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The Analytic Approach Vs. The Simulation Approach to Determining Safety Stock

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Abstract

This article compares two basic approaches to determining safety stock – the analytic method and simulation. For analytic solutions, the behavior of the stock relationship is described by way of functional relations. The author's work is based on extensive research involving 26 different analytic methods for determining safety stock. All methods were applied to data for a specific company with the goal of verifying the practical application and effectiveness of the specific methods. The research showed that, in practice, using the specific analytic methods presents a number of problems. This concerns, in particular, the assumption on the normal distribution of demand, the stationary demand process and the insignificance of some uncertainty factors. As a result, calculated safety stock fluctuated in a range of 10 to 235 pieces for the specific stock item. During simulation, experiments are carried out with a model of a real inventory supply system in order to understand its behavior and assess the various system options, which differ in shipment size, length of the replenishment cycle and the safety stock level. Simulation was carried out by using the Monte Carlo method with an XP Excel spreadsheet. The level of security attained against a stockout for various levels of safety stock was monitored. In addition, the size of stockholding costs and stockout costs were calculated for the specific safety stock levels. On the basis of the minimum overall costs criterion, it was recommended that the company maintain a safety stock of 64 items, which ensures a cycle service level of 92% and a fill rate of 98%.

Key words: Safety stock, analytic approach, simulation, Monte Carlo method, cycle service level, fill rate.

Introduction

More and more attention in logistics has been devoted to inventory management. The main reason is that capital tied up in stock inventories is, in a certain way, frozen. It lacks the potential for financing technical development, and therefore its solvency is threatened. In addition, stock inventories consume additional labor and resources and run the risk of depreciating, becoming obsolete or losing their sales potential. For these reasons, inventories must be as small as possible.

From a functional point of view, inventory as a whole may be divided into several subcategories. These include cycle stock, safety stock, anticipation inventory, in-process inventory, strategic inventory, speculative inventory, and technological inventory.

An entire range of models and approaches for managing cycle stock, in particular, may be found in the literature. Less attention is paid to safety stock, despite the fact that in many companies it may be up to 50% of the total inventory size (Sandvig, 1998) and holding costs for safety stock may be as high as 20% to 40% of the average stockholding value (Sandvig and Reistad, 2000). It goes without saying then that correctly setting the level of safety stock can help to substantially reduce a company's costs.

The task of safety stock is to capture, to a certain degree, the deviations that occur in the real inventory process against expected or planned inventory. These deviations can occur in a company's input material (size and interval of shipments) and in the company's product output (size and interval of stock depletion). Deviations could also occur in consumption when processes have an uncertain cycle time or uncertain yield.

Two basic approaches may be used to determine the level of safety stock – the analytic approach and the simulation approach. The objective of this article is to describe the pros and cons of applying both approaches to a real business environment.

The analytic approach to determining safety stock

With an analytic solution, the behavior of the inventory supply system is described using functional relationships that can be expressed with the help of mathematical formulas. The advantage of the analytic solution is its relative simplicity. The safety stock size is obtained by entering concrete parameter values into the formula. This is why the analytic approach is preferred by many managers. The disadvantage of the analytic approach is its static nature. The level of safety stock is influenced by the effect of several random variables (typically: the level of demand, the length of the lead time, and the size of a shipment). Difficulties are encountered when attempting to include all sources of uncertainty in an analytic model, and this could create very complicated relationships that have very little practical application. These complex relationships for specific inventory management systems are presented, for example, by Ter-Manuelianc (1980). In practice, a less complicated approach is usually used – one or two main sources of deviation in the inventory supply process are chosen, and it is assumed that the remaining factors do not affect inventory size. The notion of real inventory system behavior, however, is obscured to a certain degree by this.

As a part of his dissertation work, the author has carried out extensive research on this subject matter and has, in turn, identified 26 different analytic methods for determining safety stock (Zizka, 2002b). Some of the methods even offer several different varieties. Moreover, another method has been created by the author – number 24 in Table 1 (Zizka, 2002a). These methods may be divided into two basic groups. The first group of methods (24 methods in all) sets a fixed level of safety stock. This group is useful for stock items with stationary demand over time. The second group (3 in all) works with variable safety stock and is useful for stock items with non-stationary demand. Unfortunately, the professional literature often does not respect this difference, and the methods are considered to be universally valid.

All 27 methods were applied to data for one specific company with the goal of verifying the practical application of each method. Data were obtained from the company on the size and intervals of shipments, on daily or monthly demand, and on the stock inventory status of 3 selected items for the past three years. The results of the calculation are presented in this article for one item with the following characteristics: average monthly demand 117 pieces, standard deviation of monthly demand 47 pieces, coefficient of variation for monthly demand 0.40. In the following analysis (Zizka, 2002b), the existence of a statistically significant trend and seasonal demand fluctuation was demonstrated. Safety stocks were calculated for a cycle service level of 95%, which corresponds to a safety factor level of 1.65. The results of the calculations are summarized in Table 1 and Table 2.

It is clear from Table 1 and Table 2 that the calculated levels of safety stock vary greatly in size (sometimes by a hundred pieces or more). The minimum calculated safety stock size was 10 pieces for this item and the maximum size 235 pieces. In practice, the research showed that there are a number of obstacles when applying the individual methods. The conditions on which the methods are based are often not met. This involves, for example, the assumption of the normal distribution of demand, the stationary character of demand, and the insignificance of some uncertainty factors (e.g. assumption of the constant length of the uncertainty interval, the non-existence of shipment fluctuations, etc.). The methods described in the literature are often based on the specific conditions of companies and may by no means be applied to all stock items universally. As mentioned earlier, another disadvantage is the infeasibility of including in the calculation all sources of deviation that occur during the inventory process.

Table 1

Comparison of safety stock size for the specific methods (Methods with fixed safety stock)

Method no.	Safety stock (pieces)	Description of method	Method no.	Safety stock (pieces)	Description of method
1	10	Sandvig (1998)	12	36	Krupp (1997)
2	54	Tomek and Tomek (1996), Tomek and Vavrova (1999)	13a	35	Zinn and Marmorstein (1990), Coyle et al. (1992), Evers (1999), Kubat (1999)
3a	235	Tomek and Tomek (1996), Tomek and Vavrova (1999)	13b	28	Uncovsky (1980)
3b	70	Tomek and Tomek (1996), Tomek and Vavrova (1999)	14	39	Mann (1979)
4	127	Blaha (1982)	15	57	Schreibfeder (1999)
5a	78	Tomek and Tomek (1996), Prazska and Jindra (1997)	16	39	Mann (1979)
5b	167	Tomek and Tomek (1996), Prazska and Jindra (1997)	17	34	Horakova and Kubat (1999)
5c	229	Tomek and Tomek (1996), Prazska and Jindra (1997)	18	44	Zeng (2000)
6	91	Blaha (1982)	19	64	Tomek and Tomek (1996), Tomek and Vavrova (1999)
7a	25	Sedlacek (1999)	20	54	Tomek and Tomek (1996)
7b	38	Sedlacek (1999)	21	39	Tomek and Tomek (1996)
8	112	Lambert, Stock and Ellram (2000)	22	48	Krajcovic (1999)
9	11	Burstiner (1994)	23	105	Graves (1999)
10	92	Mann (1979)	24	96	Zizka (2002a)
11a	32	Weiss and Gershon (1989), Fawcett et al. (1992), Chase and Aquilano (1995), Diaz-Adenso (1996), Tomek and Tomek (1996), Lavallee and Raymond (1998), Sandvig (1998), Sandvig and Reistad (2000)	MAX	235	
11b	40	Tomek and Tomek (1996)	MIN	10	
			R	225	

Table 2

Comparison of safety stock size for the specific methods (Methods with variable safety stock)

No.	Month												Description of method
	1	2	3	4	5	6	7	8	9	10	11	12	
25	33	57	35	29	41	21	36	57	28	51	34	40	Krupp (1997)
26	61	62	93	61	52	67	40	63	89	52	81	59	Mann (1979)
27	41	40	65	40	34	46	25	43	66	35	60	42	Horakova and Kubat (1999)
MAX	105	105	105	105	105	105	105	105	105	105	105	105	
MIN	33	40	35	29	34	21	25	43	28	35	34	40	
R	72	65	70	76	71	84	80	62	77	70	71	65	

The simulation approach to determining safety stock

Simulation can be characterized as a process that generates a model of a real system and then performs experiments with the model in order to better understand the behavior of the studied system or to assess various functions of the system. Simulation experiments may be repeated and the results statistically processed and interpreted. Simulation is considered to be more of a descriptive tool, because it searches for an appropriate solution through an iterative solution approach that is not necessarily optimal.

The most common type is computer model simulation. Calculators or specialized software products may be used to construct and implement these simulations. Simulation models may be categorized according to a number of criteria. In this paper, we use stochastic (or Monte Carlo) simulations when determining safety stock.

For comparing results, the calculation was made for the same stock item as in the analytic methods. The simulation was carried out with the help of the Monte Carlo method, which tries to imitate a random variable on the basis of knowledge about the probability distribution of the random variable set most often by monitoring the random variable in the past. For the purpose of creating the value sequence for the random variable, a cumulative probability distribution is set and then a range of random numbers is defined. For selected stock items, the probability distribution for demand (Table 3) was set by the analysis of data given in the study by Zizka (2002b). If the variable value was situated at the edge of an interval, it was shifted to the higher interval. The created model assumes that all shipments have a consistent size of 100 pieces and a fixed replenishment cycle of 21 days. These assumptions are based on the existing experience with the supplier, who fills the orders by the set deadlines and in the set quantity. For this reason, it is not necessary to deal with fluctuating size and intervals for shipments when setting the dimensions of safety stock.

All calculations were generated with an XP Excel spreadsheet calculator. The RANDBETWEEN function, which serves to generate whole pseudo-random numbers from the interval (a, b), was used to create the pseudo-random numbers. The probabilities of obtaining even cumulative probabilities in Table 3 are rounded to 3 decimal places, and therefore, three-digit pseudo-random numbers were used. The set range of random numbers is then used for the simulation.

Table 3

Demand probability distribution

Range (pieces)	Mean interval	Probability of occurrence	Cumulated probability	Range of random numbers
0	0	0.877	0.877	000 - 876
1 - 12	6	0.001	0.878	877
12 - 24	18	0.040	0.918	878 - 917
24 - 36	30	0.031	0.949	918 - 948
36 - 48	42	0.015	0.964	949 - 963
48 - 60	54	0.022	0.986	964 - 985
60 - 72	66	0.005	0.991	986 - 990
72 - 84	78	0.003	0.994	991 - 993
84 - 96	90	0.003	0.997	994 - 996
96 - 108	102	0.003	1.000	997 - 999

The solution can be broken down into the following steps:

1) Generate the random size of demand (Table 4, column 3),

2) Add to the table the size of shipments, which are delivered in intervals of 21 days (Table 4, column 4),

3) Set the closing stock balance (CB) for each day, which is also the opening balance for the next day, i.e.

Closing balance = opening balance + shipment size – demand size

4) If there is a stock deficit (i.e. CB < 0), the closing stock balance is, of course, equal to zero and the missing stock quantity is entered in column 6 in Table 4. It is assumed that this quantity will be filled using the next shipment.

A simulation of 50 replenishment cycles (1050 days) was carried out with the help of an XP Excel spreadsheet. This quantity of cycles should already provide a representative notion about the behavior of the model stock system.

Due to limited space, only a simulation of 25 day was selected from the 46th and 47th replenishment cycle in Table 4. The process of the total stock balance during the overall simulation (with and without safety stock) is illustrated in Figure 1. Table 4 can be used to determine safety stock (SS). It was revealed in the simulation that, if the company does not hold any safety stock, the cycle stock inventory would only cover demand for a period of 900 days. The corresponding fill rate is only 900/1050 = 0.8571 (85.71%). The simulation also shows that the maximum stock deficit amount is 148 pieces. This means that it is not logical to maintain a safety stock of more than 148 pieces.

A column with safety stock can be easily added to Table 4 to monitor how the stock balance and size of the stock deficit will develop at various levels of safety stock. On the basis of the analysis of stock deficit, the author recommends maintaining a safety stock of 96 pieces for this item (Table 1, method 24). We will, therefore, add column 8 to Table 4 and monitor the actual balance of safety stock. At the start of the simulation, the safety stock balance is 96 pieces. If the cycle stock is depleted, demand is covered with safety stock (the stock balance in this case is lower than 96 pieces). When a new shipment arrives, the safety stock is replenished to a level of 96 items, and then the remaining pieces are used to replenish the cycle stock.

Table 4

Simulation of stock balance

Day	Pseudo-random number	Demand	Shipment	Stock balance without SS	Deficit without SS	Stock balance with SS	Safety stock (SS)	Deficit with SS
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
958	214	0		0	2	94	94	0
959	882	18		0	20	76	76	0
960	151	0		0	20	76	76	0
961	381	0		0	20	76	76	0
962	6	0		0	20	76	76	0
963	897	18		0	38	58	58	0
964	983	54		0	92	4	4	0
965	886	18		0	110	0	0	14
966	902	18		0	128	0	0	32
967	767	0	100	0	28	68	68	0
968	313	0		0	28	68	68	0
969	271	0		0	28	68	68	0
970	648	0		0	28	68	68	0
971	363	0		0	28	68	68	0
972	523	0		0	28	68	68	0
973	748	0		0	28	68	68	0
974	931	30		0	58	38	38	0

Table 4 (continuous)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
975	295	0		0	58	38	38	0
976	547	0		0	58	38	38	0
977	735	0		0	58	38	38	0
978	611	0		0	58	38	38	0
979	477	0		0	58	38	38	0
980	823	0		0	58	38	38	0
981	476	0		0	58	38	38	0
982	812	0		0	58	38	38	0

The purpose of the calculation is to measure how the set safety stock protects the company against a stockout. This service measure can be calculated either by the cycle service level (probability that stock will not be depleted during one cycle) or by the fill rate (probability that demand for the item can be completely satisfied immediately after requested from the stock inventory). Considering that for analytic methods the safety stock was standardized for the cycle service level (95%), this criterion was used first in view of the comparability of results. A cycle service level of 95% requires that stockholdings not be depleted in 95% of the cycles (i.e. 47.5 cycles out of 50).

When using a spreadsheet calculator, the calculation may be easily modified for another safety stock size. The cycle service levels and the fill rates achieved in relation to safety stock size are given in Table 5. It is clear from Table 5 that the cycle service level changes abruptly.

The precisely requested value of 95% was not achieved. Therefore, a safety stock in a range of 90 to 128 pieces that secures a cycle service level of 94% or 98% can be considered. A concrete decision on the amount of safety stock should be backed up by an in-depth analysis of stockholding costs and stockout costs.

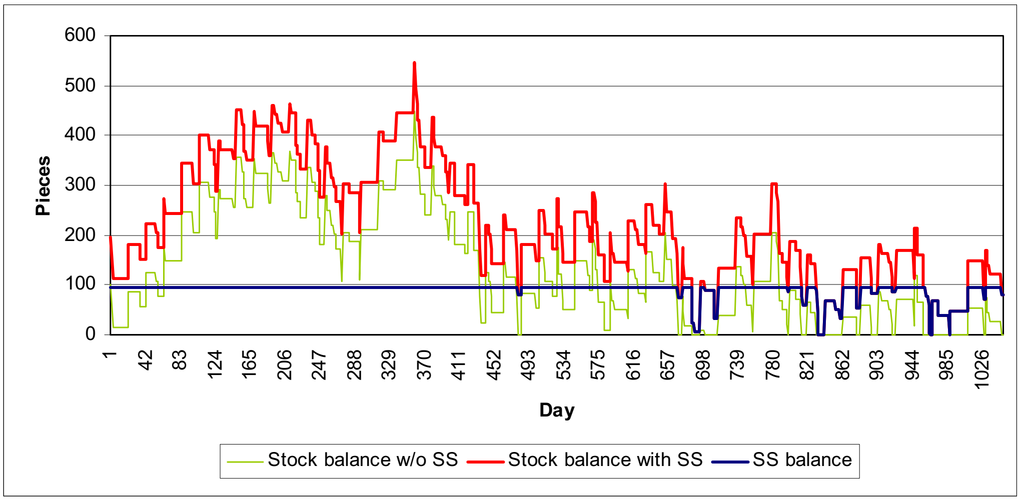

Fig. 1. Balance of total stock during simulation

Table 5

Results of the simulation after 50 cycles

Safety stock (pieces)	Cycle service level (%)	Fill rate (%)
0	68.00	85.71
50	88.00	95.90
60	88.00	97.24
64	92.00	97.62
70	92.00	98.00
80	92.00	98.19
90	94.00	98.19
100	94.00	98.95
128	98.00	99.05

Cost analysis

Companies hold safety stock in order to reduce the risk of depleting stock inventories, and in turn, the risk of not satisfying customer demand. With increasing safety stock, the number of temporarily unfilled orders from customers is lowered, and the costs related to a stockout are reduced as well. On the other hand, stockholding costs increase. It is generally the case that a very high service measure necessitates a very high level of safety stock. The optimum size of safety stock is a size that minimizes the overall costs for holding and storing stock and for a stockout.

Stockholding costs for selected stock items amounted to $ 0.093/piece/day and stockout costs were $ 4/piece. The calculation of overall costs for various safety stock sizes is given in Table 6.

Table 6

Overall costs after 50 cycles

Safety stock (pieces)	Stockholding costs ($)	Stockout costs ($)	Total costs ($)
0	12 799	25 880	38 679
50	17 193	5 736	22 929
60	18 129	4 160	22 289
64	18 508	3 728	22 236
70	19 080	3 224	22 304
80	20 034	2 448	22 482
90	20 989	1 688	22 677
100	21 950	1 240	23 190
128	24 646	80	24 726

On the basis of the minimal overall costs criterion, the optimal size of safety stock is 64 pieces. According to Table 5, this safety stock size ensures a cycle service level of 92.00% and a fill rate of 97.62%. An important conclusion gained from this is that the manner of setting the optimality criterion (autonomously or on the basis of costs) has a significant impact on the amount of safety stock.

Conclusion

The use of simulation is especially beneficial in cases where demand is not governed by some theoretical model distribution and only empirical data models are available. Simulation also allows for the verification of various inventory supply systems with differences in the shipment size, length of the service cycle, or the level of safety stock.

Simulations are supported by a number of specialized software products, which are too costly for many small and medium-size firms. The advantage of carrying our simulations with an Excel spreadsheet is that this software is easy to obtain, user friendly, and available at a relatively affordable price. Only a basic knowledge of the function and tools of spreadsheet calculators is needed to set up a simulation model.

In conclusion, it should be said that the issue of safety stock management, however extensive it may be as a whole, cannot be dealt with in an isolated environment, but always in context with management of the overall inventory supply system. Flawed approaches to the management of other stock items are reflected in the high level of safety stock, regardless of the chosen calculation method. In such a case, this ensures only that the required service measure against deviations will be achieved. If a company's goal is to reduce the amount of safety stock, then it is necessary, first and foremost, to simplify and rationalize corporate and extra-corporate material and information flow. In the end, safety stock will also be less as a result of reducing the swings in demand, shipment supplies and acquisition terms.

References

1. Blaha, P. Industrial Sales Organization. – Prague: SNTL, 1982. – 80 pp.
2. Burstiner, I. Basic Retailing. – Prague: Victoria Publishing, 1994. – 882 pp.
3. Chase, R.B., N.J. Aquilano. Production and Operations Management. Manufacturing and Services. – Chicago: Irwin, 1995. – 853 pp.
4. Coyle, J.J., E.J. Bardi, and C.J. Langley. The Management of Business Logistics. – St. Paul: West Publishing Company, 1992. – 580 pp.
5. Díaz-Adenso, B. How many units will be short when stockout occurs? // International Journal of Operations & Production Management, 1996. – № 4. – pp. 112 - 118.
6. Evers, P.T. The effect of lead times on safety stocks.// Production and Inventory Management Journal, 1999. – № 2. – pp. 6 - 10.
7. Fawcett, P., R.E. Mc Leish, and I.D. Ogden. Logistics Management. – London: Pitman Publishing, 1992. – 297 pp.
8. Graves, S.C. A single-item inventory model for a nonstationary demand process.// Manufacturing & Service Operations Management, 1999. – № 1. – pp. 50 - 61.
9. Horakova, H., J. Kubat. Inventory Management. Logistic Approaches, Methods, Applications, and Practical Tasks. – Prague: Profess Consulting, 1999. – 236 pp.
10. Krajcovic, M. Determining the Level of Safety Stock according to the Real Distribution of the Random Demand Variable.// Logistika, 1999. – № 5. – p. 49.
11. Krupp, J.A.G. Managing demand variations with safety stock.// Journal of Business Forecasting Methods & Systems, 1997. – № 2. – pp. 8 - 11.
12. Kubat, J. An Objective Approach to Choosing a Supplier.// Logistika, 1999. – № 10. – p. 27.
13. Lambert, D.M., J.R. Stock, and L.M. Ellram. Fundamentals of Logistics Management. – Prague: Computer Press, 2000. – 589 pp.
14. Lavallee, I., W. Raymond. Utilizing forecast information to drive Solutia's supply chain.// Journal of Business Forecasting Methods & Systems, 1998. – № 2. – pp. 7 - 14.
15. Mann, Q. Optimizing Inventory in Practice. – Prague: SNTL, 1979. – 176 pp.
16. Prazska, L., J. Jindra. Business Ventures. Retail Management. – Prague: Management Press, Ringier CR, 1997. – 880 pp.
17. Sandvig, J.Ch. Calculating safety stock.// IIE Solutions, 1998. – № 12. – pp. 28 - 29.

18. Sandvig, J.Ch., A. Reistad. Safety stock decision support tool.// Production and Inventory Management Journal, 2000. – № 4. – pp. 8 - 10.
19. Schreibfeder, J. A New Look at Safety Stock. [online]. – Coppell (Texas): EIM, 1999. <http://www.effectiveinventory.com/article29.html>
20. Sedlacek, R. An Objective Choice of Supplier.// Logistika, 1999. – № 6. – pp. 26 - 27.
21. Ter-Manuelianc, A. Mathematical Models of Inventory Management. – Prague: Institut rizeni, 1980. – 170 pp.
22. Tomek, G., J. Tomek. Supply Marketing. – Prague: Grada Publishing, 1996. – 176 pp.
23. Tomek, G., V. Vavrova. Production Management. – Prague: Grada Publishing, 1999. – 439 pp.
24. Uncovsky, L. Stochastic Models of Operations Analysis. – Bratislava: ALFA, 1980. – 416 pp.
25. Weiss, H.J., M.E. Gershon. Production and Operations Management. – Massachusetts: Allyn and Bacon, 1989. – 798 pp.
26. Zeng, A.Z. Efficiency of using fill-rate criterion to determine safety stock: A theoretical perspective and a case study.// Production and Inventory Management Journal, 2000. – № 2. – pp. 41 - 44.
27. Zinn, W., H. Marmorstein. Comparing two alternative methods of determining safety stock levels: The demand and the forecast systems.// Journal of Business Logistics, 1990. – № 1. – pp. 95 - 110.
28. Zizka, M. Setting Safety Stock Size on the Basis of a Stock Deficit Analysis.// Proceedings from 2nd International Post-Graduate Conference IMEA 2002, Technical University of Liberec. – pp. 85 - 91.
29. Zizka, M. Methods of Setting a Standard for Safety Stock Size.// Unpublished Ph.D. dissertation, Fakulty of Economics, Technical University of Liberec, 2002. – 202 pp.