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# ANALYZING THE IMPACT OF SPACE UTILIZATION AND PRODUCTION PLANNING ON PLANT SPACE REQUIREMENTS – A CASE STUDY AND METHODOLOGY

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In 2001, the authors took part in a study aimed at evaluating the costs and benefits of centralizing warehousing activities for a network of four plants at a first-tier automotive supplier. A key issue raised during the study centered on how much space was available at each of the plants, and how much space could be recaptured through improved layout and space utilization efforts, and through improved production planning practices. This paper focuses on the steps carried out to 1) quantify the space at each plant, 2) estimate manufacturing, inventory storage, and shipping and receiving space utilization levels, and 3) estimate the impact of production planning on inventory space requirements.

**Significance:** A methodology is presented which explicitly considers the impact of space utilization and production planning on plant space requirements. The results obtained were pivotal to the manufacturer's decision to forego a new centralized warehouse, and instead focus on better utilizing current space and eliminating excess inventories driven by the manufacturer's current planning and control practices.

**Keywords:** Warehouse design, Facilities design, Production planning and control.

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## 1. INTRODUCTION

This paper describes one part of a larger study carried out on behalf of a global first-tier supplier of automotive parts and subassemblies. The supplier operated five U.S. plants., four of which (Plants 2 through 5) were located within 80 kilometers of one another.

The supplier used an integrated logistic system to coordinate material flows between the plants. However, each plant was still responsible for managing its own warehousing operations, including production inventory and maintenance, repair and operating (MRO) supplies.

The objective of the larger study was to compare the costs and benefits of maintaining warehousing and inventory functions within each of the Plants 2 through 5, versus centralizing these functions in a single distribution center. To do a complete job, the study firm personnel had to consider:

1. The space requirements at the various plants;
2. The costs and savings associated with opening a new centralized warehouse; and:
3. The internal politics and personnel issues associated with moving warehousing and inventory management functions into a single location.

Rouwenhorst et al. (2000) classify warehouse decisions into three levels: strategic, tactical, and operational. Operational and tactical warehousing decisions typically lend themselves to more standardized approaches than do strategic decisions. In contrast, strategic warehousing decisions – such as the one addressed in this study – present a complex mix of "soft", organizational issues and "hard", quantitative ones ( Hunnicutt, 2001).

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This paper focuses on a methodology we developed to deal with the first issue, estimating the space requirements at the various plants. In particular, the study firm wanted to know what impact space utilization practices and production planning rules had on space requirements. The methodology described here is generalizable to other environments, and has several key advantages. First, it is based on data provided by the study firm itself, thereby helping to gain managerial acceptance of the results. Second, the methodology uses space density factors, described below, to estimate how well current space is utilized. Third, the methodology explicitly considers the impact of planning and control practices on space requirements. This last point is especially important, since it is often not apparent through physical inspection what inventory is actually needed for smooth plant operations.

From a generic strategic warehousing decision-making perspective, this paper focuses on a methodology to support the decision to consolidate warehouses in a multistage production system. This specific topic, to the best knowledge of the authors, has not been previously addressed in the literature. The literature that deals with the warehouse consolidation problem usually addresses this problem in the context of distribution networks and the relevant factors that are analyzed here are of a completely different nature from the ones accounted for in this paper (see, e.g., Melachrinoudis, et al (2005), Lim et al (2003) and Özdamar and Yazgaç (1999)).

## 2. METHODOLOGY

Table 1 summarizes the four steps of the methodology, which are described in the remainder of the paper.

Table 1. Methodological steps for estimating requirements

| Step | Data (Source) |
|---|---|
| 1. Quantify current space allocations and the value of freed-up space at each plant. | • Blueprints of current plant layouts and space cost estimates (plant management) |
| 2. Develop space density factors for the manufacturing and storage areas at each plant. | • On-site inspection of storage areas within each plant (plant personnel and authors) |
| 3. Estimate the impact of production planning procedures on inventory space requirements. | • Production planning records (planning personnel)<br>• Container sizes, stacking heights, and capacity data (materials management personnel)<br>• Excel simulation of production planning activities (authors) |
| 4. Estimate the combined impact of space density and production planning procedures on plant space requirements. | • Output from Steps 1 – 3 and Excel spreadsheet analysis |

**Step 1: Quantify current space allocations and the value of freed-up space.**

The first step involved quantifying current space allocations and the cost of floor space at each of the plants. We started by sending a detailed form to each of the plant managers. The form included questions covering, among other things, space usage for manufacturing processes, WIP, storage, and shipping / receiving. We followed up with on-site visits to each plant, where we confirmed or modified the estimates with the help of plant personnel, internal documents (including plant blueprints), and plant inspections. From this data, we developed the following estimates for each plant:

1. "Manufacturing area" - the space currently allocated to manufacturing and WIP, even if not totally occupied.
2. "Storage area" - all the warehouse space, with the exception of shipping and receiving.
3. "Shipping / receiving area"
4. "Manufacturing space costs" - this variable is broadly defined as the value that management attributes to freed up space at the plant. Since each of the plants was facing space constraints, management pegged this as the cost to acquire additional manufacturing space ($50 per square foot).

Table 2 summarizes the results.

Table 2. Base-line space allocations at the study plants

| | Plant Areas (square footage) | | | | |
|---|---|---|---|---|---|
| | Plant 2 | Plant 3 | Plant 4 | Plant 5 | **Total** |
| Manufacturing | 126,400 | 316,000 | 65,000 | 72,800 | **580,200** |
| Storage | 24,000 | 14,000 | 5,800 | 43,500 | **87,300** |
| Shipping / Receiving | 4,800 | 800 | 6,600 | 19,980 | **32,180** |
| **Grand Total** | | | | | **699,680** |

**Step 2. Develop space density factors.**

During the on-site visits, it became apparent that allocated plant space was not being fully utilized at any of the facilities. This was particularly true for the storage and shipping / receiving areas. Because current utilization levels would have an impact on whether or not additional space was needed, we introduced a new variable, called space density factors. Space density factors are defined as the percentage of currently allocated space that is not being utilized. Table 3 summarizes the estimated space density factors. It is important to note that these estimates were developed jointly by the authors and plant personnel. (Later on, we evaluate how sensitive the results are to changes in these estimates.)

Table 3. Space density factors

| | Space Density Factors | | | |
|---|---|---|---|---|
| | Plant 2 | Plant 3 | Plant 4 | Plant 5 |
| Manufacturing | 2% | 2% | 30% | 17% |
| Storage | 60% | 50% | 30% | 20% |
| Shipping / Receiving | 60% | 0% | 50% | 20% |

To illustrate how the space density factors were used, we calculated how much space could be saved in Plant 2 by multiplying the space estimates (Table 2) by the appropriate density factors:

Plant 2:
Manufacturing: 126,400 * 2% = 2,528
Storage: 24,000 * 60% = 14,400
Shipping / Receiving: 4,800 * 60% = 2,880
Total Space Savings: 19,808 square feet

As the space density factors suggest, space utilization tended to be significantly better in the manufacturing areas than in the storage and shipping / receiving areas. There were several reasons for this. First, the manufacturing processes had already been laid out to minimize movement times and maximize the number of workstations that could be handled by a worker. In contrast, the storage and shipping / receiving areas were plagued by numerous problems. For example:

- Racks and floor storage areas often had fixed space assignments, meaning that a particular item could only be stored in one place. Therefore, extra space had to be built into each assigned area.
- Containers were not standardized. As a result, racks and floor storage areas had to be planned around the biggest container, resulting in even more dead space.
- Space assignments had not been re-evaluated as the needs of the business had changed, resulting in large, empty storage areas.

**Step 3. Estimate the impact of production planning procedures.**

It also became apparent that improving space utilization was not the only way the plants could free up space. Specifically, the age of some of the items in storage, as well as inventory turns at the plants, suggested that the production planning procedures built a lot of "fat" into the system. The result was excessive WIP and raw material inventories that inflated space requirements.

To develop a detailed picture of the impact production planning procedures had on storage space requirements, we built simulation models that precisely replicated the study firm's MRP system for two representative end items, Product A and Product B. These products were selected because plant personnel identified them as representative of the plants' product lines, and any conclusions drawn for these two products could be extrapolated to the remainder of the product line.

To build the simulation models, planning personnel provided us with actual demand, production orders and inventory records for all the major components within Products A and B. We also collected information that allowed us to trace the routings of these major components. Because we wanted to understand the impact of planning and control procedures on space requirements, we paid particular attention to lot sizes, safety stock policies, and container sizes.

From this information, we built Excel spreadsheets that replicated the MRP logic for the major components found within Products A and B. These spreadsheets allowed us to:

1. Show component inventory levels for a ten-week period, based on actual decision rules followed by the plants.
2. Calculate the resulting space requirements for the major components.
3. Evaluate the simultaneous impacts of inventory cuts and unexpected demand surges on inventory levels and space requirements.

To make the simulations as realistic as possible, we carried them out under the following conditions:

1. Container sizes, lot sizes, and safety stock policies were derived from the company's MRP records, decision rules, and interviews with materials management personnel.
2. Beginning inventory and demand numbers covering a time interval of ten weeks were taken from the company's actual MRP records.
3. Production quantities were frozen over the plant's stated lead times.

The experimental conditions were as follows:

- Product A or Product B demand was bumped up by 0% (base case), 5%, 10%, 20%, 30% and 40% for each of the first eight weeks;
- Beginning inventory and safety stock quantities were cut across the major components by 0% (base case), 10%, 20%, 30%, 40% and 50%.

If none of the components experienced a stockout, even as demand was increased and inventory levels decreased, we could conclude that there was excessive inventory in the system. We next illustrate how the simulations worked for two sample components. Figure 1 shows a simplified bill of material for Product A, which includes Components C and D.

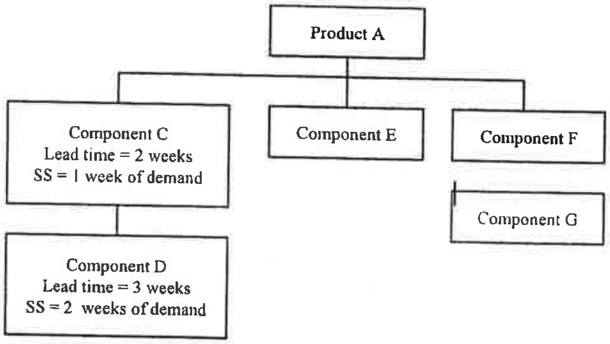


Figure 1. Simplified BOM for Product A

Figures 2 and 3 show the Excel spreadsheet used to perform the simulations. Figure 2 contains results for the base case, while Figure 3 contains results for one of the experimental conditions. The "Base Assembly Schedule" contains actual assembly schedule numbers for the major product, in this case Product A. The "Demand adjustment" cell allows the investigator to vary to demand over the first eight weeks, resulting in the "Modified Assembly Schedule."

The "Beginning inventory & SS adjustment cell" allows the investigator to vary beginning inventory levels and safety stock levels for the components. For example, if the base case rule is to end each period with enough inventory to cover the next two weeks worth of gross requirements, putting a value of 70% into this cell will result in an ending inventory level equal to 70% of this amount.

Because Component C was a Level 1 MRP component and had a 1-to-1 relationship with Product A, the modified assembly schedule becomes the gross requirements for Component C. MRP results for Weeks 1 and 2 are shaded due to that fact that Component C has a two-week lead-time. Scheduled Receipts for the first two weeks are therefore frozen. Because the study firm wanted to keep a one-week safety stock, scheduled and planned receipts are set to ensure that "Projected Ending Inventory" for each week equals "Gross Requirements" for the following week.

The MRP record for Component D is essentially the same, except that gross requirements comes from the planned orders for Component C, and scheduled receipts are frozen for the first three weeks. In addition, scheduled and planned receipts are set to ensure that "Projected Ending Inventory" for each week equals "Gross Requirements" for the following two weeks.

The final two tables of numbers in Figures 2 and 3 translate the MRP average inventory numbers into space requirements. Component C was stored on pallets containing up to 50 items each. These pallets have a footprint of 17.3 square feet, and could be stacked three high. Therefore, for Week 1 of the base case (Figure 2):

$$\text{Average inventory} = \frac{\text{Beginning Inventory} + \text{Ending Inventory}}{2} = \frac{1000+1100}{2} = 1050\,;$$

Number of pallets $= \dfrac{1050}{50} = 21$ pallets;

Number of stacks $= \dfrac{21}{3} = 7$;

Square footage required $= 7 * 17.3 = 121.10$ square feet.

Figure 2 shows that, for the base case, Component C required, on average, 128.75 square feet of floorspace, while Component D required 69.2 square feet. In Figure 3, the assembly schedule quantities for Product A are increased by 30% in each of the first eight weeks. Simultaneously, starting inventory levels and safety stocks for Components C and D are lowered by 30%. Note that, even under these conditions, the study firm would not have run out of either component. Still, average floorspace requirements for Components C and D fell to 60.55 and 29.95, respectively.

Figures 2 and 3 show just two of the experimental conditions. Complete simulation results for all of Product A's and B's components are summarized in Tables 4 and 5, respectively. To show how the tables are interpreted, consider Table 4. In one simulation experiment, we cut beginning inventories and safety stock values for all of Product A's major components by 10% and bumped Product A demand for the next 8 weeks by 10%. Even under these extreme conditions, none of the components that went into Product A experienced a stockout. However, space requirements were reduced by 12% over the base case due to the lower inventory levels and higher usage rates.

Table 4. Square footage savings for Product A's components (as a % of base case)

| | | **Demand Bump (Weeks 1 - 8)** | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0% | 5% | 10% | 20% | 30% | 40% |
| **Beginning and safety stock cut** | 0% | 0% | 1% | 2% | 4% | stockout | stockout |
| | 10% | 9% | 11% | 12% | stockout | stockout | stockout |
| | 20% | 20% | 21% | stockout | stockout | stockout | stockout |
| | 30% | stockout | stockout | stockout | stockout | stockout | stockout |
| | 40% | stockout | stockout | stockout | stockout | stockout | stockout |
| | 50% | stockout | stockout | stockout | stockout | stockout | stockout |

Table 5. Square footage savings for Product B's components (as a % of base case)

| | | **Demand Bump (Weeks 1 - 8)** | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0% | 5% | 10% | 20% | 30% | 40% |
| **Beginning and safety stock cut** | 0% | 0% | 1% | 2% | 4% | 6% | stockout |
| | 10% | 10% | 11% | 12% | 14% | stockout | stockout |
| | 20% | 20% | 21% | 22% | 24% | stockout | stockout |
| | 30% | 31% | 31% | 32% | stockout | stockout | stockout |
| | 40% | 41% | 41% | 43% | stockout | stockout | stockout |
| | 50% | 51% | 51% | 52% | stockout | stockout | stockout |

Tables 4 and 5 suggest that, through targeted inventory and safety stock cuts, the company could achieve significant space savings without seriously jeopardizing its ability to ship products on time. Based on these simulation results, we developed jointly with study firm personnel a set of inventory reduction factors for each of the plants. These inventory reduction factors represented both parties' best estimates of how much plant inventory levels could be reduced through more efficient production planning.

Table 6. Inventory reduction factors, based on simulations of current production planning systems

| | Plant 2 | Plant 3 | Plant 4 | Plant 5 |
|---|---|---|---|---|
| Inventory reduction factor | 20% | 20% | 30% | 20% |

**Product A**

Week

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Assembly Schedule | | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 |
| Demand adjustment | 100% | | | | | | | | | | |
| Modified Assembly Schedule | | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 |
| Beginning inventory & SS adjustment | 100% | | | | | | | | | | |

**Component MRP Records**

**Component C (Lead time = 2 weeks; Safety stock = 1 week)**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gross Requirements | | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 |
| Scheduled Receipts | | 1100 | 1200 | | | | | | | | |
| **Proj. Ending Inventory** | **1000** | **1100** | **1200** | **1300** | **1400** | **1500** | **1600** | **1700** | **1800** | **1900** | **1900** |
| Planned Receipts | | | | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 1900 |
| Planned Orders | | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 1900 | 1900 | 1900 |

**Component D (Lead time = 3 weeks; Safety stock = 2 weeks)**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gross Requirements | | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 1900 | 1900 | 1900 |
| Scheduled Receipts | | 1500 | 1600 | 1700 | | | | | | | |
| Proj. Ending Inventory | **2700** | **2900** | **3100** | **3300** | **3500** | **3700** | **3800** | **3800** | **3800** | **3800** | **3800** |
| Planned Receipts | | | | | 1800 | 1900 | 1900 | 1900 | 1900 | 1900 | 1900 |
| Planned Orders | | 1800 | 1900 | 1900 | 1900 | 1900 | 1900 | 1900 | 1900 | 1900 | 1900 |

**Resulting pallet and space requirements (dervied from MRP inventory records)**

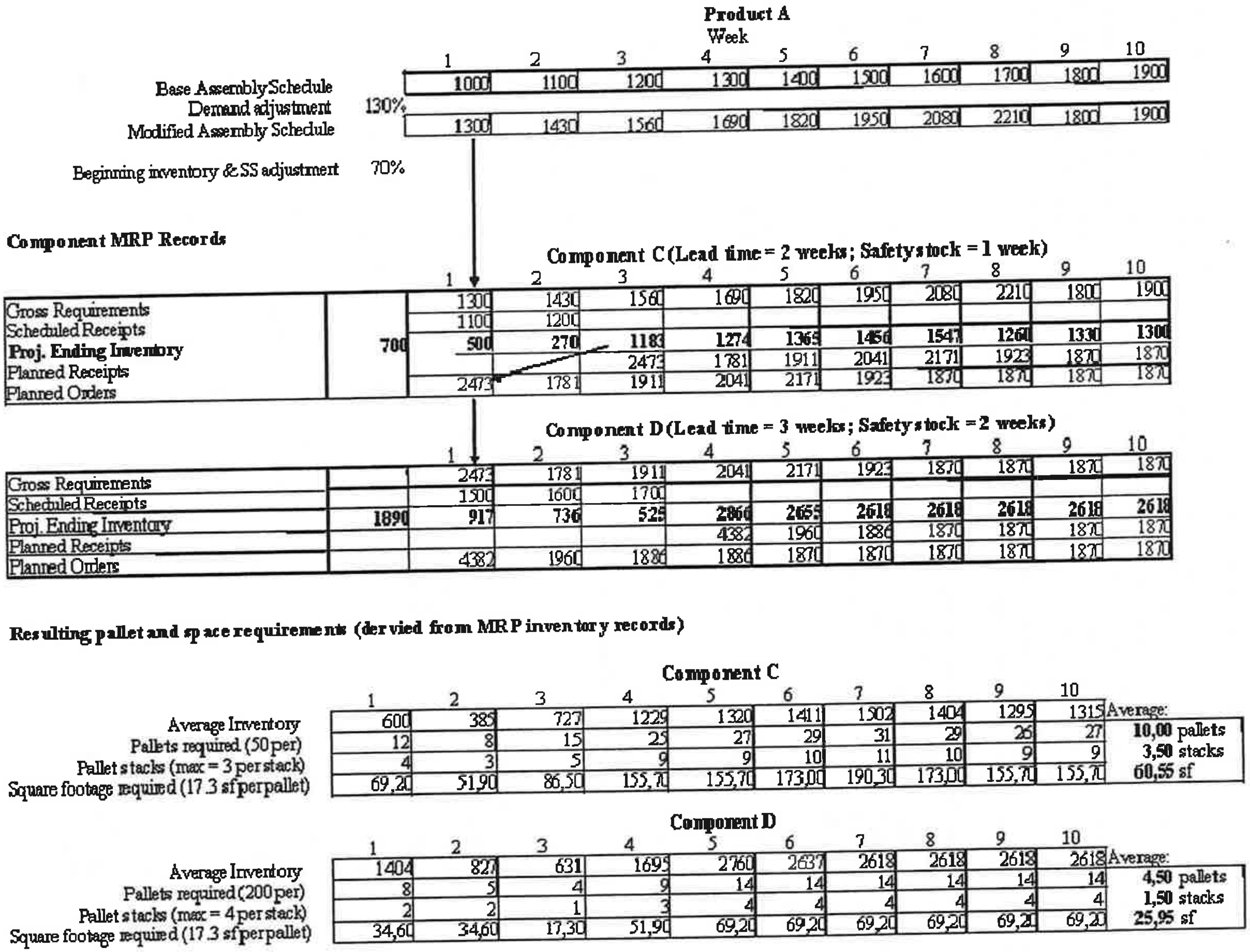
**Component C**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average: |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Inventory | 1050 | 1150 | 1250 | 1350 | 1450 | 1550 | 1650 | 1750 | 1850 | 1900 | |
| Pallets required (50 per) | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 38 | **22,00 pallets** |
| Pallet stacks (max = 3 perstack) | 7 | 8 | 9 | 9 | 10 | 11 | 11 | 12 | 13 | 13 | **7,50 stacks** |
| Square footage required (17.3 sf perpallet) | 121,10 | 138,40 | 155,70 | 155,70 | 173,00 | 190,30 | 190,30 | 207,60 | 224,90 | 224,90 | **129,75 sf** |

**Component D**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average: |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Inventory | 2800 | 3000 | 3200 | 3400 | 3600 | 3750 | 3800 | 3800 | 3800 | 3800 | |
| Pallets required (200 per) | 14 | 15 | 16 | 17 | 18 | 19 | 19 | 19 | 19 | 19 | **15,50 pallets** |
| Pallet stacks (max = 4 perstack) | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | **4,00 stacks** |
| Square footage required (17.3 sf perpallet) | 69,20 | 69,20 | 69,20 | 86,50 | 86,50 | 86,50 | 86,50 | 86,50 | 86,50 | 86,50 | **69,20 sf** |

Figure 2. Base case MRP simulation for components C and D



**Product A**

Week

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Assembly Schedule | | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 |
| Demand adjustment | 130% | | | | | | | | | | |
| Modified Assembly Schedule | | 1300 | 1430 | 1560 | 1690 | 1820 | 1950 | 2080 | 2210 | 1800 | 1900 |

| | |
|---|---|
| Beginning inventory & SS adjustment | 70% |

**Component MRP Records**

**Component C (Lead time = 2 weeks; Safety stock = 1 week)**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gross Requirements | | 1300 | 1430 | 1560 | 1690 | 1820 | 1950 | 2080 | 2210 | 1800 | 1900 |
| Scheduled Receipts | | 1100 | 1200 | | | | | | | | |
| **Proj. Ending Inventory** | **700** | **500** | **270** | **1183** | **1274** | **1365** | **1456** | **1547** | **1260** | **1330** | **1300** |
| Planned Receipts | | | | 2473 | 1781 | 1911 | 2041 | 2171 | 1923 | 1870 | 1870 |
| Planned Orders | | 2473 | 1781 | 1911 | 2041 | 2171 | 1923 | 1870 | 1870 | 1870 | 1870 |

**Component D (Lead time = 3 weeks; Safety stock = 2 weeks)**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gross Requirements | | 2473 | 1781 | 1911 | 2041 | 2171 | 1923 | 1870 | 1870 | 1870 | 1870 |
| Scheduled Receipts | | 1500 | 1600 | 1700 | | | | | | | |
| Proj. Ending Inventory | **1890** | **917** | **736** | **525** | **2866** | **2655** | **2618** | **2618** | **2618** | **2618** | **2618** |
| Planned Receipts | | | | | 4382 | 1960 | 1886 | 1870 | 1870 | 1870 | 1870 |
| Planned Orders | | 4382 | 1960 | 1886 | 1886 | 1870 | 1870 | 1870 | 1870 | 1870 | 1870 |

**Resulting pallet and space requirements (dervied from MRP inventory records)**

**Component C**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average: |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Inventory | 600 | 385 | 727 | 1229 | 1320 | 1411 | 1502 | 1404 | 1295 | 1315 | |
| Pallets required (50 per) | 12 | 8 | 15 | 25 | 27 | 29 | 31 | 29 | 26 | 27 | **10,00 pallets** |
| Pallet stacks (max = 3 per stack) | 4 | 3 | 5 | 9 | 9 | 10 | 11 | 10 | 9 | 9 | **3,50 stacks** |
| Square footage required (17.3 sf per pallet) | 69,20 | 51,90 | 86,50 | 155,70 | 155,70 | 173,00 | 190,30 | 173,00 | 155,70 | 155,70 | **60,55 sf** |

**Component D**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average: |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Inventory | 1404 | 827 | 631 | 1695 | 2760 | 2637 | 2618 | 2618 | 2618 | 2618 | |
| Pallets required (200 per) | 8 | 5 | 4 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | **4,50 pallets** |
| Pallet stacks (max = 4 per stack) | 2 | 2 | 1 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | **1,50 stacks** |
| Square footage required (17.3 sf per pallet) | 34,60 | 34,60 | 17,30 | 51,90 | 69,20 | 69,20 | 69,20 | 69,20 | 69,20 | 69,20 | **25,95 sf** |

Figure 3. MRP simulation for components C and D, demand increased by 30% and beginning inventory cut by 30%

**Step 4. Estimate combined impact on plant space requirements.**

The final step in the analysis was to pull together the results from Steps 1 – 3 to get a comprehensive picture of the actual space requirements in the plants, and the savings (in space and dollar terms) associated with improving space utilization and production planning procedures. The results are shown in Table 7.

The first two matrices in Table 7 show the impact of improving space density on Plants 2 through 5. Estimated net savings was nearly 82,740 square feet, or (82,740 / 699,680) = 11.8% of the total current space. The second two matrixes show the combined impact of space density *and* inventory reduction vis-à-vis improved production planning procedures. Note that improvements to production planning *only* affected the storage areas. Under this combined scenario, net savings of 94,238 square feet could be achieved, or (94,238 / 699,680) = 13.4% of current space. At $50 a square foot, the monetary savings per year were estimated to be $50 * 94,238 = $4,711,900.

To test the sensitivity of our analysis, we performed two additional tests:

- Sensitivity Test 1. All estimated space density and inventory reduction factors were reduced by 25% each. For example, a space density factor that was originally 60% would now be 60%*(1-25%) = 45%. This allowed us to see what the results would be if the current factor values grossly *over-estimated* the potential space savings.
- Sensitivity Test 2. All estimated space density and inventory reduction factors were increased by 25% each. This allowed us to see what the results would be if the current case factor values grossly *under-estimated* the potential space savings.

Table 8 contains the summary results for the sensitivity tests. Even under the most conservative estimates (Sensitivity test 1), the results suggest that the manufacturer could save nearly 72,000 square feet in space, worth approximately $3.5 million, by improving space utilization and production planning practices.

Table 7. Summary results, using space density and inventory reduction factors from Tables 3 and 6

| **Space requirements w/ improved density** | | | | | |
|---|---|---|---|---|---|
| | | **Plant 2** | **Plant 3** | **Plant 4** | **Plant 5** |
| Manufacturing | | 123,872 | 309,680 | 45,500 | 60,424 |
| Storage | | 9,600 | 7,000 | 4,060 | 34,800 |
| Shipping & Receiving | | 1,920 | 800 | 3,300 | 15,984 |
| **TOTAL** | | **135,392** | **317,480** | **52,860** | **111,208** |
| **GRAND TOTAL:** | **616,940** | | | | |
| **Net Savings due to improved density** | | | | | |
| | | **Plant 2** | **Plant 3** | **Plant 4** | **Plant 5** |
| Manufacturing | | 2,528 | 6,320 | 19,500 | 12,376 |
| Storage | | 14,400 | 7,000 | 1,740 | 8,700 |
| Shipping & Receiving | | 2,880 | 0 | 3,300 | 3,996 |
| **TOTAL** | | **19,808** | **13,320** | **24,540** | **25,072** |
| **GRAND TOTAL** | **82,740** | | | | |
| **Space requirements w/ improved density & inventory reduction** | | | | | |
| | | **Plant 2** | **Plant 3** | **Plant 4** | **Plant 5** |
| Manufacturing | | 123,872 | 309,680 | 45,500 | 60,424 |
| *Storage* | | 7,680 | 5,600 | 2,842 | 27,840 |
| Shipping & Receiving | | 1,920 | 800 | 3,300 | 15,984 |
| **TOTAL** | | **133,472** | **316,080** | **51,642** | **104,248** |
| **GRAND TOTAL:** | **605,442** | | | | |
| **Net Savings due to improved density & inventory reduction** | | | | | |
| | | **Plant 2** | **Plant 3** | **Plant 4** | **Plant 5** |
| Manufacturing | | 2,528 | 6,320 | 19,500 | 12,376 |
| Storage | | 16,320 | 8,400 | 2,958 | 15,660 |
| Shipping & Receiving | | 2,880 | 0 | 3,300 | 3,996 |
| **TOTAL** | | **21,728** | **14,720** | **25,758** | **32,032** |
| **GRAND TOTAL:** | **94,238** | | | | |

Table 8. Sensitivity analysis results.

| | Current factor values (Table 7) | Sensitivity Test 1 (factor values decreased by 25%) | Sensitivity Test 2 (factor values increased by 25%) |
|---|---|---|---|
| Space requirements w/ improved density and inventory reduction (sf), Grand Total | **605,442** | 627,775 | 583,927 |
| Net savings (sf), Grand Total | **94,238** | 71,905 | 115,753 |
| Estimated monetary savings ($50 per sf) | **$4,711,900** | $3,595,256 | $5,787,656 |

## 3. CONCLUSIONS

The results of the analysis proved to be pivotal to the manufacturer's decision about whether or not to put in place a centralized warehouse. The analysis indicated that there was plenty of space available in the plants to meet growth requirements over the next five years, if the plants worked to improve space utilization and production planning procedures. And unlike the centralized warehouse option, the additional space could be reclaimed without making a significant capital investment.

From an academic perspective, the methodology described here makes a contribution to the literature because it 1) focuses attention on two additional drivers of space requirements – poor space utilization and excessive inventory due to poor production planning procedures -- and 2) demonstrates ways in which researchers may explicitly consider the impact of these drivers.

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