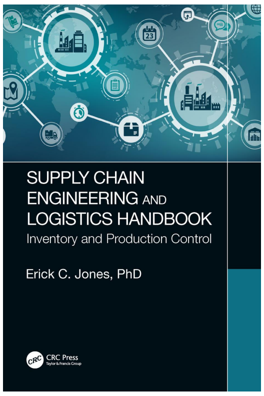

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5

Inventory Control

Erick C. Jones

History is important because I believe lessons are repeated until they are learned.

Erick C. Jones

Inventory amount and size decisions are traditionally driven by the costs of maintaining inventories and costs of being out of stock. Operations managers seek to maintain inventory levels that minimize the total cost of both.

In this section, we discuss closed-loop inventory control. The approaches discussed here are relatively unsophisticated. There is a large amount of information available in other academic texts, along with consultative materials available in industry. We will discuss certain aspects of inventory control theory so that the impact that radio frequency identification (RFID) technologies have can be recognized.

5.1 Inventory Carrying Costs

Inventory carrying costs fall into several categories. They include the following:

1. Storage costs are the costs associated with occupying space in a storeroom, warehouse, or distribution center. Inventory costs such as insurance for fire, flood, and theft are included in the expense of storing goods.
2. Theft or inventory shrinkage identifies when more items are recorded entering warehouses than leaving.
3. Obsolescence describes when items in an inventory eventually become out of date.
4. Depreciation or deterioration of inventory as a function of time, not usage.
5. Interest refers to the interest charges for the money invested in inventories. Oftentimes, this represents the investment into company inventories, as opposed to money that can be invested in other investments.
6. Taxes refer to when inventories are taxed. Traditionally the tax is derived on the basis of the inventory on hand on a certain date. Most companies make a concentrated effort to have inventory present on that day to be as low as possible.
7. Carrying costs include inventory tax, and costs associated with avoiding or evading the inventory taxes.
    a. Consider products such as fresh produce which may deteriorate in only a few days. The depreciation portion of a produce company's carrying costs might be as high as 50% per day. Other products depreciate completely given their expiration dates including products such as dairy products, drugs, bread, some soft drinks, and camera film. For these products, the rate of depreciation can be calculated because expired products that are unsold must be removed from the shelf.

TABLE 5.1

Component Breakdown of the 25% Figure

Insurance	0.25%
Storage facilities	0.25
Taxes	0.50
Transportation	0.50
Handling costs	2.50
Depreciation	5.00
Interest	6.00
Obsolescence	10.00
Total	25.00%

Source: Adapted from L. P. Alford and J. R. Bangs (eds.), *Production Handbook* (New York: Ronald, 1955), pp. 396–397.

b. Specialized inventory costs are related to pets and livestock which have costs related to being watered and fed. Security cost for high-value items such as computer chips may increase inventory carrying costs.
c. Inventory carrying charges are expressed as a percentage of the inventory's value, and widely cited estimate is that carrying costs approximate 25% per year of a product's value (Table 5.1).

Opportunity costs are not traditionally included in most carrying costs calculations. Most companies must consider the trade-off of holding inventory against the having inventory to meet the fluctuations of customer demand.

5.1.1 Stock-Out Costs

Stock-out refers to the event that occurs when an item is out of stock when a customer wants to buy the item. Stock-out costs are difficult to determine and oftentimes effect customer satisfaction. The difficulty of determining cost that is lost due to stock-outs is that it requires a good understanding of company's customer behavior. Customer can have many varied reactions to stock-outs. We suggest that the responses can be placed into three categories:

- Future sale
- Lost sale
- Loss of customer.

Consider a set of 500 customers who experienced stock-outs for a given product. The three types of customers responses may suggest of the 500 customers, 50 will return as a future sale, 325 customers may go to another store which represents a lost sell, and 125 customers may never return to the company. The percentages represented by future sale, lost sale, and loss of the customer are 10%, 65%, and 25%, respectively. These percentages can be considered probabilities of the events taking place and can be used to determine the average cost of a stock-out.

Table 5.2 illustrates the procedure. Each cost is multiplied by the likelihood that it will occur, and the results are added. A delayed sale has no cost because the customer is brand loyal and purchases the product when it is again available. The lost sale alternative results in loss of the profit that would have been made on the customer's purchase. The lost customer situation is the worst. The customer tries the competitor's product and prefers it to the product originally requested. The customer is lost, and the cost involved is that of developing a new, brand-loyal customer. These costs

TABLE 5.2

Determination of the Average Cost of a Stock-Out

Alternative	Loss	Probability	Average Cost
1. Brand-loyal customer	$0.00	0.10	$0.00
2. Switches and comes back	$37.00	0.65	$24.05
3. Lost customer	$1,200.00	0.25	$300.00
Average cost of a stock-out.		1.00	$324.05

are usually determined by a firms marketing department, but we use the suggested numbers for demonstration purposes.

5.1.2 Safety Stocks

Firms usually maintain **safety stocks** or excess inventory in order to prevent an excessive number of stock-outs. Analysis is required in order to minimize the amount of safety stock and to determine the optimum level of safety stock. This is illustrated in Table 5.3.

We consider this example to demonstrate safety-stock analysis. Consider that goods must be ordered from a wholesaler in multiples of 10. The carrying cost of an additional or marginal 10 units is $1,200. However, by stocking an additional 10 units of safety stock and maintaining it throughout the year, the firm is able to prevent 20 stock-outs. The average cost of a stock-out has already been determined to be $324.05. We derive that saving 20 stock-outs saves the firm $6,481.00 ($324.05 × 20). In this case, the savings justify the investment costs. Next, we consider an alternative that maintains a safety stock throughout the year of 20 units. This adds $1,200 to the costs but prevents 16 additional stock-outs from occurring, thereby saving $5,184.80.

The optimum quantity of safety stock is 60 units. With this quantity, the carrying cost of 10 additional units is $1,200, but $1,296.20 is saved. If the safety stocks are increased from 60 to 70 units, the additional carrying cost is again $1,200, while the savings are only *$972.15*. We conclude that the firm would be more profitable by permitting three stock-outs to occur each year. Note that these concerns determine a level of customer service.

Safety stocks indicate that a firm will attempt to meet customer demand for out-of-stock items. Many firms choose not to maintain safety stock due to the high carrying cost for inventory. Some mass merchandisers do not replace many items given their profit margins and the fact that customers are not loyal to buying at that firm. In these situations, customer behavior is to buy a complete set of items and/or fixtures needed to complete a project. They understand that the merchandiser may not have that product in the future. This is evidenced in popular "closeout" stores such as Big Lots and Hobby Lobby in which

TABLE 5.3

Safety Level Analysis

Number of Units of Safety Stock	Total Value of Safety Stock ($480 per Unit)	25% Annual Carrying Cost	Carrying Cost of Incremental Safety Stock	Number of Additional Orders Filled	Additional Stock-out Costs Avoided
10	$4,800	$1,200	$1,200	20	$6,481.00
20	9,600	2,400	1,200	16	5,184.80
30	14,400	3,600	1,200	12	3,888.60
40	19,200	4,800	1,200	8	2,592.40
50	24,000	6,000	1,200	6	1,944.30
60	28,800	7,200	1,200	4	1,296.20
70	33,600	8,400	1,200	3	972.15

the firm buys large quantities of a product and sells it at a discount. When the product is sold out, there is no expectation of that product appearing at the store in the future.

5.1.3 Economic Order Quantity

Safety stock level is the minimum inventory a firm tries to keep on hand. Commonly, determining the inventory level, how they should be reordered, and how much should be ordered each time are determined by the economic order quantity (EOQ). We will provide a brief overview of EOQ. Further reading is available in academic texts that discuss operation and production planning.

The typical inventory order size problem can be dealt with calculating the proper order size based on minimizing the total of two costs: (1) the costs of carrying the inventory, which are in direct proportion to the size of the order that will arrive; and (2) the costs of ordering, which mainly involve the paperwork associated with handling each order, irrespective of its size. Consider if there were no inventory carrying costs, customers would hold inventory and avoid reordering. If there were no costs associated with ordering, one would place orders continually and maintain no inventory at all, aside from safety stocks.

Mathematically, the EOQ is determined using this formula:

$$\text{EOQ} = \sqrt{\frac{2AB}{I}}$$

where

EOQ = The most economic order size, in dollars
A = Annual usage, in dollars
B = Company costs per order of placing the order
I = Carrying costs of the inventory (expressed as an annual percentage)

If $1,000 of an item is used each year, if the order costs are *$25* per order submitted, and if carrying costs are 20%, what is the EOQ?

$$\text{EOQ} = \sqrt{\frac{2 \times 1{,}000 \times 25}{0.20}} = \sqrt{250{,}000} = \$500 \text{ order size}$$

Because of the assumption of even outward flow of goods, inventory carrying costs are applied to one half the order size that would be the average inventory on hand, as illustrated in Table 5.4.

EOQs, once calculated, may not be the same as the lot sizes that the product is bought and sold at a company. EOQs can also be calculated in terms of the number of units that should be ordered. The formula is

$$\text{EOQ} = \sqrt{\frac{2(\text{Annual use in number of units})\,(\text{Cost of placing an order})}{\text{Annual carrying cost per item per year}}}$$

Assume that an item in Table 5.4, for example, costs *$5*. Substituting numbers in the new formula yields

$$\text{EOQ} = \sqrt{\frac{2 \times 1{,}000 \times 25}{0.20}} = \sqrt{\frac{10{,}000}{1}} = 100 \text{ units}$$

The earlier EOQ formula and Table 5.4 showed that $500 was the best order size, and because the product is priced at $5.00 per unit, the answer is the same.

The simple EOQ formulation just given does not take into large volume discounts. We can review Table 5.4 and visualize how discounts would have an impact on total costs as the figures. By imputing different values into the table horizontally, volume discounts can be evaluated and marketed to increase future business.

TABLE 5.4

EOQ Calculations

Number of Orders per Year	Order Size	Ordering Cost	Carrying Cost of Average Inventory in Stock	Total Cost
1	$1,000	$125	$100	$125
2	500	50	50	100
3	333	75	33	108
4	250	100	25	125
5	200	125	20	145

5.2 Inventory Flows

In the previous section, we utilize the figures from the EOQ and the safety-stock calculations as an analysis tool. We cannot utilize these same calculations to determine inventory policy. We must first take the given information and use it to develop an **inventory flow** diagram. Assume that the EOQ, in this instance, has been determined to be 120 units, that the safety stock level is 60 units, that average demand is 30 units per day, and that the replenishment or order cycle is 2 days. On day 1 (in the Figure 5.1), an EOQ of 120 units arrives.

We will consider a common inventory flow diagram suggested in other texts. Consider the following, total inventory (point A) is 180 units (one EOQ plus 60 units of safety stock). Demand is steady at 30 units per day. On day 3, total inventory has declined to 120 units (point B), which is the reorder point, because it takes 2 days to receive an order and during this time, 60 units would be sold. If the inventory policy mandates that safety stock is not to be used under normal circumstances, reordering at 120 units means that 60 units (safety stock) will be on hand 2 days later when the EOQ arrives. The EOQ of 120 units arrives at point C, and then, total inventory increases to 180 units at point D.

If the rate of sales doubles to 60 units per day, the reorder point is hit at 120 units (point E), and an additional EOQ is ordered. However, it will not arrive for 2 days. A day after the reordering, the regular inventory is exhausted, and at point F, the safety stock is starting to be used. At point G, the EOQ

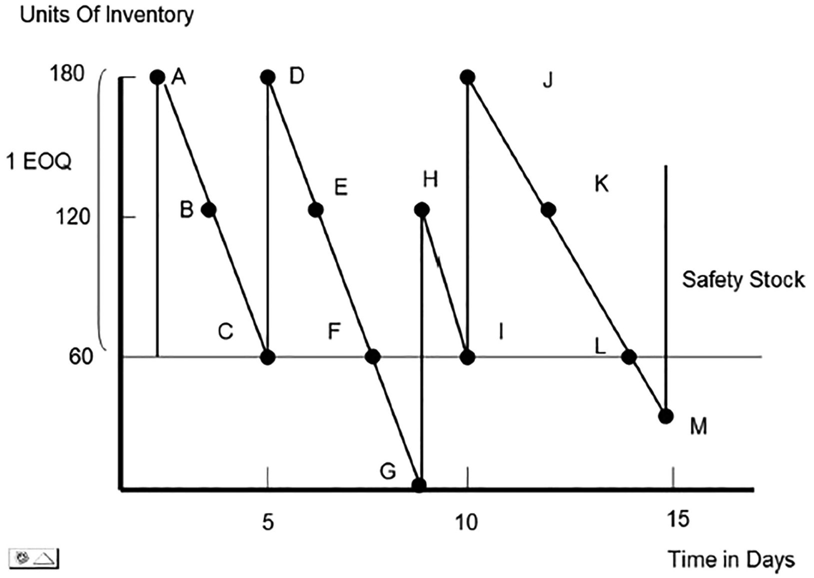

FIGURE 5.1 Inventory flow diagram.

arrives just as the safety stock is about to be exhausted. If the EOQ arrived later than day 8, a stock-out would have occurred. The new EOQ boosts the inventory to 120 units, which is also the reorder point. Therefore, at point H, another EOQ is ordered. Starting on day 8, the demand settles back to the old average of 30 units per day.

If it appeared that the demand rate of 60 units per day was going to become the average demand rate, the EOQ will need to be recalculated. Recall that a basic input into the EOQ formula is annual sales of the product. If this number changes, then the EOQ must be determined again.

Starting at point H, demand is again 30 units per day. The next EOQ arrives on schedule at point I, and total inventory increases to 180 units at point J. The reorder point is at 120 units, and an EOQ is ordered on day 12. Demand stays constant, but the transportation mode delivering the EOQ is delayed one day. Instead of arriving on day 14, it arrives on day 15. Safety stock is entered at point L on day 14. A stock-out is again prevented because the EOQ arrives at point M. Note that safety stock protects against two problem areas: increased rate of demand and an increased replenishment cycle.

When an EOQ is used, as illustrated in Figure 5.1, the time between orders varies. The normal time between orders was 4 days, but when sales doubled, the time between orders was only 2 days. One requirement for the effective utilization of an EOQ is that the level of inventory in the system must be monitored constantly. The ability of RFID to allow for this type of monitoring holds great promise for using EOQ theories more effectively. Then, when the reorder point is hit, an EOQ is ordered. With the advent of computerization, many firms have the capability to constantly monitor their inventory and hence have the option of using an EOQ system. A reorder point for each item can be established in the computer's memory, so it can indicate when the stock has been depleted to a point where a new order should be placed. The integration of RFID will allow for middle wear, decision support, and execution systems to transmit the purchase order to the vendor electronically.

A variation of the EOQ method is the *fixed-order quantity* method, used in repetitive purchases of the same commodity. This method can be initiated with RFID technologies, triggering the reorder points. An example would be when a materials' retailer located in China buys product by the barge load (approximately 1,000 tons per load). The retailer would wait until its product is out of stock before ordering another barge load. RFID would enable this type of activity by triggering the point-of-sale (POS) checkout counter system to order the next lot of products from the China manufacturer directly. Tying the technical knowledge of the quantity to order with the automatic information capture of RFID will provide tremendous value in the future.

5.3 Fixed-Order-Interval System

An alternative inventory concept that is also commonly used is known as the fixed-order-interval system. In this system, EOQs are not used; instead, orders are placed at fixed intervals, such as every 3 days or twice a month. In the EOQ system, the time interval fluctuates, with the order size remaining the same. In fixed-interval systems, the opposite holds, and order sizes may vary.

Fixed-interval systems are used in many situations. One situation is when the firm does not maintain automatically updated stock levels. Such firms are manually checked to verify the levels of all items and determine which stocks are running low. This task is assigned on a regular basis and may be laborious. Another situation is when vendors offer the firm significant discounts if it will place its orders at certain fixed-time intervals. Because the discounts are greater than the advantages of using the EOQ system, the fixed-interval ordering system is utilized. Further, an additional condition is when the firm buys free on board (FOB) origin and tries to utilize its private trucking fleet whenever possible. If one of the firm's trucks travels empty in one direction without freight, commonly called deadheads, from a point near a supply source back to the firm's plant on a regular basis, the firm may decide to buy FOB origin and carry supplies in its own truck.

The fixed-order-interval system is commonly used with a safety-stock inventory. It usually requires more safety stock than the EOQ system because the EOQ system requires constant monitoring of its inventory levels. In an EOQ system, if sales start to increase, the reorder point will be moved to an earlier time and a new order for an EOQ system needs to be placed. Stock-outs can still take place, but only during the restocking cycle after the new order has been placed. With the fixed-order-interval system, the inventory levels are not monitored and a stock-out can occur during both the order cycle and the time before order placement.

Most fixed-order-interval systems do borrow one element from EOQ systems. Next to each bin or slot in the warehouse is a barcode, card, or indicator that will allow for determination of the minimum quantity for that product. When the order pickers note that the stocks have been reduced to this level, they notify their supervisor, who decides whether the reorder should occur immediately or on the next scheduled date.

Cyclical buying is a very specialized form of fixed-interval ordering. This practice occurs in the women's fashion industry, in which retailers place their orders directly with the manufacturer for each season's fashions, and there is almost no possibility of reordering. Another example is a grocery retailer's purchase of Halloween pumpkins or Christmas trees.

5.4 Just-in-Time Inventory Systems

An inventory system that has received widespread attention is the just-in-time (JIT) system. The concept is related to the fixed-order-interval system, and customers place orders with their suppliers on set schedules that frequently involve daily or hourly deliveries. In comparison to the EOQ system, the concept is based on the assumption that ordering costs are negligible; hence, firms order frequently to minimize inventory holding costs. In JIT systems, inventory is kept at a minimum because the processes create perpetual motion and continuous movement.

In addition to the JIT inventory systems, there are several other, more traditional systems for replenishing inventory stocks. Nearly, all inventory systems require some formal stock-level monitoring capability. In practice today, the JIT systems may be incorporated into execution systems that are stand-alone, which are often termed best of breed or within a larger enterprise-wide system. Software applications that create perpetual motions and execution include warehouse management systems (WMS), transportation management systems (TMS), and order management systems (OMS).

5.5 RFID and Inventory Control

Some researchers suggest that operational labor can be reduced in distribution operations by as much as 30%. Kearney (2004), a notable supply chain consulting firm, suggests that labor savings of 7.5% are possible from reduction inventory cycle counting by using RFID. Distribution inbound receiving along with inventory cycle counting inventory reductions was recognized by Accenture Consulting. Other researchers have reported savings in stocking and retail checkout operations (Chappel et al., 2002).

Opportunities in which RFID passive implementations can save money in operations in the future include

- Automatic replenishment from reserve stocking area
- Safety-stock reduction
- Automatic picking and stocking routing
- Automatic order generation from current inventory availability.

5.6 Automatic Replenishment

Optimizing replenishments within warehouse or distribution centers (replenish primary picking locations, cross-docking, and kitting operations), within retail operations (replenish shelves from the back room to the retail floor), and within the supply chain (replenish or stock inventory between different nodes in the supply chain) are the practical applications for implementing RFID.

5.7 Safety-Stock Reduction

Researchers have investigated inventory control models and their impact on safety stock. Some research suggests transactional errors lead to variability in planning and inflate the need for safety stock. Transaction errors create excess inventory due to miscounting of inventory, and buffer stock becomes necessary to meet service for these errors. The buffer stock for errors and the excess stock maintained due to the bullwhip effect created by inventory timing create a large amount of excess inventory (Kok and Shang, 2007).

So commonly, the optimal amount of inventory ordered traditionally derived by the EOQ or that includes a reorder component is represented by a continuous review (Q, R) system. Oftentimes, to account for the scheduling and lack of real-time information, an adjusted periodic-review system is used which includes safety-stock inventory. Recently, researchers have addressed how RFID can influence the amount of inventory. Consider the following model from Lee et al. (2005).

1. Here, lead time is defined as placing an emergent order $q(q = \alpha Q, \alpha < 1)$ at any time point b based on RFID real-time information as l, and cost to place the emergent order is $k(l)$.
2. l is much less than the lead time of the regular order (Q). Additionally, the probability the emergent order will arrive before the regular order to be $p(l)$ if the regular order is already on its way and an emergent order is released anyway.
3. Moreover, assume that expected total cost associated with inventory position IP and RFID reading point b without releasing emergent order is $C_0(IP, b)$ and the according total cost with emergent order release is $C_1(IP, b)$.
4. So, we can compare the two different costs under periodic review without RFID implementation and continuous review with given RFID real-time information in order to decide whether an emergent order should be placed.

$$C_1(IP,b) = K(l) + P(l) * C_0(IP,b) + (1 - P(l)) * C_0(IP + q,b)$$

Other researchers such as utilize similar continuous review application models to determine inventory levels in a real-time manner. In summary, current research models suggest that inventory can be reduced using RFID technologies due to the fact that their real-time data capture abilities allow for common periodic models to move closer to the theoretical optimal continuous review models. The largest challenge is moving this theory to practice. Currently, in order for this model to work in practice, a fixed infrastructure of antennas and readers is in place at the operational level. This would, in reality, cost operations more in process redesign than the theoretical inventory reduction savings.

5.8 Picking and Routing

Using RFID technology, such as real-time locator systems, the promise of capitalizing on employee location information and inventory status to optimize employees order picking and stocking routes can be realized. This use of RFID builds on picking routes and stocking strategies commonly used in WMS.

An RFID system's ability to provide real-time information will further help optimize order picking schedules. The opportunities to reduce labor cost in these activities may be realized, and the significance in labor savings may be large. Labor reduction of 20% for picking and stocking labor is commonly mentioned by users of WMS that employ these types of algorithms.

5.9 Order Batching of Waves

Using RFID to group orders, commonly called waves, is automatically based on the latest inventory availability. The opportunity to use inventory as it is being received at the dock for immediate shipments can be utilized, dramatically reducing labor for stocking, replenishment, and picking. This theory, commonly called cross-docking, requires a considerable amount of receiving labor to be realized. The promise of RFID will truly enable this one of many opportunities to effectively organize, group, and fulfill orders automatically.

Next, the importance of order wave batching is critical in high-speed operations, but inventory inaccuracies can reduce the quality of these batching of orders and reduce their effectiveness. Specifically, in order management modules of WMS or enterprise resource system (ERP), the order bid processes within the software schema orders compete against one another for resources to meet their specific goals, described as the bid process in the negotiation schema. The real-time ability of RFID to provide inventory accuracy and identify secondary location of the inventory immediately can improve the accuracy of the wave batches.

5.10 Summary

In summary, the contribution of RFID systems to closed-loop distribution logistics can produce significant contributions in three areas: (1) inventory reduction with respect to safety-stock reduction, (2) optimization of order grouping and releases, and (3) labor reduction with respect to picking and stocking labor.

The real benefit of RFID will be based on its ability to provide the inventory accuracy benefits of current technologies such as barcodes and translate the non-line of sight benefits into inventory savings. The areas that will be investigated in the future from a closed-loop perspective in distribution operations, including the aforementioned areas, are listed below:

1. Physical and cycle inventory counts
2. Inventory replenishment
3. Order picking
4. Inventory stocking
5. Order cross-docking
6. Order kitting
7. Many other common distribution operations.

The realization of these savings will more than likely result as RFID is integrated into common execution software, such as WMS, LES, and TMS, quantifying labor savings.

We previously discussed the benefits of RFID technology as a closed-loop systems framework. Traditional automatic identification systems are closed loop in the fact that they are static and traditionally are used within one tier of the supply chain. Consider a tote barcode or pallet tag that is used within a company's distribution center or between other distribution centers. Rarely is this barcode integrated between other unknown partners or even the customer to evaluate the history of that unit load, as opposed to a system in which information is passed from one intelligent automatic identification technology to another.

Consider each technology acting as an intelligent agent. So, if a customer desires to know the history of a product, the UPC transfers information to a barcode, which transfers information to a passive RFID tag, which transfers information to an active RFID tag, and which passes information to a Global Positioning System (GPS). This daisy chain type of interlinking provides an open loop concept that provides all potential players a look into the supply chain's effective visibility. This nesting of Auto ID technologies may be an intermediate step to profitability for most intermediate RFID implementations. We next consider a framework that describes these types of technologies.

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