AN INTEGRATED APPROACH FOR WAREHOUSE DESIGN AND PLANNING

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ABSTRACT

Warehouse design and planning is a great challenge in the field of Supply Chain Management. Inventory level management, warehouse design and operations, and customers' requirements are examples of important challenges in this context. Throughout this work we discuss a mathematical model aiming to support some warehouse management decisions and inventory decisions. Our aim is to show model's potentialities and weaknesses when applied to real world problems and to identify challenging research opportunities for developing more global warehouse decision support models to fill the gap between researchers and warehouse practitioners.

INTRODUCTION

Within a supply chain network, products need to be physically moved from one location to another. During this process, they may be buffered or stored at certain facilities (*warehouses*) for a certain period of time. In this context, warehouses play an important role in supply chains and are a key aspect in a very demanding, competitive and uncertain market.
Although many companies examined the possibilities of direct supply to customers, there are still many circumstances where this is not appropriate. According to Bartholdi and Hackman (2006) there are four main reasons why warehouses are useful:

- To consolidate products in order to reduce transportation costs and to provide customer service;
- To take advantage of economies of scale;
- To provide value-added processing and
- To reduce response time.

Thus, warehouses will continue to be an important node at the logistic network.

In distribution logistics where market competition requires higher performances from warehouses, companies are compelled to continuously improve the design and planning of warehouse operations. Furthermore, the ever-increasing variety of products, the constant changes in customer demands and the adoption of management philosophies also bring new challenges to reach flexible structures that provide quality, efficiency and effectiveness of the logistics operations. In practice, warehouses must be modular, adaptable, compact, accessible and flexible, and must be capable to respond to changing conditions, to improve space utilization and to reduce congestion and movement.

Warehouse design and planning typically runs from a functional description, through a technical specification, to equipment selection and determination of the layout.

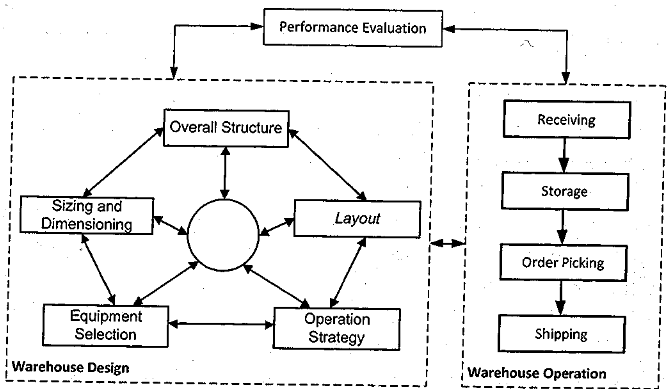

Figure 1: Framework for design and operation problems (adapted from Gu *et al.*, 2007).

Figure 1 illustrates the five major decisions involved in warehouse design according to Gu *et al.* (2007). The overall structure decision determines the material flow patterns within the warehouse, the specification of functional areas and the flows between areas. Sizing and dimensioning decisions determine the total size of the warehouse as well as the space allocation among functional areas. Layout definition is the detailed configuration within a functional area and equipment decisions define an automation level for the warehouse and identify equipment types. Finally operating policies refer to storage, picking and routing decisions.

Hassan (2002) presented a framework for the design of warehouse layout. The proposed framework accounts for several factors and operations of warehousing such us:

1. Specification of warehouse type and purpose;

2. Analysis and forecasting demand;
3. Definition of operating policies;
4. Establishment of inventory levels;
5. Class formation;
6. Definition of functional areas and general layout;
7. Storage partition;
8. Selection of equipment for handling and storage;
9. Design of aisles;
10. Determination of space requirements;
11. Location and number of I/O points;
12. Location and number of docks;
13. Arrangement of storage;
14. Zone formation.

Once warehouse decisions are strongly interrelated, warehouse design is a highly complex task where frequently conflicting objectives impose specific trade-offs.

Although interrelated, decisions are dealt independently in a pyramidal top-down approach. Strategic decisions create limits to decisions taken at the tactical and operational levels and tactical decisions limits operational decisions. Also decisions taken at each level are handled independently and sequentially (Van den Berg 1999).

The majority of scientific research studies addresses isolate problems. However, most real problems are unfortunately not well-defined and often cannot be reduced to multiple isolated sub-problems. Therefore, warehouse design often requires a mixture of analytical skills and creativity. Anyhow, research aiming an integration of various decisions models and methods is badly needed in order to develop a methodology for systematic warehouse design (Rouwenhorst *et al.* 2000).

In this paper we discuss a high-level warehouse and inventory model, adapted from Strack and Pochet (2010). The model jointly integrates:

- The size of the functional areas;
- The assignment of products to storage locations in the warehouse;
- The allocation of products to warehouse systems;
- The replenishment decision in the inventory management.

In the next section, we will make a brief review of the literature available on warehouse design and planning. Then, the integrated model for warehouse design developed by Strack and Pochet (2010) will be extended, analysed and some computational results presented. Finally some conclusions and future work are mentioned.

WAREHOUSE MANAGEMENT

Warehousing is concerned with all the material handling activities that take place within the warehouse. They include the receiving of goods, storage, order-picking, accumulation and sorting and shipping. Basically, one can distinguish two types of warehouses: *distribution warehouses* and *production warehouses*. According to Van den Berg and Zjim (1999), a distribution warehouse is a warehouse in which products from different suppliers are collected (and sometimes assembled) for delivery to a number of customers. On the other hand, a production warehouse is used for the storage of raw materials, semi-finished products and finished products in a production facility.

Warehouse activities

In this section we consider the flow of material in a warehouse. There are many activities that occur at a warehouse. Typically, distribution warehouses receive products - Stock Keeping Units (SKU) - from suppliers, unload products from the transport carrier; store products, receive orders from customers, assemble orders, repackage SKU and ship them to their final destination. Frequently, products arrive packaged on large scale units and are packaged and shipped on small units. For example, SKU may arrive in full pallets but must be shipped in cases.

Figure 2 shows the typical functional areas and flows within warehouses. Next, a short description of the most common areas and product flows is presented.

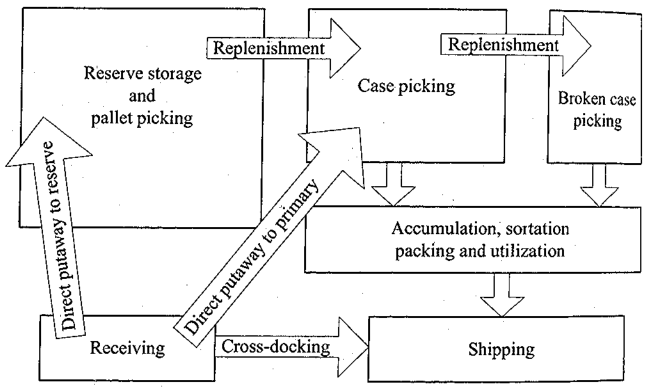

Figure 2: Typical warehouse functions and flows (adapted from Tompkins *et al.*, 2003).

At the receiving area products are unloaded and inspected to verify any quantity and quality inconsistency. Afterwards items are transferred to a storage zone or are placed directly to the shipping area (this is called a cross-docking operation). We can distinguish two types of storage areas: reserve storage area and forward or picking area. The reserve area is the place for products to stay until they are required by costumers' orders. The picking area is a relatively small area typically used to store fast moving products. Most of the flows between areas are the result of replenishment processes. Order picking is one of the most important functions in most warehouses. SKU are retrieved from their storage positions based on customers' orders and moved to the accumulation and sorting area or directly to the shipment area. The picked units are then grouped by customer order, packaged and stacked on the right unit load and transferred to the shipping area.

Warehouse design and planning

Warehouse design can be defined as a structured approach of decision making at distinct decision levels in an attempt to meet a number of well-defined performance criteria. At each level, multiple decisions are interrelated and therefore it is necessary to cluster relevant problems that are to be solved simultaneously. According to Rouwenhorst *et al.* (2000) a *warehouse design problem* is a "coherent cluster of decisions" and they define decisions to be coherent when a sequential optimization does not guarantee a globally optimal solution.

The design of a warehouse is a highly complex problem. It includes a large number of interrelated decisions involving warehouses processes, warehouse resources and warehouses organizations (Heragu, 2005). Rouwenhorst *et al.* (2000) classify management decisions concerning warehousing into strategic decisions, tactical decisions and operational decisions. Strategic decisions are long term decisions and always mean high investments. The two main issues are concerned with the design of the process flow and with the selection of the types of warehousing systems. Tactical management decisions are medium term decisions based on the outcomes of the strategic decisions. The tactical decisions have a lower impact than the strategic decisions, but still require some investments and should therefore not be reconsidered too often. At the operational level, processes have to be carried out within the constraints set by the strategic and tactical decisions made at the higher levels. At this level, the concern includes the operational policies such as storage policies and picking operations.

After determining warehouse location and its size, layout decisions must include areas definition and what size should be allocated to each functional area. The forward-reserve problem (FRP) is the problem of assigning products to the functional areas. In this problem the critical decision concerns the choice of products that will be stored in the forward area. Van den Berg *et al.* (1998) proposed a binary programming model to solve de FRP in the case of unit load replenishment and presented efficient heuristics that provide tight performances guaranties. Those replenishments can occur during busy or idle picking periods. The objective was to minimize the number of urgent or concurrent replenishments of the forward area during the busy periods.

Although addressing this problem is a strategic decision problem, it is strongly associated upon some tactical problems such as how the items will be distributed among the functional areas. However, the approach usually adopted is to solve the problems sequentially by generating multiples alternatives for the functional area size problem and then determine how the products can be allocated for each of the alternatives.

Gray *et al.* (1992) developed an integrated approach to the design and operation of a typical order-consolidation warehouse. This approach included warehouse layout, equipment and technology selection, item location, zoning, picker routing, pick generation list and order batching. Due to the complexity of the overall problem, they developed a multi-stage hierarchical decision approach. The hierarchical approach used a sequence of coordinated mathematical models to evaluate the major economic trade-offs and to reduce the decision space to a few alternatives. They also used simulation technique for validation and fine tuning of the resulting design and operating policies.

Heragu *et al.* (2005) developed a mathematical model and a heuristic algorithm that jointly determines the functional areas size and the product allocation in a way that minimizes the total material handling and storage costs. The proposed model uses real data readily available to a warehouse manager and considers realistic constraints.

Geraldes *et al.* (2008) adapted the mixed-integer programming model proposed by Heragu *et al.* (2005) to tackle the storage allocation and assignment problems during the redesign process of a Portuguese company warehouse.

In addition to warehouse management decisions, an appropriate inventory policy may result in a reduction of the total warehousing costs and can also improve the efficiency of the operating policies within the warehouse. The adoption of new management philosophies compels companies to eliminate or reduce inventory levels. The aim of inventory management is to minimize total operating costs satisfying customer service requirements (Ghiani *et al.* 2004).

To accomplish this, an optimal ordering policy will answer to questions such us when to order and how much to order. There exist two different inventory policies (Hadley and Whitin, 1963): continuous review policy and the periodic review policy. The first policy implies that the stock level will be monitored continuously. A fixed quantity will be ordered when the stock reaches the reorder point. In the second policy, the stock level is checked after a fixed period of time and an ordering decision will be made to complete the stock to an upper limit, if necessary. The operating costs taken into account are the procurement costs, the holding costs and the shortage costs. Those basic policies can be adapted to take into account special situations such us single or multi-item models with or without a constraint on the total storage space, deterministic or stochastic demands, lost sales, etc.

MATHEMATICAL MODEL FORMULATION

The model presented by Strack and Pochet (2010), probably the most robust approach found in this area, integrating multiple aspects as mentioned above, still assumes fixed capacities for both forward and reserve areas. Our approach will then try to give this model the capacity of obtaining optimal sizes for functional areas, i.e., functional areas would be model decision variables.

We consider a warehouse with the following functional areas: receiving, reserve, forward and shipping. Thus, the three following material flow patterns are possible:

- Flow 1: Receiving → Reserve → Shipping
- Flow 2: Receiving → Reserve → Forward → Shipping
- Flow 3: Receiving → Forward → Shipping

The forward area is divided into locations and each product in the forward area is allocated to a number of locations. Before the picking period, the forward area is replenished in advance from the reserve area. Nevertheless, if the stock level in the forward area reaches the reorder point, to avoid shortages, concurrent replenishments can take place during the picking period. The issues that are simultaneously addressed are the decision of the flow pattern taken by the different products in the warehouse and the quantity of the products allocated to the forward and/or the reserve area. In addition, the optimal frequency of the external supplies will be optimized as well as the safety stocks.

Model assumptions

We assume that the total space of available storage space is known. Nevertheless, it is possible to rent external storage space if the space available in the warehouse is insufficient to store all products.

Due to its purpose, the forward area will be handled through a dedicate storage policy. So, if a product is not available in the warehouse the location of this product will be empty and there will be unused space. On the other hand, in the reserve area, a random storage policy is assumed.

During the picking period we will consider the following activities: (i) concurrent and advanced replenishments of the forward area from the reserve area; (ii) picking from the forward and reserve areas; (iii) external supply of the forward and reserve areas.

Finally, concerning the external supply of the products, we will assume an inventory control policy based on continuous review policy (reorder point system).

Model formulation

In formulating the model, the following notation is used.

Parameters:

The indexes used are $i: 1, \dots, I$ to denote products and $j: 1, \dots, J$ to denote the number of locations in the forward area.

α_i: Number of units of product i that can be stored in a single location of the forward area
$CapaT$: Available storage capacity of the warehouse
$CostRepA$: Cost of advanced replenishment
$CostRepC$: Cost of concurrent replenishment
$PickF$: Picking cost in the forward area
$PickR$: Picking cost in the reserve area
$CostR$: Reception cost for the reserve area
$CostF$: Reception cost for the forward area
$CostCapS$: Additional capacity cost
$CostCar$: Inventory carrying cost
$CostAcqu_i$: Acquisition cost of product i
$CostShort$: Shortage cost
$E(U_i)$: Expected value of the demand of product i
$E(p_i)$: Expected value of the number of picks of product i
d_i: Demand of product $i$during supply lead time
μ_i^L: Average demand of product i during supply lead time
σ_i^L: Standard deviation of demand of product i during supply lead time
u_{ij}: The increase in the expected number of replenishment if we allocate an additional location in the forward area to product i

Decision variables:

$$x_{ij} = \begin{cases} 1 & if\ product\ i\ has\ a\ Flow\ 2\ pattern\ with\ j\ locations\ allocated\ in\ the\ forward\ area \\ 0 & otherwise \end{cases}$$

$$y_i = \begin{cases} 1 & if\ product\ i\ has\ a\ Flow\ 3\ pattern \\ 0 & otherwise \end{cases}$$

$$z_i = \begin{cases} 1 & if\ product\ i\ has\ a\ Flow\ 1\ pattern \\ 0 & otherwise \end{cases}$$

$CapaR$: Capacity of the reserve area
$CapaF$: Capacity of the forward area
$CapS$: External storage capacity
Q_i: Replenishment quantity of product i
r_i: Reorder point of product i

The general formulation of the model can be stated as:

$$\begin{aligned} min \sum_{i=1}^{I} CostRepA \times x_{i1} + \sum_{i=1}^{I}\sum_{j=1}^{J} CostRepC \times x_{ij} \times u_{ij} \\ + \sum_{i=1}^{I} CostR \times \frac{E(U_i)}{Q_i} \times (z_i + x_{i1}) + \sum_{i=1}^{I} CostF \times y_i \times \frac{E(U_i)}{Q_i} \\ + \sum_{i=1}^{I} PickF \times E(p_i) \times (x_{i1} + y_i) + \sum_{i=1}^{I} PickR \times E(p_i) \times z_i \\ + CostCapS \times CapS \\ + \sum_{i=1}^{I} CostCar \times \left(\frac{Q_i}{2} + r_i - \mu_i^L\right) + \sum_{i=1}^{I} CAcqu_i \times E(U_i) \\ + \sum_{i=1}^{I} CostShort \times \left(\frac{E(U_i)}{Q_i}\right) \times \int_{r_i}^{\infty} (d_i - r_i)\, f\,(d_i)\, dd_i \end{aligned} \quad (1)$$

Subject to:

$$x_{ij} \leq x_{ij-1} \quad \forall_{i,j} : j \geq 2 \quad (2)$$

$$\sum_{j=1}^{J} (x_{ij} + z_i + y_i) = 1 \ \ \forall_i \quad (3)$$

$$\sum_{i=1}^{I} \left[\left(\sum_{j=1}^{J} x_{ij} \right) + \left(\frac{Q_i + r_i - \mu_i^L}{\alpha_i} \right) y_i \right] \leq CapaF \quad (4)$$

$$\sum_{i=1}^{I}\left[\left(\frac{Q_i}{2}+r_i-\mu_i^L\right)(z_i+x_{i1})-\sum_{j=1}^{J}\alpha_i x_{ij}\right] \leq CapaR + CapS \quad (5)$$

$$CapaF + CapaR \leq CapaT \quad (6)$$

$$LL_R \leq CapaR \leq UL_R \quad (7)$$

$$LL_F \leq CapaF \leq UL_F \quad (8)$$

$$CapaF, CapaR, CapS, Q_i, r_i \geq 0 \quad (9)$$

$$x_{ij}, y_i, z_i \in \{0,1\} \forall_{i,j} \quad (10)$$

The objective function (1) is the expected warehouse and inventory costs per picking period. Concerning the warehouse costs, we have taken into account the: (i) costs of advance and concurrent replenishments of the forward area; (ii) reception costs; (iii) picking costs of the forward and reserve areas; (iv) rental cost of the additional storage capacity. The traditional inventory costs are composed by the carrying costs, the acquisition costs and by the shortage costs.

The model's integrity is observed by ensuring sequencing constraints (2), specifying that a j^{th} location can be assigned to a product i only if $j-1$ locations have already been assigned. In addition, each product can only follow one flow pattern in the warehouse (3). Constraints (4)-(5) ensure that the space constraints for the forward and reserve areas are met, and constraint (6) guarantees that the total available space in the warehouse is not exceeded. Constraints (7)-(8) serve to enforce upper and lower limits on the space that can be allocated to forward and reserve areas. Finally, a set of variables must be nonnegative (9) and another is considered binary (10).

Comparatively to the original model this formulation adds two new decision variables, since the size of the reserve are forward areas are now unknown, and three new constraints (6)-(7)-(8).

Mathematical model analysis and methodology

The above programming model integrates inventory and management decisions. The reception costs involve the warehouse (i.e. y_i, z_i, x_{ij}) and the inventory (i.e. Q_i) variables which highlights the link between warehouse and inventory decisions. However, it makes the objective function (1) and constraints (4)-(5) nonlinear and consequently the model is a mixed-integer nonlinear programming model (MINLP) with a large number of variables and constraints.

To demonstrate the computational complexity involved, the model was solved using LINGO12.0 commercial solver on an Intel Core 2Duo 1.4 GHz CPU and 3GB RAM. For a randomly generated instance with 5 products (SKU) and a warehouse with a total available storage space of 5 locations we have to solve a problem with a total of 48 decision variables of which 35 are integer, and with 29 constraints (3 of them nonlinear). It is a very small size instance for which we only were capable to find local optimums within three hours of CPU time.

Given the complexity of solving this model to optimality, such as Strack and Pochet (2010), we suggest to solve the model sequentially. For this propose we decompose our model in two sub-models: (i) an inventory management sub-model and (ii) a warehouse management sub-model. These two sub-models are solved sequentially: first we solve the inventory sub-model and then the optimal values of the inventory variables are fixed and used to solve the warehouse sub-model.

To obtain the inventory management sub-model we have to eliminate the costs and constraints related to the warehouse management problem. We also condensed the model assuming a customer service level for each product and an approximation of the objective function assuming that the reception costs are independent of the flow pattern taken by the product. Moreover, the capacity constraints for the reserve and forward areas are relaxed. By this, we mean that we will consider only one capacity constraint for the entire storage area.

The resulting inventory management sub-model is a nonlinear programming model defined as:

$$\begin{aligned} min \sum_{i=1}^{I} CostCar \times \left(\frac{Q_i}{2}+r_i-\mu_i^L\right) + \sum_{i=1}^{I} CAcqu_i \times E(U_i) \\ + \sum_{i=1}^{I} CostShort \times \left(\frac{E(U_i)}{Q_i}\right) \times \int_{r_i}^{\infty}(d_i-r_i)\, f\,(d_i)\, dd_i \\ + \sum_{i=1}^{I} CostRecp \times \frac{E(U_i)}{Q_i} + CostCapS \times CapaS \end{aligned} \quad (11)$$

Subject to:

$$\sum_{i=1}^{I}\left(Q_i+r_i-\mu_i^L\right) \leq CapaT + CapS \quad (12)$$

$$CapS, Q_i \geq 0 \quad (13)$$

The considered objective function (11) is independent of the products flow patterns and consequently independent of warehouse decisions. Also, the capacity constraint (12) is independent of the flow patterns taken by the different products. Nevertheless, the inventory variables will be dependent of the available storage capacity, and in a certain way we can consider that this sub-model integrates an inventory decision and a warehouse decision.

Warehouse management sub-model is obtained fixing the inventory variable (Q_i), based on the solution of the inventory sub-model.

The resulting warehouse sub-model is a mixed-integer problem that can be stated as:

$$
\begin{aligned}
min \sum_{i=1}^{I} CostRepA \times x_{i1} &+ \sum_{i=1}^{I}\sum_{j=1}^{J} CostRepC \times x_{ij} \times u_{ij} \\
&+ \sum_{i=1}^{I} CostR \times \frac{E(U_i)}{Q_i} \times (z_i + x_{i1}) + \sum_{i=1}^{I} CostF \times y_i \times \frac{E(U_i)}{Q_i} \\
&+ \sum_{i=1}^{I} PickF \times E(p_i) \times (x_{i1} + y_i) + \sum_{i=1}^{I} PickR \times E(p_i) \times z_i \\
&+ CostCapS \times CapS
\end{aligned} \tag{14}
$$

Subject to:

$$x_{ij} \leq x_{ij-1} \quad \forall_{i,j} : j \geq 2 \tag{15}$$

$$\sum_{j=1}^{J} (x_{ij} + z_i + y_i) = 1 \ \ \forall_i \tag{16}$$

$$\sum_{i=1}^{I} \left[\left(\sum_{j=1}^{J} x_{ij} \right) + \left(\frac{Q_i + r_i - \mu_i^L}{\alpha_i} \right) y_i \right] \leq CapaF \tag{17}$$

$$\sum_{i=1}^{I} \left[\left(\frac{Q_i}{2} + r_i - \mu_i^L \right) (z_i + x_{i1}) - \sum_{j=1}^{J} \alpha_i x_{ij} \right] \leq CapaR + CapS \tag{18}$$

$$CapaF + CapaR \leq CapaT \tag{19}$$

$$LL_R \leq CapaR \leq UL_R \tag{20}$$

$$LL_F \leq CapaF \leq UL_F \tag{21}$$

$$CapaF, CapaR, CapS \geq 0 \tag{22}$$

$$x_{ij}, y_i, z_i \in \{0,1\} \, \forall_{i,j} \tag{23}$$

Now, in the warehouse management sub-model the flow pattern variables and the size of the functional areas (reserve and forward) will be optimized taking into account the global storage capacity and the upper and lower limits imposed to the functional areas. The optimal value of the additional capacity is re-optimized.

Computational results

To evaluate the computational performance involved on solving the proposed sub-models test problems were solved using LINGO12.0 commercial solver on an Intel Core 2Duo 1.4 GHz CPU and 3GB RAM. Instances for different scenarios (Table 1) were randomly generated. Table 2 shows parameter values used to generate the testing problems.

Table 1: Analysed scenarios

Scenario	SKU [units]	Total Storage Capacity [No. of Locations]
I	10	7
II	100	70
III	500	300
IV	1000	600
V	5000	3000

Table 2: Parameter values for the numerical examples

Parameter	Value
$CostRepA$	10
$CostRepC$	25
$PickF$	3
$PickR$	10
$CostR$	3
$CostF$	5
$CostCapS$	50
$CostCar$	3
$CostShort$	100
U_i	Uniform [1, 50]
p_i	Uniform [1, 5]
d_i	$N(\mu_i, \sigma_i)$

The computational results obtained for the sub-models are shown in Tables 3 and 4.

Table 3: Inventory sub-model computational results

	Scenario				
	I	II	III	IV	IV
Total variables	11	101	501	1001	5001
Nonlinear variables*	10	100	500	1000	5000
Iterations	167	593	1887	17418	48389
CPU time [mm:ss]	00:01	00:16	00:48	03:55	12:08
State	Global Opt.	Global Opt.	Global Opt.	Global Opt.	Global Opt.

* Variables involved in the model's nonlinear relationships.

Table 4: Warehouse sub-model computational results

	Scenario				
	I	II	III	IV	IV
Total variables	43	2203	38503	152003	3760003
Binary variables	40	2200	38500	152000	3760000
No. of constraints	24	2004	37504	150004	3750004
Iterations	0	0	849	2798	-
CPU time [mm:ss]	00:01	00:01	00:17	02:10	-
State	Global Opt.	Global Opt.	Global Opt.	Global Opt.	**

** Due to the size of the generator matrix, the computer did not have sufficient memory.

As it can be seen it was possible to analytically solve both sub-models to optimality for the first four scenarios in a very satisfactory computational time. Nevertheless, for large instances (Scenario V), the number of binary variables and constraints of the warehouse management sub-model increases considerably. Consequently solving the model using a branchand-bound based algorithm for mixed-integer programming problems takes significant computational time and memory.

CONCLUSIONS AND FUTURE WORK

In an uncoordinated manner inventory decisions are taken without any warehouse considerations and vice-verse. In this work our aim was to show the value of integrating some decisions that occur during the design and planning of a warehouse.

For that purpose a mathematical model for inventory and warehouse management was extended and analysed. The proposed mixed-integer nonlinear programming model jointly integrates: (i) the size of the functional areas; (ii) the assignment decision of products to storage locations; (iii) the allocation decision and; (iv) the replenishment decision.

Nevertheless, and due to the complexity of the analytical model obtained, an optimal global solution is definitely difficult to achieve. For this reason, the model was decomposed in two sub-problems which were solved using a hierarchical sequential approach

First a nonlinear inventory model was solved taking into account only the total capacity of the available storage. The second sub-model refers to warehouse decision. Model was obtained fixing the inventory variables bases on the solution of the first sub-problem. This sub-model allows us to jointly determine the flow pattern for each product, the dimensions of the functional areas and the eventual need of rent some external storage area.

To have a single decision model that integrates several decisions concerning warehouse design and planning is a very complex problem due: to the large amount of information to be processed; to the tremendous amount of existing alternatives; to the existence of various and often conflicting objectives and to the uncertainty inherent in the material flow into, through and out of the warehouse.

As Ashayeri and Gelders (1985) we also believe that an analytical approach can be used to solve simplified models and simulation technique can be used to validate the models and to incorporate dynamic aspects not yet included in the model. For example, we could use the gathered solution of the considered sub-problems and then simulation can be used to introduce demand fluctuations or operational decisions related with storage or picking policies. Therefore, with the application of this dual technique, we believe that the major features of both techniques can be enjoyed in the warehouse design and planning problem.

These considerations allow us to say that there exist many challenging opportunities for developing more global warehouse decision support models.

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