A Comparison Between the Current and Proposed Inventory and Procurement Policies for the Deep Space Network

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A comparison is made between the performance of a proposed policy and that of the current inventory and procurement procedures for the Network Supply Depot and the Complex Supply Facilities. Both procedures were simulated on a computer using identical input demand data. The comparison is based on four criteria: average inventory level, frequency of procurement orders, frequency of shortages and average inventory cost per year. The results of the study indicate that, with reference to maintenance and operating items, the inventory cost would be reduced by about 25% if the proposed policy were put into effect.

I. Introduction

The purpose of this article is to present the results of a computer simulation that compares the performance of a proposed policy (Ref. 1) to that of the current inventory and procurement procedure for the Network Supply Depot (NSD) and the Complex Supply Facilities (CSFs). Subsection II describes how the simulation program operates. Subsection III describes the operation of both the proposed policy (Method 1) and the current inventory and procurement policy (Method 2), and Subsection IV summarizes the simulation results.

It should be noted that in our preparation of a simulated global inventory system, no attempt was made to duplicate the overall software package of the Integrated Logistic System described in Ref. 2. Also no attempt was made to incorporate the numerous software tasks of the current Supply Inventory System as discussed in Ref. 3. The specific features simulated in this investigation were the determination of order sizes and reorder levels, and the procurement and shipping tasks of an inventory system.

The criteria for inventory performance used in the simulation are the same ones used in Ref. 1. These criteria are:

(1) Average inventory level (NSD and CSFs combined).

(2) Frequency of procurement orders.

(3) Frequency of shortages.

(4) Average inventory cost per year.

The average inventory cost per year is computed using cost parameters h and k. The parameter h is the *holding cost* per unit per year, i.e., the cost resulting from buying one unit a year in advance of the demand and maintaining it in inventory. Values of h between 5 cents and 2 dollars were used. The parameter k is the *order cost*, i.e. the fixed portion of the cost of placing an NSD procurement order. The value of k was taken to be 5 dollars in all the simulation runs performed. Varying k along with h is unnecessary since the actions of Methods 1 and 2 depend only on the ratio of h and k. As the description in Subsection III indicates, the actions of Method 2 are unaffected by h and k, being based entirely on estimated demand rates.

Penalty costs for shortages were not considered in the present investigation since it is not feasible to assign a dollar cost to the possible consequences of maintenance and operations (M & O) items shortages, such as loss of tracking station operational availability and loss of n kilobits of data. The criticality of shortages is expressed, instead, by a parameter q called the *cost-criticality quantile* (Ref. 1). It denotes the probability of incurring no shortage at a given CSF during one order cycle. The value of this parameter can be adjusted to achieve an acceptably low frequency of shortages. The higher the quantile q, the higher the CSF minimum stockage levels. Thus, as q is increased up to 1, the frequency of shortages is reduced to zero, but at the cost of higher inventory levels and costs.

II. How the Simulation Program Operates

The simulation program operates in a very straightforward way. True mean demand rates for the six CSFs are input and are used to generate purely random demands for a single inventory item at the CSFs on a day-to-day basis. Thus, in the simulation, as in the real world, random fluctuations cause higher than average demand experience at some times, lower than average at other times. But the true mean demand rates used to generate the demand data remain fixed throughout a simulation run. The same day-to-day demand experienced at the CSFs is fed simultaneously to Methods 1 and 2 and they respond by taking actions of two types: placing procurement orders (which arrive at NSD in 45 days) and making shipments from NSD inventory to CSFs (which arrive in 60 days). The computer keeps track of such things as inventory levels (and backorders) at NSD and at the CSFs, shipments enroute to CSFs, and procurement orders enroute to NSD. The computer also tallies shortages (units not available from a CSFs inventory when demanded), procurement orders made by NSD, and total inventory levels in the system. All of this bookkeeping is done separately for Method 1 and Method 2. At the end of a 100-year run, the key outputs are the average (total) inventory levels for Methods 1 and 2, the number of procurement orders each method placed, and the number of shortage units each method incurred at all CSFs combined. The first two of these outputs are combined using assumed cost parameters, h and k, to yield an overall *inventory* cost for each method.

What information is supplied to determine the actions of Methods 1 and 2? Rather than let the two procedures operate with full knowledge of the true CSF demand rates, which would be unrealistic, the simulation program only allows the two methods to keep track of the CSF demand histories for the most recent three years. (The idea is that demand data more than three years old are probably of doubtful reliability in practice.) As a consequence of this 3-year data base, both methods function with continuously updated *estimates* of CSF demand rates. These estimates of annual demand rates are made simply by dividing the observed 3-year demands by 3, with one important exception. One of the key features of the proposed inventory policy is the setting of CSF minimum levels by a Bayesian estimation approach. (A discussion of the advantages of this technique is given in Ref. (4).) This approach is used in Method 1 and is based upon the same information as the straightforward demand estimates; namely, the most recent 3 years' experience. In addition to the recent demand histories, both Methods 1 and 2 base their actions on the daily-updated information about NSD and CSF inventory levels, backorders (if any), and CSF shipments and NSD procurements enroute. Thus, the two methods operate in the simulation approximately as they would in practice.

Another feature of the simulation program is the allowance it makes for demands of different order sizes occurring at the CSFs. The idea is that a CSF may experience demands not just for a single unit, but perhaps more than one unit at a time. This possibility obviously places a greater strain on CSF inventories and makes the problem of minimizing shortages more difficult. Some of the simulation runs were performed with demands of size 1, 3, and 5 occurring, some with sizes 1 and 3; most were performed with only demands of size one allowed.

III. How Methods 1 and 2 Operate

The operation of Method 1 is discussed thoroughly in Ref. 1. We give here only a brief summary to emphasize the differences from Method 2. The procurement policy incorporates the conventional economic order quantity

(EOQ) considerations, but also takes into account the fact that coordination of inventory cycles between CSFs increases efficiency. Thus, NSD procurement orders are apportioned to the CSFs based on their current inventory levels in such a way that their minimum levels will be reached at nearly the same time. The NSD order quantity is not fixed, but rather is designed in each instance to take this apportionment process into account and to achieve an optimal average time between NSD procurements. This optimal time depends on the demand rates and on the ratio of the holding cost parameter, h, to the order cost parameter, k. Like the conventional EOQ, it represents the optimal trade-off between ordering infrequently to reduce ordering costs and ordering frequently to reduce average inventory levels.

An additional feature of Method 1 is the incorporation of the *reserve policy* for NSD (Refs. 1 and 4). Under this policy, a portion of each procurement order (perhaps 10 to 20%) is placed in NSD inventory before apportioning, and shipping the remainder to the CSFs. Shortly before the end of the order cycle, this reserve supply is used to even out the imbalances between CSF inventory levels caused by random fluctuations in demand. This is done by apportioning the reserve supply among those CSFs that have the lowest inventory levels (relative to their minimum levels). The effect is to forestall the necessity for NSD reprocurement as long as possible, thereby getting the "best possible mileage" out of each NSD order quantity. Except for these reserve supplies, Method 1 maintains no NSD inventory.

The Bayesian estimation technique mentioned earlier in this report is the means of setting CSF minimum stockage levels under Method 1. These levels are revised as demand data accumulate (subject to the 3-year limitation imposed for this simulation study). Just as the optimal average time between NSD procurements is critical for the determination of NSD order quantities, a parameter q, called the *cost-criticality quantile* (Ref. 1), is the key determinant of minimum stockage levels. In standard inventory models (Ref. 5) the value of this parameter is derived from the demand rate and the ratio of the holding cost, h, to a so-called *penalty cost*, the cost of shortages. Thus the cost-criticality quantile is determined by trading off the "cost" of shortages against the cost of maintaining higher inventories (particularly minimum levels). Since dollar costs of shortages are very difficult to assess, we have taken the approach that the cost-criticality quantile itself is a parameter to be chosen, like h and k. It should be chosen so that the resulting average number of shortages per year is acceptable. (Our studies of the effect of q on shortage levels were reported in (Ref. 1). As Tables 1 through 4 indicate, higher values of q always yield fewer shortages, while lower values result in lower average inventory levels and costs.

In contrast to Method 1, Method 2 makes no allowance for optimal trade-offs between holding costs and ordering costs to determine NSD order quantities, or between inventory costs and frequency of shortages to determine CSF minimum stockage levels.

The station Directors Conference Proceedings, Ref. 6, described (Method 2) the current NSD Station Stockage Policy that is pictorially represented in Fig. 1. The station stockage policy is a 180-day usage (6 months supply) plus a 30-day buffer stock. The station minimum level is 105 days of stock (60 days shipping time plus 45 days procurement time) or a 4.5-month supply including the 30-day buffer stock.

Discussions with NSD personnel indicate that NSD's procurement policy is to procure the sum of all CSFs' annual demands once NSD's inventory reaches its reorder point. However, the question of NSD's reorder point is subject to evaluation. Based on preliminary assessments of Method 2, NSD's reorder level was set equal to the sum of the two largest CSF demands. The reason being that during NSD's procurement time, NSD should have a sufficient amount of stock on hand to fill at least the two CSFs that have the largest demands should both require stock shipments during NSD's procurement time. Further, as the estimated demand varies over time, the simulation program permits Method 2 to vary its reorder level at the NSD.

IV. Simulation Results

Most of the simulation runs in the present study were repeated at four levels of q: 0.65, 0.75, 0.85, 0.95. The cases presented in Tables 1 through 4 are those where the average number of units short per year was approximately 0.5 or 0.6, or the closest figure available on the low side. In some instances the results for two different values of q (with the same h) are given to illustrate the trade-off between cost savings and low frequency of shortages. Each of the Tables 1 through 4 shows the results of the simulation for a different true annual demand rate. The ratios of demand rates for the six CSFs were fixed in all cases for Table 1 as 1:2:3:4:5:5; for Table 2 the ratios of demand were 4:5:6:7:8:9; for Tables 3 and 4 the ratios were 4:5:6:7:8:10. In each table, only a single column of outputs is shown for Method 2, these being the averages over the different runs made for different values of h (which do not affect the actions of Method 2). The average inventory cost for Method 2 depends on h, however, since one part of that cost is h times the average inventory. The percentage cost savings in Table 1 illustrate a typical pattern. If we make some allowance for differences in shortage frequencies, the per cent cost savings realized by Method 1 decrease to a minimum and then increase as h varies through its range. The smallest cost reduction in Table 1 is 16% in the case $h = 0.2$. This value is smaller than the others because the optimum order cycle length in this case is very close to one year, which is the length used by Method 2 in all cases. For smaller h than 0.2, Method 1 achieves additional savings by ordering less frequently than once per year, because the reduced ordering costs more than offset the cost of the increased average inventory level. As h increases past 0.2, Method 1 saves additional money by ordering more frequently, since the optimal trade-off calls for lower inventory levels as the holding cost per unit gets larger. Other patterns appear in Tables 1 through 4. For instance, the per cent cost savings will be seen to increase as the annual demand gets larger.

Table 4 gives some results for a more complicated pattern of random demands. It is assumed that demands for 3 or 5 units at a time can also occur and that these account for 20% and 10% of the demands, respectively. Method 1 is specifically designed to accommodate this type of demand pattern (Ref. 1), while Method 2 is not. Thus, Table 4 reveals much higher frequencies of shortage for Method 2 than previous levels. The choices of q in Table 4 were made to control the frequency of shortages, as in previous cases, which requires higher minimum stockage levels than the unit demand pattern. This accounts for the lower percentage savings in inventory cost.

Useful information about the numbers of maintenance and operating items at various holding cost values is not presently available. However, the results in Tables 1 through 4 indicate that an average reduction of 25% in inventory cost per year is a reasonable estimate if Method 1 is utilized.

References

1. Eisenberger, I., Maiocco, F. R., and Lorden, G., *Proposed Inventory and Procurement Policy for the Deep Space Network*, JPL Document 890-25, Jet Propulsion Laboratory, Pasadena, Calif., October 1, 1972 (JPL internal document). See also, "An Inventory and Procurement Policy for the Deep Space Network," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. XII, pp. 131–148, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1972.
2. Atwood, R. E., *System Requirements Document, Integrated Logistic System, Supply Management Subsystems*, Report 337D-2B1-1, M & O Document, DSIF Operations Section, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 5, 1971 (JPL internal document).
3. Atwood, R., *Supply Inventory System (SIS) User's Guide*, Revision 1, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 23, 1971 (unpublished rough draft of a JPL internal document).
4. Eisenberger, I., Maiocco, F. R., and Lorden, G., "An Inventory Policy for the Deep Space Network," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. IX, pp. 84–87, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1972.
5. Wagner, H. M., *Principles of Operations Research*, Chapter 19, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1969.
6. *1972 DSIF Station Directors' Conference Proceedings*, Report 337-5A1, Section IV, pp. 4-1 to 4-8, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 1, 1972 (JPL internal document).

Table 1. Simulation results: annual demand, 40 units

Category	Method 2	Method 1					
		$h = 0.05$	$h = 0.2$	$h = 0.5$	$h = 1.0$		$h = 2.0$
		$q = 0.65$	$q = 0.65$	$q = 0.75$	$q = 0.75$	$q = 0.85$	$q = 0.85$
Shortages/year	0.44	0.23	0.41	0.48	0.65	0.38	0.38
Procurements/year	0.95	0.42	0.78	1.07	1.34	1.40	1.61
Average inventory	69.7	85.5	58.9	49.3	43.6	50.1	45.8
Average inventory cost/year	—	6.40/8.20[a]	15.70/18.70[a]	30.00/39.60[a]	50.30/74.50[a]	57.00/74.50[a]	99.70/144.20[a]
% cost savings		22	16	24	33	23	31

[a]Average inventory cost/year: Method 1/Method 2.

Table 2. Simulation results: annual demand, 78 units

Category	Method 2	Method 1						
		$h = 0.05$	$h = 0.2$		$h = 0.5$		$h = 1.0$	
		$q = 0.75$	$q = 0.75$	$q = 0.85$	$q = 0.85$	$q = 0.95$	$q = 0.85$	$q = 0.95$
Shortages/year	0.27	0.2	0.53	0.22	0.44	0.1	0.6	0.26
Procurement orders/ year	0.97	0.56	1.0	1.01	1.46	1.5	1.82	1.83
Average inventory	119.4	119.7	79.9	86.0	70.5	80.2	65.4	74.4
Average inventory cost/year	—	8.80/10.80[a]	21.00/28.80[a]	22.30/28.80[a]	42.60/64.60[a]	47.60/64.60[a]	74.50/124.30[a]	83.60/124.30[a]
% cost reduction		19	27	23	34	26	40	33

[a]Method 1/Method 2.

Table 3. Simulation results: annual demand, 200 units with unit order sizes

Category	Method 2	Method 1			
		$h = 0.05$	$h = 0.2$		$h = 0.5$
		$q = 0.85$	$q = 0.85$	$q = 0.95$	$q = 0.95$
Shortages/year	0.094	0.18	0.51	0.05	0.21
Procurement orders/year	0.99	0.88	1.58	1.47	2.14
Average inventory	286.6	198.8	139.1	175.5	130.8
Average cost/year	—	14.30/19.30[a]	35.70/62.20[a]	42.50/62.20[a]	76.10/148.10[a]
% cost reduction		26	43	32	49

[a]Method 1/Method 2.

Table 4. Simulation results: annual demand, 200 units with multiple order sizes

Category	Method 2	Method 1	
		$h = 0.05$	$h = 0.2$
		$q = 0.95$	$q = 0.95$
Shortages/year	2.75	0.16	0.8
Procurement orders/ year	0.98	0.95	1.68
Average inventory	290.7	251.7	197.4
Average cost/year	—	17.30/19.40[a]	47.90/58.10[a]
% cost reduction		11	24

[a]Method 1/Method 2.

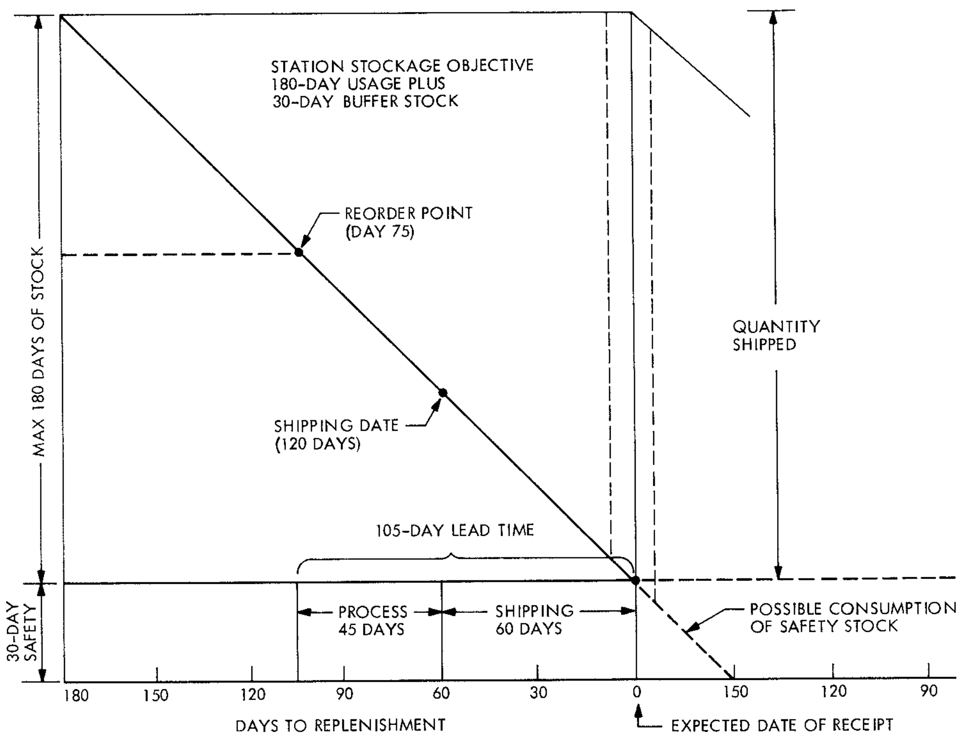

Fig. 1. Station stockage objective