A New Framework for Safety Stock Management

Executive Summary

In today's dynamic global economy, with highly fluctuating demand for products, inventory management has become even more challenging. Within inventory, safety stock management has always been a dilemma for supply chain professionals. Key questions that haunt inventory management professionals include:

- Whether to keep any safety stock.
- How much safety stock to maintain to prevent lost sales and minimize inventory carrying costs.

This paper answers these questions and provides a framework for planning and managing a flexible safety stock.

Maintaining Safety Stock

Inventory management has always been a challenging task for organizations selling numerous products and buying raw material to make those products. An important aspect of inventory management is when and how much to order.

Traditionally, inventory management experts have calculated a fixed economic order quantity (EOQ) that minimizes the cost of ordering and keeping stock. Some organizations use fixed maximum and minimum order quantity (MOQ) which ranges around EOQ for stocking various parts. These quantities are ordered at a specific stock level called the reorder point. The reorder point is calculated as the stock level required to meet the demand for finished product and raw material, taking into account the time required for supply replenishment after the order has been made. The time taken for replenishment is called lead time.

The reorder point works well when a manufacturer knows beforehand the exact demand and lead time for procuring a product. However, knowing them with precision would be equivalent to solving all the problems within the supply chain. Demand can remain constant, varying or determinable, but in most situations demand is uncertain.

In an ideal case, when we know the demand and lead time, our reorder point (ROP) will be:

*ROP = d*l, d being demand during lead time l.*

However, there is always an error in forecasting demand and predicting lead time. Thus, relying on the above calculation could lead to inventory stock-out and an inability to meet customer demand. This can have an adverse effect on customer loyalty. This is why companies guard against this uncertainty by maintaining extra inventory, traditionally referred to as safety stock.

In this case ROP = d*l + SS, where SS is the level of safety stock, d and l are estimation of demand and lead time and the multiple is called demand during lead time (DDLT).

The terms "safety stock" and "buffer stock" are used interchangeably, with a slight semantic difference. Buffer stock prevents the producer from being unable to meet customer demand whereas safety stock helps the producer to meet variations in the supply of raw material. Here we will use the words "safety stock" to refer to both upstream safety and downstream buffer stock.

Thus, we see that safety stock guards against variations in demand (d) and variations in supply lead time (l).

A Necessary Evil

Safety stock is sometimes referred to as a necessary evil. Higher safety stock than required can block capital and increase operational costs, whereas low or no safety stock can lead to lost sales and customer dissatisfaction. Figure 1 enumerates the impact of high and low safety stock for manufacturers and retailers.

Methods of Calculating Safety Stock

Different companies have different methods to arrive at the safety stock number. These methods can be broadly classified under three umbrellas:

- Fixed safety stock.
- Time-based calculation.
- Statistical calculation.

Fixed Safety Stock

Companies can set a fixed level of safety stock for their goods. This number may be based on judgment or calculations. This method may lead to high inventory costs or stock-outs since demand is not always constant.

Time-based Calculation

Time-based safety stock level is used to calculate the stock required over a fixed period. In addition to the cycle stock (expected demand during lead time), usually a percentage or a day's average sales (or a week's average sales) is added. For example, if the lead time is two weeks a company may carry three or four weeks of safety stock. This method also has a drawback, particularly when items are slow moving: It can result in a large amount of capital tied up in safety stock.

Statistical Calculation

The statistical method of calculation uses the normal curve or bell curve. It assumes that the error between the forecasted demand and the actual demand follows a normal probability distribution. A normal distribution is characterized by two parameters — mean and variance. Since there is an equal likelihood that predicted demand is greater or less than actual demand, the mean of the error distribution is assumed to be zero. In the language of statistics, it is equivalent to saying that there is no bias in forecasting demand.

The variance of the normal distribution, (denoted as σ) reveals the spread of the error. In the statistical method, the concept of service level is used. In terms of business, it signifies how many times, expressed as a percentage, a manufacturer can service the customer without facing stock-out. So, if no safety stock is kept, then as per the curve, a company will be able to serve customers 50% of the time during the lead time period. If a safety stock of σ is kept then one will be able to serve customers 85% of the time and if 2σ is kept then 98% of the time. Here the percentage numbers — 50, 85 and 98 — denote service levels and the numbers 0, 1 and 2 denote service factors.

We will use Z as a function that converts the desired service level into a service factor. Safety

Impact of High & Low Safety Stock

	Manufacturers	Retailers
High Safety Stock	• High safety stock distorts true store demand thus category management and related efforts are less accurate and effective. • High costs of maintaining inventory. • Excessive capital tied up in inventory.	• Operational costs increase as management of excess stock is required. • High safety stock distorts true shopper demand thus decreases forecasting and ordering accuracy.
Low Safety Stock	• Low safety stock reduces the impact of promotions. • Leads to irregular ordering from retailers. • Loss of brand loyalty and brand equity. • Out-of-stock encourages competitors sales.	• Increases possibility of stock outs. • Loss of revenue due to stock outs. • Decreased customer satisfaction. • Loss of store loyalty. • Competitor gains.

Figure 1

Lead-time Probability Curve

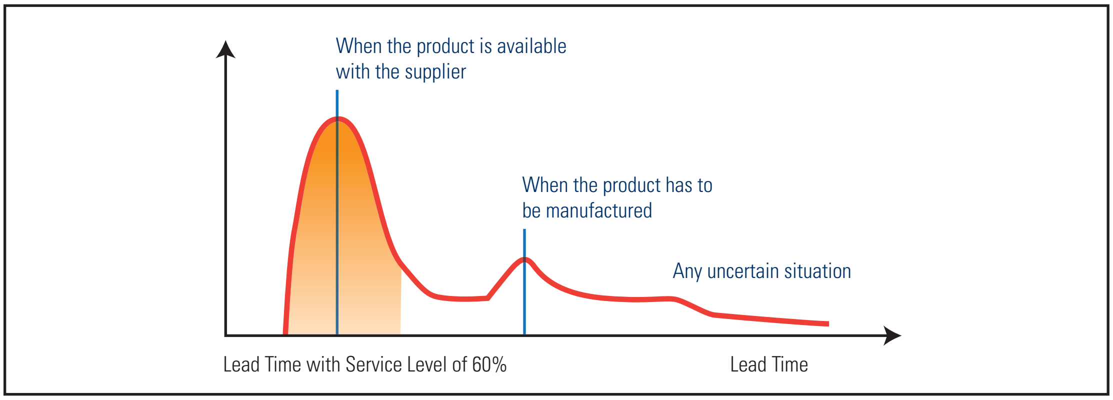

Figure 2

stock calculation by this method is SS = Z*σ. This is applicable when lead time is the same as the forecast period. But that's not the case for the vast majority of the parts. So in most cases a lead time factor is multiplied in; this factor is calculated as the square root of the ratio of lead time period l and the forecast period t. Thus, SS = Z*σ*√(l/t). The reorder point comes to be ROP = d*l + Z*σ*√(l/t).

Until recently, inventory managers have just incorporated demand-side variations, since the assumption has been that lead time is always known and determinable. But supply-side variations expressed in terms of variation in lead time also need to be taken into account.

Unfortunately, lead time does not follow a normal curve distribution. A probability curve for lead time variation is depicted in Figure 2.

Usually the time taken to transport material is the same unless unforeseen circumstances arise. Therefore, in the distribution curve shown in Figure 2 the first crest represents the lead time when the product is available with the supplier and only transportation is required. There may be situations when the product is not available with the supplier. In that case the product has to be manufactured by the supplier, which results in a greater lead time, as represented by the second crest. Depending on the service level that a company wants to achieve, a corresponding lead time in the curve above is chosen and used in the formula ss = Z*σ*√(l/t), to calculate the reorder point and safety stock.

Statisticians have developed many other formulas to calculate safety stock. These formulas usually incorporate the four parameters shown in

Basic Parameters for Calculating Safety Stock

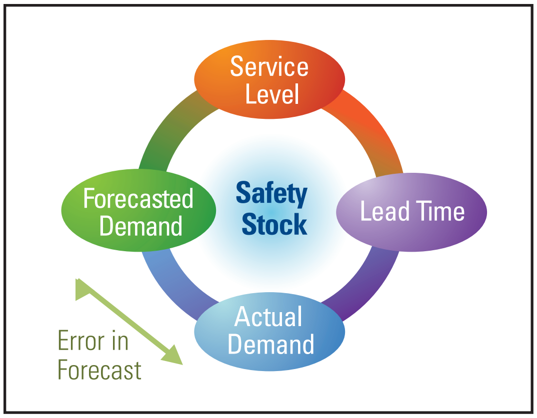

Figure 3

Figure 3. (See appendix for example of formulas.) The ERP systems widely used by companies also pick up values of these parameters from past data and use similar statistical formulas to yield a value of safety stock.

In today's business environment, relying on these parameters is insufficient. In fact, they may result in reorder points and safety stock levels that do not adjust to actual market demand or seasonality. There are many other factors that should be considered. Moreover, most organizations use a fixed value of safety stock over several ordering cycles and don't revisit the numbers frequently. This creates high inventory in the supply chain.

Parameters to Consider

This section covers other key parameters (in addition to the ones discussed above) that have an impact on the level of safety stock. It explains why and how certain factors affect safety stock.

Factors Affecting Safety Stock

<table>
<tr><th>Factor</th><th colspan="2">Sub factor</th></tr>
<tr><td rowspan="4">Lifecycle Stage of the Product</td><td colspan="2">Introduction: When a product is introduced in the market, the error in the forecasted demand will be high. The error can be either positive or negative depending on customer response and hence a moderate level of safety stock is required.</td></tr>
<tr><td colspan="2">Growth: During growth phase it makes sense to keep a high safety stock to meet increase in demand.</td></tr>
<tr><td colspan="2">Maturity: At this stage the safety stock should be kept as low as possible or completely removed because demand prediction is almost precise.</td></tr>
<tr><td colspan="2">Decline: Safety stock should be completely removed.</td></tr>
<tr><td>Product Shelf Life</td><td colspan="2">Perishable products: Short shelf life requires a low level of safety stock.</td></tr>
<tr><td rowspan="4">Business Importance</td><td>Highly profitable product.</td><td rowspan="4">All these situations call for a high safety stock level. (If a product doesn't feature among the top sellers for a company then it doesn't make sense to worry about its safety stock number).</td></tr>
<tr><td>High growth prospects.</td></tr>
<tr><td>Product falls in focus category of company's vision.</td></tr>
<tr><td>Average sales number for the product is high.</td></tr>
<tr><td rowspan="2">Sales Pattern</td><td colspan="2">Seasonal: Just before the season, demand picks up; it makes sense to maintain a high stock level.</td></tr>
<tr><td colspan="2">Regular: Low levels of safety stock should be maintained.</td></tr>
<tr><td rowspan="6">Supply Side Constraints</td><td colspan="2">Distance from vendors: High safety stock should be maintained if distance is large.</td></tr>
<tr><td colspan="2">Relationship with suppliers: If suppliers are reliable and can cushion against supply variability, then it makes sense to have a low level of safety stock.</td></tr>
<tr><td colspan="2">Logistics costs: High logistics cost calls for a high level of safety stock.</td></tr>
<tr><td colspan="2">Capability of the supplier to deliver on time: If high, then low level of safety stock should be maintained.</td></tr>
<tr><td colspan="2">Bargaining power with supplier: If high, then low stock can be maintained.</td></tr>
<tr><td colspan="2">Number of suppliers: If a number of suppliers can supply the same product, then a low safety stock will suffice.</td></tr>
<tr><td rowspan="2">Demand</td><td colspan="2">Stable: Notwithstanding the seasonal sales cycle the demand for some products are determinable and stable. Low level of safety stock is required in such case.</td></tr>
<tr><td colspan="2">Fluctuating: If a product's demand is abrupt and exhibits random behavior, then it makes sense to maintain a high value of safety stock.</td></tr>
<tr><td rowspan="4">Interaction with Customers</td><td colspan="2">Type of customer: Profitable customers call for maintaining a high value of safety stock.</td></tr>
<tr><td colspan="2">Promotions: Promotions will lead to abrupt increase in demand and would require high safety stock for serviceability.</td></tr>
<tr><td colspan="2">Customer tolerance time: How long is customer prepared to wait for the product? If time is high, then low safety stock level would suffice.</td></tr>
<tr><td colspan="2">Relationship with distributors/dealers: If it's possible to postpone the assembly of end product to dealers then rather than end product safety stock, component safety stock should be given elevated importance.</td></tr>
<tr><td rowspan="2">Costs</td><td colspan="2">Unit cost: If cost is high then high level of safety stock will lead to too much capital being tied up in inventory. In such case low level of safety stock should be maintained.</td></tr>
<tr><td colspan="2">Cost of stock-out: If high then it calls for maintaining a high level of safety stock.</td></tr>
<tr><td rowspan="3">Quantity Considerations</td><td colspan="2">Transport quantity: It saves lot of cost when full truck load of material is ordered as compared to half truck load.</td></tr>
<tr><td colspan="2">Quantity discounts: If quantity discounts from a supplier is high, then the company should purchase more and maintain a high level of safety stock.</td></tr>
<tr><td colspan="2">Purchase frequency: If high, then low levels of safety stock would be sufficient to ensure serviceability.</td></tr>
<tr><td>Obsolescence Risk</td><td colspan="2">Some products can quickly become obsolete while on the shelf. If such a probability is high then, low level of stock should be maintained.</td></tr>
<tr><td>Usability in Other Products</td><td colspan="2">If a product can be used as a raw material to manufacture several products then the company may not be worried if safety stock level for such product is high.</td></tr>
<tr><td>Replenishment Model</td><td colspan="2">If it's a Vendor Managed Inventory then safety stock requirements would be less, for order based inventory management stock requirements would be more. If both co-exist then the safety stock strategy should be evaluated on individual product basis.</td></tr>
</table>

Figure 4

Dynamic Inventory Management

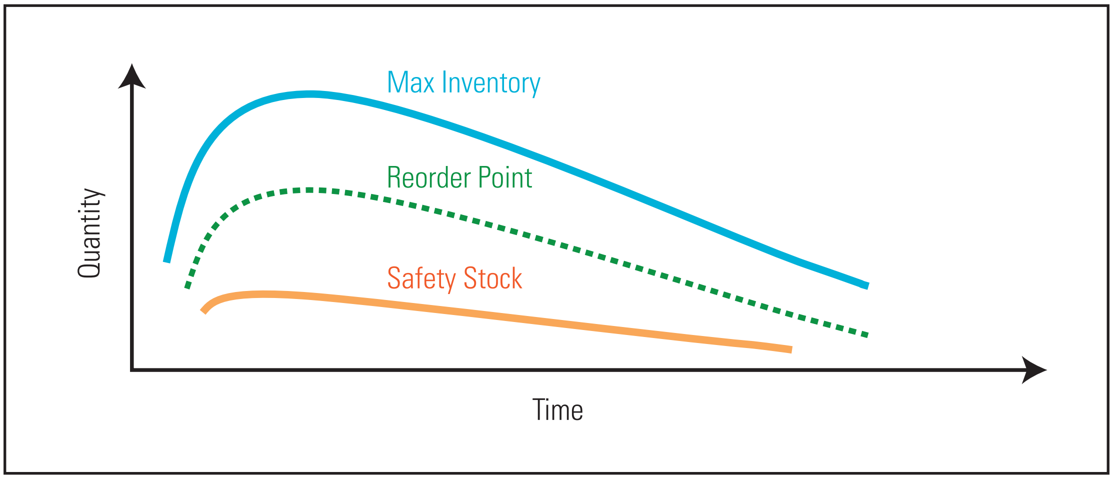

Figure 5

Some additional points worth considering are:

- The factors discussed in Figure 4 are additional to forecast error, serviceability and lead time (which we discussed earlier). These factors may affect the safety stock levels directly or indirectly by affecting forecast error, serviceability or lead time.
- The factors mentioned in the figure are indicative and cannot be considered as exhaustive. It may also happen that some of these factors are not applicable to some products.
- All these factors have been considered "as rules" for safety stock management (i.e., "If this factor is applicable then safety stock level should be moderate/high/low").
- A thorough statistical treatment of these factors/parameters may be required to discover the interdependency between them and remove redundancies.
- Safety stock represents the minimum quantity of stock that must be kept without increasing inventory costs and affecting the serviceability of customers.
- Apart from minimum safety stock it also makes sense to place a cap on the maximum quantity of product that should be kept as inventory. Usually the tendency is to order EOQ at the reorder point. Again, the traditional formulas for EOQ do not take into account several other parameters which ideally should be considered. A similar set of parameters such as those detailed in Figure 4 can provide a fair amount of insight as to what maximum inventory policy should be irrespective of EOQ.
- Minimum inventory (safety stock) and maximum inventory, once determined, should not be fixed forever. Rather, these figures should be frequently recalculated as parameters change. This will lead to dynamic safety stock and maximum stock levels, as shown in Figure 5.

Application of Parameters

This section provides weights to the parameters discussed above (in Figure 4) by taking note of two products – crowbars from the steel industry, sold by a steel products manufacturing company, and SUVs from the automobile industry, sold by major automakers. We have chosen a scale of 1 to 5, with 1 denoting a low safety stock level requirement and 5 denoting a high one. Only parameters relevant to the products have been considered.

Crowbars

A crowbar is a stainless steel product used for opening nails and digging soil. It is used mainly in the construction and mining industry. Its safety stock factors are shown in Figure 6.

Application of Parameters: Crowbars

Factor	Sub-factor for product- Crowbar	Product (Steel)
	Weight 1 to 5: 1- Low safety stock required, 5- High safety stock required	
Product Lifecycle	Maturity	2
Product Shelf Life	Nonperishable	3
Business Importance	Highly profitable	5
Sales Pattern	Stable Less during the rainy season	3
Supply Side Constraints	Distance of suppliers – Not far from factory	2
	Relationship – Made within the company, raw material billet is procured at market prices	2
	Logistics cost – Shipping distance over 1000 kms.	5
	Capability – Easily available , if institutional order , fulfillment takes some time	3
Demand	Stable	2
Interaction with Customers	Type of customer – Institutional Customers like Govt. orders	3
	Promotions – Monthly promotions	3
	Customer tolerance time – Govt. orders have to be delivered on time	4
	Relationship with distributors/dealers – Distributers are small in size so can wait	2
Costs	Unit cost – High (Sold at high price)	1
Quantity Considerations	Transporting full truck load saves a lot of cost	4
	Quantity discounts – Bonanza Scheme, TOD scheme (Turnover Discount)	4
	Purchase frequency – Distributor purchase frequency in a month	2
Obsolescence Risk	High – Faces risk of being replaced by drilling machines and chisel. Company also has chisel in its product line. Chisel is not sold in those markets where demand of crowbar is high as chisel will cannibalize sales	1

Figure 6

SUVs

SUV is a general term used to describe midrange utility vehicles. The supply chain of such a product is fairly long and there is a tendency to maintain larger than required safety stock at each level, which can eat up capital. We have taken the hypothetical example of a newly-launched SUV which is in a growth phase. The relevant factors are detailed in Figure 7.

Figures 6 and 7 show how the parameters influence safety stock requirements for industry-specific products. However, for application in a real-life scenario statistical treatments (from available data) of these parameters are imperative, in order to:

- Learn the interdependencies between parameters and eliminate redundant ones.
- Discover the type of relationship of parameters with safety stock (e.g., linear, quadratic, etc.).
- Calculate a "summary statistic" to incorporate all weights and then include them in final calculation for safety stock (minimum inventory level) and maximum inventory level.

Application of Parameters: SUV

Factor	Sub-factor for product- SUV	Weight
	Weight 1 to 5: 1- Low safety stock required, 5- High safety stock required	
Product Lifecycle	Growth	4
Product Shelf Life	Nonperishable	3
Business Importance	Highly profitable	5
Sales Pattern	Seasonal – High during festival season	2
Supply Side Constraints	Distance of suppliers – Not far from factory	1
	Relationship – Long-term suppliers	2
	Logistics cost – Distributors all over country.	5
	Capability of suppliers – Quite capable	2
	No. of suppliers – More than one for most of the critical parts	1
Demand	Fluctuating	4
Interaction with Customers	Type of Customer – Retail customers	2
	Promotions – Festival discounts	4
	Customer tolerance time – Customers can wait for a month	2
	Relationship with distributors/dealers – Distributers are big players and demand quick replenishment	3
Costs	Unit Cost – High (sold at high price)	1
Quantity Considerations	Purchase Frequency – Distributor wants just-in-time product	3
Obsolescence Risk	Low	3

Figure 7

Correctness of Safety Stock

Merely calculating safety stock is not enough. It's also essential to capture relevant data to find out if safety stock is meeting its real purpose. Data such as:

- Number of stock-outs.
- Trend between stock-out and machine down time; if both are high something is wrong.
- Forecast accuracy.
- Lost sales due to stock-outs.

Calculating sales loss is not easy. Actual demand needs to be captured along with actual sales.

Lost Sales = Actual Demand – (Actual Sales + Sales of Own Substitute Product + Sales Postponed)

In this case, we are assuming that substitute products of competitors are not purchased.

Acquiring a new customer is also extremely costly. A company may lose the customer due to stock-outs, and the cost of losing the customer should also be factored in. Lost sales are not always product specific but are associated with the customer's shopping basket. One example: A customer goes to buy fruits, toothpaste and a cold drink from the store. When he finds his preferred toothpaste brand is out of stock, he leaves the store and purchases all the items from a competitor.

After lost sales due to stock-out are ascertained, as well as when, the table factors change. The company must then revisit its safety stock number and update it to avoid too much or too little inventory.

Appendix — Safety Stock Formulas

- {Z * SQRT (Avg. Lead Time * Standard Deviation of Demand ^2 + Avg. Demand ^2 * Standard Deviation of Lead Time ^2}
- SS = √ [(σ FE)2 x (LTI/FI)beta + (σ LT)2 x D2] x Z x (FI/OCI)beta, where: SS = safety stock, FE = forecast error, LT = lead time interval, FI = forecast interval (pick a beta between 0.5 and 0.7), D = average demand during lead time, Z = normal distribution service factor based on desired service level, OCI = order cycle interval
- To calculate the safety stock, first calculate the standard loss function, designated as L(z). This function is dependent on the values of the desired fill rate f, the demand μ and its standard deviation σ, the time between orders p, and the replenishment lead time l : $L(z) = (1 - f) \leftrightarrow \mu p/\sigma (p + l)^{1/2}$. Once L(z) is known, z can be found in a look-up table and the safety stock can be calculated by: Safety Stock $= z \sigma (p + l)^{1/2}$
- Safety stock = (standard deviation) *(service factor) *(lead time factor) *(order cycle factor)*(forecast-to-mean-demand factor)

References

Optimizing Safety Stock, Dave Piasecki, http://www.inventoryops.com/safety_stock.htm

Safety Stock, Charles Atkinson, June 2005, http://www.inventorymanagementreview.org/2005/06/safety_stock.html

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