ETM

ENGINEERING & TECHNOLOGY MANAGEMENT

Warehouse Storage Optimization

Course Number/ Title: ETM 540/Operations Research
Instructor: Dr. Tim Anderson
Term- Year: Winter-2011

Author(s): Abdussalam Alawani
Abrahim Sater
Ashok Bhatla
Mohamed Borgan
Mohammad Mansour

Group Project Report
Type: Group
Note:

Table of Contents

Abstract 3
Introduction 3
Problem Statement 5
Literature review 7
Methodology 10
Results & Discussion 14
Recommendations 16
Future Work 17
Conclusion 18
References 18
Appendix I - Models Formulation 20
Appendix II - MS Excel & Solver Implementation 22

Abstract

Warehouses operations are very complex and inefficiencies in the storage operations can directly impact a Company's bottom line. For Companies like Amazon which ship millions of orders every day, efficient warehouse operations are at the heart of their operation. Design, layout and operation of a typical warehouse involve different factors to keep in mind and optimizing all the decision variables and still operating efficiently can be very challenging. This paper tries to look at the warehouse operations of a beverage company which manufactures and distributes a variety of drinks to major grocery stores. Whole operation involves storing the produced goods in the aisles, picking from the aisle as per the sales order and minimize the time to load a truck.

Introduction

One of the most critical challenges for manufacturing companies' management is indeed warehouse operations management. The criticality of managing warehouses (raw material and finished goods) comes from its direct effect on the overall company performance and efficiency. Thus, many companies invest heavily on automating warehouse operations both physically and electronically.

In this paper, we will be focusing on a company called J Food Products (JFP) which is a pseudonym for a confidential company that is located in Libya, North Africa. The company currently produces milk and Juices (Grape, orange, mango and more). JFP is currently ranked second among food production companies in its local market. However, international companies also compete in the local market, which makes the level of local competition higher for JFP. As a result, the J Foods has focused on optimizing its internal operations across different functions in order to maintain its competitive advantage.

In order to understand the challenges associated with warehouse management, we will start with defining warehousing operations. Warehousing can be categorized into three main functions: (a) Receiving goods from a source; (b) Storing goods until they are needed by a customer (internal or external); (c) Retrieving the goods when requested [1].

Storing material for an internal customer implies the need for work-in-process storage, whereas storing goods for an external customer may imply the need for finished products storage. However, the functions of warehousing remain the same and successful warehouse layouts must accomplish the following objectives, regardless of material being stored [8]:

(a) Maximize the use of space – Aisle space is at a premium. More stuff we can store in the least amount of space, better it is for a company's bottom line (b) Maximize the use of equipment and labor - Companies always have limited number of forklifts and other handling equipment to use in a warehouse. Efficient utilization of these resources will ensure that they need minimum resources for operations of the warehouse and can minimize the cost (c) Minimize the Order Pick up and loading Time - When a warehouse receives a sales order, they have to minimize the time of pickup and loading so that trucks can fulfill the orders quickly and orders get dispatched as soon as possible.

When people think of optimizing warehouse operations, they usually think of warehouse management software, automated handling, and bar coding robots etc. Although Technology is one of the main instruments driving the optimization techniques in warehouses, still we should not neglect little things which usually require little to no investment and can sometimes have an enormous impact on operations [3]. Product Consumption and Product value must also be taken into account when solving complex warehouse problems [9].

Problem Statement

As part of its efforts to increase competitive capabilities and internal operation efficiency, JFP has purchased a very advance and sophisticated warehouse storage system called Automated Racking System-ARS (see figure 1). The system will help minimizing storing and loading time which will affect the overall warehouse operations efficiency. ARS consists of two major components: the first is hardware component which includes storage aisles, small forklifts, medium forklifts and the spider forklift (the one presented in figure 1) and all the other hardware control devices associated with them. The second component is the software system which includes software models that help manage the warehouse operations including product storage and retrieval operations. However, and due to financial issues, JFP didn't buy the software part of the system (costs over 1 million US dollars) and here when the problem raised.

Figure 1- Warehouse Racking System

Without the software component of ARS, JFP has to develop its own manual products storage and retrieval system. Unfortunately, this was not an easy job to do with people who lack experience in such complex systems. Thus, JFP decided to hire a team of programmers to solve this problem by developing an in-house system to manage all these operations.

The problem that JFP programmers has faced was how to allocate and organize the products and place them in certain locations on the Aisle of the warehouse in order to reduce the time and effort to dispatch orders out of the warehouse. The problem included time optimization for the overall warehouse operations. Time here includes the time that spider forklifts need to travel from an aisle to another aisle, and the time for medium forklifts need to deliver the order to particular docks. In fact, the problem has an impact on the warehouse staff and affects the overall efficiency of the distribution process and a solution to this problem is needed as soon as possible to overcome the difficulty that the warehouse staff is facing with the current configuration.

Since software development is a long process that could take more than a year, JFP IT department developed a manual system that allowed warehouse management to carry on with their daily tasks. The solution included assigning products to certain fixed locations in the warehouse. However, everyone in the company knew that this is just a quick fix and operation efficiency was quit low. Up to this day, the company is still using this manual system and software development efforts is not actually achieving the required results due to the limited experience the programmers has with management sciences and operation research field.

In our project, we tried to develop a solution to this problem by implementing linear models that find the appropriate configuration of product allocation across all storage location within the warehouse. This solution minimizes the amount of time to dispatch the orders from the warehouse to the docks. Consequently, this reconfiguration would have an enormous impact on the efficiency of the warehouse.

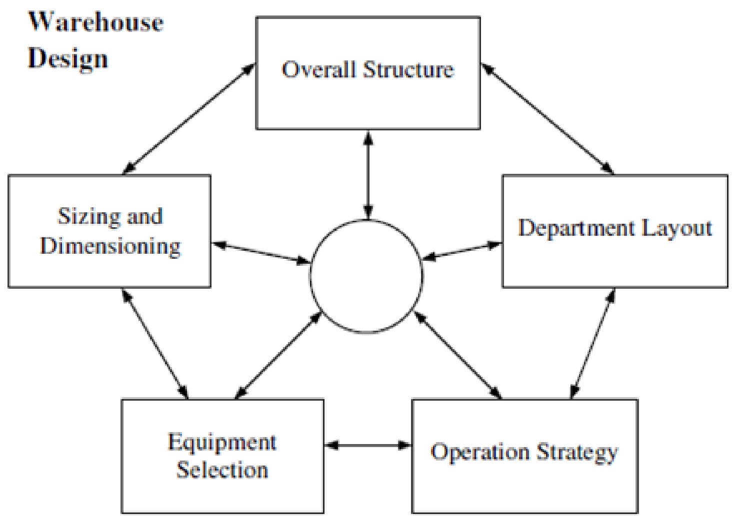
Literature review

Warehouse operations are getting more and more automated – with robots for handling inventory and enterprise software for supply chain. Warehouse operations are no longer manual operations – particularly the big warehouses which serve the needs of online shoppers. Companies in retail business spend almost 20% of their technology budgets on supply chain [4]. Lots of software products are now available in the markets which provide some sort of optimization features. All these products use some sort of Linear Programming concepts and advanced network modeling. XJ technologies is one such company offering such a software based solution for optimizing [10].

Warehouses have four types of problems. These include: (a) Too much inventory (b) Incorrect inventory mix (c) Inventory placed in non-optimal locations in the warehouse (d) Inefficient pick or put away processes (e) High reliance on paper within the warehouse. Optimizing a warehouse and implementing best practice techniques can have a huge impact if a company focuses on these five areas of waste. Whatever the specific deliverable most warehouse simulation solutions address the following needs [5].

(a)The required quantity and type of transportation and material handling equipment; (b) Floor space requirements and layout; (c) Ultimate scenarios of equipment lay out an arrangement; (d) Resource utilization rates, inventory levels, etc; (e) Calculating and optimizing warehouse operational expenses; (f) Determining the optimal number of loading and unloading gates;

Warehouse Design Diagram [2]

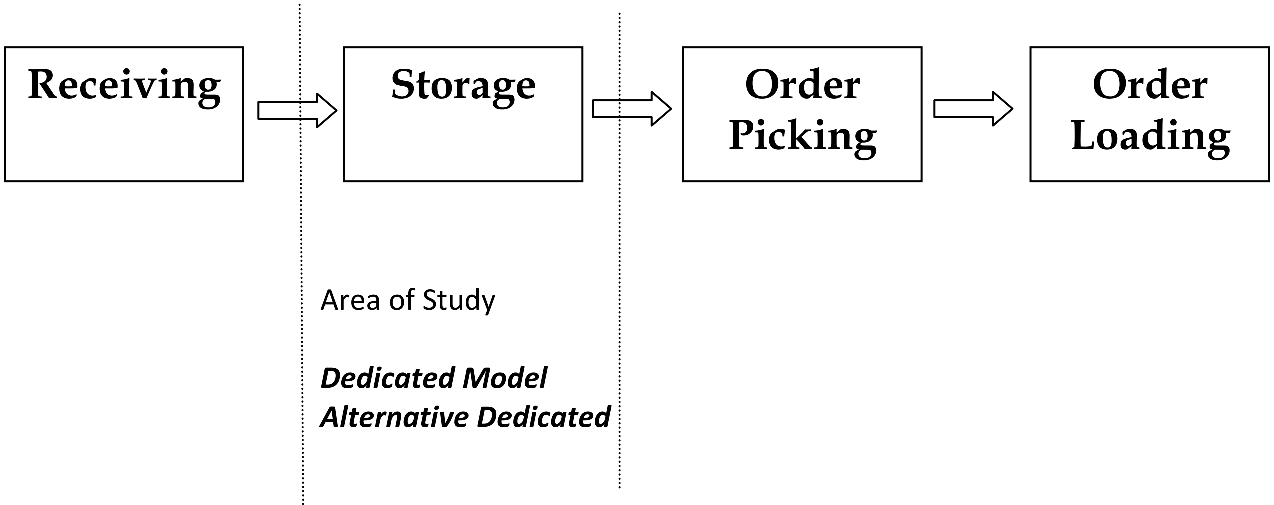


Model

One of the largest challenges to the efficient use of any warehouse is to determine the optimal use of available cubic space [12]. Therefore, we are mainly concentrating on the Storage Operations in a warehouse in this paper. We want to optimize the storage so that the time to move the products is minimized.

Various advanced tools like MATLAB have been used in the optimization of Warehouse Operations [7]. These methods can cover all areas like production planning, supply chain, inventory control and shipping. Since we are studying only a specific area of warehouse operations, we will just use the Excel solver for Linear Programming (LP).

Flow Diagram within a warehouse – [6]



Dedicated Model

As the name implies, in a dedicated storage layout, specific locations are assigned to a single product. It might be the whole aisle or parts of it, depending on how an aisle has been looked at from a unit address point of view. Once a location is assigned to a product, no other type of product can share it even if space is available. In general, this is not an efficient way of space utilization, but it simplifies the storing/delivering process as the operator or the equipment does not have to search for items [11].

The item location allocation is tied to the frequency of the item request from/to an Input/output station, total time to pick-up/delivery from/to an Input/output station, and to the total number of location allocated for that specific item.

Original Random Model

In this model, items are stored in any location without any criteria. When more locations are available for storage, Items have equal probability of being assigned to any of those locations. However, in practice, item gets assigned to the closest location.

Alternative/Modified Dedicated Model

This model is very similar to the basic dedicated one in its general terms of definition. The difference appears in the way of terms tied together in order to come up with the allocation configuration. In brief, factors which impact the model are (a) the frequency of the item request over the operational period of time (b) time for delivery of the items (c) the total number of positions assigned to it, and finally (d) the frequency of travel that item make to an loading station over the period of operation [13].

Methodology

As it has already been mentioned earlier, our main efforts were focused on finding the best way, or in other words the most efficient way of storing products' pallets in the warehouse locations so that we can minimize their travel time from storing aisles to shipping docks. Where to store various products' pallets in the warehouse was the angle from which we tackled the problem. Again, the focus will be on minimizing the throughput of the warehouse which basically the time required to retrieve a product. Many benefits can be gained by achieving this optimization. For instance, minimizing the time of storage tasks will give the company manpower more time to perform other activities. As a result, the overall warehouse efficiency will increase significantly.

In order to achieve this goal, we will first start with information gathering process which will help us implement and assess our models. Second, with applying linear programming concepts, two storage systems, namely the Dedicated & the Alternative Dedicated storage layouts, will be implemented based on the information we've got from JFP. Using Microsoft Excel Solver we will be able to figure out the best way of allocating products in the warehouse. The results of these two models (product allocation configuration) then will serve as "best efficiency" allocation reference that JFP

Company will use to evaluate its warehouse operations. Third we will apply the current warehouse products allocation map (configuration), that JFP use in its current manual system, into: first the Dedicated model and second into the Alternative Dedicated Model in the MS-Excel Model. By doing so, MS-Excel (without the need to the solver) will allow us to accurately calculate the efficiency of JFP current products allocation maps and hence evaluate the overall warehouse operation efficiency.

The LP models developed relies on the following facts and assumptions (See Appendix - I for complete models formulation):

(a) The static nature of storage was not a constraint. The current warehouse maximum capacity will never be exceeded by the demands (b) Supply availability is not a limiting factor. The company, based on its historical demand (orders) database, operates to maintain extra 5 to 10% products available (c) Handling equipment, such as forklifts, is not a constraint (d) The item, product, unit is the pallet; All pallets for all products are of the same size and in general have the same weight (d) Orders quantity and mixes are anticipated based on historical trend therefore; the frequency of product delivery to a, or any, dock could be controlled (e) Peak demand period are well defined and the company adjust its production rate to fulfill the needs (f) The aisles were divided into two halves with a unit delivery time associated with each half. More sections could have been chosen, but we did not, for the sake of minimizing the overall variable numbers for Solver to handle.

We describe our LP model in the following sections. We will do so by defining the Variable(s), the Objective Function(s), and the Constraints along with a list of definitions for the various labels (abbreviations) used in the formulas.

Labels:

$j \equiv$ number of storage (locations) positions $j \in \{1,...,n\}$.

$i \equiv$ number of items (products) $i \in \{1,...,m\}$.

$k \equiv$ number of docks $k \in \{1,..., p\}$.

$F_i \equiv$ Frequency of item i per day; How many pallets of products i per day is delivered to a dock.

$F_{ik} \equiv$ Frequency of item i to dock k; How many pallets of products i per day is delivered to dock k.

$T_{jk} \equiv$ Travel time from storage location j to dock k.

$S_i \equiv$ number of Storages dedicated for item i.

$P_k \equiv$ percentage of trips to dock k per day.

Variables:

For both of the storage layouts, the only needed variable for our linear programming models is the Location (position) where a specific product would be stored. The perfect fit for the models is the Binary variable that would assume a value of 1 when a specific product i gets stored in that specific location j.

$$L_{ij} = \begin{cases} 1 & \text{item } i \text{ stored in position } j. \\ 0 & \text{otherwise.} \end{cases}$$

Objectives:

The objective for both models is to optimize the storage locations of different products so that the total travel time for an item (from storage aisle to loading dock) will be minimized.

For the Dedicated model, the terms that come into play are first, the frequency of any item to any loading dock, meaning the number of pallets of any products delivered to a specific loading dock during a period of time. Second, the time needed move any product from a certain location in the warehouse to a certain loading dock. Third, the total number of storage spaces dedicated to any product (item), and finally the Binary

Variable that would assume the value of 1 or 0 depending on whether or not a specific product is stored in that specific location. The relation among these terms should be minimized via the following formula:

$$\min \quad \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{\sum_{k=1}^{p} T_{jk} F_{ik}}{S_i} L_{ij} \quad \} \text{minimizing delivery time.}$$

For the Alternative Dedicated model, five factors can be taken into account. The frequency of any item per period of time which is basically the number of pallets of any products delivered during that period. Second, the time needed move any product from a certain location in the warehouse to a certain loading dock. Third, the total number of storage dedicated to any product (item). Next, is the percentage of trips/utilization of each loading dock during a period of time, which translates to how many times that dock had been used. Finally, the binary variable that would assume the value of 1 or 0 depending on whether or not a specific product is stored in that specific location. The relation among these terms should be minimized via the following formula:

$$\min \quad \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{\sum_{k=1}^{p} P_k T_{jk} F_i}{S_i} L_{ij} \quad \} \text{minimizing delivery time.}$$

<u>**Constraints:**</u>

Our variable representing whether a Location is assigned to a product or not must be binary and will flip on/off (1 or 0) by the objective function.

$$L_{ij} \quad \} \text{Binary for all } i \text{ and } j$$

The sum of locations assigned to a product must be equal to the predefined number of storage dedicated for that product (item).

$$\sum_{j=1}^{n} L_{ij} = S_i \quad \forall i \ \} \text{linking constraint, the core of the dedication.}$$

And finally, only one item (product) could be stored in a location.

$$\sum_{i=1}^{m} L_{ij} = 1 \quad \forall j \quad \} \text{one product } i \text{ per storage location } j.$$

Results & Discussion

Due to the lack of actual data from JFP, the data input to both the dedicated and the alternative dedicated LP models developed was formulated based on previous experience of one of authors who worked at JFP Co. For the dedicated model, the following input data was formulated: (a) table of frequencies of moving item i to loading dock j per period of time (i.e number of milk pallets dispatched via loading dock 1 per period of time, etc) (b) number of storage located allocated to every product c) table of approximate time consumed to dispatch an item from location *j* to loading dock *k*. As for the alternative dedicated model, a similar set of data was formulated: a) frequency of moving any item per period of time (regardless of the loading dock) (b) number of storage located allocated to every product (c) the percentage of trips/utilization of dock *k* per period of time. Using this data set, both the dedicated and the alternative dedicated models were constructed and solved using Microsoft Excel solver add-on (See appendices I & II for the models formulation and Excel/solver implementation.

Two different solution options were obtained by solving both models using the data set presented above. Each solution provided a unique optimal product allocation that satisfied the objective function for that solution. For both models the objective is to minimize the total time to move products to each loading dock per unit of time. The key output for both models is the set of binary decision variables that determine the allocation of each storage location to each product which stratifies the objective function. As an example, the dedicated model solution resulted in an objective function value of 9435.5 where the alternative dedicated 2861.62, which doesn't necessarily mean that alternative dedicated model is better than the dedicated model. A key observation from the dedicated model is that the optimal solution is generally achieved by placing products that have high frequency/demand to a certain loading dock closer to that dock. For instance, in the dedicated model, Milk has a the highest frequency to loading docks 1 & 2 (121 & 119 from Appendix II) and as expected the optimal solution allocated all Milk to storage locations 1 through 6 which are the closest to these loading docks. The same pattern is observed for the rest of the products allocation in the model.

As for the alternative dedicated model, the key observation is that the optimal solution generally places products having large frequencies and requiring less storage locations near the loading docks. For instance, in the alternative dedicated model, Milk & Apple products have frequencies of 150 and 85 and storage requirements of 6 and 4 respectively and as expected the optimal solution allocated both products closer to loading docks 1,2,3, and 4 in this case (see Appendix II). This observation will be more obvious of there is a noticeable difference between frequencies and storage requirement among all products which is not the case in this example.

Based on the outcome of both model, deciding which model to adopt should be based on the application and trend of the data set available. If the data shows that products have different loading frequencies to every loading dock then the dedicated model can be applied. On the other hand, if the warehouse operation shows that the frequency of loading every product to a certain loading dock is assumed the same but the percentage of using every loading dock is different, then the alternative dedicated model can be applied.

In order to show the benefit of implementing one of the models developed in this research over what's currently being implemented in the warehouse, we performed a reverse LP model solving. In this case, we assigned the decision variable in every model manually based on the previous experience of the one of authors and compared the values of the objective function obtained to the ones obtained by the actual solving the LP models. As expected, the objective function values for the manual assignment of product allocation (decision variables) based on heuristic models is higher than the values obtained from solving the LP models. This means that JFP Co. would definitely gain a significant time saving by adopting one of these models to allocate products to storage location instead following the arbitrary technique that's currently being used.

Finally, it's important to mention that the data that has been formulated to solve both models (such as the frequencies and times) is very close to the actual data from JFP which represents a curtail fact for the validity of our discussion and conclusions above.

Recommendations

Based on the results that the two models suggest and based on the comparison we had between the current warehouse products allocation configuration and the ones suggested by the two models implemented in this paper we recommend the following:

- JFP should implement the dedicated model or the alternative dedicated model’s product allocation configuration which will increase the overall warehouse efficiency.
- The Warehouse Management System software that is being developed by JFP IT department must not use heuristic models in handling warehouse operations. As we’ve seen in our research, these types of problems are better solved using operations research methodologies such as LP.
- JFP should use the order information history for the previous years to implement even better product allocation configuration that can be changed during different periods of the year based on the production schedules and country seasons.

Future Work

Due to some political issues at the country where the JFP is located during the time of this research, we've faced a difficulty in getting the required data from their decision makers to execute the dedicated and the alternative dedicated model developed in this paper. Most of the information we've used is based on the experience of one of the authors who worked for the company before. Thus, real data samples must be used in order to accurately validate the results. The data should include, order inputs per day, dock usage, actual distances between storage aisles, order picking docks and current assignment of products across the warehouse and more.

Along with the above mentioned data, the information about the cost associated with any pallet movement from a certain location to the other could improve the benefit of these storage optimization models. Both models can give cost ratios of implementing a specific products allocation configuration in the warehouse. By incorporating cost information to the model, the company can know how much money it loses with its current warehouse configuration compared to the two configurations we suggested by dedicated and alternative dedicated model.

As mentioned earlier in the methodology section, we've decided to tackle the problem from the prospective of product allocation in order to minimize time to handle products to loading trucks. However, taking the nature and the complexity of this JFP's warehouse operations, we recommend solving this problem using simulation techniques. The main problem that JFP faces in managing its warehouse operations is coming from the variety of product handling machines that cause different levels of delays and handling issues. Thus, an alternative solution for such a problem is to simulate the movement of each of these machines in order to accurately estimate and optimize the trimming of each warehouse operation. In addition, simulation can accurately accommodate the products that aren't only leaving the warehouse but also the ones are coming from the production lines. By doing so, all warehouse aspects can be analyzed and better results can be obtained.

Conclusion

Storage allocation in a warehouse is a challenging task even for experienced professionals. It is very difficult to ensure that all the available space is utilized all the time in the most efficient way. We have tried to use proven methods of linear programming to solve two models of storage allocation. Both models can provide efficient way of storage based on products variety and demand. Models used in this paper are robust as these are using mathematical formula and we have not made any unjustified assumptions. Many companies have developed enterprise level warehouse optimization software which works in conjunction with inventory control software. As said earlier, optimizing warehouse operations can result in potential savings for an organization leading to increased profits. Therefore, companies need to look into this area in detail and make sure that they are using all the available tools for efficient utilization of resources in the warehouse.

References

[1] Gill Rebecca, Fast Methods for Warehouse Operations - *November/December 2006 issue of* Progressive Distributor.
[2] Gu, Jinxiang, Goetschalckx, Marc *, Leon F. McGinnis; Research on Warehouse Operations – A Comprehensive Review, European Journal of Operational Research 177 (2007) 1–21
[3] Ratliff, *Donald H,* Nulty, William G; Logistics Composite Modeling – The Logistics Institute at Georgia Tech, 1996
[4] Tompkins A.J, Smith J.D, Warehouse Management Handbook, Tompkins Press, 2nd Edition, 2000
[5] Leon F. McGinnis, Wen-Chih Chen, Paul Griffin, Gunter Sharp, T. Govindaraj, Doug Bodner; Benchmarking Warehouse Performance School of Industrial & Systems Engineering, Georgia Institute of Technology, 2002
[6] Leon F. McGinnis, Marc Goetschalckx, Gunter Sharp, Doug Bodner, T. Govindaraj; Rethinking Warehouse Design – School of Industrial and Systems Engineering - Georgia Institute of Technology, 2000
[7] Joel Goh Melvyn Sim ; ROME Example – Warehouse Management, Sep 2009

[8] Filippo Queirolo, Flavio Tonelli, Maurizio Schenone , DIP University of Genoa; Warehouse Layout Design – Minimize Travel Time with a genetic and simulative approach – Methodology and case study, 2002
[9] Miroljub Kljajic, DAvorin Kofjac, Andrea Skraba, Valter Rejec ;Warehouse Optimization in Uncertain Environment , University of Moribor, faculty of Organizational Sciences
[10]Warehouse Operations and Layout Optimization http://www.xjtek.com/consulting/solutions/logistics/warehouse/
[11] Chang, S.-H., Egbelu, P.J., 1997. Relative pre-positioning of storage/retrieval machines in automated storage/retrieval systems to minimize expected system response time. IIE Transactions 29, 313–322.
[12] Ten Ways to Improve Efficiency and Reduce Cost in the Warehouse http://www.fcbco-blog.com/10-ways-to-improve-efficiency-and-reduce-costs-in-your-warehouse-operations/
[13] Sunderesh S. Heragu, Jason C.S. Huang; Mathematical Modeling for Warehouse Design and Product Allocation; Rensselaer Polytechnic Institute, 2003

Appendix I - Models Formulation

LP Modeling For The Dedicated Model :

Labels :

$j \equiv$ number of storage locations $j \in \{1,\ldots,n\}$.

$i \equiv$ number of items (products) $i \in \{1,\ldots,m\}$.

$k \equiv$ number of loading docks $k \in \{1,\ldots,p\}$.

$F_{ik} \equiv$ frequency of item i to loading dock k.

$T_{jk} \equiv$ travel time from storage location j to loading dock k.

$S_i \equiv$ number of storages locations dedicated for item i.

Variables :

$$L_{ij} = \begin{cases} 1 \text{ item } i \text{ stored in position } j. \\ 0 \text{ otherwise.} \end{cases}$$

Objective :

$$\min \quad \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{\sum_{k=1}^{p} T_{jk} F_{ik}}{S_i} L_{ij} \quad \} \text{ minimizing loading time.}$$

Constraints :

L_{ij} binary.

$$\sum_{j=1}^{n} L_{ij} = S_i \quad \forall i \quad \} \text{ linking constraint, the core of the dedication.}$$

$$\sum_{i=1}^{m} L_{ij} = 1 \quad \forall j \quad \} \text{ one product } i \text{ per storage location } j.$$

LP Model For *Alternative* Dedicated Model :

Labels :

$j \equiv$ number of storage location $j \in \{1,\ldots,n\}$.

$i \equiv$ number of items (products) $i \in \{1,\ldots,m\}$.

$k \equiv$ number of loading docks $k \in \{1,\ldots,p\}$.

$F_i \equiv$ frequency of item i per period of time.

$T_{jk} \equiv$ travel time from storage location j to loading dock k.

$S_i \equiv$ number of storage locations dedicated for item i.

$P_k \equiv$ percentage of trips to loading dock k per period of time.

Variables :

$$L_{ij} = \begin{cases} 1 \text{ item } i \text{ stored in position } j. \\ 0 \text{ otherwise.} \end{cases}$$

Objective :

$$\min \quad \sum_{i=1}^{m}\sum_{j=1}^{n}\frac{\sum_{k=1}^{p} P_k T_{jk} F_i}{S_i} L_{ij} \quad \}\text{minimizing delivery time.}$$

Constraints :

L_{ij} binary.

$$\sum_{j=1}^{n} L_{ij} = S_i \quad \forall i \quad \}\text{linking constraint, the core of the dedication.}$$

$$\sum_{i=1}^{m} L_{ij} = 1 \quad \forall j \quad \}\text{one product } i \text{ per storage location } j.$$

Appendix II - MS Excel & Solver Implementation

Product Allocation Binary Variables

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
Milk	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Apple	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	4
Mango	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Orange	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	0	0	0	0	0	4
Grape	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Guava	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	2
Cocktail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	3
SUM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Objective Function

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Milk	522.33	375.67	449.00	302.33	416.00	342.67	397.83	265.33	437.33	252.00	366.50	249.67	440.67	313.83	461.67	329.33	545.67	384.67	527.67	440.00	612.00	441.00	729.67	504.33
Apple	680.00	520.00	600.00	440.00	545.00	465.00	510.00	386.25	531.25	326.25	407.50	280.00	463.75	318.75	452.50	306.25	517.50	343.75	475.00	381.25	568.75	377.50	672.50	440.00
Mango	550.67	407.33	479.00	335.67	434.00	362.33	395.33	277.33	439.00	248.33	343.00	227.67	411.00	285.67	420.67	296.00	506.33	344.33	483.00	392.67	563.00	391.00	674.67	452.67
Orange	712.50	540.00	626.25	453.75	565.00	478.75	518.75	391.25	551.25	327.50	420.00	288.75	487.50	335.00	481.25	323.75	562.50	375.00	527.50	426.25	638.75	430.00	751.25	495.00
Grape	548.00	402.00	475.00	329.00	432.00	359.00	398.00	274.00	441.00	251.00	353.00	237.00	425.00	299.00	439.00	310.00	524.00	361.00	502.00	412.00	584.00	411.00	699.00	474.00
Guava	595.00	444.00	519.50	368.50	472.00	396.50	437.50	312.50	473.00	278.00	373.00	252.50	440.00	307.50	445.50	310.50	523.00	356.00	493.00	401.50	577.50	398.50	689.50	462.00
Cocktail	606.00	469.33	537.67	401.00	482.67	414.33	431.00	347.33	460.33	266.33	320.00	211.67	360.33	231.33	339.00	220.67	414.00	259.00	384.00	297.33	478.67	303.00	559.00	350.67

Time cost from docks to

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Dock 1	4	2	3	1	4	3	6	3	6	4	7	5	8	6	9	7	10	8	10	9	11	9	13	10
Dock 2	6	4	5	3	4	3	3	1	4	2	4	3	6	5	7	5	8	6	8	7	9	7	11	8
Dock3	8	6	7	5	6	5	4	3	6	2	3	1	4	2	4	3	7	4	7	5	8	5	10	6
Dock 4	10	8	9	7	8	7	7	7	7	4	4	3	4	2	3	1	4	2	4	3	7	4	7	4
Dock 5	12	10	11	9	10	9	10	8	9	7	7	5	7	5	6	4	5	3	3	2	3	1	4	2

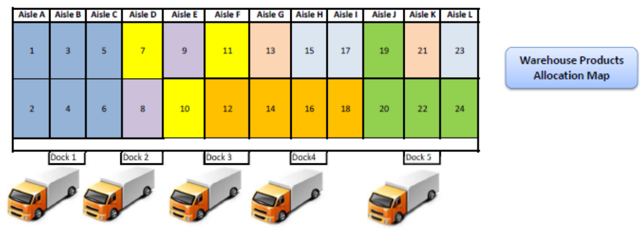
Objective Function
9435.416667

Frequency of Product per loading dock per time period

	Dock 1	Dock 2	Dock 3	Dock 4	Dock 5
Milk	121	119	86	60	54
Apple	50	60	55	70	85
Mango	40	54	56	30	35
Orange	50	80	60	85	70
Grape	30	40	34	20	22
Guava	28	37	32	24	30
Cocktail	20	23	55	62	45

Required Storage quantity

	Storage Req.
Milk	6
Apple	4
Mango	3
Orange	4
Grape	2
Guava	2
Cocktail	3



Dedicated Model

Product Allocation Binary

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
Milk	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	6
Apple	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4
Mango	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	3
Orange	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0	0	4
Grape	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Guava	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
Cocktail	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	3
SUM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Objective Function

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Milk	200.00	150.00	175.00	125.00	160.00	135.00	150.00	110.00	160.00	95.00	125.00	85.00	145.00	100.00	145.00	100.00	170.00	115.00	160.00	130.00	190.00	130.00	225.00	150.00
Apple	170.00	127.50	148.75	106.25	136.00	114.75	127.50	93.50	136.00	80.75	106.25	72.25	123.25	85.00	123.25	85.00	144.50	97.75	136.00	110.50	161.50	110.50	191.25	127.50
Mango	144.00	108.00	126.00	90.00	115.20	97.20	108.00	79.20	115.20	68.40	90.00	61.20	104.40	72.00	104.40	72.00	122.40	82.80	115.20	93.60	136.80	93.60	162.00	108.00
Orange	170.00	127.50	148.75	106.25	136.00	114.75	127.50	93.50	136.00	80.75	106.25	72.25	123.25	85.00	123.25	85.00	144.50	97.75	136.00	110.50	161.50	110.50	191.25	127.50
Grape	160.00	120.00	140.00	100.00	128.00	108.00	120.00	88.00	128.00	76.00	100.00	68.00	116.00	80.00	116.00	80.00	136.00	92.00	128.00	104.00	152.00	104.00	180.00	120.00
Guava	148.00	111.00	129.50	92.50	118.40	99.90	111.00	81.40	118.40	70.30	92.50	62.90	107.30	74.00	107.30	74.00	125.80	85.10	118.40	96.20	140.60	96.20	166.50	111.00
Cocktail	165.33	124.00	144.67	103.33	132.27	111.60	124.00	90.93	132.27	78.53	103.33	70.27	119.87	82.67	119.87	82.67	140.53	95.07	132.27	107.47	157.07	107.47	186.00	124.00

Time cost from docks to

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Dock 1	4	2	3	1	4	3	6	3	6	4	7	5	8	6	9	7	10	8	10	9	11	9	13	10
Dock 2	6	4	5	3	4	3	3	1	4	2	4	3	6	5	7	5	8	6	8	7	9	7	11	8
Dock3	8	6	7	5	6	5	4	3	6	2	3	1	4	2	4	3	7	4	7	5	8	5	10	6
Dock 4	10	8	9	7	8	7	7	7	7	4	4	3	4	2	3	1	4	2	4	3	7	4	7	4
Dock 5	12	10	11	9	10	9	10	8	9	7	7	5	7	5	6	4	5	3	3	2	3	1	4	2

Objective Function
2861.616667

Frequency of Product / Required Storage quantity

	Freq	Storage Req.
Milk	150	6
Apple	85	4
Mango	54	3
Orange	85	4
Grape	40	2
Guava	37	2
Cocktail	62	3

The precentage of docks usage

	Percent
Dock 1	0.2
Dock 2	0.2
Dock3	0.2
Dock 4	0.2
Dock 5	0.2

Alternative Dedicated Model

Product Allocation Binary

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
Milk	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	6
Apple	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Mango	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	3
Orange	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	4
Grape	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Guava	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2
Cocktail	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	3
SUM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Objective Function

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Milk	522.33	375.67	449.00	302.33	416.00	342.67	397.83	265.33	437.33	252.00	366.50	249.67	440.67	313.83	461.67	329.33	545.67	384.67	527.67	440.00	612.00	441.00	729.67	504.33
Apple	680.00	520.00	600.00	440.00	545.00	465.00	510.00	386.25	531.25	326.25	407.50	280.00	463.75	318.75	452.50	306.25	517.50	343.75	475.00	381.25	568.75	377.50	672.50	440.00
Mango	550.67	407.33	479.00	335.67	434.00	362.33	395.33	277.33	439.00	248.33	343.00	227.67	411.00	285.67	420.67	296.00	506.33	344.33	483.00	392.67	563.00	391.00	674.67	452.67
Orange	712.50	540.00	626.25	453.75	565.00	478.75	518.75	391.25	551.25	327.50	420.00	288.75	487.50	335.00	481.25	323.75	562.50	375.00	527.50	426.25	638.75	430.00	751.25	495.00
Grape	548.00	402.00	475.00	329.00	432.00	359.00	398.00	274.00	441.00	251.00	353.00	237.00	425.00	299.00	439.00	310.00	524.00	361.00	502.00	412.00	584.00	411.00	699.00	474.00
Guava	595.00	444.00	519.50	368.50	472.00	396.50	437.50	312.50	473.00	278.00	373.00	252.50	440.00	307.50	445.50	310.50	523.00	356.00	493.00	401.50	577.50	398.50	689.50	462.00
Cocktail	606.00	469.33	537.67	401.00	482.67	414.33	431.00	347.33	460.33	266.33	320.00	211.67	360.33	231.33	339.00	220.67	414.00	259.00	384.00	297.33	478.67	303.00	559.00	350.67

Time cost from docks to

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Dock 1	4	2	3	1	4	3	6	3	6	4	7	5	8	6	9	7	10	8	10	9	11	9	13	10
Dock 2	6	4	5	3	4	3	3	1	4	2	4	3	6	5	7	5	8	6	8	7	9	7	11	8
Dock3	8	6	7	5	6	5	4	3	6	2	3	1	4	2	4	3	7	4	7	5	8	5	10	6
Dock 4	10	8	9	7	8	7	7	7	7	4	4	3	4	2	3	1	4	2	4	3	7	4	7	4
Dock 5	12	10	11	9	10	9	10	8	9	7	7	5	7	5	6	4	5	3	3	2	3	1	4	2

Objective Function
10410.66667

	Dock 1	Dock 2	Dock 3	Dock 4	Dock 5
Milk	121	119	86	60	54
Apple	50	60	55	70	85
Mango	40	54	56	30	35
Orange	50	80	60	85	70
Grape	30	40	34	20	22
Guava	28	37	32	24	30
Cocktail	20	23	55	62	45

Frequency of Product per loading dock per time period

	Storage Req.
Milk	6
Apple	4
Mango	3
Orange	4
Grape	2
Guava	2
Cocktail	3

Required Storage quantity

Aisle A	Aisle B	Aisle C	Aisle D	Aisle E	Aisle F	Aisle G	Aisle H	Aisle I	Aisle J	Aisle K	Aisle L
1	3	5	7	9	11	13	15	17	19	21	23
2	4	6	8	10	12	14	16	18	20	22	24

Dock 1 Dock 2 Dock 3 Dock4 Dock 5

Warehouse Products Allocation Map

Dedicated Model with Current Configuration

Product Allocation Binary

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	SUM
Milk	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	6
Apple	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Mango	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	3
Orange	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	4
Grape	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Guava	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2
Cocktail	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	3
SUM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Objective Function

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Milk	200.00	150.00	175.00	125.00	160.00	135.00	150.00	110.00	160.00	95.00	125.00	85.00	145.00	100.00	145.00	100.00	170.00	115.00	160.00	130.00	190.00	130.00	225.00	150.00
Apple	170.00	127.50	148.75	106.25	136.00	114.75	127.50	93.50	136.00	80.75	106.25	72.25	123.25	85.00	123.25	85.00	144.50	97.75	136.00	110.50	161.50	110.50	191.25	127.50
Mango	144.00	108.00	126.00	90.00	115.20	97.20	108.00	79.20	115.20	68.40	90.00	61.20	104.40	72.00	104.40	72.00	122.40	82.80	115.20	93.60	136.80	93.60	162.00	108.00
Orange	170.00	127.50	148.75	106.25	136.00	114.75	127.50	93.50	136.00	80.75	106.25	72.25	123.25	85.00	123.25	85.00	144.50	97.75	136.00	110.50	161.50	110.50	191.25	127.50
Grape	160.00	120.00	140.00	100.00	128.00	108.00	120.00	88.00	128.00	76.00	100.00	68.00	116.00	80.00	116.00	80.00	136.00	92.00	128.00	104.00	152.00	104.00	180.00	120.00
Guava	148.00	111.00	129.50	92.50	118.40	99.90	111.00	81.40	118.40	70.30	92.50	62.90	107.30	74.00	107.30	74.00	125.80	85.10	118.40	96.20	140.60	96.20	166.50	111.00
Cocktail	165.33	124.00	144.67	103.33	132.27	111.60	124.00	90.93	132.27	78.53	103.33	70.27	119.87	82.67	119.87	82.67	140.53	95.07	132.27	107.47	157.07	107.47	186.00	124.00

Time cost from docks to

	Aisle A		Aisle B		Aisle C		Aisle D		Aisle E		Aisle F		Aisle G		Aisle H		Aisle I		Aisle J		Aisle K		Aisle L	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Dock 1	4	2	3	1	4	3	6	3	6	4	7	5	8	6	9	7	10	8	10	9	11	9	13	10
Dock 2	6	4	5	3	4	3	3	1	4	2	4	3	6	5	7	5	8	6	8	7	9	7	11	8
Dock3	8	6	7	5	6	5	4	3	6	2	3	1	4	2	4	3	7	4	7	5	8	5	10	6
Dock 4	10	8	9	7	8	7	7	7	7	4	4	3	4	2	3	1	4	2	4	3	7	4	7	4
Dock 5	12	10	11	9	10	9	10	8	9	7	7	5	7	5	6	4	5	3	3	2	3	1	4	2

Objective Function
2968.75

Frequency of Product

	Freq	Storage Req.
Milk	150	6
Apple	85	4
Mango	54	3
Orange	85	4
Grape	40	2
Guava	37	2
Cocktail	62	3

Required Storage quantity

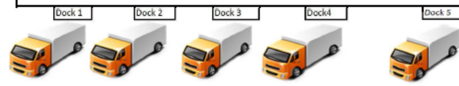
	Percent
Dock 1	0.2
Dock 2	0.2
Dock3	0.2
Dock 4	0.2
Dock 5	0.2

The precentage of docks usage

Aisle A	Aisle B	Aisle C	Aisle D	Aisle E	Aisle F	Aisle G	Aisle H	Aisle I	Aisle J	Aisle K	Aisle L
1	3	5	7	9	11	13	15	17	19	21	23
2	4	6	8	10	12	14	16	18	20	22	24

Dock 1 Dock 2 Dock 3 Dock4 Dock 5

Warehouse Products Allocation Map



Alternative Dedicated Model with Current Configuration