reach a good feasible solution. Surely such an answer will be greatly reduced the time of solving this problem. With achieving to this feasible solution, in fact an upper bound for this problem is achieved. In order to achieve better solutions continue the solution space with branching. The main idea of this algorithm is in this part; where the branching is done whether defined operational constrains of this problem and penalty of all types of neighboring are simultaneously considered. In other words, searching solution space based on changing neighbors for products that allocate to more than one location is done and all of possible cases are evaluated. Results of running this algorithm on some problems show the capability of this algorithm. In the following we present the proposed algorithm.

Proposed algorithm:

- 1- Scoring all locations based on distance to the door.
- 2- Rating all products based on displacement rate per day.
- 3- Determine initial deployment:
 - 3-1- select unallocated product with the highest rank and allocate that on the best empty storage location.
 - 3-2- In cases where the volume of products is more than one storage location, next storage locations (regardless of neighborhood priorities) are used.
 - 3-3- If one product is not yet assigned return back to step 3-1.
- 4- Determine all neighbors for each storage location.
- 5- Until another product remains, following steps are done , otherwise go to step 6 .
 - 5-1- Select product with highest score.
 - 5-2- Select Storage location with the highest score (if there were several storage location with the same score all of them should be examined).
 - 5-3- The selected storage location filled from the top with selected product.
 - 5-4- Two states will be happened:
 - 5-4-1- If storage location was enough go to step 5-5.
 - 5-4-2- If storage location wasn't enough, check all of neighbors with considering priorities and order related penalty for all added neighbors.
 - 5-4-3- Go to step 5-4-1.
 - 5-5- Add total score with following value:
 - 5-6- If solution of this step had penalty, go to step 5-2 and select empty storage location with the highest score (if there were several storage location with the same score all of them should be examined).
- 6- Subtract following value from total score:

In which approximate score, calculated from the cost of all products with the product as a whole, in one storage location with unlimited capacity and a distance equal to the average distance of all storage locations until exit door.

- 7- Select solution that has the highest total score (with respect to how to select neighbors and storage locations with the same score). In which the objective function value (final cost) is equal to inverse of the total score hat this algorithm was calculated.

5-Numerical example:

As it was said in previous sections, the studied warehouse has 24 storage locations placed in 3 rows and 8 columns. The warehouse has one I/O door placed on the left side. In the studied problem, there are 49 types of products which were handled in different pallets. The proposed heuristic algorithm was coded in C# (is a software) and a practical software to solver similar problems with different assumptions were developed. The designed software can present the best solution at any moment. As the proposed method to

computing an initial solution reach to high quality solutions, in many cases achieved solutions of early steps are almost near to optimum solution. But to convergence completely and reaching to optimum solution, the software must run more time. For examples the results of the software on the studied warehouse is as follow: Calculated score in 1 minute equals to 283, in 5 minutes 1000, in 15 minutes 8000, in an hour and 3 hours equals to 9000 and 10000 respectively (as demonstrated in diagram 1). The result obtained after 15 minutes is very close to warehouse managers' opinion and they confirm that.

As we mentioned before our problem is too large and we see that the solution after a certain time does not change so much, as a result we can observe solution that are near optimum solutions in less time in large scale problems such our study.

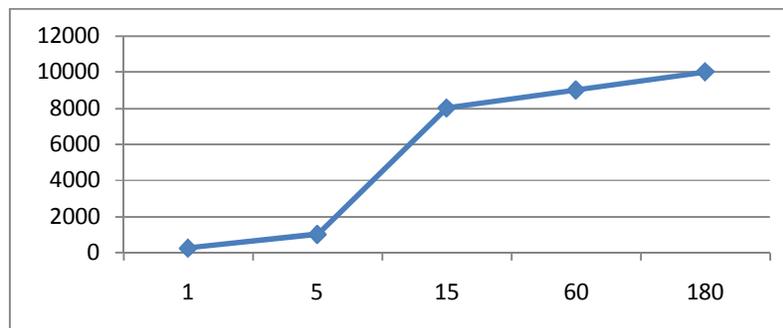


Figure3: Calculate score in different times

6- Conclusions:

An effective storage location assignment policy, in addition to its potential for optimal usage of warehouse space, reduces travel times related to storage, retrieval and order-picking activities. Moreover, helps to reduce congestions also enhances the balance among different warehouse activities. While previous research works exist regarding warehouse space allocation problem, considering modern concepts of logistics systems and also specific limitations for each case, further research in this respect is needed. As we observed in this article, we modeled a problem of space assignment for the products in a warehouse considering various operational constraints. These constraints are mainly set to prevent decentralization of products in storage locations considering more explicit and more exquisite inventory control. A linear integer programming model and a heuristic algorithm based on the branch and bound method is proposed to solve the problem. Further, a software has been developed based on proposed algorithm for industrial usage. An experimental study, based on real data from an auto-industry shows the efficiency of the proposed algorithm achieving reasonable solutions.

Presented algorithm prevent scattering types of products in warehouse and simplify inventory management and usage of transportation equipment, and also operational constraints have been added to the model. For this purpose a series of penalties was considered and these penalties were considered in the objective function and as a result in addition to minimizing the flow cost, penalties are minimized, too. Also this algorithm uses to solve large scale problems in less time. In this research we can consider pallets with different sizes. Also we design a software to solve such problems, in the other hand with using proposed algorithm in this research, we can solve more varied problems.

Finally, we can compare this algorithm with other heuristic and metaheuristic algorithms in future and solve some problems with this algorithm for take more validities.

References:

1. Venkata reddy muppani ,gajendra kumar adil, 2007, "A branch and bound algorithm for class based storage location assignment"
2. Venkata reddy muppani ,gajendra kumar adil, 2007, "Efficient formation of storage classes for warehouse storage location assignment: a simulated annealing approach"
3. Peter baker , marco canessa, 2009, "Warehouse design:a structured approach", European Journal of Operational Research, 425-436
4. Rene´ de Koster , Tho Le-Duc, Kees Jan Roodbergen, "Design and control of warehouse order picking: A literature review" European Journal of Operational Research, Pages 481-501
5. B. Rouwenhorst, B. Reuter,et.al, 2006, "Warehouse design and control: Framework and literature review", European Journal of Operational Research, Volume 122, Issue 3, 1 May 2000, Pages 515-533 1999
6. Jinxiang Gu, Marc Goetschalckx. Research on warehouse operation: A comprehensive review; European Journal of Operational Research, Volume 177, Issue 1, 16 February 2007, Pages 1-21J.PJ.
7. Ashayeri, L. F. Gelders. Warehouse design optimization ; European Journal of Operational Research, Volume 21, Issue 3, September 1985, Pages 285-294
8. Semih Önüt, Umut R. Tuzkaya, Bilgehan Doğaç. A particle swarm optimization algorithm for the multiple-level warehouse layout design problem ; Computers & Industrial Engineering, Volume 54, Issue 4, May 2008, Pages 783-799
9. Jinxiang Gu, Marc Goetschalckx, Leon F. McGinnis. Research on warehouse design and performance evaluation: A comprehensive review European Journal of Operational Research, Volume 203, Issue 3, 16 June 2010, Pages 539-549

10. Letitia M. Pohl, Russell D. Meller, Kevin R. Gue. An analysis of dual-command operations in common warehouse designs ; *Transportation Research Part E: Logistics and Transportation Review*, Volume 45, Issue 3, May 2009, Pages 367-379
11. Jason Chao-Hsien Pan, Ming-Hung Wu . A study of storage assignment problem for an order picking line in a pick-and-pass warehousing system; *Computers & Industrial Engineering*, Volume 57, Issue 1, August 2009, Pages 261_268