A Decision Support System for Integrated Inventory Management

by

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A pervasive business problem is the conflict between keeping inventory low to minimize inventory cost and the need to have products available for customers at the right place and the right time. This problem is exacerbated when products have a high cost per unit and customer service requirements are high.

This problem is examined for a major international manufacturer of medical diagnostic equipment. A decision support tool is developed to assist the organization in deciding where service parts should be inventoried and in what quantity to minimize total inventory and logistics cost, while meeting a demanding customer service requirement.

Many organizations have wrestled with the issues of inventory locations and stocking levels. When it is critical to have inventory available for customers, the traditional approach has been to place a large amount of inventory at all locations. Carrying an excessive amount of inventory achieves a high service level, but can be enormously costly, especially if the product has a high cost per unit.

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In today’s increasingly competitive marketplace organizations cannot afford to carry excessive levels of inventory. At the same time customer service, which includes having the product available for the customer at the right place and the right time, is increasingly important. To balance these two issues it is critical for an organization to set a service level goal and strategically plan their inventory logistics to achieve this goal at minimum cost.

This critical issue was studied for a service parts inventory where the organization had made a challenging service commitment of an eight hour response time.

Background

Roche Diagnostics is a major international manufacturer of medical diagnostic systems. Their customers include medical laboratories of all kinds such as those in hospitals, research centers, medical clinics, etc. Over 12,000 laboratories around the world utilize their diagnostic systems. A pending acquisition will put sales in excess of three billion dollars annually.

The Integra is a recently developed innovative medical diagnostic apparatus that consolidates the operation of many different pieces of lab equipment. This reduces the cycle time of medical tests and increases the efficiency of the lab. The Integra is an integrated system of hardware, software, and reagents which offers economic viability through task consolidation. The majority of laboratory workload can be streamlined on this single multi-tasking system.

As a result, the operation of the Integra is critical to the operation of the lab. Regular preventative maintenance is used to minimize the amount of unscheduled down time, and remote diagnostics capabilities allow many service requests to be handled without an on-site visit. For service
requests that require a site visit, Roche offers customers within the continental U.S. a service commitment of responding within eight hours or less. This is with the exception of remote areas.

Response time refers to the time from when the field technician is dispatched until the needed part and the technician arrive at the customer location. Thus, supporting customer Integras involves two separate problems: (1) ensuring that service technicians can travel to customer locations within eight hours, and (2) ensuring that parts arrive within eight hours.

Technicians travel by car, so they need to be strategically located around the U.S. to provide coverage. This is a location decision and is covered in Amini and Retzlaff-Roberts (1999). This article focuses on the parts inventory problem and its probabilistic issues. Managers must decide which parts should be inventoried at each location and in what quantity to keep total inventory and logistics costs to a minimum while providing a high service level to customers. There are various inventory locations available, which are discussed below.

**Inventory Locations**

The inventory locations and inventory flows are shown in Figure 1. The world parts center (WPC) is in Europe and serves as the distribution center (DC) from which most U.S. inventory locations are replenished. The primary U.S. inventory location is the urgent replenishment platform (URP) which is centrally located within the continental U.S. The next level of inventory location consists of platforms. The intended purpose of platforms is to have as few locations as possible and utilize “next flight out” (NFO) shipping to get parts to customers as quickly as possible. This literally refers to putting a package on the next flight out to the intended destination, making it essential that platforms are located near busy airports with good flight availability.

The URP also acts as a platform and serves the central portion of the U.S. In fact, by utilizing NFO shipping, this central location is considered capable of covering most of the continental U.S. Only two additional platforms are needed, with one being in the Northeast and the other on the West Coast. This means there are a total of three platforms with one being the URP.

Since the Integra is repaired only by company trained and employed technicians who travel by car to the customer site, another inventory location is in the car’s trunk. The final inventory location is actually at the customer location, referred to as the “customer uptime kit.” The intent of the customer kit is to allow the customer to quickly resolve simple problems that do not require the on-site expertise of a technician. Technical assistance is available by phone to help the customer identify and resolve the problem. Thus, a restriction which does not apply to other inventory locations is that the customer kit must contain only parts which customers are capable of replacing themselves.

The inventory policy for all locations is that there is a designated stock-up-to level for each part, and that a replacement is ordered as soon as possible after the part is used. Reorders are placed at regular intervals, such as every two days or once a week. All inventory locations other than the two non-URP platforms are replenished directly from the WPC as shown in Figure 1. The solid arrows in Figure 1 indicate parts moving from one inventory location to another inventory location. Dashed arrows indicate parts moving out of inventory and being installed in a non-operational Integra for an urgent repair.

... an integrative approach to inventory management is necessary to effectively balance the need to keep inventory low while simultaneously keeping the service level high.
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Decision and Objective

The decision is to determine which parts should be inventoried at each location and in what quantity. The objective of this decision is to minimize the total inventory and logistics cost.

There are hundreds of different parts involved, with some parts costing less than $1 per unit and others costing more than $15,000 per unit. As a result of this wide range in unit value, a “one size fits all” inventory strategy is not appropriate. A plan that utilizes a mixture of all three alternatives (platform, trunk, and customer kit) is needed, where the inventory decision needs to be mass customized for each part based on the part’s cost, reliability, and other factors.

For example, if there are 100 technicians, then at least 100 of a given part are required if they are kept in the trunk stock. However, if this part were kept instead at the platforms and based on the part’s reliability, a total inventory level of ten may be sufficient among the three platforms. Clearly high-cost, high-reliability parts belong at the platforms because the savings in inventory cost will more than offset the NFO shipping cost. Inexpensive parts belong in the customer kit or trunk. The question is “where are the break points for moving from one location to the next?”

To make the best decision, development of a model for doing “what-if” cost calculations is necessary. This means being able to quantify the total inventory and logistics costs for any given part for each inventory location, thus allowing a decision maker to answer questions such as “What if we kept part xyz at the platforms? How much inventory would we need? What are the costs involved?”

Cost Calculations

In considering the total inventory and logistics costs there are actually two types of cost involved: (1) the annual logistics cost, and (2) a one-time inventory set-up expense. These two costs cannot be combined because one is an annual expense and the other is a one-time expense.
The total annual logistics cost includes five cost categories (Stock and Lambert, 1987):

1. Transportation costs,
2. Warehousing costs,
3. Order processing costs,
4. Lot quantity costs,
5. Inventory carrying costs

Further details on what is included in each of these cost categories are given in the Appendix.

Inventory set-up cost is the one-time cost of initially placing the appropriate amount of inventory. “The appropriate amount” refers to having a sufficient amount to achieve the desired service level. Again, this cost is important to measure because of the potentially large differences among inventory alternatives.

**Interrelationships of Parameters**

In calculating the above costs there are a number of data values, decision variables, and dependent variables that interact and lead to the logistics and inventory costs. Figure 2 shows the relationships and interdependencies. Keep in mind that this is a “what-if” analysis for a given inventory location for a given part. Data is indicated by rectangles, decision variables by diamonds, and dependent variables by ovals.

Begin at the left end of Figure 2 with the part’s reliability, as measured by the average time between failures, and the number of Integras supported. These two determine the part demand distribution, which in turn yields the average annual throughput for the part. For example, if a part fails on average every six months and there are 100 Integras in the U.S., then the average annual throughput is 200 per year.

**Figure 2: Inventory and Logistics Cost Calculation Flow Chart**

(For a Given Part and Inventory Location)
This demand, of course, is not evenly distributed over the year. Parts fail randomly; in one instance the part may last one week, and in another it may last two years. The part demand distribution accounts for this random “arrival” of part failures. This distribution must be considered along with the lead time distribution in choosing a stock-up-to level, as indicated in Figure 2.

The lead time is defined here as the time from when a part is used until it has been replaced in inventory, so the period between orders as well as the shipping time must be considered. For example, if replenishment orders are placed once a week and arrive two to three days later, the lead time could be anywhere from two days to ten days depending on when in the order cycle the part was used.

Both of these distributions, part demand and lead time, must be considered in choosing the appropriate stock-up-to level. Certainly no organization wants to experience a stock-out, but similarly no organization wants to maintain an excessive amount of inventory. Depending on the relative consequences of each, managers should determine the desired service level, which is directly related to how large a stock-out probability they are willing to have. For some organizations, a stock-out probability of five percent or larger may be acceptable. For others, one percent or even smaller may be desired if there are severe consequences for a stock-out.

An organization is at risk of a stock-out from the time the last unit in inventory has been used until the replenishment has arrived. Since the arrival of part demands and the length of the lead time are both random, determining the appropriate stock-up-to level is not a simple calculation.

A what-if analysis for a given stock-up-to level can be conducted and the probability of experiencing a stock-out determined. If the probability is unacceptably high, the stock-up-to level can be increased and the analysis repeated.

Based on the chosen stock-up-to level, the resulting average inventory level can be determined by the what-if analysis. A computer simulation can show how the inventory level will randomly go up and down over time as orders and replenishments randomly arrive.

Once the average annual throughput and the average inventory level are known, the costs can be calculated. As shown in Figure 2, the average annual throughput along with logistics cost data determine the transportation, warehousing, and order processing costs. The average inventory level multiplied by the part cost and carrying cost percent yield the inventory carrying cost. Further information on these costs can be found in the Appendix. Finally, the inventory level and part cost determine the inventory set-up cost. Any costs to initially “place” the inventory, such as shipping, may also be included in inventory set-up cost.

By conducting this analysis for each of the inventory alternatives, managers can observe the expected what-if costs and choose the best inventory alternative for the part under consideration.

**Decision Support Model**

A decision support model was developed to conduct the above described what-if analyses. The model calculates the costs simultaneously for all three inventory location alternatives for a given part. In the first stage, a user enters the data elements shown in Figure 2 and described above. In the second stage, the model calculates stock-out probabilities for all inventory locations for a spectrum of stock-up-to levels. Managers can then choose the appropriate stock-up-to level for each inventory location based on the service level goal. In the final stage, the inventory and logistics costs are calculated, allowing managers to compare the alternatives, objectively evaluate the trade-offs, and decide whether the part should be inventoried in the platforms, trunks, or customer kits.
Spreadsheet Methodology

The most accurate method of accomplishing the what-if analysis would be to use a computer simulation package. However, this study developed a spreadsheet-based decision support model to provide the organization a tool flexible enough to be utilized throughout the product’s lifecycle. In addition to flexibility, a spreadsheet-based model offers simplicity, accessibility, and understandability. Thus, it is felt that the amount of accuracy sacrificed for this application is small while the advantages are many.

Flexibility is important because many of the data elements involved may change dynamically over the life cycle of the product or require the flexibility to evaluate a range of values. For example, the number of Integras supported will be increasing as the product is early in its life cycle. The lead time distribution may change if the organization changes the frequency of replenishment orders. In fact, lead time could be viewed as a decision variable and what-if analyses conducted to allow the organization to ask questions such as “What if we cut the lead time to two days? How would this affect our costs and inventory levels?”

Part reliability also requires flexibility because historical part life data was unavailable at the time of the study, as the Integra was a new product. For example, if a given part was expected to last on average somewhere between four and twelve months, it would be useful to evaluate this range of part reliability. If it is found that the same inventory alternative is best for the entire range, managers can feel very comfortable with the decision despite the uncertainty in part reliability. If it is not the same, the break point can be determined and the situation reevaluated as more data on part reliability is gathered.

In addition to flexibility, spreadsheet packages are easily accessible and easily used by those without extensive management science backgrounds. The spreadsheet was chosen because it was essential to provide a tool as simple and easy to use as possible to facilitate use on a regular and on-going basis.

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Example Scenarios

Table 1 illustrates the use of this tool in the decision making process by showing some example what-if calculations. For the four scenarios shown in Table 1, data values for the number of Integras supported, lead time distributions, and logistics costs are identical. Part cost and reliability vary. The stock-up-to level varies with part reliability, but stock-up-to levels were chosen with a consistent service level.

For each of the four scenarios shown, which represent four different parts, the inventory set-up cost (referred to as set-up cost) and the expected annual logistics cost (referred as the annual cost) have been determined for the platforms and the trunks. Notice that the term “expected” is applied only to the annual logistics cost. This is because the inventory set-up cost is fairly deterministic after the stock-up-to level is chosen, whereas the annual logistics cost will vary from year to year based on the random failure of parts. The expected annual cost is the long-term average.

The customer kits are ignored here for simplicity and because the choice between platforms and trunks is the one where the decision support tool is most needed. The customer kit is intended for inexpensive parts that customers can install themselves.

The lower right portion of Table 1 indicates the costs for a $1000 part with an average reliability
of 12 months. The set-up cost for the platforms is $60,818 lower than for the trunks because considerably less inventory is necessary. The expected annual costs are very similar with the platforms’ annual cost being only $413 higher. This makes a clear case for choosing the platforms because there is a substantial savings in the set-up cost which easily offsets the slightly higher annual cost.

The break-even point, without considering the time value of money, would be 147.3 years. This means if the platforms were chosen, the initial savings (over the trunk option) would be $60,818, but each year the platforms would cost $413 more than the trunks. It would take 147.3 years ($60,818 ÷ $413) for the total costs of the two alternatives to be equal. Prior to this break-even point the platforms would be less costly. For this part, the platform inventory option with its NFO shipping is a considerable money saver.

For a $500 part with the same reliability, the costs are shown in the lower left portion of Table 1. Again the platforms have a much lower setup cost, amounting to a savings of $30,410. However, the annual cost at the platforms is $6496 higher on average. It is less clear here which inventory alternative to choose. Managers need to use some judgment to make a decision about the trade-offs of these two types of costs.

Is it worth spending on average an extra $6496 per year to save $30,410 at the outset? Without considering the time value of money, the break-even point would be 4.7 years.

Moving to the upper right portion of Table 1, there is a similar situation for a $1000 part with a six month reliability. Again the set-up cost is much lower at the platforms, in fact, $56,637 lower than for the trunks. The average annual cost is $13,828 higher at the platforms. The break-even point would be 4.1 years.

The final portion of Table 1 is for a $500 part with a six month average reliability. The platforms’ set-up cost is $28,318 lower and the average annual cost is $19,491 higher. The break-even point is 1.45 years. Here it seems worthwhile to place this part in the trunk inventory and incur the extra $28,318 in set-up cost, in order to have annual costs that are on average $19,491 lower.

Being able to quickly and easily perform these what-if calculations will help managers determine where the break points are between the platforms and the trunk locations over time. Keep in mind that many other values, in addition to the part’s cost and reliability, are involved. The location of the break points can change as the various parameters shown in Figure 2 change.

### Table 1: Costs Of Example Scenarios

<table>
<thead>
<tr>
<th>Part Reliability</th>
<th>$500</th>
<th>$1000</th>
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</thead>
<tbody>
<tr>
<td><strong>6 months</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set-up cost</td>
<td>Platform</td>
<td>$4,045</td>
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<tr>
<td></td>
<td>Trunks</td>
<td>$32,363</td>
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<tr>
<td>Annual cost</td>
<td>Platform</td>
<td>$32,964</td>
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<tr>
<td></td>
<td>Trunks</td>
<td>$13,473</td>
</tr>
<tr>
<td><strong>12 months</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set-up cost</td>
<td>Platform</td>
<td>$3,272</td>
</tr>
<tr>
<td></td>
<td>Trunks</td>
<td>$33,682</td>
</tr>
</tbody>
</table>
Conclusion

This case study illustrates how an organization can strategically plan their inventory logistics to achieve the desired service level while minimizing inventory and logistics costs. This study focused on a service parts inventory; however these principles apply to any type of inventory. When product demands arrive randomly, there are probabilistic issues to account for. In this study part reliability and the number of Integras supported determined the demand distribution, as shown in Figure 2. In another application the demand distribution might be based on the arrival rate of customer orders. If Figure 2 were modified to begin simply with "Demand Distribution" it would be generalizable to virtually any inventory scenario.

Having inventory available for customers when and where it is needed is important for customer service and for the bottom line. In a dynamic real-world setting, an integrative approach to inventory management is necessary to effectively balance the need to keep inventory low while simultaneously keeping the service level high.

In a multi-location inventory system, critical issues involve determination of (1) geographic location of parts, (2) stock-up-to level of parts in each location, and (3) the resulting inventory and logistics costs. As the number of items, inventory locations, and customer locations increase, the aforementioned issues generate an intractable number of inventory policy alternatives with different costs. Determination of the "best" inventory policy becomes a cumbersome task and requires a holistic modeling approach that takes into account all related issues and parameters simultaneously.

References


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Appendix

The make-ups of the various types of transportation and logistics cost are described below. Additional details may be found in a logistics text such as Stock and Lambert (1987).

Transportation Costs

As shown in Figure 1, there are two different kinds of shipping involved. First, there is the urgent shipment where an Integra is non-operational and the part is needed for immediate installation, indicated by the dashed arrows in Figure 1. For platforms this involves NFO shipping cost. For trunk stock and customer kits, this cost is effectively zero.

The inventory policy utilized in this study requires that whenever a part is used, a replacement is ordered, so the other type of transportation cost is replenishment shipping, indicated by the solid arrows in Figure 1. This cost varies by inventory location and chosen lead time, but is less expensive than NFO shipping due to a lower level of urgency. As shown in Figure 1, most replenishment shipments come from Europe, with the exceptions of the two non-URP platforms.

Warehousing Costs

There are also two kinds of warehousing costs: fixed costs and throughput costs. Costs related to the amount of inventory stored should be included in inventory carrying cost rather than here. To decide where to place a given part, we are interested in the difference in costs among the possible inventory locations, so fixed costs can be ignored in this application. All inventory locations under consideration will be utilized, so fixed costs will be incurred.

Throughput costs cannot be ignored because they will differ among the inventory alternatives for a given part. Throughput costs are those associated with moving parts into and out of a storage location. There is a cost for this at platforms, but for trunks and customer kits this cost is effectively zero.

Order Processing Costs

Order processing costs include the costs associated with receiving, processing, and preparing an order for shipment. Just as there are two kinds of shipments, urgent and replenishment, there are two kinds of order processing costs. For urgent orders there is an order processing cost at the platforms, and it is a direct cost since a third party runs them. However, for trunks and customer kits this cost is effectively zero. For replenishment orders there is a direct cost for the non-URP platforms since they order from the URP. However, all other replenishment orders come from the WPC so any internal costs associated with these can be ignored because (similar to fixed warehousing costs) the cost does not differ among inventory locations.
Lot Quantity Costs
Lot quantity costs are manufacturing related costs that vary with the chosen logistics system. These costs are not involved in this study because they will not vary with the alternatives under consideration.

Inventory Carrying Costs
Carrying cost is calculated as a percent of the value of inventory placed. Carrying cost should account for the cost of capital, cost of taxes and insurance, risk of “shrinkage” (due to damage or theft), risk of obsolescence, etc. The correct percentage to use can be difficult to accurately estimate because of the intangible nature of some of the costs involved. Most organizations have a standard percentage for the cost of capital, but may not increase from this value sufficiently to account for the other intangible costs. As a result, many organizations underestimate their inventory carrying cost. While there is no single “right” percentage for all situations, something in the range of 20-25 percent is often recommended.