SRC TR 88-4

How to Optimize Raw Materials Storage Space Requirements

by

G. Harhalakis and P. Sharma

How to Optimize Raw Materials Storage Space Requirements

G. Harhalakis[1], P. Sharma[1]

Systems Research Center
and Department of Mechanical Engineering

University of Maryland, College Park, MD 20742.

[1] Supported in part by the NSF under grant CDR-85-00108

American Society for Engineering Management

Engineering Management: The Challenges and Changes

Proceedings of the Eighth Annual Meeting

Adam's Mark Hotel St. Louis
St. Louis, Missouri

October 11-12-13, 1987

American Society for Engineering Management • 1987 Annual Meeting

How to Optimize Raw Materials Storage Space Requirements

G. Harhalakis and Phani Sharma[1]
W.S. Zachmann[2]

[1]University of Maryland
College Park, Maryland
[2]OHMEDA

Abstract

Storage space is an expensive "Resource". Timely planning, accurate estimation and efficient utilization of storage space for raw materials in manufacturing industry are both necessary and strategically important. Hitherto, warehouse planning has been treated as a separate function and performed in isolation, without accounting for its interactions with other manufacturing functions. Even the most sophisticated Manufacturing Resource Planning Systems (MRP II), have failed to identify and treat storage space as a resource.

In this paper, a technique for incorporating Warehouse planning with an enhanced MRP II System shall be discussed. A significant improvement in stock turns and optimum storage space utilization are achieved with the proposed model. Appropriate assumptions are made and explicitly described.

This technique has been tested and successfully implemented in a plant, manufacturing Infant Care Equipment.

1.1 Introduction

The principal functions of warehousing are [1], 1. Receipt of raw material, 2. Storage of raw material, 3. Distribution of raw material and 4. Control of raw material. It is in the interests of the manufacturing industry, that each of the functions mentioned are to be handled in a cost effective manner, with maximum conservation of space and capital. Each of these four functions must be handled accurately, and chances for error exist in each one of them. The information that is needed before the planning of a Warehouse is begun, includes:

1. Inventory levels

Efficient storage space planning cannot be carried out without ample knowledge of normal inventory levels.

2. Order Quantities

or average order size.

3. Unit Volume

Unit volume for each of the components has to be determined or estimated.

4. Storage Requirements

The means of storage which could be bins, shelves, drawers, racks or pallets.

1.2 Previous Work

Work has been done on warehouse planning, but as stated earlier, it has been treated as an isolated function. At Xerox corporation [2], the warehousing activity was analyzed, and storage space was estimated for purchased parts, taking into account the forecasts for end products. In another source [3], the analysis is based on daily loading records, provided by the operating departments.

It is evident, in both these references, no thought was given as to how to optimize the storage space and also to reduce inventory levels by increasing purchasing frequencies, thereby improving the stock turns.

However, an attempt has been made to optimize storage space [1]. In this study, inventory is analyzed by listing each line item, i.e. Stock Keeping Unit (SKU). Next, the dimensions of each SKU are recorded. From the forecasts, maximum and minimum inventory levels are estimated. Using dimensions and volumes, the total cubic footage needed to store the item is calculated. Then the optimum storage mode is determined, based on the costs of stocking, storage and order selection.

Although the method of estimation and optimization of storage is quite effective, it is not integrated with other manufacturing functions such as purchasing, inventory, engineering etc.

Apparently, the system does not provide real time management control, i.e., the ability to make management decisions based on constant updating of information.

1.3 Existing Software on Warehousing Applications

Many independent organizations have developed software for warehousing applications [4]. One of the better known software systems is developed by Catalyst, U.S.A., which contains features such as;

Storage

Designation of type, size, status of storage location, search for new location, change of a storage location, replenishment of picking line slots, selection of the most efficient pattern.

Management Information

Purchasing and inventory management, improved control over products and real time inventory control.

Others have concentrated on just one or some of the features mentioned above and an overall picture is that there has been no mention about the integration of MRP II system and Warehousing and physical distribution, the advantages of which shall be discussed in a later section.

2.1 Problem Definition

Large number of end products, highly fluctuating production plans, difficulties in obtaining and compiling large amounts of data sometimes cause problems in accurate estimation of storage space for future manufacturing needs. Also, there has to be some kind of decision making tool to aid the decision maker to look for alternatives; for example, when to lease or expand additional warehousing space, etc.

Now that most of the manufacturing plants have realized the importance of implementing MRP II systems, it is highly beneficial for the organizations to integrate the warehousing function with MRP II systems.

Such incorporation of Warehousing with an enhanced MRP II system has many advantages.

1. Duplication of data is entirely eliminated: Data gathering, entry and manipulation involves a great deal of time, effort and money. Since the data that is necessary is available in the MRP II systems, duplication of data is entirely eliminated.

2. Forecasts: Within the warehousing system, any erroneous assumption regarding sales forecasts are avoided, since the Master Scheduling module of the MRP II system provides the sales forecasts. In addition to this, forecasts for spare parts, if any, could also be obtained.

3. Management performance: Additional information such as buyer performance and aggregate stock turns could be made available.

4. The most significant advantage of the proposed system is that it provides a real time management control, thereby enabling management to make decisions based on the updated information.

All of the above mentioned benefits are realized in addition to optimal storage space and reduced inventory levels. The system can be designed to compare the existing storage space to that of the required space, giving an opportunity for the manager to decide, when to lease or expand for additional warehousing space.

Once the proposed technique is widely implemented, the manufacturing industry can claim to have achieved a high degree of Integration in all of its manufacturing resources.

2.2 The Approach

2.2.1 Classification of End-Products

It is common in most manufacturing industries to have more than one end-product. It is also true that these end-products have different production plans. End-products which resemble each other in product structures are usually grouped in families and assigned with product codes.

Each product code may contain one or more end-products, having different production plans and product structures. The purpose of such classification and assignment of product codes is to necessitate easy computing for the estimation of storage space and aggregate stock turns for each family of products.

2.2.2 Forecasts

Once the end-products are classified and assigned with product codes, their production plans for a future period of time are extracted from the Master Schedule module of the MRP II system.

It is advantageous to have the information regarding average, minimum, and maximum production plans for a given set of products, so that, average, minimum and maximum inventory levels to be stored respectively can be established. There are forecasting techniques that are available to compute the average, minimum and maximum production plans for a given period of time.

Another technique of forecasting [5], which measures the forecasting error is the Mean Absolute Deviation (MAD). This accounts for the erratic demand patterns in the forecast data and eliminates those data points which deviate too much from the mean. The use of this technique is to estimate accurately the production plans with different levels of confidence [6]. Therefore the system is designed to provide the user with options regarding the type of forecast to be used.

Once the forecast option is selected by the user, the production plans are extracted from the MRP II system, for all the end products belonging to all the product codes.

2.2.3 Purchased Parts

The proposed model, considers purchased parts as the only items to be stored, although it could be easily expanded to incorporate intermediate finished parts and subassemblies, if they are kept in stock for sometime. The source to identify purchased parts is the Bill Of Material(BOM) module of the MRP II system. Their source code is usually "P" for purchased.

Each of the End-products belonging to the product codes defined earlier, is exploded to capture the purchased parts which have a source code of

"P". Parts with other source codes are ignored. Normally, most of the MRP II systems reflect Engineering type of BOM structures [7]. In such cases, one has to be careful while capturing the purchased parts, because engineering BOM structures reflect the dependents of the purchased parts, which also have a source code of "P". One of the reasons this is done, is to display components of purchased assemblies which are occasionally procured to be supplied as spare parts.

Obviously, these parts are not purchased and stored separately for production purposes. Therefore the dependents of the purchased parts should be omitted for the purposes of this paper.

If the BOM's were to reflect manufacturing type of structures, then the identification of purchased parts could be easily done using the summarized BOM listings of the products. Once the purchased parts are identified, their quantity per assembly is stored and if the same part is used elsewhere in the same end-product, then the quantity per assembly is summed up to get the total quantity of the part required for that end product.

The procedure is iterated until all the purchased parts in all the products in all the class codes are identified.

The output of this exercise should comprise, the purchased part number, number of products making use of the part and total quantity of the part used in all the product codes.

2.2.4 Volume and Cost Data

The next step is to extract unit volume and unit cost data for purchased parts identified. These data are obtained from the Part Master Records (PMR's) of the MRP II system.

When unit cost and unit volume data are extracted, they are multiplied by the respective total quantity of the purchased part.

The resulting figures from this exercise are the part number, number of products making use of this part, total quantity of the part, unit cost, unit volume, total cost and total volume. The total cost and total volumes are then multiplied by the monthly production forecasts of the end products, thus yielding the total monthly requirements of the storage volume and cost.

A typical output would like this:

TABLE I

PART #	DESC.	TOTAL QTY	UNIT COST	UNIT VOL.	PROD.	T.COST	T.VOL
123	SCREW	500	0.50	0.005	500	125000	1250
345	BOLT	200	0.05	0.07	700	7000	9800

3.1 The Algorithm

To optimize both the cash-flow requirements and storage space requirements, two techniques are considered.

1. A standard optimization technique employing Lagrange Multipliers [8], and

2. A technique employing an application of ABC Analysis.

3.2.1 Optimization by the application of Lagrange multipliers

The objective of this study is to optimize both cash-flow and storage space requirements. In a typical Inventory system, both cash-flow i.e., the working capital, and storage space constrain an effective operation.

By employing Lagrangian analysis, optimum order quantities and frequencies can be determined.

Lagrange Multipliers with Kuhn-Tucker Conditions: Following are the symbols used and their definitions.

C- Order cost per order. (Assumed constant).
H- Annual inventory holding cost fraction.
G- Total monthly incremental cost
 = Order cost + Holding cost
i- Number of inventory items (i = 1,....,n)
J- Maximum size of average inventory in $
Pi- Unit purchase cost of part i
Qi- Order quantity for part i
Ri- Annual demand for part i in units
Ti- Order interval for part i
vi- Unit volume of part i
V- Maximum total storage for all parts
Y- Maximum number of annual orders
l- Lagrange Multiplier

In this analysis, it is assumed that the only unknowns are the order quantity Qi and the Lagrange Multiplier l. Also, for simplicity reasons, interest rates, i.e. the cost of capital, is not accounted for.

Since the objective is defined, one can express it as a mathematical function as follows;

Minimize G = Order cost + Holding cost (1)

$$\text{i.e.,} \quad G = \sum_{i=1}^{w} \left[\frac{R_i * C}{12} * Q_i + Q_i \frac{*P_i * H}{24}\right]$$

Subject to the constraints;

$$g_1: \sum_{i=1}^{n} \frac{P_i * Q_i}{2} <= J \tag{2}$$

$$g_2: \sum_{i=1}^{n} v_i * Q_i <= V \tag{3}$$

This is a standard minimization with two inequality constraints and hence, Lagrange multipliers l_1 and l_2 are introduced to solve for the unknowns.

With the introduction of Lagrange multipliers, the minimization problem can be expressed as;

$$L = \frac{C}{12} * \sum_{i=1}^{n} \frac{R_i}{Q_i} + \frac{H}{12} * \sum_{i=1}^{n} \frac{P_i*Q_i}{2}$$

$$+ l_1 \left[\sum_{i=1}^{n} \frac{P_i*Q_i}{2} - J\right] + l_2 \left[\sum_{i=1}^{n} V_i*Q_i - V\right] \quad (4)$$

Using the standard Lagrangian procedure, equation (4) is reduced to the following simultaneous equations:

$$\frac{dl}{dQ_i} = \frac{-C*R_i}{12*Q_i^2} + \frac{H*P_i}{26} + \frac{l_i*P_i}{2} + l_2 V_i = 0 \quad (5)$$

$$l_1*(g_1-J) \Rightarrow l_1*\left[\sum_{i=1}^{n} \frac{P_i*Q_i}{2} - J\right] = 0 \quad (6)$$

$$l_2*(g_2-V) = l_2*\left[\sum_{i=1}^{n} V_i*Q_i - V\right] = 0 \quad (7)$$

Where $l_1 = 0$ if $g_1-J < 0$ $\quad$ $l_2 = 0$ if $g_2-V < 0$

$l_2 > 0$ if $g_1-J = 0$ $\quad$ $l_2 > 0$ if $g_2-V = 0$

From equation (5) it follows that,

$$Q_i = \sqrt{\frac{2*C*R_i/12}{(H/12*P_i) + l_1*P_i + 2*l_2*V_i}} \quad (8)$$

Substituting for Qi i.e. (8) in (6) and (7);

The following equations are obtained:

$$\left[\sum_{i=1}^{n} \sqrt{\frac{2*C*R_i*P_i**2}{(\frac{H}{12}*P_i) + l_1*P_i + 2*l_2*V_i}} - J\right] = 0 \quad (9)$$

$$\left[\sum_{i=1}^{n} \sqrt{\frac{2*C*R_i\ v_1**2}{(\frac{H}{12}*P_i) + l_1*P_i + 2*l_2*V_i}} - W\right] = 0 \quad (10)$$

By testing different combinations of values of l_1 and l_2, it is possible to determine the optimum order quantity Qi for all parts, that meet the constraining conditions g_1 and g_2. The iterative procedure is performed on a computer, with l_1 and l_2 set equal to zero, and then one is held constant while the other is incremented, and vice versa.

The output of this exercise is the purchased part number, total quantity per month, unit price, unit volume and order quantity. Once the order quantities for all the parts in the system are computed, they are multiplied by the unit cost and unit volume respectively.

This computation yields the total storage volume for parts and the total cash for the individual parts.

3.2.2 Bin Sizes

Due to the fact that purchased parts have different sizes and shapes, it is advantageous to introduce multiple bin sizes and or pallet sizes, so that unutilized space is reduced to a minimum, to further reduce the space needed. The suggested procedure is as follows:

1. The total volume of each part to be stored is divided by the smallest bin size. If the result exceeds a prespecified number of bins per part, it is divided by the next higher size bin and so on. The reason for setting a limit on number of bins is to avoid excessively high number of bins to store the same part. Same computation holds good for pallets or other storage devices.

2. Efficiency: The total volume to be stored for a part is divided by the number of bins it is stored in and the volume of the bin, to give individual storage efficiency. Eg; suppose 'x ' Cu.In. of total volume is stored in ' n ' number of size 'v '; then the individual storage efficiency is given by,

$$n\% = x/(n*v) * 100$$

Note: If two bin sizes, say, may satisfy the storage of a part without exceeding the limit on the number of bins, then the bin with the higher efficiency is selected.

The problem with the use of Lagrangian analysis is that it is heavily dependent on the convergence factor of the equations derived to compute the values of l_1 and l_2. Another disadvantage is that of selecting optimum ordering quantities without considering the end-product demands. Hence, the relationship between independent demand and dependent demand tends to be ignored. In such cases, the second technique, i.e., the application of ABC Analysis proves to be equally effective and easier to implement.

3.3 Application of ABC Analysis

In ABC Analysis,[9], items of a population are ranked in a descending order of some exhibited activity, in this case both cost and volume factors, and appropriate techniques are developed to handle the high activity "A" group items, with perhaps different techniques for handling the medium activity "B" items and low activity "C" items. Such differentiation in techniques for physical handling, control or management gives substantially superior results than treating both the important and unimportant items in the same way.

3.3.1 Classification of parts into A, B, and C

In a classical sense, A, B, and C groupings are based on cost factor i.e., high cost, high turnover items are grouped as "A" items, Medium-cost, medium turnover items are grouped as "B" items, and low-cost, low turnover items are grouped as "C" items. However, since our constraints are both working capital and storage space, the classification of parts into A, B, and C is based on both cost and volume factors.

To aid the decision maker to place a pre-determined emphasis on "More-Critical" resource, i.e., cost or volume, weighing factors are introduced.

By defining the weighing factors, either stock turns can be increased if total cost of a part is given higher weighing factor or storage space requirements can be decreased if total volume of a part is given a higher weighing factor or equal weighing factors can be assigned to both part cost and part volume.

3.3.2 Part Classification Procedure

At the instant where purchased parts are identified and their total quantities are computed, the total quantities are multiplied by unit cost and unit volume respectively to yield total cost to be committed and total volume to be stored, (see table 1).

Once the results are computed, part cost and part volume ratios are calculated as follows:

$$\text{Part Cost Ratio (PCR)} = \frac{P_i*Q_i - \sum_{i=1}^{n} \frac{P_i*Q_i}{n}}{\sum_{i=1}^{n} \frac{P_i*Q_i}{n}}$$

$$\text{Part Volume Ratio(PVR)} = \frac{V_i*Q_i - \sum_{i=1}^{n} \frac{V_i*Q_i}{n}}{\sum_{i=1}^{n} \frac{V_i*Q_i}{n}}$$

Whence, the parts combined ratio is computed as follows:

Parts Combined Ratio = PCR*WFc + PVR*WFv

Where,

- Pi - Unit purchase cost of the part i
- Qi - monthly usage of the part i
- vi - Unit volume of the part i
- n - Total number of parts in the system
- WFc- Cost weighing factor
- WFv- Volume weighing factor

The parts' combined ratios thus computed for all the parts are subjected to A, B, and C analysis in the following manner: The parts combined ratios are ranked in descending order. The first 10% (depending on the user's decision) of parts are classified as class "A" parts which signify high activity parts, the next 20% (or user defined) of the parts are classified as class "B" parts and the rest as class "C" parts.

As the parts are classified into groups, the manager should in his or her judgement, determine, as to how many months of stock is to be carried for each group. For example, not more one month of stock for class "A" parts, not more than three months of stock for class "B" parts and so on.

After the purchasing policies are defined, the total volume and the total cost are multiplied by the respective months of inventory to be stored.

The output of this exercise is the part number, total quantity of usage per month, unit cost, unit volume, class to which the part belongs, purchasing policy, total cost and total volume of the part to be stored.

3.3.3 Assignment of Bins and Pallets

The assignment of Bins and Pallets is done as described in section 3.2.2.

3.4 Productivity Indicators

The effectiveness of the system is best measured through the use of ratios and productivity indicators which have to be studied and managed for improvement over a considerable period of time. Two such indicators are considered here.

1. Overall Storage Efficiency
2. Aggregate Stock turns

3.4.1 Overall Storage efficiency

Overall Storage efficiency is computed as follows:

$$n\% = \frac{\text{Tot. vol. of parts to be stored}}{\sum_{i=1}^{n} N_i*W_i} * 100$$

Where, Ni - total number of bins of size i
Wi - volume of the bin i

It is evident that the greater the efficiency the lower is the warehousing or storage cost.

3.4.2 Aggregate stock turns

Theoretically, Inventory stock turn or turnover is defined as;

$$\text{Stock Turn} = \frac{\text{Annual cost of sales}}{\text{Cost of average inventory on hand}}$$

Often, people responsible in manufacturing industries judge inventory turns [10], by dividing the annual cost of sales by average inventory level, thus failing to measure the performance on an item-by-item basis. The theoretical stock turns do not reflect the true movement of the inventory.

For example, take the case of a firm whose inventory turned an average of five times a year. But, on an item-by-item analysis showed that 15% of the items were moving 25 times annually, while 85% of the items were moving only twice a year. On an item-by-item basis, the firm is not performing ideally.

Taking this facet into account, a technique is proposed here [11], to compute turnovers on an item-by-item basis.

The suggested procedure is as follows:

Step 1: The total costs per month ($) associated with each part belonging to class A, are grouped together and summed up to get the parameter "a".

i.e., $a = \sum_{i=1}^{n} Q_i * P_i$, i belonging to class A

Where, Pi - unit cost of part i
Qi - number of parts per month of part i

Similarly, the parameters "b" and "c" are established for classes "B" and "C" respectively.

Let $a + b + c = T$ (1)

Step 2: The cost proportions are calculated as follows:

Let $r_1 = a/T$

$r_2 = b/T$

$r_3 = c/T$

Step 3: The number of turns in months is calculated as follows:

For class "A" parts,

Turns At = 24/frequency of purchase in months

Similarly, Bt and Ct are calculated for classes B and C respectively.

Step 4:

Let $R_1 = r_1/At$

$R_2 = r_2/Bt$ and

$R_3 = r_3/Ct$

and let $R = R_1 + R_2 + R_3$

Finally, the Aggregate stock turns, A_st, is obtained by taking the inverse of R:

i.e., $A_st = 1/R$

Note: 1. The quantities A_t, B_t and C_t will depict the number of times each class is moving.

2. It is interesting to note at this point, that the higher the stock turns, the lower will be the overall storage efficiency of the warehouse. This is due to the fact that stock turns is a measure of frequency of purchase, and the higher the frequency, the less stock is stored in the same storage area. Consequently, the efficiency of the warehouse space reduces.

So far, a model for estimating storage space requirements and computing aggregate stock turns has been defined. The following section describes in detail, the implementation of the proposed model in a company manufacturing Health Care Equipment.

4.1 Inventory Requirements Analysis

4.1.1 Background

The company in which the system has been implemented, is part of a multinational organization, and mainly caters to the needs of Health care organizations, typical customers being hospitals.

During a study it has been found that, the company manufactures over one hundred types of end-products. The chief products are Intensive Care Incubators, Infant Warmer systems, Transport Incubators and Pediatric Tents.

Each of the above mentioned equipment has at least 300-400 component parts and a majority of them are purchased from vendors. The company also acts as a distribution center, and has to stock spare parts for the products already sold.

Different products have different production plans and hence it is very difficult to estimate the storage space requirements. A tool was developed to let know the manager at what point in time the company has to expand or lease for additional warehouse space.

Some parts that go into the end-products are bulky and are expensive, and some are tiny and expensive. Parts are also in all kinds of shapes and sizes.

Managing a typical inventory of nearly 8000 parts and finding storage space for all of them, at the same time maintaining a high customer service is not a small task, and to manage efficiently and effectively is much more difficult.

Therefore a planning and control tool was modelled to aid the decision maker to take corrective actions at the appropriate time.

4.1.2 IRA System

The IRA (Inventory Requirements Analysis) system incorporates two sub-systems; the main system itself and a model specific sub-system. The two systems are described in detail, in the following paragraphs.

4.1.3 Main System

The main system (Table 2) of the IRA comprises a set of default parameters built into it. These parameters will be used system wide unless the user changes them.

Table 2 depicts the Main Menu of the IRA system, from which the user could choose and or modify the parameters suitable to his or her needs. The Model Specific Sub-System Menu is very much similar to that of the main menu, but for few changes.

TABLE 2

```
            Inventory Requirements Analysis

SYS         current ACTIVE MODEL : GEORGE           MAIN MENU

0  IRA Description            4  LIST ALL MODELS
SYS OPTIONS-- MODEL OPTION CONTROL-----
--DEFAUALT MODEL Params--  --Purch/story Params Gen model results
11 Purch cost/vol WEIGHTS   51 Purchcost/vol     71 I,B Classify
12 Purch freq groups %      52 Purch group %     List Model reslts
13 Overide Purchg group     53 Overide pur grp.  81 End-prod F/C
14 Available Bins           54 Available Bins    82 List P/c Summ.
15 Available Pallets        55 Available Pallet  83 List Bin Summ.
16 Designated Pallet parts  56 pallet parts      84 Pallet Summ.
17 *Sel End-prod by Class   --F/C qty.-----      85 List parts
18 *Sel E-P F/C,/FPO's      61 Sel E-P By Class
(* Required by opt.21)      62 Sel E-P F/C,/FPO's
--MANMAN INTERFACE--                                9 EXIT from IRA
21 I,B GET F/C,/FPO's       63I GEN E-P F/C
22 List F/C,/FPO's          64 LIST/modify E-P F/C
31U, I, B Get Parts         65I,B Gen part F/C
32 LIST BOM                 66 LIST part F/C      ---------------
33 LIST part:Summ.BOM                             Enter OPT. # ---
34 LIST part:Where used
                                                   --------------
```

Note: The option to modify system-wide parameters is limited to key personnel in the organization.

The system-wide default parameters are defined as follows:

1. Weighing factors: Weighing factors, as described in an earlier section are used to classify parts into different classes based both on cost and volume. The default values of the weighing factors in the IRA system are 50 for for cost and 50 for volume.

2. BIN and PALLET sizes: The bin and pallet sizes that are defined in the main system are:

TABLE 3

Bin size	Volume	Pallet size	Volume
4x4x4	64	36x21x36	27216
6x12x6	432	36x42x36	54432
17.5x8x6	892	-	-

In the main system, a maximum of 5 bins can be used for the first two sizes of bins.

3. CLASS CODES: The IRA system is designed to extract all the class codes that are present in the MRP II system.

4. FORECASTS: The main IRA system is designed to extract forecasts for next six months beyond the current month.

5. percentage OF CLASSES: Three classes A, B, and C are defined and their percentages are 10%, 20% and 70% respectively.

6. FREQUENCY OF PURCHASE: The frequency of purchase is defined as follows; 1 month for class "A" parts, 3 months for class "B" parts and 6 months for class "C" parts.

4.2 Model Specific Sub System

4.2.1 Model

Model is a "Real-Life" representation of a inventory status, represented by a set of parameters. Generally models are used to assist with the analysis of a system; to specify relationships and processes; or to present a situation in symbolic terms that may be manipulated to derive predictions. This last purpose, to provide a prediction that can be manipulated to aid the decision-maker, is perhaps the most important attribute of models.

IRA is one such system which analyzes the present situation in terms of storage space requirements and stock turns, and suggests alternatives, based on the requirements of the user.

Since only authorized personnel can modify the system wide parameters, it would not be possible to examine "What-If" type of situations within the IRA main system.

Therefore, a model specific sub-system has been designed to simulate "What-If" situations. This model specific sub-system is exactly the same as that of the main system, but the user can modify the input parameters, depending on his or her needs. In this sub-system, the user may define the class codes he is interested in, bin and pallet sizes to study the efficiency of storage, storage and cash requirements in a particular month, weighing factors, percentage of parts belonging to each class (up to 10 classes can be defined) and their respective frequency of purchases. The user can try different alternatives and try to implement the most feasible and beneficial solution.

When the user modifies any or all of the parameters described earlier and the algorithm is run, the model specific parameters override the system-wide parameters and consequently, the results are based on the parameters defined in the model specific subsystem.

4.2.2 Capabilities of the IRA System

The IRA system is capable of letting the user know the exact storage space requirements based on production forecasts or firm planned orders and optimally configures the most efficient bin and pallet utilization depending on the individual part volume and usage. In addition to this, the system measures the storage efficiency, stock turn ratios and the projected cash required for procurement of vendor items. The system is an excellent tool to examine "what-if", situations.

4.2.3 Interface

The IRA system is interfaced with an MRP II system, called MANMAN, developed by ASK Computer Systems. The MANMAN is a fully integrated manufacturing system which includes modules such as Part Master Records, Bill of Material (BOM), forecast, Inventory, Purchasing, Routing and Workcenter Information. For the sake of IRA system, other modules of MANMAN are not considered here. The IRA system extracts data such as cost and volume from the MFG/ Part Master Records and Indented BOM from the MFG/ BOM module, product forecasts or firm planned orders from the MFG/ Master Schedule (Forecast module), order quantities and buyer codes from the MFG/ Purchasing module, and the inventory locations from the MFG/ Inventory module.

4.2.4 End-Product Classification

As described earlier end-products having similar product structures are grouped as a family. In this company, the criterion for grouping similar products into a family is as follows:

A given end-product has several attachments. The customer could opt for all or any one of the attachments for the end product, depending upon his or her needs. Each one of the attachments or accessories has its own product structure, comprising component parts. When each one of these attachments is combined with the basic product, the result is that the final product has almost the same product structure as compared to the end-product with a different accessory. Thus, end-products comprising a basic product structure and an accessory are grouped into a family and are assigned with product codes, in this case class codes.

Hence, several end-products could belong to the same class code, but each individual end-product has its own product structure.

4.3 The Methodology

The MFG/BOM module of the MANMAN system is extracted. As mentioned already, the source to identify purchased parts is the Indented BOM. The class codes are identified and each end-product belonging to that class code is exploded to capture the purchased parts. Once the purchased parts are identified, their quantity per assembly are stored and if the same part is used elsewhere in the same end-product, then the quantity per assembly is summed up to get total quantity per unit. The process is iterated until all parts in all products in all class codes are accounted for.

4.3.1 Volume Data Collection

The MFG/ Inventory control module of the MANMAN system has the ability to generate and sort reports in several ways. For example, it can generate a report sorted by part number. This report has information such as the part number, description, the bin or pallet location, and the quantity on hand.

It can also generate a report according to bin or pallet location, in an ascending order. Basically, these two reports have the same information, but portrayed differently. Obtaining accurate volume data for several hundred parts is cumbersome and often not feasible. So, it is easier and faster to estimate the volume for each part.

STEP 1: Purchased parts, as identified by the IRA system, are ticked off on the "Location Inventory status report", sorted by part numbers. The corresponding bin and pallet locations are also ticked off on the report.

STEP 2: The location numbers thus obtained are then transferred to "Location Inventory status report", this time sorted by Location.

This report now has the location, part number and the quantity on hand. This is now the working document. The reason for doing this is to simplify the procedure of obtaining volume data. Since the parts are not stored sequentially, but by random, it is only logical to move according to locations rather than by part numbers.

STEP 3: With the working document on hand, one has to go to each location, and if the part is a bulky item, length, breadth, and height are measured or if the part is small (usually in bins), volume is estimated according to the following procedure: The volume of the bin is known. Quantity on hand is given in the report. Using some discretion one has to estimate, how much of the bin space the given quantity is occupying.

Example: Suppose the bin volume is 892 Cu.In. and the quantity on hand is 500 and is occupying half the bin space, then

$$\text{Unit volume} = \frac{892}{500 * 2} = 0.892 \text{ Cu.In}$$

Once the volume data for all the purchased parts are calculated, they are entered into the Part Master Records of the MANMAN system.

4.3.2 Forecasts

To accurately estimate the number of bins and pallets required for different production plans, the IRA system interfaces with the MFG/ Forecasting module of the MANMAN system. The user has to define minimum and maximum number of months from the current month, the IRA system has to look into the future for production plans, so that it can extract the production forecasts within the date-range specified.

The user has three options to define the nature of production of forecasts. They are; 1. Average forecast, 2. Maximum forecast and 3. Mean Absolute Deviation (MAD). The user has to specify one of the three. The use of such options is as follows:

1. Average forecast: Suppose the user opts for average forecast; the IRA system computes the average monthly production forecast within the date-range specified. (Apparently, rounding off is performed either up or down or standard or none, as specified by the user). This type of forecast is used to determine the average inventory level to be maintained in the company.

2. Maximum forecast: If the user opts for this type of forecast, the IRA system takes into consideration the maximum production plan for a month within the date-range specified by the user. This type of forecast must be employed when a "Pessimistic" result regarding warehouse space is sought.

3. Mean Absolute Deviation: by definition, forecasts are potentially going to be inaccurate to some degree, whenever a decision is going to be made based on forecast quantities. However, it is useful to know how inaccurate that forecast is going to be. MAD is one of the better known techniques for measuring forecast errors.

MAD is mathematically defined as follows:

$$\text{MAD} = \sum_{i=1}^{n} \frac{A_i - F_i}{n}$$

where, A_i - actual demand for month i
F_i - forecasted demand for month i
n - number of periods in summation

Since the actual demand data is not available, the IRA system considers the sum of differences between the average forecast for the month within the date-range specified. An example of MAD is considered, to better understand the term:

TABLE 4

MONTHS	FORECAST	ACTUAL	DEVIATION
1	500	400	-100
2	500	550	+50
3	500	610	+110
4	500	440	-60
5	500	490	-10
6	500	530	+30
		TOTAL =	360

Therefore, MAD = 60.

Actually, MAD is mathematically related to the Standard Deviation by the equation,

1 MAD = 0.8 * Standard Deviation.

Thus, in the above example, MAD is found to be 60 units, it follows that the standard deviation is 48 units. Now, if the control limits are set at plus or minus 3 Standard Deviations, (or +- 3.75 MAD's), then 99.7% of the data points would fall within these limits.

Furnished below are the percentages of points included within the control limits for a range of 0 to 4 MAD's.

TABLE 5

Number of MAD's	Number of S.D.'s	% within the limits
+ (-) 1	0.798	57.048
+ (-) 2	1.596	88.946
+ (-) 3	2.394	98.334
+ (-) 4	3.192	99.856

It is clear that, to increase the confidence level, use of higher number of MAD is recommended.

4.4 Using the IRA system

Depending upon the user's option, either the main system or the model specific sub-system can be used to simulate a given situation.

The inputs to either of the systems are:

1. Part cost weighing factor 0-100; defined in the main system.
2. Part volume weighing factor 100-0;
3. Part classification groupings A, B, C..... up to 10 classes can be defined.
4. Percentage of parts in each of the groups defined in [3] above. (The default values in the main system are 10% for A, 20% for B and 70 % for C).
5. Frequency of purchase in months (in the main system, 1 month for class A, 3 months for class B and 6 months for class C).
6. Size and volume of the bins and pallets, and maximum number of bins per part.
7. Class codes to be considered (all or part of the class codes in the MANMAN).
8. Type of forecast (average, maximum or MAD).
9. Type of rounding off desired (up, down, standard or none).
10. User Defined Overrides: As a rule, the IRA

system, depending upon the class to which it belongs, assigns the frequency of purchase (defined by the user) to that part and then computes the total cost and total volume to be stored.

If in the opinion of the user, the order policy conflicts with that of the vendor, he or she could override the policy, by manually entering the new order policy into the system, for the parts having such conflicts.

Once the inputs are clearly defined, the IRA system is designed to employ the ABC Analysis technique described under the algorithm section earlier.

4.4.1 System Outputs

Once the model is created and initiated, the following results are obtained.

1. The system gives a detailed breakdown of the purchased parts, parts description, source code, part's monthly cost, part's monthly volume to be stored, part cost ratio, and part's combined ratio.

2. Based on part's combined ratio, the class to which the part belongs, frequency of purchase and the buyer code for the part are provided.

3. Depending upon the total volume to be stored, size and number of bins or pallets required and the parts storage efficiencies are displayed and or printed.

4. In a summary report, the IRA system gives production forecasts for each product, type of forecast, total number of bins and pallets required, comparison between the available storage space and required storage space, overall storage efficiency and aggregate stock turns.

4.4.2 Interpretation of Results

1. The IRA system highlights the difference between the available and required storage space (Table 6). Based on this information, management can make a decision as to expand the existing warehouse or lease additional space.

TABLE 6

Bin and Pallet Summary for GEORGE IRA

Cost wt. --50 Vol. wt.---50

Bin/Pall	Unit vol	Lmt	Avail	Req	Var	Vol Req	Vol. Uti	Eff%
C	892	0	3080	5994	-2914	5346648	5041061	94.28
A	27216	0	882	627	255	17064432	14624381	85.70
Total Storage						22411080	19665442	87.50

2. The inventory turns (Table 7), computed by the IRA system, indicate the performance of the purchasing personnel. If the turnovers are very low, one can easily identify the source or class of parts causing it and make suitable corrections.

TABLE 7

Inventory Requirements Analysis
Purchasing Group Summary for GEORGE:

Cost Weight --50 Vol. Weight -- 50

Pur.grp	frq	%	Stock turns	Mon.Cost	Cost%	VOL.%
A	1	10	24	344745.629	61.48	88.55
B	2	20	12	124640.816	22.23	10.35
C	6	70	4	91360.457	16.29	1.10
TOTAL		100	11.78	560746.902	100.00	100.00

3. The individual part storage efficiencies can be used to detect parts which have low storage efficiencies, and if feasible, could be transferred from bins to pallets or vice versa.

4.5 Conclusion

The idea of integrating all manufacturing resources brings substantial benefits if properly implemented. Strangely enough, storage space, which is an expensive resource has been greatly ignored.

In this study, techniques were developed to be incorporated into MRP II systems, to estimate storage space for raw materials and also to accurately compile the inventory turns. Based on the information provided by the IRA system, corrective action can be taken at an appropriate time.

The IRA software system, has been developed and implemented in a manufacturing plant.

5.1 Acknowledgements

The authors greatly appreciate the help and support from the staff and managers of OHMEDA, for their excellent support and cooperation, during the whole length of the project. Thanks are also due to William Rhoad, for his help regarding the development of the system on the mainframe.

6.1 References

1. Warehousing and Physical Distribution Productivity Report, volume 17, number 10, Oct. 15, 1982.
2. John H.Volpel, "Warehouse Space-How Much?" Journal of Industrial Engineering, January 1969.
3. David Einbinder, "Daily Loading Records Predict Warehousing Needs", Journal of Industrial Engineering, June 1971.
4. Warehousing and Physical Distribution Productivity Report, volume 17, number 10, January 15, 1982.
5. Roger G. Schroeder, " Operations Management" Decision Making in the Operations Function. McGraw-Hill series in management, second edition.

6. Chase and Aquilano, "Production and Operations Management".

7. Murdick and Ross, "Information Systems for Modern Management", Prentice Hall, second edition.

8. Richard H. Tersine, "Materials Management and Inventory Systems, North-Holland Publishing Company.

9. "Industrial Applications of ABC Curves", AIIE Transactions, volume 8, number 2, June 1976.

10. Kenneth B. Ackerman, "Practical Hand Book of Warehousing", pp. 331-332, I Edition, Traffic Service Corp. 1983.

11. Berne J. Hanford, "The Measure of a Well Turned Inventory Part III", P & IM Review, September 1986.

BIOGRAPHY

Dr. George Harhalakis qualified as a Mechanical Engineer at the National Technical University of Athens, in 1971. He has worked in industry in Greece and in Britian for twelve years in the areas of manufacturing, production planning and control and manufacturing management.

He joined the University of Manchester Institute of Science and Technology in September 1980. In October 1981 he obtained his MSc degree in Manufacturing Technology and in May 1984 he obtained his PhD degree while he specialized in Computer Integrated Manufacturing Systems.

He has also worked as a consultant with Ingersoll Rand (UK) Co., Ltd., Staveley Vessels and Joseph Adamson Co., Ltd. in England.

In September 1984, he was appointed as an Assistant Professor by the University of Maryland, Mechanical Engineering Department. He is teaching at both graduate and undergraduate levels and his research evolves around computer integrated manufacture (MRP II systems, integration of MRP II with CAD and Production Scheduling techniques).

Finally, he is a full member of the American Society of Mechanical Engineers (ASME), American Production & Inventory Control Society (APICS), the International Project Management Association (INTERNET) and the American Society for Engineering Management (ASEM).

Mr. Phani Sharma is a graduate student in the department of Mechanical Engineering, at the University of Maryland, College Park. He obtained his Bachelors degree in Industrial and Production Engineering from University of Bangalore, India, in 1984. He worked as a Production Planning Engineer in an aluminum extrusion company, for nearly a year and later joined the University of Maryland Master's degree Program. His academic interests are Inventory Management, MRP II and Industrial Engineering Techniques.

Mr. William Zachmann is an Industrial Economist from the Universidad de Los Andes in Bogota, Colombia in 1975. He has 5 years experience in warehousing, distribution and store operations in the supermarket industry in Colombia.

In 1982 he completed his MBA degree in Harvard Business School and joined the BOC Group, Inc. working in internal consulting, materials management, production management and operations management for their Health Care Group.

He has taught Business Logistics in Colombia and is a member of APICS.