Take a scientific approach
to inventory decisions

Optimizing economic order quantity

By Dave Piasecki

Inventory models

for calculating optimal order quantities and reorder points existed long before the arrival of the computer. When the first Model T Fords were rolling off the assembly line, manufacturers were already reaping the financial benefits of inventory management by determining the most cost-effective answers to the questions of when and how much. Long before acronyms such as JIT, TQM, TOC, and MRP rolled off the tongues of industrial engineers, companies were using those same (then-unnamed) concepts to manage production and inventory.

I recently read Purchasing and Storing, a textbook that was part of the “Modern Business Course” at the Alexander Hamilton Institute in New York. The textbook, published in 1931, was essentially a how-to manual on inventory management in a manufacturing environment. The core concepts of managing a business have changed very little with time, and reading about these concepts in a vintage text is a great way to reinforce the value of the fundamentals. The occasional references to “the War” (World War I) keep it interesting, and the complete absence of acronyms is refreshing.

This 70-year-old book contained a section on minimum cost quantity, which is what we now refer to as economic order quantity (EOQ). I can imagine that in the 1930s an accountant — or more likely a room full of accountants — would have calculated EOQ and other inventory-related formulas one item at a time in a dimly lit office using the inventory books, a mechanical adding machine, and a slide rule. Time-consuming as this was, some manufacturers of the period recognized the financial benefits of taking a scientific approach to making these inventory decisions.

So why is it that in these days of advanced information technology, many companies are still not taking advantage of fundamental inventory models? Part of the answer lies in poor results they may have received due to inaccurate data inputs. Accurate product costs, activity costs, forecasts, history, and lead times are crucial to making inventory models work. Ironically, software advancements may also be to blame, in part: Many ERP packages have built-in calculations for EOQ that work automatically, so the users do not know how it is calculated and therefore do not understand the data inputs and system set-up that control the output. When the output appears to be out of whack, it is sim-
ply ignored. This can create a situation in which the executives who purchased the software incorrectly assume that material planners and purchasing clerks are placing orders based on the system’s recommendations. In addition, many organizations find these built-in EOQ calculations inadequate and in need of modification to deal with the diversity of their product groups and processes.

Corporate goals and strategies can sometimes conflict with EOQ. Measuring performance by inventory turns is one of the most prolific mistakes made in the name of inventory management. Many companies have achieved aggressive goals in increasing inventory turns only to find their bottom line has shrunk due to increased operational costs.

EOQ is essentially an accounting formula that determines the point at which the combination of order costs and inventory carrying costs are the least. The result is the most cost-effective quantity to order. In purchasing this is known as the order quantity, in manufacturing it is known as the production lot size.

While EOQ may not apply to every inventory situation, most organizations will find it beneficial in at least some aspect of their operation. Any time there is repetitive purchasing or planning of an item, EOQ should be considered. Obvious applications for EOQ are purchase-to-stock distribution and make-to-stock manufacturing; however, make-to-order manufacturers should consider EOQ when they have multiple orders or release dates for the same items and when they plan components and sub-assemblies. Repetitive maintenance, repair, and operating (MRO) inventory is also a good application for EOQ. Though EOQ is generally recommended in operations where demand is relatively steady, items with demand variability such as seasonality can still use the model by going to shorter time periods for the EOQ calculation. (Just make sure the usage and carrying costs are based on the same time period.)

Doesn’t EOQ conflict with just-in-time? While I don’t want to get into a long discussion on the misconceptions of what JIT really is, I will address the most common misunderstanding: that JIT means all components should arrive in the exact quantities “just in time” for the production run. JIT is actually a quality initiative with the goal of eliminating wasted steps, wasted labor, and wasted cost; EOQ should be one of the tools used to achieve this. EOQ is used to determine which components fit into this JIT model and what level of JIT is economically advantageous for an operation.

As an example, let us assume you are a lawn equipment manufacturer and you produce 100 units per day of a specific model of lawn mower. While it may be cost effective to have 100 engines arrive on the dock each day, it would certainly not be cost effective to have 500 screws (a one-day supply) shipped daily. To determine the most cost-effective quantities of screws or other components, you need to use the EOQ formula (Figure 1).

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EOQ = \sqrt{\frac{2 \times \text{Annual usage in units} \times \text{Order cost}}{\text{Annual carrying cost per unit}}}
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Figure 1. The standard economic order quantity formula.

While the calculation itself is fairly simple, the task of determining the correct data inputs to represent your inventory and operation accurately is a bit of a project. Exaggerated order costs and carrying costs are common mistakes made in EOQ calculations. Using all costs associated with purchasing and receiving to calculate order cost or using all costs associated with storage and material handling to calculate carrying will result in highly inflated costs and therefore inaccurate results from the EOQ calculation. I also caution against using benchmarks or published industry standards in calculations. I have seen references in magazine articles and product brochures to average purchase order costs of $100 to $150. Often, these references trace back to studies performed by advocacy agencies working for businesses that directly benefit from exaggerated costs used in return-on-investment calculations. I am not denying that some operations may have costs in this range (especially if there is frequent re-sourcing, re-quoting, or buying from overseas vendors). However, if an operation is primarily involved with repetitive buying from domestic vendors, which is more common, you’ll likely see purchase order costs in the substantially lower $10 to $30 range.

As you prepare to undertake this project, keep in mind that even though accuracy is crucial, small variances in the data inputs generally have very little effect on the outputs. The following explanations of the data inputs will give added insight into each.

![Inventory costs](http://solutions.iienet.org)

**Figure 2. The relationship of order cost and carrying cost to total cost.** This example shows an item with an order cost of $15, a carrying cost of 20 percent, a unit cost of $20, and annual usage of 300 units. The result is an EOQ of 47 units with a total annual operational cost of $190. (This cost does not include the product cost itself.) Note that the total cost changes very little from 40 to 55 units and is dramatically higher below 20 and above 100 units.
Annual usage
Expressed in units, annual usage is generally the easiest part of the equation: Simply input the forecasted annual usage.

Order cost
Also known as purchase cost or set-up cost, order cost is the sum of the fixed costs that are incurred each time an item is ordered. These costs are not associated with the quantity ordered but primarily with physical activities required to process the order. For purchased items these would include the cost for entering the purchase order or requisition, approval steps, processing the receipt, incoming inspection, invoice processing, and vendor payment. In some cases a portion of the inbound freight may also be included in order cost.

It is important to note that these are costs associated with the frequency of the orders, not the quantities ordered. For example, the time spent checking in the receipt, entering the receipt, and doing other related paperwork in the receiving department should be included; the time spent repacking materials, unloading trucks, and making deliveries to other departments should likely not be included. If there is inbound quality inspection in which a percentage of the quantity received is inspected, the time to get specs and process the paperwork should be included. On the other hand, if a fixed quantity per receipt is inspected, include the entire time for inspecting, repacking, etc. In the purchasing department, include all time associated with creating the purchase order, the approval process, contacting the vendor, expediting, and reviewing order reports; do not include time spent reviewing forecasts, sourcing, getting quotes (unless quotes are obtained each time there is an order), and setting up new items. All time spent dealing with vendor invoices would be included in order cost.

Associating actual costs to the activities surrounding order cost is where many an EOQ formula runs afoul. Do not make a list of all of the activities and then ask the people performing the activities how long it takes them to accomplish each one. The results of this type of measurement are rarely even close to accurate. It is more accurate to determine the percentage of time that is consumed performing specific activities in the department, multiplying that number by the total labor costs for a given time period (usually a month), and then dividing by the line items processed during that same period.

It is extremely difficult to associate inbound freight costs with order costs in an automated EOQ program, and I suggest it only if the inbound freight cost has a significant effect on unit cost and its effect on unit cost varies significantly based upon the order quantity.

In manufacturing, the order cost should include the time to initiate the work order, the time associated with picking and issuing components (excluding time associated with counting and handling specific quantities), all production scheduling time, machine set-up time, and inspection time. Production scrap directly associated with the machine set-up should be included in order cost, as should any tooling that is discarded after each production run. There may be times when you want to inflate or deflate set-up costs artificially. If you lack the capacity to meet the production schedule using the EOQ, you may want to increase set-up costs artificially to increase lot sizes and reduce overall set-up time. If you have excess capacity, you may want to decrease set-up costs artificially, which will increase overall set-up time and reduce inventory investment. The idea is that if you are paying for the labor and machine overhead anyway, it makes sense to take advantage of the savings in reduced inventories.

For the most part, order cost is primarily the labor associated with processing the order; however, costs for such things as phone calls, faxes, postage, and envelopes can be included as well.

Carrying cost
Also called holding cost, carrying cost is the cost of having inventory on hand. It is primarily made up of the costs associated with inventory investment and storage. For the purpose of the EOQ calculation, if the cost does not change based on the quantity of inventory on hand, it should not be included in carrying cost. In the EOQ formula, carrying cost is represented as the annual cost per average on-hand inventory unit. The primary components of carrying cost include:

- **Interest.** If you had to borrow money to pay for inventory, the interest rate would be part of the carrying cost. If you did not borrow for the inventory but have loans on other capital items, the interest rate on those loans can be used since a reduction in inventory would free up money that could be used to pay the loans. If by some miracle you are debt-free, you need to determine how much you could make if the money were invested.

- **Insurance.** Since insurance costs are directly related to the total value of the
inventory, they are included as part of carrying cost.

- **Taxes.** If you are required to pay any taxes on the value of inventory, include that amount.

- **Storage.** Mistakes in calculating storage costs are common in EOQ implementations. Generally, companies take all costs associated with the warehouse and divide the total by the average inventory to determine a storage cost percentage for the EOQ calculation. This tends to include costs that are not directly affected by the inventory levels and does not compensate for storage characteristics. Carrying costs for the purpose of the EOQ calculation should only include costs that are variable based upon inventory levels.

For pick/pack operations in which there are fixed picking locations assigned to each

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item and the locations are sized for picking efficiency (not designed to hold the entire inventory), that portion of the warehouse should not be included in carrying cost since changes to inventory levels do not affect costs here. The overflow storage areas would be included in carrying cost, however. Operations that use purely random storage for their product should include the entire storage area in the calculation. Areas such as shipping/receiving and staging are usually not included in the storage calculations; however, if an additional warehouse has to be added to house overflow inventory, all areas of the second warehouse should be included, as should freight and labor costs associated with moving the material between warehouses.

Since storage costs are generally applied as a percentage of the inventory value, you may need to classify inventory based on a ratio of storage space requirements-to-value in order to assess storage costs accurately. Let's say you're opening a new e-business called BobsWeSellEverything.com. You calculated overall annual storage costs at 5 percent of the average inventory value and applied this to your entire inventory in the EOQ calculation. The average inventory on a particular piece of software and on 80-pound bags of concrete mix both came to $10,000. The EOQ formula applied a $500 storage cost to the average quantity of each of these items even though the software took up only one pallet position while the concrete mix consumed 75 pallet positions. Categorizing these items would place the software in a category with minimal storage costs (1 percent or less) and the concrete in a category with extreme storage costs (50 percent), which allows the EOQ formula to work correctly.

There are situations in which you may not want to include any storage costs in the EOQ calculation. If your operation has excess storage space for which it has no other use, you may decide not to include storage costs since reducing the inventory will not provide any savings in storage costs. As your operation grows near a point at which the physical operations require expansion, you would then start including storage in the calculation.

- **Time.** A portion of the time spent on cycle counting should also be included in carrying cost. Remember to apply costs that change based on changes to the average inventory level. So in cycle counting, include the time spent physically counting but not the time spent filling out paperwork, doing data entry, and traveling between locations.

- **Other costs.** These include factors associated with obsolescence, damage, and theft. Do not factor in these costs unless they are a direct result of the inventory levels and are significant enough to change the results of the EOQ equation.

**Implementing EOQ**

There are primarily two ways to implement EOQ, both of which require that the associated costs are predetermined. The simplest method is to set up the calculation in a spreadsheet program, manually calculate EOQ one item at a time, and then manually enter the order quantity into the inventory system. If the inventory has fairly steady demand and costs and there are less than a couple thousand SKUs, you can probably get by using this method once a year. If there are more than a couple thousand SKUs or high variability in demand and costs, you will need to program the EOQ formula into the existing inventory system. This allows you to recalculate EOQ quickly and automatically as often as needed. A hybrid of the two systems can be used by downloading data to a spreadsheet or database program, performing the calculations, and then updating the inventory system manually or with a batch program. Whichever method you use follow these steps:

- Prior to final implementation, test the programming and set-up. Run the EOQ program and manually check the results using sample items that are representative of the variations of your inventory base.

- Run a simulation or use a representative sampling of items to determine the overall short-term and long-term effects the EOQ calculation will have on warehouse space, cash flow, and operations. Dramatic increases in inventory levels may not be immediately feasible. If this is the case, you may temporarily adjust the formula until arrangements can be made to handle the additional storage requirements and compensate for the effects on cash flow. If the projection shows inventory levels dropping and order frequency increasing, you may need to evaluate staffing, equipment, and process changes to handle the increased activity.

- The values for order cost and carrying cost should be evaluated at least once each year, taking into account changes in interest rates, storage costs, and operational costs.

- Use it. The EOQ calculation is hard science: If you have accurate inputs, the output is absolutely the most cost-effective quantity to order based on current operational costs. To further increase inventory turns, you will need to reduce order costs. E-procurement, vendor-managed inventories, bar coding, and vendor certification programs can reduce the costs associated with processing an order. Equipment enhancements and process changes can reduce costs associated with manufacturing set-up. Increasing forecast accuracy and reducing lead times, which result in the ability to operate with reduced safety stock, can also reduce inventory levels.

**For further reading**


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