Deloitte.

**Typical pitfalls in
inventory management**

The EOQ formula will not necessarily lead to a minimal lead time, thereby potentially resulting in an increased safety stock.

Determining the lot size in production/inventory systems
Critical side-notes on the EOQ formula

More than a century ago, the well-known EOQ formula saw the light: Ford Whitman Harris published an article explaining how the EOQ formula balances fixed ordering costs and holding costs (Harris, 1913). The formula is robust under a wide variety of circumstances and often leads to good results. Consequently, it should not come as a surprise that the EOQ formula is still often used in practice. Nonetheless, some critical remarks on the EOQ formula might be justified.

Let us focus on a company where finished goods are produced on stock. In this case, it is common practice to define order quantities (and thus production lot sizes) in the production environment based upon the traditional EOQ formula. This is indeed a good way to proceed when production results in a fixed production completion time (i.e., the production time is independent of the lot size under consideration) or when transportation times are notably larger than production times (Benjaafar et al., 2005). But what happens if lot sizes do have a significant impact on production times and if replenishment lead times are determined to a large extent by these production times?

Based on the chosen lot sizes which determine production times and resulting lead times, safety stocks have to be set to the appropriate level to buffer against variability in demand during lead times, thereby ensuring the appropriate customer service level. Unfortunately, lot sizes based on the EOQ formula will not lead to minimal lead times. Consequently, it might as well be that the EOQ-based lot size results in pretty high production lead times, thereby raising safety stocks and leading to increased inventory holding costs.

Instead of assuming that inventory and production are completely independent entities, it makes sense to gain insight into the relationship between an order quantity and the resulting expected lead time, given that safety stock levels depend heavily on lead times. A U-shaped relationship will often exist between lot sizes and expected lead times consisting of a setup effect (also called a congestion effect) and a batching effect.

Decreasing the size of lot sizes (and therefore increasing their frequency) causes a raise in the number of machine setups and consequently in the utilization rate of available resources within the production environment. An increased utilization rate leads to larger waiting times and the setup or congestion effect is a fact. Extremely small lot sizes could even cause the number of setups and the utilization rate to increase such that it is not feasible anymore to produce the expected annual demand within a year given the limited capacity.

Assuming that there is some time required to produce every single unit, which is part of the same order, we know that also large lot sizes may result in long lead times given that the number of units within an order has increased. We call this the batching effect.

The combination of the setup and the batching effect results in a U-shaped relationship between lot sizes and expected lead times (Karmarkar, 1987).

Figure: Illustration of the EOQ formula balancing fixed ordering and holding costs.

$EOQ = \sqrt{(2\ D\ K) / h}$

The economic order quantity formula with
D: the annual demand
K: the fixed ordering cost
h: the annual unit holding cost

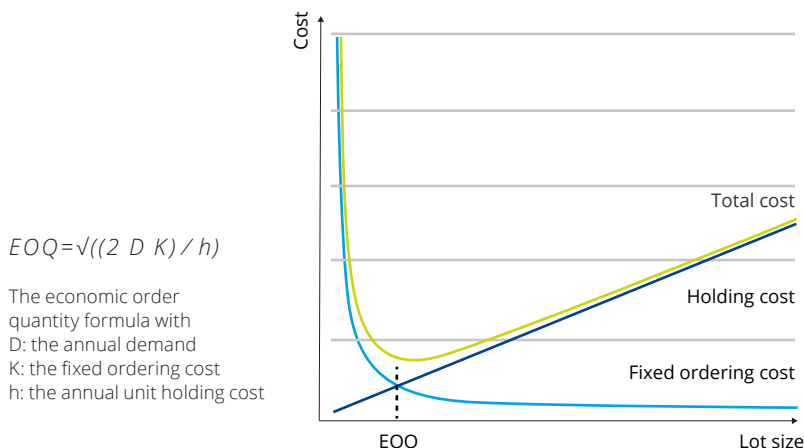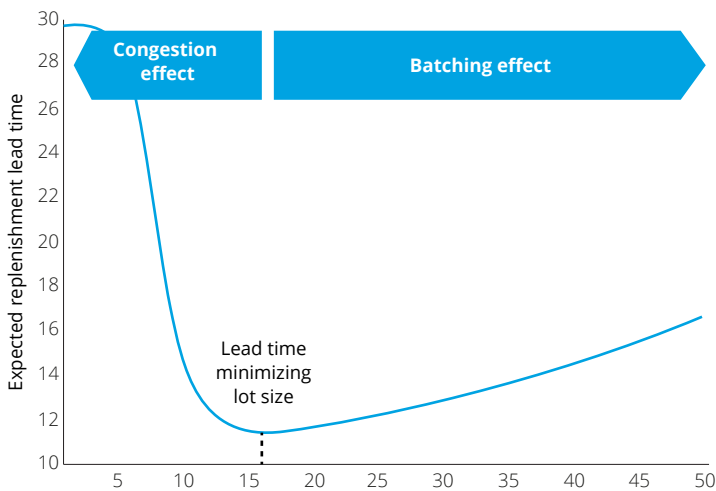**Typical pitfalls in inventory management**

Figure: Illustration of the U-shaped relationship between production lot size and expected lead time (also called Karmarkar-effect).

As mentioned before, the EOQ formula will not necessarily lead to a minimal lead time, thereby resulting in an increased safety stock and consequently larger safety stock holding costs. Can we do any better than this? A potential alternative could be not to select lot sizes based on the EOQ formula, but based on lead time minimization (i.e., the lot size which results in the minimum of the U shape). In this case, inventory holding costs resulting from safety stock will be minimized. However, we are still not sure that total inventory related costs of safety stock and cycle stock are optimal.

We advise the reader to follow the iterative procedure (or algorithm) below when computing order quantities:

Step 1.
Compute the EOQ (call this lot size EOQ_0), the resulting lead time, safety stock, total cost (i.e., the sum of inventory holding cost and fixed ordering costs).

Step 2.
Set $EOQ_{i+1} = EOQ_i - x$, compute the resulting lead time, safety stock, total cost (TC_{i+1}).

Step 3.
Set $EOQ_{i+2} = EOQ_i + x$, compute the resulting lead time, safety stock, total cost (TC_{i+2}).

Step 4.
If $TC_{i+1} < \min(TC_i, TC_{i+2})$, repeat from step 2 onwards with $i = i + 1$,
If $TC_{i+2} < \min(TC_i, TC_{i+1})$, repeat from step 2 onwards with $i = i + 2$,
Otherwise, stop the algorithm and set the lot size equal to EOQ_i. Note that it would make sense to start the algorithm with large "x" (e.g., 10% of EOQ_0), while gradually decreasing the size of "x" as the difference between TC_{i+1} and TC_{i+2} gets smaller.

Confusion between fill rate and cycle service level will result in too high inventory levels

Based on the algorithm, the order quantity will be iteratively adjusted such that expected total costs are decreased, while simultaneously still satisfying the required service level. Only when no cost reduction can be achieved when changing order quantities slightly, we are quite sure to know the optimal order quantity. Unfortunately for the interested reader, this type of analysis will not be easy nor straightforward and quite time-consuming. However, we do claim that depending upon the specificities of the situation (e.g., dependent upon setup times and fixed order costs), the cost impact of optimizing the order quantity might be significant, and can range up to 60% of total inventory-related costs (fixed ordering costs, holding costs and backlogging costs).

Safety stock and service level – A common misunderstanding

It is common knowledge that service levels act as a crucial input parameter when defining safety stocks, with larger service levels leading to an increase of the required safety stock. However, the actual interpretation of this relationship might not be that straightforward.

We highlight two different service level definitions: cycle service level and fill rate. In fact, cycle service level is used as input for the commonly used safety stock formula. It refers to the probability of not having a stock out during the replenishment cycle (i.e., the time between placing an order and the corresponding replenishment). For example, imagine that your company has to send one customer home empty-handed during every replenishment cycle. Clearly, the corresponding cycle service level is zero in this example.Fill rate, on the other hand, is merely a volume-based definition of service level. It represents the percentage of demand that is fulfilled straight out of inventory. Let us go back to the example, where very bad performance (having a stock-out during each replenishment cycle!) led to a low cycle service level. Let us assume that only a single customer with very limited demand (relative to the total yearly demand for this SKU) is dissatisfied during subsequent replenishment cycles. As a result, when looking at the percentage of demand fulfilled out of inventory, the corresponding fill rate is still 95%.

This example illustrates the importance of a correct understanding and definition of target service levels. Confusion between the concept of fill rate and cycle service level will result in an overestimation of safety stock and too high inventory levels (given that the fill rate is always greater than or equal to the cycle service level, Srinivasan 2010).

Figure: The cycle service level is event-driven, whereas the fill rate is volume-driven.

Low cycle service level, high fill rate

Low cycle service level, low fill rate
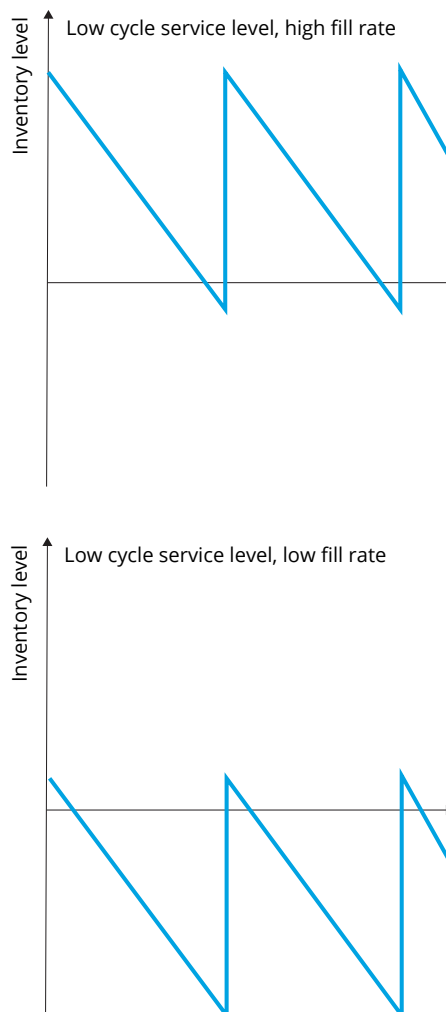
As cycle service level is based on the probability of a stock-out during a replenishment cycle, a change in cycle stock will not affect the cycle service level (all other aspects such as safety stock and replenishment lead time kept constant). The fill rate on the other hand will be impacted: Higher lot sizes lead to a higher average inventory level, which results in a larger fill rate. Therefore, not taking the impact of cycle stock on fill rate into account, will lead to too high inventory levels. In order to calculate safety stock based on fill rate, one can use the following equation, thereby taking the relation between fill rate, number of shortage per cycle and lot size into account:

Fill rate=1- ((expected number of units short per replenishment cycle)/(lot size))

The expected shortage per replenishment cycle will follow from the current cycle service level, the safety stock level and the distribution of demand during lead time (e.g., Srinivasan, 2010). As a result, the translation of the target fill rate into the corresponding cycle service level will allow you to correctly calculate the required safety stock level (for a given lot size). In certain cases, it might even be that a zero (or negative!) safety stock is sufficient to guarantee the target fill rate when considering the average cycle stock.

In this Point of View, we wanted to stress the importance of a correct understanding of key parameters in inventory management, such as lot size, safety stock, replenishment lead times and service level, and their interdependence. A joint optimization of lot sizes and safety stocks will soon become rather complex. However, sound insights (combined with the appropriate use of heuristics), will help to define appropriate inventory levels.

Ignoring the impact of lot sizes on fill rate leads to too high inventory levels.

References

Benjaafar, S., Cooper, W., Kim, J.-S., 2005. On the benefits of pooling in production-inventory systems. Management Science 51 (4), 548–565.

Harris, F., 1913. How many parts to make at once. Factory, the Magazine of Management 10 (2), 135–136, 152.

Karmarkar, U., 1987. Lot sizes, lead times and in-process inventories. Management Science 33 (3), 409–418.

Srinivasan, G., 2010. Quantitative modes in operations and supply chain management. New Delhi: PHI Learning Private Ltd.

Contacts

For more information, please contact:

Paul Delesalle
Partner
EMEA Supply Chain practice
Deloitte Consulting
+ 32 476 49 50 08
pdelesalle@deloitte.com

Peter De Labey
Manager
Deloitte Consulting
+ 32 476 97 56 48
pdelabey@deloitte.com

Philippe Rottiers
Manager
Deloitte Consulting
+ 32 476 53 57 55
prottiers@deloitte.com

Ann Noblesse
Senior Consultant
Deloitte Consulting
+ 32 494 90 92 14
anoblessse@deloitte.com

Deloitte.