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A PROPOSED INTERACTIVE INVENTORY CONTROL SIMULATION

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ABSTRACT

A proposed interactive simulation model of inventory control in a physical distribution system is presented. This model is intended to provide an exercise in which a student can attempt to control inventory so as to achieve a specified level of customer service while minimizing total cost. The student must decide when and how much to order in an environment characterized by imperfect information about exogenous, stochastic demands and lead times. A programmed method of statistical inventory control uses the same information with the same demands and lead times to provide a comparative level of performance. Possible extensions of the model to more complex situations are described.

INTRODUCTION

The objective of effective inventory control in a physical distribution system is to provide a specified level of customer service for the lowest possible cost. The manager must make two operational decisions in controlling inventory; how much to order, and when to order. If the manager has some information as Co the estimated demand for the product, the value of the product, the annual carrying cost, and the cost of placing an order then the Economic Order Quantity (EOQ) model can be used to determine how much to order. The EOQ model minimizes the total annual cost of ordering and carrying inventory. Similarly, if demand rates and lead times are known then setting the reorder point is simple. However, often uncertainty exists. Inventory decisions in a physical distribution system may be affected by demand uncertainty, and/or lead time uncertainty. Thus, the problem of controlling inventory so as to achieve a specified service level objective while minimizing costs becomes more complex.

Achieving a target level of service under conditions of uncertainty requires safety stock. The quantity of safety stock required to achieve a particular service level, as measured by the level of unit demand satisfied, is influenced not only by demand and lead time, and their uncertainty, but also by the order quantity. Larger order quantities result in fewer orders per time period, and therefore fewer opportunities to stockout, but at higher inventory carrying costs. Brown (1] provides an inventory control method which includes order size, and Schary [5] provides examples of the application of Brown's method.

The purpose of the interactive inventory simulation described in this paper is to provide the student with an understanding of the problems of effective inventory control in an uncertain environment; to show the level of performance which can be achieved using scientific inventory control; and to provide the student with practice in applying the techniques they learn to a realistic situation. This model is targeted at students in a first physical distribution or logistics course. It could also be applied in a production/operations course. This simulation is intended be used as an adjunct to classroom approaches to learning inventory control techniques. The situation modeled represents basic conditions which might be encountered in managing inventory in a physical distribution system.

This exercise allows the student to manage inventories in an environment characterized by demand and lead time uncertainty, with the goal of achieving a specified level of service. The simulation will, using programmed inventory control procedures, attempt to achieve to same objective. A comparison of the student's effectiveness versus the effectiveness of the programmed approach will be provided.

A number of physical distribution and inventory simulation models exist, e.g., Buloga II, Simchip, and the Stanford Business Logistics Game. However, a review of the descriptions of these mode's provided in Horn and Cleaves [3] indicates that these physical distribution simulations are generally comprehensive, requiring decisions not just for inventory control, but also in such areas as transportation, warehousing, and production scheduling. These models are generally competitive and are used over a continuing period of time. A number of production simulations include inventory control in a production context. As in the logistics games these tend to be comprehensive games , including not just inventory control but also production scheduling, and other operational decisions. Based on the description of Horn and Cleaves, an exception is "Inventory Simulation" (INSIM) by Carl E. Ferguson (3, p. 605]. INSIM is similar to the concept described in this paper. However, INSIM focuses on order quantity and order point decisions under different parameter values, but apparently neither explicitly includes the policy variable of the desired service level, nor a comparison of the student's decisions with a programmed inventory control technique. QCLAB, as described by Frazer [2], supplies the operational characteristics of an interactive exercise with a programmed procedure providing a basis for evaluating the effectiveness of the student's decisions. However, QCLAB deals with quality control decisions.

METHODOLOGY

The methodology of this exercise is detailed in the context of a student using the model. Explanation of the procedures used by the model during the process are described below. The basic aspects of the inventory control techniques used by the programmed method are also described.

The proposed model is an interactive model which requires the individual student to make inventory control decisions during each "day" of a simulated period with the objective of achieving a specified revel of customer service at the minimum cost over the total time period simulated. The student must decide when to place replenishment orders for a facility which is subject to exogenous, stochastic demand, and stochastic load times. The student is responsible for inventory control decisions relating to a single product at the lower level of a two-level distribution system. There are no limits on the availability of the product at the upper level, nor are there constraints on the amount of inventory which the lower level can carry.

The costs which are included are the cost of ordering, at a fixed cost per order; the cost of carrying inventory based on an annual inventory carrying cost rate times the dollar value of the product per unit times the average inventory; and the cost of excessive stockouts. It is assumed that the chosen target service level is a policy variable which represents the optimal trade off of the cost of ordering and carrying inventory, against the cost of stockouts. Therefore, stockout costs will be assessed only on those units that represent stockouts which are in excess of the expected stockout quantity based on the actual demand and the target customer service level for the total period simulated. The following example enumerates the method by which stockout costs are computed. If, for example, the target service level is to satisfy 90% of unit demand, and the actual demand is 20,000 units while the demand filled is 17,695 units, then the service level achieved would be 88,475%, If the penalty cost for excessive stockouts is 20% of the unit value of stockouts in excess of the expected number, then the penalty cost for excessive stockouts is 20% of the unit value of stockouts in excess of the expected number, and the penalty cost would be applied to 1.525% (90.00% - 88.475%) of the total demand. In the above example if the unit value were $ 50.00 per unit then the excess stockout cost would be:

$ 3050.00 (0.01525 x 20,000. x $ 50.00 x 0.20) (1)

The stockout penalty cost rate is arbitrary and could be set to any value deemed appropriate.

Prior to starting the exercise, the student must specify the target level of service, within the range of 80% to 100% of unit demand satisfied. In addition the student must specify the unit value of the item, the cost of placing an order, and the annual inventory carrying cost rate. The student must also indicate the number of days, between 150 and 350 for which the exercise will run.

The simulation program at this point will generate an average daily demand as a integer value between 40 and 100, and an average lead time as an integer value between 4 and 10. Standard deviations for both values will be set to 25% of the average value. The student does not receive this information. The student must complete the exercise under conditions of imperfect information.

The program will then use the average and standard deviation of the demand to generate an array of 375 random normal demands, and the average and standard deviation of the lead time to generate an array of 375 random normal lead times. The first 25 daily demands and lead times will be displayed for the student to estimate, by whatever method he or she may wish, the average and standard deviation of the demand and lead time. This will provide the student with the same information to estimate the average and standard deviation of the demand and lead time that the programmed approach uses. It is expected that many students who have not been exposed to scientific inventory control will not be able to use this information effectively. After studying inventory control techniques the student should be able to effectively use this information to complete the exercise.

The program will also generate a beginning inventory level, of between 1.5 and 2.5 times the product of the average demand and the average lead time. By starting with a relatively high beginning inventory the student will have a relatively large number of simulated “days” to become familiar with the operation of the simulation before he or she must place a replenishment order.

At each step where information is presented for the student’s evaluation, or where a decision is required, the simulation will require a response from the student before proceeding. Upon an indication that the student is ready the simulation will continue. Starting with day 1 the screen will display information as shown in the example below:

Daily Operations Summary

Day	1
Beginning inventory available	720
Shipments received	0
Total available	720
Demand	71
Ending inventory available	649
Stockout quantity	0
Beginning quantity in-transit	0
Less shipments received	0
Plus orders shipped	0
Ending quantity in-transit	0
Quantity ordered	0
Total demand to date	71
Total demand filled to date	71
Service level % to date	100

A rolling display of as many days’ information as space permits will be shown.

The user would then be asked whether he or she wishes to place an order. If the answer was “no”, the game would proceed to day 2 and repeat the process. If the answer to the above question was “yes”, the student would be asked Lot the order quantity. The student would input the quantity to be ordered. The program would request verification that the quantity ordered was correct. If incorrect, the student would be able to correct the order quantity. Once the correct order quantity was verified the information for day I would be redisplayed indicating the quantity ordered. The simulation would then proceed to day 2 and the process would be repeated. This process would be repeated until the specified number of days were simulated. The demands in the daily demand array would be used sequentially.

Orders placed on any given day would be shipped on the next day. The shipment would then be scheduled to arrive on the order day plus the lead time. Lead times would be determined by sequentially using the lead times from the previously generated array.

The information provided above would indicate to the student what was happening in the simulated system. The student could use this information for decision making purposes.

As the simulation proceeded a variety of statistics would be collected. At the end of the specified simulation period the student would receive the information shown in the example below:

Final Summary Information

Total Demand	19,589
Demand filled	17,042
Stockout Quantity	2,547
Service Level	87.00%
Target service level	95.00%
Inventory carrying cost	$ 18,450.
Ordering cost	$ 1,125.
Stockout cost	$ 12,470.
Total cost	$ 32,945.

The simulation would then use the same demand and lead time arrays to repeat the process using the programmed inventory control method to make inventory control decisions for the same simulated time period. The techniques used by the programmed inventory control method are described below.

The programmed method would develop the reorder quantity using the EOQ model, and would develop a combined standard deviation for the lead time and demand, based on the sample of 25 demands and 25 lead times as previously described using a procedure described by Lambert and Stock [4, p. 288]. The formula for combining the demand and lead time standard deviations as:

$$\sigma c = (\bar{R}\,\sigma D^2 + \bar{D}^2 \sigma R^2)^{1/2} \qquad (2)$$

where:

σc = combined standard deviation of lead time and demand
$\bar{R}$ = average lead time
σR = standard deviation of the lead time
$\bar{D}$ = average daily demand
σD = standard deviation of the daily demand

he combined standard deviation and the order quantity would be used to develop the appropriate safety factor, i.e., the number of combined standard deviations, to provide the required service level as described by Schary [5, p. 153] as:

$$E(K) = Q(1-P)/\sigma c \qquad (3)$$

where:

σc = the combined standard deviation of demand and lead time
$E(K)$ = The partial expectation, the expected probability of units being out of stock
Q = the order quantity of the Lead time
P = the target service level in per cent

the partial expectation E(K) can be used to derive the appropriate safety factor K, the number of standard deviations of safety stock required to achieve the target level of service, by a table lookup, or by a rational approximation developed by Brown [1, p. 93] and represented as:

$$K = (E(K) -).399)(-1.753 + 0.444E(K) - 0.071E(K) - (0.176/(E(K)+0.044)) - (0.001/(E(K) + 0.0003))) \qquad (4)$$

where:

K = the safety factor, the number of standard deviations required

This information is used to calculate the reorder point, as described by Schary [5, p. 135]:

$$S = K\sigma c + \bar{R}\,\bar{D} \qquad (5)$$

where:

S = the reorder point, the inventory level at which a reorder is placed

Both the reorder quantity and the reorder point would be recomputed each time an order was received based on the additional information available. This information would be each additional lead time, and the additional daily demands since the last shipment was received.

After the simulation performed the inventory control function for the same simulated period as the student, an evaluative summary would be presented. This evaluative summary would contain the students summary statistics (as described above), the identical summary statistics for the programming method, and a comparison of the students performance relative to the performance of the programmed method.

This would indicate the effectiveness of the students inventory control decisions compared to the programmed scientific method. Prior to active study of inventory control methods it would be expected that the student would have difficulty achieving the same level of service and/or cost as the program. After study, it would be expected that the student could achieve a level of performance similar to that of the programmed method. The comparison of the student’s results versus the program’s results would indicate whether or not the student was using the techniques correctly. If *the* results were similar, this would indicate that the technique had been applied correctly by the student, while discrepancies would indicate that the student was applying the technique incorrectly.

SUMMARY

The model discussed is intended to provide students with an interactive computer-based approach to learning about inventor:; control in a physical distribution system. Students are required to decide when and how much to order in a system characterized by imperfect information about lead times and demand, and with uncertain lead times and demands. It is intended hat the student would use this program both prior to, and after, studying inventory control techniques. By using the model prior to study the difficulty of making effective decisions would be shown by the student’s experience, while the ability to deal effectively under the conditions described would be illustrated by the performance of the programmed techniques. Using the simulation after study would provide the student with practice applying the techniques learned, and would verify that the student applied the techniques correctly. The model could also be used to consider the impact of changes in parameter values, for example unit value or inventory carrying cost rate, on the cost of providing a specified level of customer service. The effect on costs of changes in the target service level could also be explored by the student.

The model described above is viewed as the starting point for a group of models which would develop exercises related to more complex problems of inventory control in a physical distribution system. Extensions could include the addition of in-transit inventory costs and transportation costs. This could include the selection of transportation modes from a variety which supply different levels of service and have different costs. Similarly, different transportation costs could be included for different shipment sizes, i.e., truckload versus less-than truckload. Joint order effects could be included by having multiple products. Multiple locations could be included along with shipping or availability constraints at the upper level, or constraints on the quantity which could be held at the lower level facilities. The level of complexity would be limited only by the ability to effectively program the above listed factors and combinations of the factors.

It is hoped that this paper will foster discussion as to the appropriateness of the approach selected, the factors included, and the techniques applied to this model. The objective is to develop a simulation model which will be a useful exercise to aid in learning about inventory control in a physical distribution system, and to serve as a base for extensions which will model more complex situations.

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