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Hybrid Buffering Policies for Material Requirements Planning Systems

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Hybrid Buffering Policies for Material Requirements Planning Systems

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Abstract

Material Requirements Planning is greatly affected by uncertainty in variables such as timing and quantity. Safety stock or safety lead times can be used as buffering techniques against such uncertainty. Using a simulation study, the efficacy of each approach is analyzed when uncertainty is present, in varying amounts, in both timing and quantity simultaneously. A convex hybridization of both these techniques is suggested as an alternative policy and its performance compares very well with that of the individual pure policies. Its main appeal is that it constitutes a consistent operating policy over the entire range of uncertainty and is sensitive to the levels of uncertainty in timing and quantity.

Introduction

The operational principles of Material Requirements Planning (MRP) are best understood under conditions of certainty for demand and lead times, unlimited capacity in manufacturing facility and no economies of scale in operations. Given these assumptions, the optimal plan is a two-stage process:

(1) For each time period, evaluate the demand for each item, in the product structure, by aggregating the quantities of this item needed by items in higher levels of the product structure.

(2) Schedule this demand for the item to be produced or purchased in a time period which is calculated by offsetting the demand time period by the lead time for this item.

MRP systems implement these stages in a systematic and efficient manner.

It is a safe bet that no real world situation would fit the above assumptions and relaxing the conditions leads to a difficult problem where the modifications to the optimal plan, mentioned above, are by no means obvious. In this paper, I am going to keep the assumptions of unlimited capacity and lack of economies of scale but introduce uncertainty.

The conceptual framework for a generalized classification of uncertainty in MRP was introduced by Whybark and Williams [9]. They pointed out that there were two sides to any requirements systems, namely the demand side and the supply side and the relevant characteristics of each, to MRP, are the quantity and the timing. Therefore, all uncertainty could be categorized into those concerning

(1) demand quantity, e.g., promised cancellations, open orders

(2) demand timing, e.g., promised date changes, planned order changes

(3) supply quantity, e.g., defectives, lower level shortages

(4) supply timing, e.g., breakdowns, variations in vendor lead times.

The classical buffering system against uncertainty is the safety stock approach. Several researchers have proposed operational policies which are based on standard statistical inventory methods. Moore [5] suggest using cumulative lead time to set safety stocks for end items. Meal [4] incorporates forecast error into the statistical models. Eichert [1] indicates that only variation in unplanned demand should be buffered.

Another technique of buffering is to inflate lead times--the safety lead time approach. This was proposed by New [6] and has been used by industry either overtly or covertly for many years. The inherent drawback of this technique is that the shop-floor operators soon realize that they have more time than that indicated by due-dates and Parkinson's law takes over [8]. This leads to distorted priorities and ambiguity in keeping track of actual safety time available [3].

Partial solutions have been proposed by Huge [2] which suggest that better lead time management is essential to combat uncertainty in manufacturing. Melnyk and Piper [7] indicate that forecasting lead times and reducing forecast errors produced low inventory levels with high service levels.

Whybark and Williams [9] sought to compare the efficacy of both safety stock and safety lead time approaches to buffering against the various categories of uncertainties. The guideline that they suggest is that the safety stock approach is superior when faced with quantity uncertainty either in demand or supply and the safety lead time technique favors the timing uncertainty in either demand or supply.

This study seeks to elaborate on the simulation of Whybark and Williams. Their simulation chose to introduce uncertainty in each of the four categories, one at a time, and evaluate the use of safety stock or safety lead time techniques regarding service level and average inventory. But the question still remains: What should one do when faced with both quantity and timing uncertainties simultaneously? Is there any dominant policy or are there cross-over regions of dominance? The results of my study indicate that the dominance of each pure strategy depends on the level of uncertainty in the quantity and timing factors and that there is a smooth cross-over from one to the other. Given this indication, I propose a hybrid policy which is a linear combination of both the safety stock and safety lead time approaches with the weights varying with the degree of uncertainty in quantity and timing. The simulation study indicates that such a policy operates better in the overall spectrum of uncertainty than either of the pure policies individually. The hybridization chosen is convex in that it is synonymous with the dominant pure strategy in the relevant regions of uncertainty.

In section 2, I describe the simulation environment and the study conducted and section 3 contains the results of the study and their limitations.

2. Simulation Process

The object of the experiment is to extend the simulation environment of the Whybark and Williams [9] study to include all types of uncertainty simultaneously and to evaluate the pure strategies of safety stock and safety lead time and a mixed strategy (or hybridization) regarding average inventory level and service level.

As in [9], we study a single part which could be produced or purchased. The demand for the part was assumed to be lumpy and the coefficient of variation CV was used as an indicator. To simulate the demand, a uniform distribution was used with a positive probability that the demand actually was zero. The lead time was also generated from a uniform distribution and the lot size could be specified; the default value was lot-for-lot. The initial parameters given, the initial MRP schedule is generated for 70 periods, with the first and last ten values discarded to prevent end aberrations.

The next step was to introduce the uncertainties present in the particular simulation. This was done by focussing on the coefficient of variation CV--for every set of simulations, a total coefficient of variation TCV was fixed. This variation was comprised of the variations in the four individual uncertainties, namely demand quantity CVDQ, demand timing CVDT, supply quantity CVSQ and supply timing CVST. Since the coefficient of variation is a dimensionless variable, the total variation is the sum of the individual variations:

$$TCV = CVDQ + CVDT + CVSQ + CVST.$$

Then, all combinations of the individual uncertainties are generated with respect to a basic incremental value. For example, given TCV = 0.50 and an incremental value of 0.25, one can generate all combinations of the individual CV's with the following restrictions: they add up to

0.50 and each can have a value of 0, 0.25 or 0.5. In this way, simultaneous uncertainties are simulated in the model as well as sole individual uncertainties. This structure also helps in duplicating Whybark and Williams' study.

Once the individual CV's are fixed, the individual uncertainties are simulated in the following fashion:

(1) The actual demand quantity, in any period, will be a random variable with the mean equal to that generated in the initial MRP, for that period and a coefficient of variation CVDQ.

(2) The actual supply quantity, in any period, is centered on the supply scheduled originally, if non-zero in that period, and a coefficient of variation CVSQ.

(3) The actual period of demand timing is calculated by offsetting the original scheduled period by a random variable with mean equal to the original lead-time or a randomly chosen number from a similar distribution as the original lead time. This indeterminacy occurs due to the problem in specifying the uncertainty in demand timing--how large or small should the variance be?

(4) The shift in the originally scheduled supply period is determined via a random variable with mean equal to the original supply lead time and a coefficient of variation CVST.

All the above random variables were assumed to be normally distributed and care was taken to prevent logical errors, e.g., supply timing occurring before the placement of the order--this could occur if the shift was greater than the mean lead time.

To combat these uncertainties, three policies were implemented:

(1) The pure strategy of carrying safety stocks (SS). The quantity carried was varied from 1 to 5 periods equivalent of average demand.

(2) The pure strategy of safety lead time (SLT). The safety buffer was varied from 1 to 5 periods, maintaining parity with the safety stock strategy.

(3) A convex hybrid policy (H) using both safety stock and safety lead time. This policy is defined by:

$$H = \alpha_Q \cdot SS + \alpha_T \, SLT$$

which is a linear combination of the SS and SLT policies. The weights are defined by:

$$\alpha_Q = \frac{CVDQ + CVSQ}{TCV}$$

$$\alpha_T = \frac{CVDT + CVST}{TCV}$$

Then, α_Q measures the proportion of variation due to quantity uncertainty and α_T that of timing uncertainty. It should be noted that α_Q and α_T sum up to 1. The case of $\alpha_Q = 0$ corresponds to the pure strategy of safety lead time and the case of $\alpha_T = 0$ indicates that the safety stock policy alone is used. Thus the hybrid policy H encompasses the pure strategy policies as special cases. The motivation behind the definition of the hybrid policy H stemmed from the study of Whybark and Williams [9] who show that the SS policy is dominant when $\alpha_T = 0$ and that the SLT policy dominates when $\alpha_Q = 0$.

To compare the effects of each of these policies, it is necessary to calibrate the policies such that they are equivalent. An example of this equivalence for the case of TCV = 1.0, CVDQ = CVSQ = CVDT = CVST = 0.25:

(1) SLT = 2 weeks

(2) SS = 2 * Average demand/week

(3) H = (1 week of SLT) and (1 * Average demand/week of SS).

When the hybrid policy indicated use of fractional SLT, the total order was split up. For example, if SLT = 1.75 weeks, then the total order was split into one for 75% of the total with SLT = 2 and one for 25% of the total with SLT = 1 week.

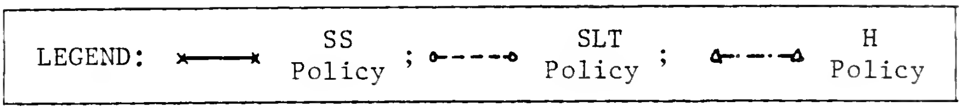
The efficacy of each of these policies was measured by determining the average inventory held and also the service level, defined as the fraction of demand that was met on time. Requirements not met during a period were back ordered and filled from the next supply arrival. The simulation was repeated five times for each combination of CV's and for each operating buffer policy and the characteristics averaged. This was done to minimize the effects of unusually distributed set of pseudo-random numbers.

3. Simulation Results

The simulation was conducted for values of CV_{TOT} ranging from 0.5 to 2.0 in steps of 0.25, and the incremental values of CV's ranging from 0.25 to 1.0 in steps of 0.25, wherever applicable. The performance characteristics, namely service level and average inventory level, were plotted for each policy, namely the SS, SLT and H policies. The data points within each policy represent incremental buffering against uncertainty.

Figures 1-10 represent the service-inventory trade-off for the various combinations of uncertainty given TCV = 0.5. Figures 1-3 are the cases where there is only quantity uncertainty and so $\alpha_T = 0$. The hybrid policy H and the safety stock policy (SS) are identical and dominate the safety lead time policy (SLT). Figures 8-10 are the cases where only timing uncertainty is present and so $\alpha_Q = 0$. The policies H and SLT are identical and dominate the policy SS. This backs up the study of Whybark and Williams [9]. Figures 4-7 represent cases where both types of uncertainties are present and in this case, in equal proportion. The graphs show that there is a dominant policy in each case (considering only SS and SLT policies) but they switch depending on the distribution of uncertainty. Unfortunately, there is no clue, at present, to the reason behind the switch and also the expectation of a dominant policy between SS and SLT is untrue at higher TCV. The hybrid policy H is different from the SS and SLT policies and follows the dominating policy in each case. In fact, where only CVDQ and CVST are present, H dominates both SS and SLT (see Figure 5).

Figures 11-13 are sample cases when TCV = 1.0. This set of simulations also provided dominant policies when only quantity or timing uncertainty was present. But when mixed uncertainties were present, unlike the previous case, there was no dominant policy, as seen in figures 11-13. In fact, there is a cross-over from the SLT to the SS



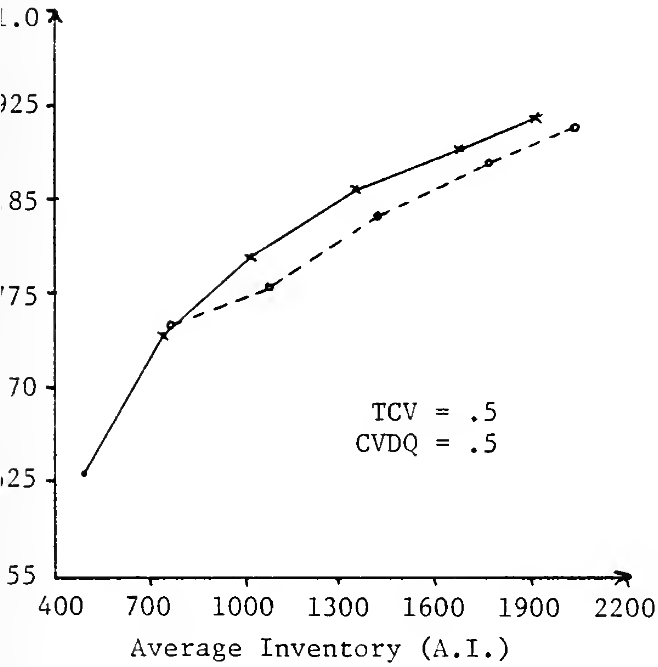


Figure 1

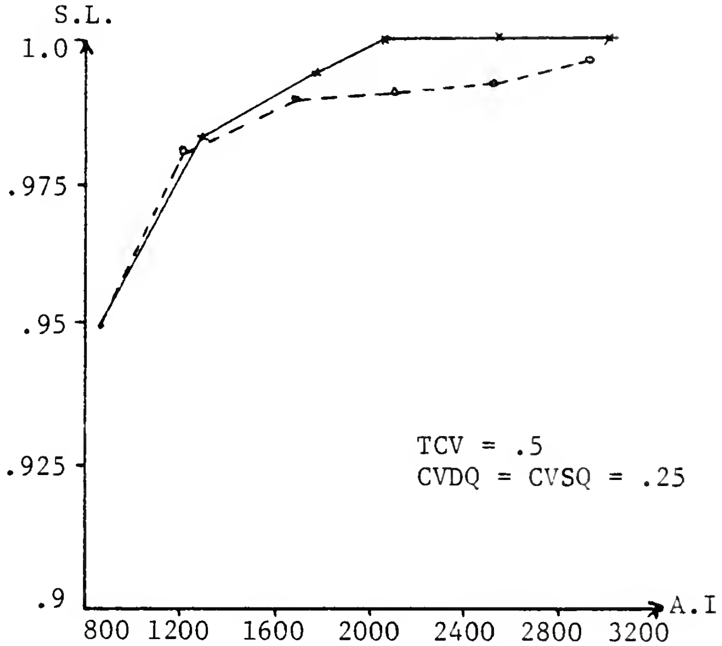
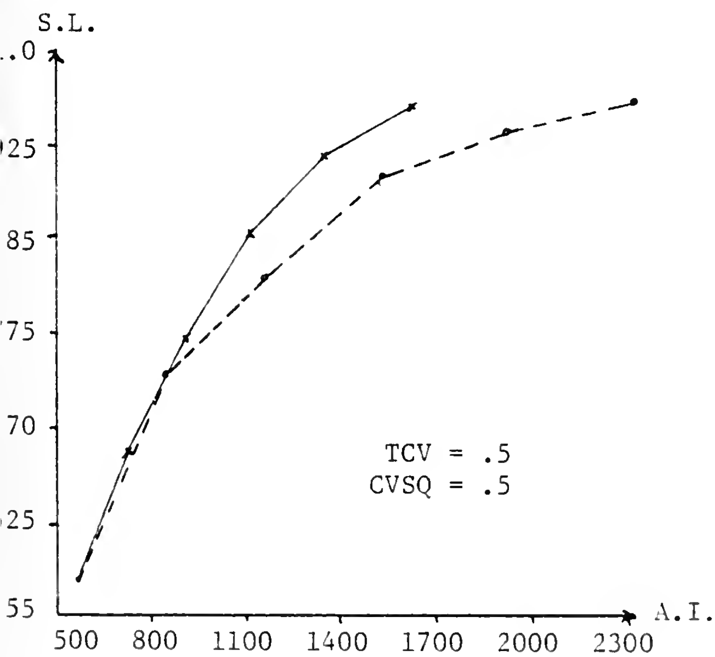


Figure 2



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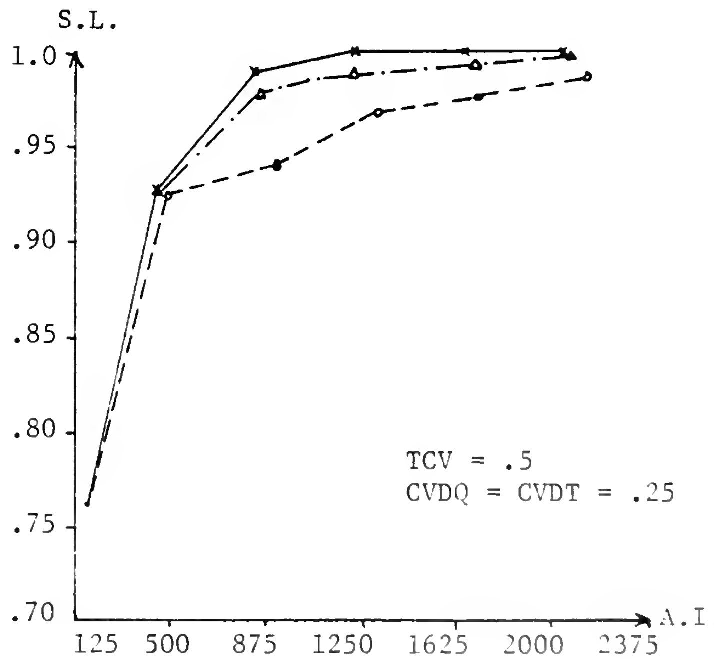

Figure 4

LEGEND: SS Policy ; SLT Policy ; H Policy

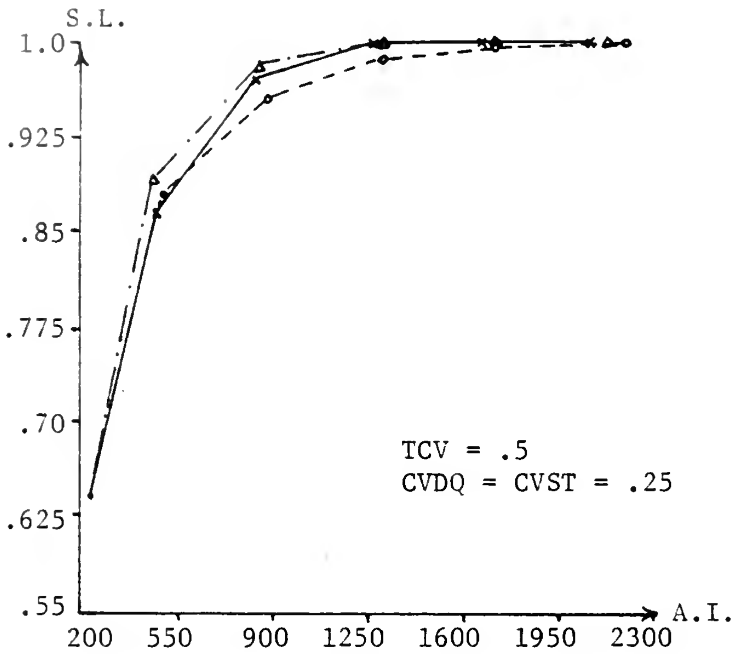

Figure 5

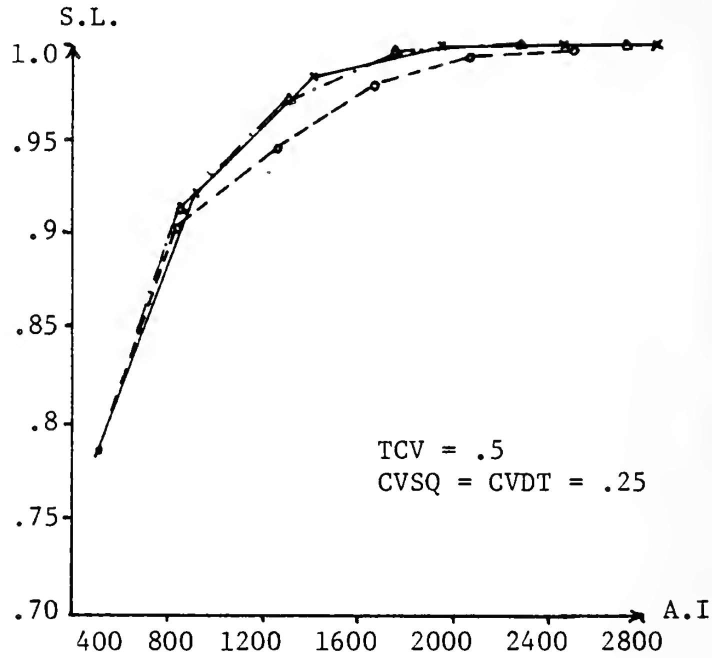

Figure 6

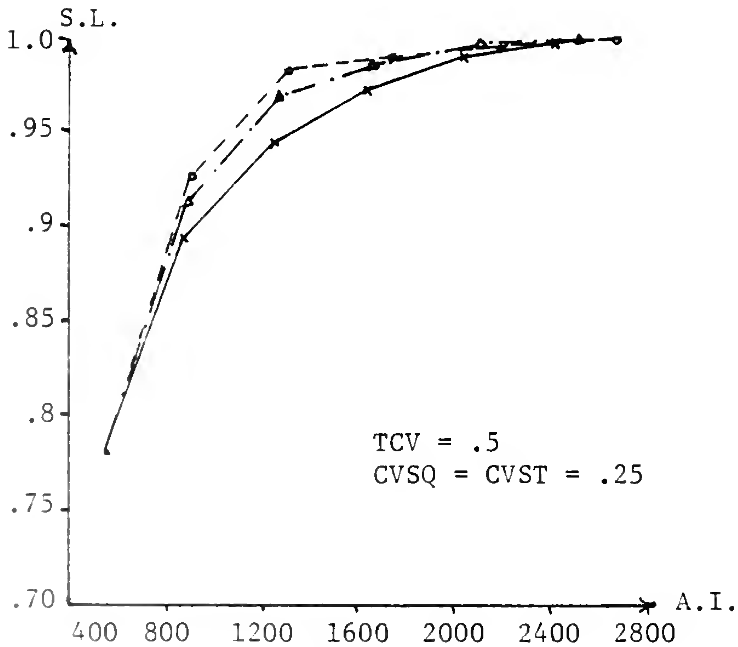

Figure 7

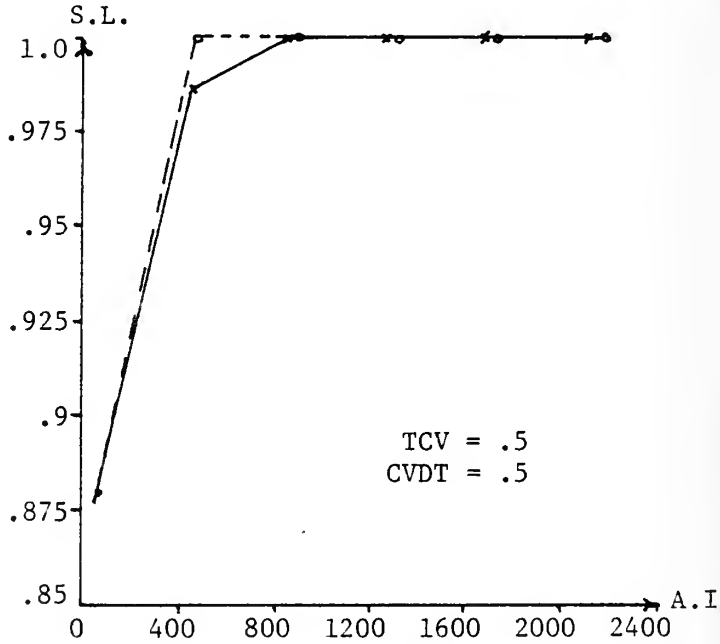

Figure 8

LEGEND: SS Policy ; SLT Policy ; H Policy

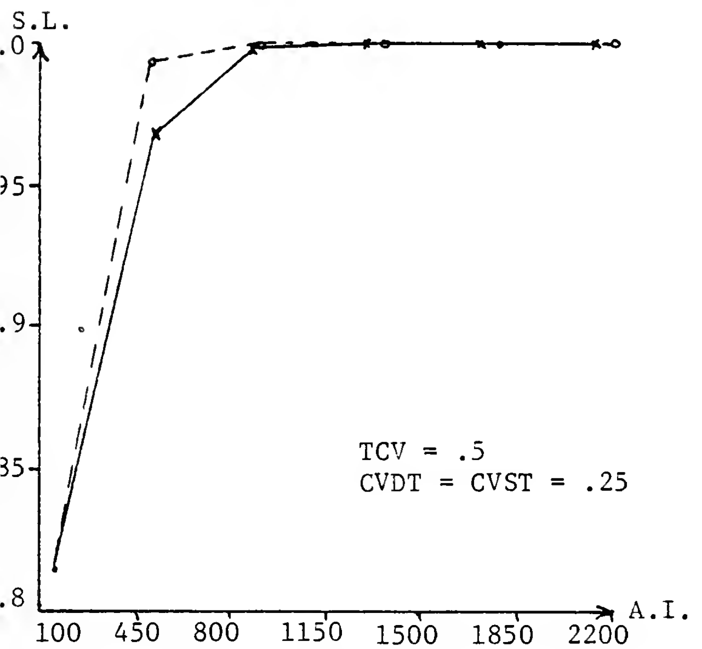

Figure 9

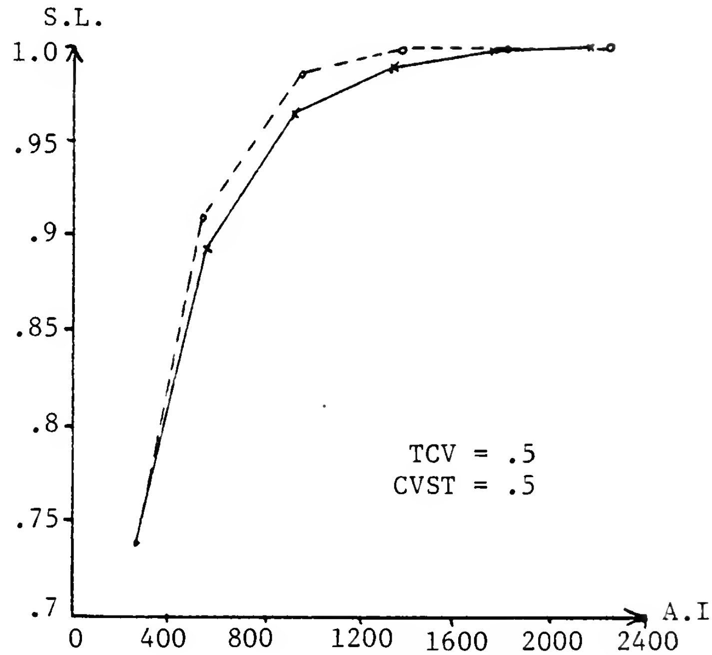

Figure 10

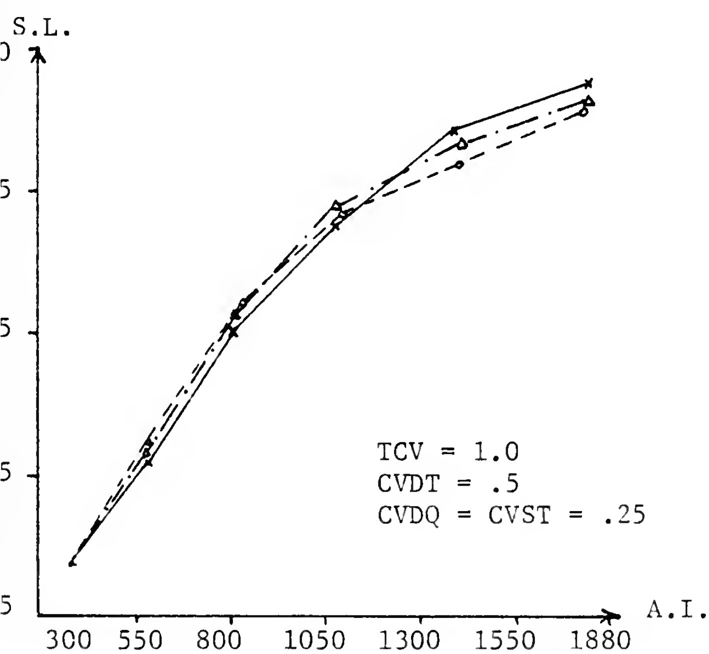

Figure 11

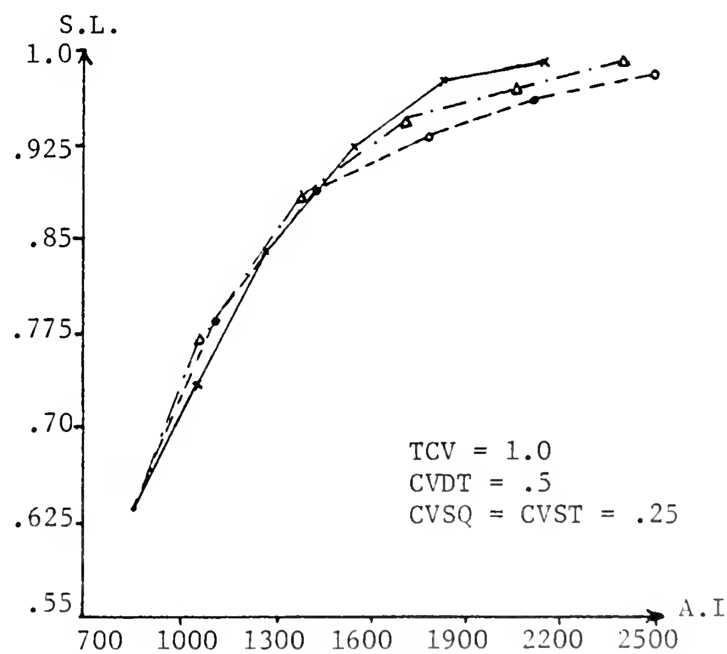

Figure 12

LEGEND: SS Policy ; SLT Policy ; H Policy

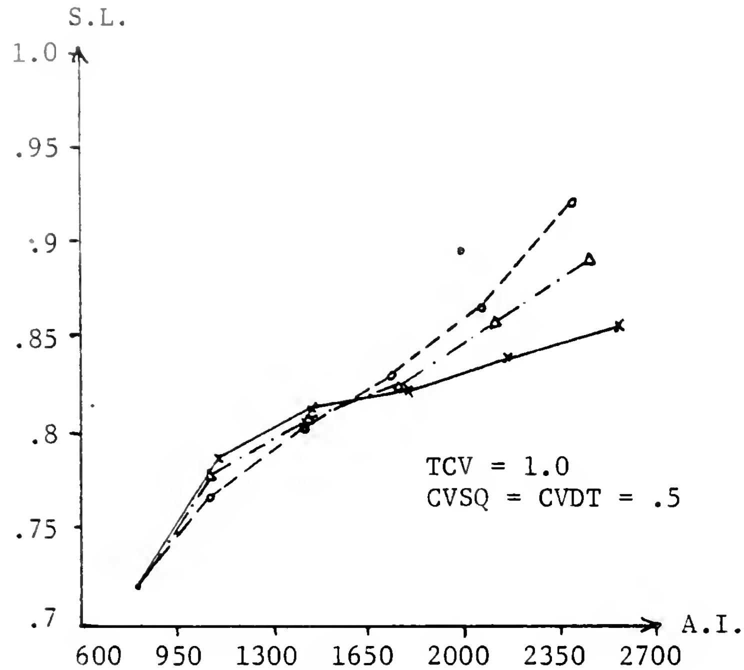

Figure 13

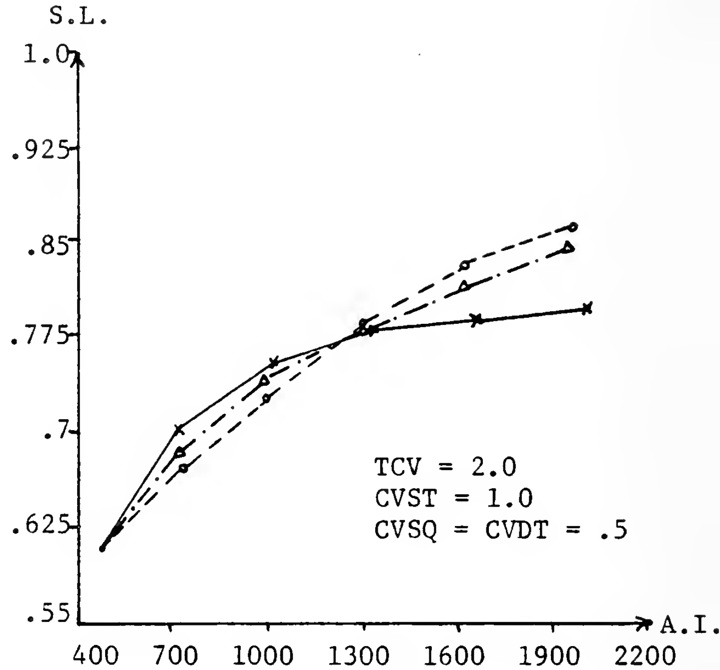

Figure 14

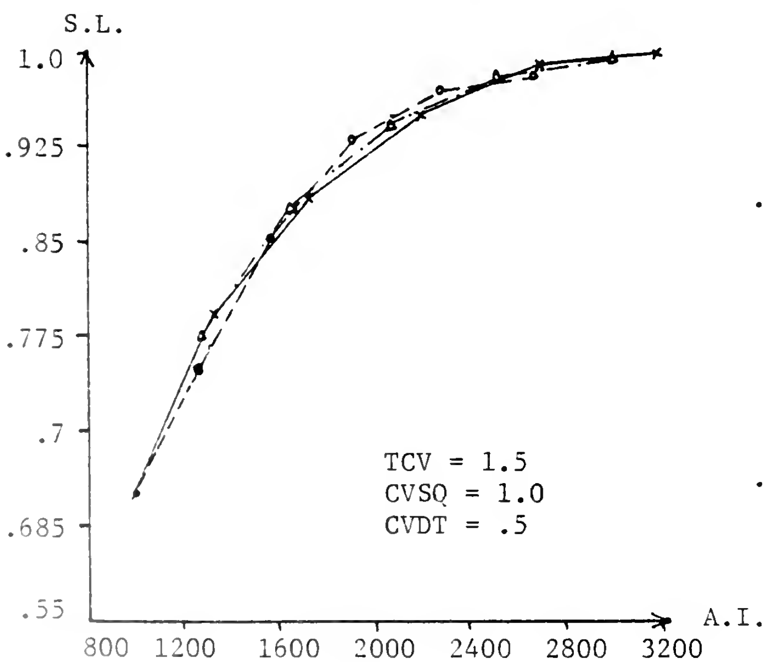

Figure 15

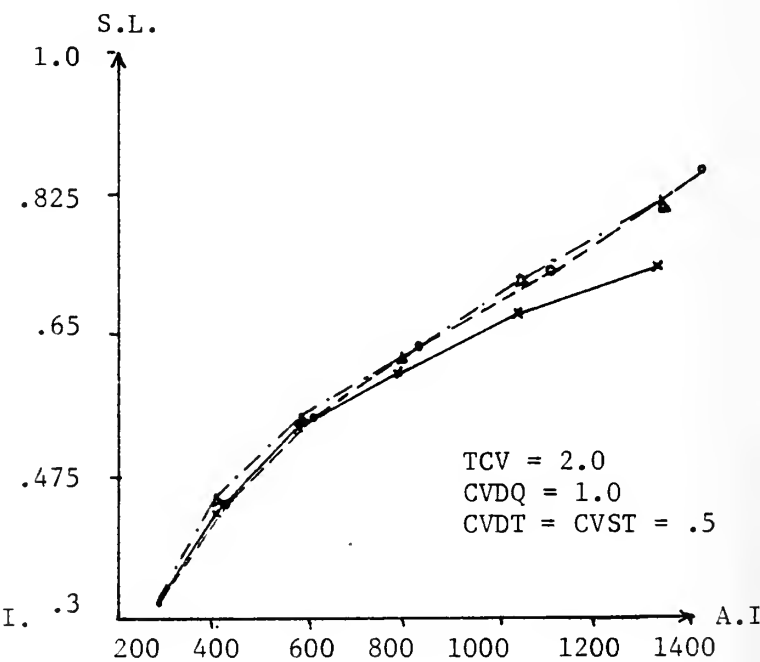

Figure 16

policy or vice versa after a certain level of buffering. Hence, depending on how much service level is needed or allowable level of inventory, the "best" policy can vary. Looking at the performance of the hybrid policy H, it follows the dominant policy closely, in figures 11 and 12, till the cross-over point, does better than both SS and SLT for some range and then falls back to following the dominant policy. In figure 13, policy H performance falls directly between the SS and SLT policies, thus being dominated by the best policy on either side of the cross-over but doing better than either individual policy over the entire range. Here again, the reason behind the cross-over, the prediction of the cross-over point and the choice of SS or SLT policies to dominate each region remains unclear.

Figure 14 shows a cross-over from SS to SLT policies, when TCV = 2.0, with the hybrid policy falling in between over the entire range, as in figure 13. Figure 15 indicates that there could be double cross-over within the same distribution of uncertainty. For TCV = 1.5, it shows the cross-over pattern being SS - SLT - SS with the hybrid policy following the dominating policy closely and in certain ranges, beating it. Figure 16 shows a performance graph with TCV = 2.0 where policy H is the dominant policy over the entire range.

Some clear conclusions can be drawn from the simulation study.

(1) The results of the Whybark and Williams' study [9] are found to hold here also. When there is only quantity uncertainty present, the SS and H policies are dominant. The SLT and H policies are dominant when faced with timing uncertainty only.

(2) At low levels of uncertainty, i.e., low values of TCV, one finds purely dominant policies but these policies switch as the distribution of uncertainty, in each category, shifts. There is no clear indication of when or why the switch occurs, when the uncertainties are mixed between quantity and timing. Using the hybrid policy produces performance characteristics close to the dominant policy, i.e., it performs better than the dominated pure strategy but worse than the dominating pure strategy in almost all cases.

(3) At higher values of TCV, i.e., higher levels of uncertainty, optimal policies could be cross-over policies, e.g., SS could be optimal for low levels of service and inventory where as SLT could be optimal for high levels of service and inventory. The cross-over point and the strategies being crossed over to depend on the levels of uncertainty in each category. The hybrid policy operates closer to the optimal cross-over policy than either pure strategy. In almost all cases, the hybrid policy performs better than the dominated strategy but worse than the dominating strategy on either side of the cross-over point. While not being optimal anywhere, for most mixed categories of uncertainty, it performs better than either pure policy in the entire service-inventory trade-off range.

In general, if a firm faces uncertainty in all four categories and the amounts of uncertainty keep changing over time, then the hybrid policy would clearly be a suitable choice over either pure policy, SS and SLT. It would give close to optimal results and at the same time, preserve a consistent policy over time rather than switching. This consistency can prove very useful in implementation of the policy. The problem of calculating the proportions α_Q and α_T is met by estimating them from past data and continually updating them. Techniques such as exponentially weighted moving averages could be used to track them.

Limitations of this study arise from the fact that a single-level MRP system is considered and the interaction effects of the safety stocks and safety lead times at different levels, along with their lot-sizing rules, are not considered. These extensions are the subject of the next set of simulation studies currently underway.

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