OPTIMIZATION OF A WAREHOUSE LAYOUT USED FOR THE STORAGE OF MATERIALS USED IN THE CONSTRUCTION AND REPARATION OF SHIPS

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RESUMEN

El artículo muestra la evaluación de la aplicación de modelos para mejorar la eficiencia en el manejo de bodegas utilizadas en astilleros, centrada en actividades de picking, packing, shipping, soportada entre otras en la propuesta de Rosenblatt y Roll (1984) para la optimización del layout para el almacenamiento y manejo de los materiales necesarios para la construcción y reparación de buques. El modelo además de proponer la mejor distribución física para el almacenamiento de las mercancías, busca minimizar tres tipos de costos: costos asociados a la inversión inicial (construcción y de mantenimiento), un costo de escasez y los costos asociados con las políticas de almacenamiento. El diseño óptimo se desarrolla con una combinación de optimización analítica y técnicas de simulación.

Palabras clave: Bodega, Almacenamiento, Modelos de Rosenblatt y Roll, Buques.

ABSTRACT

The paper shows the evaluation of the application of models to improve efficiency in the management of warehouses used in shipyards, focused in activities of picking, packing, shipping, supported among others in the propose of Rosenblatt and Roll (1984) for layout optimizing for the storage and handling of materials needed for ship construction and repair. The model besides proposing the best physical layout for the storage of goods, seeks to minimize three types of costs: costs related to the initial investment (construction and maintenance), a shortage cost and costs associated with storage policies. The optimal design is found through analytical optimization and simulation techniques.

Keywords: Warehouse, Storage, Rosenblatt and Roll model, Ships.

INTRODUCTION

The analysis of warehouses is referred from one side to the location of the various departments (reception, selection, storing, sorting and shipping) and from the other side to the distribution that each of them has. The common goal is to minimize handling costs, which in many cases are represented by a linear function of the distances covered and that in terms of logistics costs can represent up to 20%. Tompkins et al. (2003) state that the layout purpose is to minimize handling costs, which are generally represented by a linear function of the distance traveled.

In the design of a warehouse/storage building there should be considered the overall structure, its size and dimension, department’s features, selection of its strategic operation and equipment to be
used in the storage process. During the overall design, the material flow patterns, the functions of each department (reception, selection, storing, sorting and shipping) and the relationships flow that should exist between its sections is determined. The activities of receiving and picking, (Picking / Packing) are considered relevant by the cost implications involved and these are influenced and affected by the type of warehouse design considered.

Gu and Goetschalckx (2010) discussed the design of the storage department, and typify the main problems to be solved for the classification into three: identify storage stacking platform, the depth of the storage lane and the existing number of lanes. Other issues to be solved are the location of the door, the orientation of the lanes and the number of lanes that must exist throughout the store. Finally, it must be identified the number of cranes and the dimensions of the storage racks.

The design of the storage department that Gu and Goetschalckx exposed (2010) affects the performance of the warehouse in respect to the construction costs, holding costs, costs of labor, storage capacity, the use of space and use of equipment.

The Rosenblatt and Roll (1984) model aims to find an optimal solution to the physical layout and design of a storage building, considering the amount of entry and exit doors, the location of these doors, the number of aisles and its orientation and dimensions. It also takes into account the warehouse capacity and storage policies, as decision variables to apply optimization techniques which are characteristic of the model.

The Rosenblatt and Roll (1984) model, seeks to optimize three types of costs: Costs associated with the initial investment (construction and maintenance), a shortage cost and costs associated with storage policies. The subsequent investigation to find the optimum design of storage is developed by comparing the analytical optimization and simulation techniques.

The type of storage building that Rosenblatt and Roll (1984) have proposed in their model is a warehouse with only one physical plant, where products can be accommodated on shelves with a calculated amount of levels, on pallets or stacked. Besides, it has to be taken into account that this model considers the random storage policy where, in the areas that divides the warehouse, goods can be arranged randomly, no considerations are made about the composition of products or how they should be accommodated.

In this model, there should be equipments for handling and internal transport of goods, especially when considering high shelves to store the products, in order to take advantage of all the warehouse space, and decrease the shipments rejected due to lack of space; it facilitates that the products found at high altitudes can be extracted and have a good inventory turnover.

Este modelo es una buena referencia para ser objeto de estudio debido a que, además de proponer diferentes tipos de Layouts y disponer de la mejor manera de un espacio físico para el almacenamiento de las mercancías, pretende minimizar tres costos importantes en lo que respecta al diseño, manejo de materiales y almacenamiento como tal, por tanto, se considera que es un modelo prototipo que conjuga aspectos importantes que son de interés para las compañías actuales, que además de almacenar propenden por minimizar sus costos de operación.

This model is a good reference to be studied because, in addition to proposing different types of layouts and providing the best physical space for storage of goods, it intends to minimize three major costs in terms of design, material handling and storage, therefore, is considered a prototype model that combines important aspects that are of interest to actual companies, that besides storage search to minimize operating costs.

LITERATURE REVIEW

According the Layout topic, there are described the relevant studies in this field; the Rosenblatt and Roll (1984) model addresses three objectives simultaneously: store size, internal distribution and storage policies. The literature that deals with layout problems is combined with traditional storage
processes (picking, packing, shipping) describing the complexities of these activities and the need
to address these issues jointly.

Mallette and Francis (1972) and Berry (1968) found the distribution of a warehouse to minimize
maintenance costs of materials. Francis (1967), Francis and White (1974), Roberts and Reed (1972)
and Bassan, Roll and Rosenblatt (1980) found the design of the internal layout of a warehouse to
minimize construction costs of a warehouse and handling costs for materials. The has been
compared several designs of the internal layout of a storage building (Bassan, Roll and Rosenblatt;
1980), where the effects of the costs where associated with the perimeter of the storage and the
materials handling but are not associated to the cost of warehouse area. This is consistent with
Francis (1967), who assumed that the storage area is predetermined and consider only the costs of
materials handling and costs of the perimeter. The problem of the size of a warehouse is considered
by White and Francis (1971). The costs considered on his study were, construction costs, assuming
they are proportional to store size, storage costs and evaluation costs when there is a shortage of
available space for storage. A Roll and Rosenblatt (1983) document compares a series of storage
policies and their effects in the capacity of a warehouse. Hausman, Shwarz and Graves in two of
their papers (1977, 1976) have developed rules for optimal allocation of storage and the sequence
of storage in a warehouse of auto design. To assume a knowledge of feedback for various products
(or product groups), they developed a storage allocation and intercalate policies that achieve a
significant reduction in travel time of a crane.

Tompkins et al. (2003) made a description of different effective procedures for layout design;
Heragu et al. (2005) provide a model and a heuristic for the dimensioning of areas and the
allocation of products to the areas.

In general the design of internal arrangement, or aisle configuration problem, which includes
determining the number of blocks, number, length and width of aisles in each block is depicted in
figure (1).

![Diagram of warehouse layout](image)

**Figure1. Location Decisions. Source: Authors**

Roodbergen (2001) proposed a nonlinear objective function (the average travel time in terms of the
number of collections (pick) by trade and islands) to determine the aisles configuration for storage
deposits using non-dedicated systems, i.e. random (including single and multiple blocks) that seek
to minimize the duration of the tour.
Compared with manual picking systems, and order preparation, the layout design problem taking the load unit (Mainly systems AS / RS - (Automated Storage / Retrieval System) have received much attention. This case concerns the investigations of Sarker and Babu (1995), Johnson and Brandeau (1996) and Van den Berg (1999).

For random storage assignment, Bozer and White (1984) show relevant studies in this regard. Larson et al. (1997) use a heuristic approach to the design of the load unit in a warehouse and to assign classes of goods to places, in order to increase space utilization and reduction in travel distance.


Reiterating on Rosenblatt and Roll (1984) model, two data sets are assumed to be known for the procedure. The first data set consists in the distributions that govern the arrival, the composition of products to be stored. The second is the set of approximate cost models, combining the cost components to the configuration of the distribution, storage policies and shortage in storage capacity. An approximate combination of optimization techniques is applied in order to determine the total cost as a function of two decision variables: capacity of warehouse and storage policies. Then, comparing the costs of possible combinations of these variables, we obtain a global optimum store size, configuration and storage policies.

The literature on these issues is abundant; however it is found that the level of application in different industries and particularly in Colombian’s Shipyards is very low. Publications such as Bassan et al. (1980) and Rosenblatt and Roll (1984), use analysis and simulation methods to study the effects of the storage policy (i.e. how to assign products to storage locations) in accordance with the internal design of storage. Also Rosenblatt and Roll (1988) examined the effect of stochastic demands and different levels of service in the warehouse layout and storage capacity.

This literature review around layout investigations shows the relevant studies of Bassan, Rosenblatt and Roll that serve as pivot for the analysis involved in the characterization and improvement proposal for COTECMAR, adjusted to the conditions of existing resources and the size of the configuration that presents de central warehouse of the Corporation.

**NOMENCLATURE AND BASIC MODELS**

Basado en siguiente figura, para una bodega rectangular de ancho $W$ y largo $L$, con área de piso $S$, encontró las siguientes relaciones:

Based on figure below, for a rectangular warehouse with a $W$ wide and an $L$ long, with floor area of $S$, he found the following relationships:

![Diagram of a rectangular warehouse](image)

Figure 2. Size of a rectangular warehouse. Source: Authors
C = Sum of total cost per unit of length for moving an item multiplied by the expected number of items per year ($ / ft)
K = annual cost of perimeter ($ / ft) S = Area of the warehouse (ft²)
CTx, CTy = total relevant cost for setting X, Y [$ / year]

Exit / Entry Door located in X:

$$W^* = \frac{C + 8k}{2c + 8k} \sqrt{S}$$

$$L^* = \frac{S}{W^*}$$

$$CT_x = 2 \sqrt{\frac{C}{2} + 2K} \left[ \frac{C}{4} + 2K \right] \sqrt{S}$$

Exit / Entry Door located in Y

$$W^* = L^* = \sqrt{S}$$ (Square Warehouse)

$$CT_y = \left[ \frac{C}{2} + 4K \right] \sqrt{S}$$

**Shelves and aisles configuration**

**Notation**

W = width of a double shelf - sided [ft]
L = length of each storage space (for example, the width of a pallet [ft])
m = Number of storage spaces along a shelf
h = Number of storage levels in the vertical direction
n = number of double-sided shelves, two simple shelves are considered equal to a double
K = total capacity of the warehouse in storage space
a = width of an aisle [feet], assuming that everyone has the same width
u = length (long) of the warehouse [ft]
v = width of the warehouse [ft]
d = annual demand of the warehouse in storage units (eg pallets). It is assumed that a storage item uses a storage unit [items / year]
Ch = cost of material handling, of moving an item a unit of length [/ ft]
Cs = annual cost per unit area of the warehouse, for example.: air conditioning, electricity, maintenance [$ / ft²]
Cp = annual cost per unit of length of external walls [$ / ft]

The optimal number of storage spaces depends on the distribution figure adopted, a typical example for a situation with aisles in front of the door:

$$m_1 = \frac{1}{L} \sqrt{\frac{dC_h + 2aC_s + 2C_p}{2(dC_h + C_p)}} \left[ \frac{K(w + a)L}{2h} \right]$$
And the optimal number of double-sided shelves is:

\[ n_1^* = \frac{1}{w + a} \sqrt{\frac{2(dC_h + 2C_p)}{dC_h + 2aC_s + 2C_p} \left[ \frac{K(w + a)L}{2h} \right]} \]

Thus, the best configuration of the warehouse would have an optimum length of:

\[ u_1^* = n_1^*(w + a) \]

And an optimum width of:

\[ v = 2a + n_1^*L \]

For cross-aisle layout, optimal results are:

\[ m_2^* = \frac{1}{L} \sqrt{\frac{2dC_h + 3aC_s + 2C_p}{dC_h + 2C_p} \left[ \frac{K(w + a)L}{2h} \right]} \]

\[ n_2^* = \frac{1}{w + a} \sqrt{\frac{dC_h + 2C_p}{2dC_h + 3aC_s + 2C_p} \left[ \frac{K(w + a)L}{2h} \right]} \]

\[ u_2^* = 3a + m_2^*L \]
\[ v_2^* = n_2^*(w + a) \]

To minimize costs between these two alternative designs, it can be applied the following decision rule:

- If \( d < \frac{C_p}{Ch} \), select the configuration 1
- If \( d > 2 \frac{C_p}{Ch} \), select the configuration 2
- If \( \frac{C_p}{Ch} < d < 2 \frac{C_p}{Ch} \), cannot conclude

**METODOLOGY**

To make the proposal of improving the layout of the central storage warehouse of COTECMAR there was performed in situ characterization of the infrastructure, processes and activities associated with storage, through observing them and with surveys and interviews to the staff responsible of this process within the Corporation. Fieldwork was conducted with the use of tools for collecting, tabulating and analyzing data to obtain and collect information associated with the flow of materials within the warehouse and in and out of it. Besides, it was obtained information on the logistics infrastructure of the Corporation, which included making drawings of the different storage spaces in dimensions and storage equipment to obtain the storage capacity of COTECMAR in square and cubic meters.

**COTECMAR’S LOGISTIC INFRAESTRUCTURE**

COTECMAR has two main headquarters located in the ports of Mamonal (Industrial Sector) and Bocagrande (Touristic Sector) in the city of Cartagena de Indias. The company has warehouses for storing materials and supplies needed for operation at both sites.
At Mamonal headquarter there is a central storage building, a warehouse to store the materiales for the OPV (Offshore Patrol Vessel) construction project and areas for storage of specific materials. In the central warehouse of Mamonal, which is the objective of this study, there are stored the materials necessary for the construction and reparation projects and for the operation of COTECMAR facilities. This warehouse counts with spaces for materials requiring special storage conditions.

The warehouse has a welding room conditioned with temperature control equipment to maintain the solder in controlled conditions in accordance with the specifications of these materials. Similarly, the warehouse has two rooms with air conditioning for the storage of materials and equipment that cannot be kept at room temperature as resins, oils, adhesives and special material of OPV project. In these rooms is also kept the physical file of the warehouse.

COTECMAR central warehouse has 1169m² in areas of material receipt, storage, picking and shipping. The aggregate capacity of the central warehouse is 5369m³.

In 2009 COTECMAR started a project of Adaptation and Modernization of the storage buildings and other storage areas. The project was designed with the objective of optimizing the storage of materials, through the adaptation and modernization of the existing system in order to meet the present and future corporate challenges. The central warehouse of Mamonal plant has an area of 1170 m², after the expansion and investments which included the demolition of the former workshop of composites and the expansion of the warehouse. In 2009 the area of this central warehouse was of 723 m².

Además, la forma como se ubicaron las estanterías no permite la total maniobrabilidad de los equipos de carga en el almacén. Como se ilustra en la figura 4, toda una línea de estantería se encuentra sin posibilidad de acceso por parte del cargador debido a la poca disminución de altura del almacén en las zonas laterales. En esta zona la mercancía debe ser ubicada en forma manual por los operarios, lo que representa un riesgo para estos y hace ineficiente las operaciones de ubicación y recogida de materiales.

Despite the investments made in the store to be consistent with the needs of new construction projects, the acquisition of handling equipment and shelving and the adequacy of areas for conservation and storage of special materials (solder, electronic elements), the physical layout of the central warehouse of Mamonal does not obey any criteria except for the storage of certain materials under special temperature conditions.

In addition, the way the shelves were located does not allow the total maneuverability of the equipment in the warehouse. As illustrated in Figure 4, a whole line of shelving has no possibility of access by the forklift due to the low height of the warehouse in the lateral areas. In this area the materials must be placed by workers, which represents a risk to them and makes operation of location and collection of materials inefficient.
REESTRUCTURING THE LAYOUT OF THE CENTRAL WAREHOUSE OF MAMONAL PLANT

La distribución de la bodega de la planta Mamonal se muestra en la figura 5. Esta distribución presenta varios inconvenientes desde el punto de vista logístico, los cuales serán discutidos y resueltos en el desarrollo de la propuesta de reestructuración.

The distribution of central warehouse of Mamonal plant is shown in Figure 5. This arrangement has several drawbacks from the logistic point of view, which will be discussed and resolved in the restructuring proposal.

From Figure 6 it can be observed that is clearly identified a receiving, and storage of material areas, but there in notable the absence of the area responsible for the preparation of orders. For this it can be attributed the following problems encountered in the store:
• Delays in the process of compliance with orders.
• Aisles obstructed.
• Delays in the activities of storage and picking of materials from the shelves due to obstructed aisles.
• An obstructed aisle means three (3) things for the warehouse. 1. Higher cost of internal transportation of materials. 2. Decrease in the amount of usable space in the warehouse. 3. Expenditure on staff resource, which can be used in other functions such as cleaning or performance improvement activities in the warehouse.

To tackle these problems is recommended; first, to establish clearly the order preparation area. The size of the picking area should be as shown in Figure 7.

![Figure 7. Redistribution of warehouse zones. Source: Research Group GICO-SEPRO.](image)

According to this figure, we can determine that:
• For the operating conditions of the warehouse, the area designated for the receipt is properly sized.
• The area dedicated solely to deliver under the present conditions, must be shared with the area allocated for the picking or order preparation. Thus, before shipping an order, it should be organized and processed in this new area.

With the recommended setting, referring to Rosenblatt and Roll mainly, the order preparation area allows to accommodate up to 10 pallets of temporary storage, permitting normal operation with the forklift to 7 of them, as shown in Figure 8. These ten pallets provide sufficient space to ensure that any order can be prepared in that area, preventing the obstruction of the aisles during the process of collecting materials in the warehouse.

![Figure 8. Structuring the picking area. Source: Research Group GICO-SEPRO.](image)

In order to increase storage capacity and mobility of the central warehouse of Mamonal plant, it is proposed restructuring the layout, as shown in Figure 9.
This restructuring is composed of several changes, which allow achieving the following objectives:

f) Maximum use of the volume of the warehouse.
g) Use of all store shelves.
h) Improved mobility in the warehouse.
i) Improve the areas of receipt, dispatch and order picking.
j) Adjust and improve the storage areas of paints and screws.

The central rack, in blue in Figure 9, is responsible for storing the materials that can be stored on pallets, and that have regular dimensions. Table 1 gives a summary of current variables and those provided by the new distribution.

Table 1. Comparison of current store model and the proposed one.

<table>
<thead>
<tr>
<th>Description</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible storage positions</td>
<td>208</td>
<td>245</td>
</tr>
<tr>
<td>Obstructed positions</td>
<td>48</td>
<td>0</td>
</tr>
<tr>
<td>% Obstructed positions</td>
<td>23%</td>
<td>0%</td>
</tr>
<tr>
<td>Really used positions</td>
<td>160</td>
<td>245</td>
</tr>
<tr>
<td>Increase in the number of positions</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>REAL INCREASE (Real positions of storage)</td>
<td>53%</td>
<td></td>
</tr>
</tbody>
</table>

The area of material on consignment is configured as shown in pink in Figure 9. This design corresponds to a better use of space, allowing the entry of the forklift, because most of the materials that come to this area are paintings, which very often enter the store organized in pallets. Furthermore, this structure is according with the organization of the central shelf, allowing greater mobility and flexibility for daily operating activities in the warehouse. The shelf corresponding to this area is the same as that established for the central storage area, allowing the possibility of storage on a peak period, so palletized materials can be stored in this area, thanks to the possibility of maneuverability of the forklift, which provides flexibility to the warehouse.

The physical file storage area must be transferred to the cold room in the first floor of the offices according to the requirements of warehouse management. This requires designing the shelving necessary for the material, taking into account only the use of half the available space in the room, where there is a system rack, which is not removable, and the rest of the room should be used for
storing containers on the floor with materials that require temperature controlled conditions. The storage volume required for the file zone is of 20.08 cubic meters.

Figure 10 shows the distribution of the shelf designed for file storage and stationery. This shelf has 5 levels, reaching a height of 2.72 meters, the shelf width is 50 cm and the standard length is 1.15 meters. The storage volume obtained with the proposed distribution in Figure 10 is 21.62 cubic meters, which is completely satisfactory for the proposed storage.

Figure 10. Design of the file storage area. Source: Research Group GICO-SEPRO.

Figure 11 shows the design of the storage area of screws, valves and other materials. This design is based on using a sloping shelf (green shelf) in which the material is loaded by the side of the wall, and thanks to this tilt, the materials will move automatically to the other side, by which these elements will be removed. This will ensure that older materials are those that are taken out first, following the FIFO sequence. It is recommended that this shelf holds rollers, which facilitate the movement of items stored.

On the same side where the elements are removed, is a conventional shelf of 70 inches deep and 4 heights. This rack can store material with low turnover, while increasing storage capacity in this area of the warehouse.

Figure 11. Design of the area for ironmonger materials. Fuente: Grupo de Investigación GICO-SEPRO.

CONCLUSIONS

With the restructuring of the proposed layout for the central warehouse Mamonal headquarter of COTECMAR are clearly established the areas in which the warehouse should be divided so that there should be an area distinct from order preparation to solve the problems of obstructed aisles and delays in order fulfillment and storage and collection of materials. By allocating an area for this purpose the transport costs of goods in the warehouse are reduced and the usable storage space is increased.
The proposed restructuring of the shelves in the area of the warehouse for the storage will also achieve a maximum use of warehouse ensuring the accessibility of the forklift to the entire shelf and improving the provision of specific storage areas such as consignment of paints, coolers and ironmonger area. The proposed layout design for the warehouse ensures better use of space and access to all areas of the store, allowing greater mobility and flexibility for daily operating activities of the warehouse.

REFERENCES