Identifying and Setting Safety Stocks Levels via Multiple Criteria

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Abstract
In a make-to-order manufacturing environment safety stock levels on components/items/sub-assemblies have a major impact on the on-time delivery (OTD) metric. Especially because of the variable demand and supplier lead times on different items, safety stock levels can heavily influence the production schedules and due date performance. At companies that have thousands of components/items, identifying the items that should have safety stock and the level of safety stock on those items is critical because of the inventory investment budget constraints, and expected service level and OTD metric. This paper describes a structured analytical approach to identify items that should have safety stock and then identify the level of safety stock based on the level of risk associated with the items. Using a multi-criteria selection process we determine risk priority numbers (RPN) for all the items that are considered to have safety stock. The lower the RPN the lower is the risk associated with not having the component/item/subassembly in stock. Safety stock levels for parts are then calculated by setting their service levels proportionate to the RPN they hold.

Keywords
safety stock, multi-criteria selection, risk priority

1. Introduction

Smooth and lean operation of any supply chain node requires effective inventory management strategy and efficient stocking policies. Highest possible customer service at the lowest possible cost is the goal of materials management function in any organization. Thus, inventory management has gained significant importance in the past couple of decades in both academic and practitioner fields. Substantial amount of research has been conducted to determine the optimum stocking policies under various situations. Typically, materials constitute 40 to 50% of total revenue [1] in most manufacturing organizations. Thus, any reduction in materials cost directly impacts the bottom line by increasing profitability. From a supply chain perspective the reduced cost can be passed down to the customer thus ensuring more business.

Our focus in this paper is to reduce inventory holding costs, thereby reducing materials costs, by reducing the level of safety stocks using differentiated service levels. In this paper, we propose a methodology for calculating safety stock that utilizes multiple criteria classification of items combined with differentiated service levels for safety stock calculation based on the degree of risk or uncertainty associated with each item. The traditional method for calculating safety stock uses the same service level for all the items. In our approach we postulate that using the traditional method is not an efficient way of determining safety stocks. The level of safety stock should be determined by the level of risk or uncertainty associated with the item in terms of sourcing, demand, and internal criticality.

The multiple criteria classification process is based on a common quality tool, Failure Modes Effects Analysis (FMEA), that is considered to be a structured analytical technique to analyze a system, subsystem, or item, for all potential or possible failure modes. FMEA is a detailed analysis of a system down to the component level. Once all the items are classified as to the Failure Model, the Effect of Failure, and the Probability of failure, using a numerical scale from 1 to 9 to define the severity in the ascending order, they are rated as to their severity via an index called Risk Priority Number (RPN), where RPN is the product of the numerical values for the three criteria [6].

We have extended the FMEA tool by using criteria related to safety stock calculations, and associating low service levels to compute the safety factor in safety stock calculations with the items having low RPN numbers. FMEA does not clearly distinguish between the RPN numbers above the cutoff value, RPN is considered to be a dimensionless number with no real meaning to its value. In our approach, we assign a higher risk with a higher RPN number and a lower risk with a lower RPN number, which in turn determines the safety factor for safety stock calculations.

The methodology was first used to determine safety stock levels and investment at a Eaton Hydraulics' made-to-order facilities that manufactures hydraulic valves, and the results showed that inventory investments were significantly reduced. In order to test this methodology at the Center for Engineering Logistics and Distribution at the University of Arkansas, we developed a data generation procedure that closely replicates the item master and subordinate item master file in the MRP/ERP system at any manufacturing facility. We discuss this and the methodology in detail in the Section 3 of this paper. In the next section, we present a brief literature review on inventory management focusing on safety stock calculations.

2. Literature Review

A manufacturing facility's survival and growth highly depends on its customer service levels. The inventory management function is faced with the daunting task of providing superior level of customer service which becomes even more difficult when demand and lead time fluctuate rapidly. In order to ensure high levels of customer service firms invest in safety stock that acts as a buffer against uncertainty in demand and lead time. In the last few decades a lot of research has been conducted in developing various methods of determining safety stocks that achieve the customer service goals at the lowest costs.

Most of the models utilize the same service level for all the items, computed usually by employing an optimization model with a cost minimization objective function (Minimize Total Cost: ordering cost + holding cost + backordering cost) over a set of constraints. [5] describes a safety stock calculation process through a case study analysis of Nabisco Foods Group. The company uses a modified fill rate equation with one decision variable which simplifies the calculation. The standard equation $FR = 1 - \frac{\sigma G_u(k)}{Q}$ where k is the safety factor, $G_u(k)$ is the unit normal loss function, Q is the order quantity and FR is the fill rate; is modified to $FR = 1 - \frac{LT}{ROQ} G_u(k)$ where LT is the lead time and *ROQ* is the reorder quantity. By developing ratios of *LT/ROQ*, a relationship between the ratio and safety factor is approximated by power functions. This results in a somewhat differentiated service level method, but with service levels being an input to the process rather than an output.

[4] suggests a model to optimize safety factor through marginal return analysis. Utilizing data collected on lost sales by applying varying levels of safety factor to a population of representative control items, and using data generated through baseline of safety factor equal to zero to determine the full value of potential lost sales, through controlled experimentation of recouped lost sales associated with each safety factor. A graphical model of the recouped lost sales versus safety stock investment at various levels of safety factor is developed to determine the break-even or intersection point of the two curves. This intersection point defines the safety factor level at which safety stock investments equal recouped lost sales. Any factor level less than that at the intersection point yields positive benefit, while investment beyond this point yields negative returns. One of the main drawbacks of this method is the complexity of implementation and experimentation.

We think that the downside of the models and methods developed so far is that they are not easy to understand and more over difficult to implement. Our motivation behind developing the proposed multiple criteria classification and differentiated customer service level methodology was to develop a method that is easy to understand, implement, and one that achieves the expected results with the least efforts. Apart from being easy to understand and implement by using a simple spreadsheet, our methodology also disposes of the usual problems of overestimation and underestimation of safety stock.

3. Multiple criteria classification methodology and implementation

The proposed methodology begins with the elimination of items that the materials management function does not want to maintain standard levels of safety stock, determined by using the safety stock calculation formulas, like class A items (classification based on item value). Class A items usually being high value items are the ones that are most closely monitored, with lowest inventory investments. Some materials managers might choose to eliminate the class C items because the stocking policies for class C items have little consideration for safety stock. Thus a major portion of the remaining items are class B items on which standard safety stock calculations are implemented. After this elimination we implement our methodology to determine the differentiated service levels based on the associated RPN.

The base of our methodology is the three criteria used to determine the RPN: Demand Fluctuation, Supplier Responsiveness, and Internal Criticality. Each criterion is given a score from 1 to 9 based on the level of severity, the determination of which is explained later. We now move with the detailed explanation of each of the criterion.

Demand Fluctuation: Demand fluctuation is the coefficient of variation of demand for an item over a period of one year, using either weekly of monthly time buckets.

Supplier Responsiveness: Supplier responsiveness is merely the lead time for each item.

Internal Criticality: This is the only subjective criterion that has to be developed by using inputs from planning, production, and engineering functions. It is based on the requirement of the item when the production or assembly process of an order begins. If the item is required to begin production or assembly then there is a higher risk associated with going out of stock, but if the item is needed in the end then based on the total production/assembly lead time the risk associated with an out of stock situation on the item is relatively low.

The most important issue in calculating safety stock is determining the representative distribution for the demand during lead time, commonly referred to as DDLT. One of the ways is to collect a set of real time data on DDLT and fit a probability distribution to the data, [5], but this is not an easy task and requires historical data on DDLT which is rarely maintained. The other as suggested by [2] is achieved by first utilizing order size and order intensity (number of orders in a given period) to develop a compound distribution of period demand and then period demand and lead time gives rise to compound distribution of DDLT. In our methodology, we use the most commonly used and accepted distribution; the normal distribution, also suggested by [2] for fast moving items. The assumption of normal distribution to represent the demand process simplifies the safety stock calculations and more over this is a widely used and accepted approach in industry. Thus, we are in a position to determine the two parameters of the demand; mean demand μ, and the standard deviation of demand σ. With the knowledge of lead time and the standard deviation of demand over a unit period of time, it is possible to calculate the standard deviation of demand during lead time, σ_{DDLT}, as $\sigma * \sqrt{LeadTime}$, [3]. Safety stock can be calculated by using the formula $SS = z * \sigma_{DDLT}$.

Item demand and lead time can be extracted from the MRP or ERP system used at the manufacturing facility. The demand information can be used to determine the mean demand and standard deviation of demand, which can further be applied to calculate the coefficient of variation of demand. Once the values of all the three criteria have been calculated for each item under consideration, a severity score is assigned to each criteria to characterize the relative risk offered by the criteria. Table 1 and Table 2 show the criteria values and the relative scores.

Table 1: Demand fluctuation and Supplier Responsiveness Scores

Coefficient of variation of demand	Demand fluctuation Score (DFS)	Item lead lime	Supplier responsiveness score (SRS)
0.00 – 0.2	2	1	1
0.21 – 0.4	3	2	2
0.41 – 0.6	4	3	3
0.61 – 0.8	5	4	4
0.81 – 1.0	6	5	5
1.01 – 1.2	7	6	6
1.21 – 1.4	8	7	7
>1.4	9	8	8
		>8	9

Table 2: Internal Criticality Score

Criticality	Internal Criticality Score (ICS)
Very Low	1
Low	3
Medium	5
High	7
Very High	9

The Risk Priority Number (RPN = DFS * SRS * ICS) can be calculated for each item by simply multiplying the three scores for each item. Table 3 shows sample calculation for 5 hypothetical items.

Table 3: Sample RPN Calculations

Item Number	CV of demand	DFS	Item lead lime	SRS	Item criticality	ICS	RPN
UA0001	0.45	4	8	8	High	7	224
UA0002	1.26	8	1	1	Medium	5	40
UA0003	1.82	9	6	6	Very High	9	486
UA0004	0.56	4	4	4	Very High	9	144
UA0005	0.32	3	2	2	Low	3	18

The RPN signifies the risk of all the criteria combined together. Thus we conclude that lower the RPN the lower is the risk associated with the item from the stockout situation standpoint. This leads to our theory of assigning service levels based on the RPN. Our contention is that the lower the RPN the lower is the risk and thus lower the service level should be, and vice versa. With this in perspective we have developed a list of range of RPNs and the associated service levels to be used to calculate safety stock. Table 4 shows the list. Using these recommended levels assures that just the right quantity of safety stock is maintained while offering high overall customer service levels from the due date or order fill rate perspective with the lowest inventory investment. The next section describes the experiments conducted to illustrate that the methodology results in inventory investment savings.

Table 4: Determining appropriate service level

RPN Range	Service Level
< 100	70%
101 – 150	75%
151 – 200	80%
201 – 250	85%
251 – 300	90%
> 300	95%

4. Experimental Analysis

In order to maintain confidentiality of the data actually used at Eaton Hydraulics, we decided to generate our own data that would resemble an item master file and subordinate item master file in any planning system. We restrict ourselves to generating data related to item demand, lead time, and item price as these are the only to attributes of an item that we consider to implement our methodology. The data generation process uses a uniform distribution to generate the coefficient of variation of demand, average demand, lead time, and price for each item; and a discrete distribution to generate the internal criticality score. Table 5 shows the distributions and ranges in detail.

Table 5: Data generation

Characteristics	**Distribution**	**Range**	**Unit**
Average Demand	Uniform	25 - 100	Units
Coefficient of variation of demand	Uniform	1.2 – 1.5	--
Lead Time	Uniform	2 – 10	Weeks
Price	Uniform	5 – 25	Dollars
Internal Criticality	Discrete	25% Very High 25% High 20% Medium 20% Low 10% Very low	--

Using the above data generation process we created 1500 items and applied the multi-criteria classification process with differentiated service levels. To illustrate the calculations we apply the methodology on the five hypothetical items in Table 3. Table 6 shows the safety stock calculations and the corresponding inventory investment for the hypothetical items.

Table 6: Safety Stock levels and Investment

Item Number	**RPN**	**Service Level**	**Average Demand**	**Standard Deviation of demand**	**Safety Stock Level**	**Item Price**	**Investment**	**Carrying Cost @ 12%**
UA0001	224	85%	74	33	98	$8.75	$853.83	$102.46
UA0002	40	70%	50	63	33	$15.32	$506.01	$60.72
UA0003	486	95%	45	82	330	$7.02	$2318.08	$278.17
UA0004	144	75%	58	32	44	$17.01	$745.18	$89.42
UA0005	18	70%	69	22	16	$21.05	$344.76	$41.37

Table 7 and Table 8 show the results of implementation of the methodology on the 1500 items that we created.

Table 7: Implementation Results

Service Level	**Safety Stock Investment**	**Carrying cost based on 12%**
95% across the board	$4,734,984.25	$568,198.11
90% across the board	$3,689,158.95	$442,699.07
Differentiated	$ 3,364,322.36	$403,718.68

Table 8: Reduction in Carrying Costs

Comparative Savings	**Savings in Dollars**	**Percentage Reduction**
Compared to 95% service level	$164,479.43	28.9%
Compared to 90% service level	$38,980.39	8.8%

5. Conclusion

Safety stock ensures protection against variation in demand during lead time. In a made to order environment it affects the due date performance and thus maintains the expected levels of customer service. But using the same service level to calculate safety stock for all the items without giving consideration to the past fluctuation in demand, lead time period and the stage of production or assembly when the item is needed, results in overestimation of safety stock. Our methodology considers the three criteria and calculates safety stock levels based on differentiated service levels developed through risk levels indicated by Risk Priority Numbers.

Results of the experimental analysis illustrates that the methodology successfully reduces inventory investment. Also the experimental results on the artificially generated data were in line with those after implementation of the methodology to calculate safety stock investments at Eaton Hydraulics. There was a significant difference in investment with safety stock calculated by using a service level of 95% across the board than compared to 90% across the board.

6. Future work and recommendations

Although our methodology does reduce the investments in safety stock by a significant amount, there are certain aspects that need more research and observation through implementation at a facility for an extended period. The relative service levels for RPN ranges were chosen based on discussions with production and materials management professionals, rather than experimental runs. Simulating a made-to-order facility could provide a better idea of the behavior of the system, and would result in better settings. Also our methodology assumes constant lead times. This assumption can be relaxed and the lead time variability can be added as criteria to calculate RPNs and then safety stock, which would require changing the RPN ranges and the relative service levels. Another area of future research and consideration is the assignment of weights to the criteria. The RPN being a number resulting from the multiplication of three other scores, it will need some logical and mathematically sound method to determine the RPN after assigning weights to the criteria. This necessitates a change in the ranges that determine the corresponding service levels.

7. Acknowledgements

The methodology was first developed at a Eaton Hydraulics' made-to-order facility that manufactures hydraulics valves. We would like to acknowledge our colleagues at Eaton Hydraulics for their support during the development of this methodology.

8. References

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