"Spare's Inventory Optimization in a Logistic Support System : A Marginal Utility Analysis based Model

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Abstract

It is a general practice in industry to have a central depot that supplies spares to multiple locations. These location, in turn, need to keep sufficient stocks of multiple spares as a guard against the possibility of system/equipment remaining defunct until the spare is acquired from the central depot or outside supplier. Determination of optimum number of spares to be held at each location that attains the desired level of system/equipment availability is one issue, the spares procurement and provisioning policies with regard to safety stock, reorder level etc. is another. The reason, in practical situations, it may not be possible to maintain the optimum number of spares inventory by piecemeal procurement policy and if possible, the policy may not be cost effective.

This paper examines the issues of spares management in logistic support system of an enterprise with a view to determine the optimum number of spare parts needed at various locations from the view point of system availability. It further explores the provision for inter location transfer of spares in emergency situations. A model is used to determine minimum values of spares inventory level that must be kept to sustain system availability and any surplus may be transferred between locations in the event of a location facing excess requirement. This model is useful in spares management as it stipulates the maximum quantity that can be shipped from one location to another, striking an optimal balance between stock out costs and the costs of carrying inventory & transshipments.

Key Words: Logistics, spare management

I. INTRODUCTION:

Considering a logistic support system of an enterprise, having a central depot catering to demands for spares for multiple locations of system usage as shown in Figure 1.1. Each location has to store enough inventories for those components of system that are critical and or exhibit a high failure rate. Blanchard, 2001 proposed a model for obtaining optimum number of spares to be held, considering system availability.

Although for a desired value of availability the model gives the optimum number of spares to be kept by utilizing component failure rates/mean time between failures and the mission or operating time of the system, spares management factors such as safety stock recorder level & order quantity etc. have not been considered.

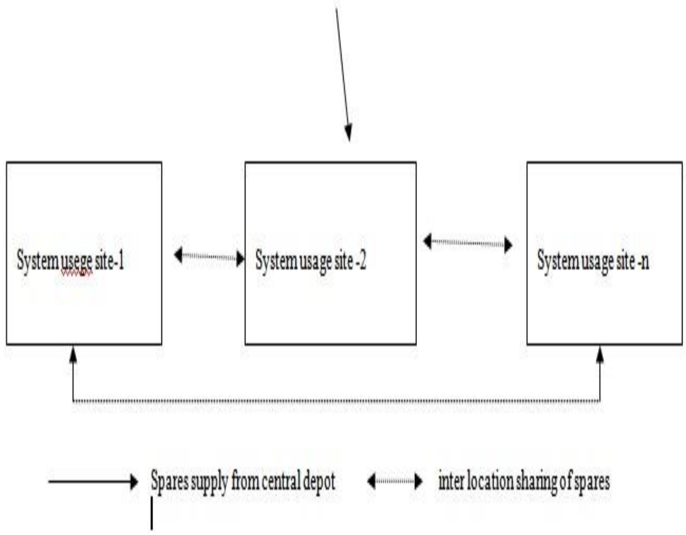

Figure — 1.1: Spares Supply from Central Depot and Inter-location Sharing.

Given the variability of component failure parameters i.e. mean time between failures, the spares demand experienced by location is also variable. Moreover, a provision of inter location transfer of spares from the one having surplus to that experiencing excessive demand to reduce the possibility of stock-outs & subsequent costs should also be considered figure (1.1).Benefits of this provision in terms of reduced inventory levels & minimum customers wait times, in the contest of product distribution from central plant to costumers through multiple retail stores, are highlighted by Evers 1997 Hill, 1992 exposed increased transportation, handling & administration costs for redistributed items. The proposed model in this chapter attempts to combine the considerations of system availability (Blanchard 2001) and heuristics emergency transshipments (Evers,2001)for effectives & economical spares parts management.

II. MODEL FORMATION:

1.1.1 Availability Consideration:

To begin with, let's consider a particular component with a specified failure rate "X". Considering random nature of failures having exponential distribution as proposed by Blanchard, 2001, the probability "P" of having a spare available at the location, for a time period "t" is

$$p = e^{-\lambda t} + (\lambda t)e^{-\lambda t} \quad \text{--------------- (1.1)}$$

Implicit in equation 1.1 is the condition that the operating & standby components are treated to be connected in parallel.

Extending the procedure by adding one more spare i.e. having two spares for one operating component, the higher value of "P" will result as given below

$$p = e^{-\lambda t} + (\lambda t)e^{-\lambda t} + \frac{(\lambda t)^2 e^{-\lambda t}}{2!} \quad \text{-----------(1.2)}$$

For maximum value of "P" i.e. unity the expression becomes

$$1 = e^{-\lambda t} + (\lambda t)\mathrm{e}^{-\lambda t} + \frac{(\lambda t)^2}{2!}e^{-\lambda t} + e^{-\lambda t} + ... \quad (1.3)$$

That is

$$f(x) = \frac{(\lambda t)^2 e^{-\lambda t}}{\mathrm{x}!} \quad \text{-------------- (1.4)}$$

Equation 1.4 is a general Poisson expression which gives the probability of spares availability for "x" failures if the component operating time is "t" For "k If quantity of the same components in the system at the location the expression become

F(x) = (k£t)x e -k£t ------------------ (1.5)
X!

Therefore the optimum number of pares to be held is given by the formula

$$p = \sum_{n=0}^{n=s}\left[\overline{R}1n(-1n\overline{R})^n\right] \text{/n! -------- (1.6)}$$

P = Probability of having a spare available when needed.

S = Number of spares in stock

R = Composite reliability (Probability of survival) (R = et)

k = Quantity of parts used of a particular type.

Equation 1.6 is derived from the Poisson distribution. Solving for a desired level of system/spare availability i.e. "P" it yields the optimum number of spares for a particular component.

1.1.2SpareInventoryManagementPolicy Considering Variations in Demand :

Consideration a situation involving two system usage locations receiving spares from a central depot or outside supplier in accordance with their separate spares inventory management parameters such as safety stock, reorder level & fixed order quantity. Demand for spares is random variable therefore any of the locations may face stock-outs that results in loss of system availability (downtime) and lost production.

Further analyzing the provision of inter location transfer of spare with associated cost consequences, with a view to determine under what condition the inter location transfer of spares is advantageous

First considering transfer of one unit from one location to other, the relevant parameters affecting costs & effectiveness are defined as follow

C1 = Transportation cost per unit

D= Actual Demand during lead time (time to procure spare from central depot/ supplier)

R= Reorder level at the location

E (D>R) = Expected stock out quantity per cycle

C2= Cost of placing a single order

Q=Fixed order quantity (Economic Order Quantity)

D Average demand during lead time

C3=Cost of one unit stock out

The costs associated in shipping one unit from one location to another facing stock out are

Transportation Cost = C1

Ordering cost for shipping location as a consequence of ordering one more unit from central depot = C2
Q

Stock out cost of the shipping location

$$= \frac{C_3\overline{D}}{Q}\left[E(\mathrm{D} > \mathrm{R}-1) - \mathrm{E}(\mathrm{D} > \mathrm{R})\right]$$

It is due to the fact that the shipping location runs the risk of stock out later as its one unit is supplied to another location. This situation arises if its current inventory is at or below reorder level which is on an average D /Q of the time.

Hence total cost associated with the policy of inter-location transfer.

$$TC_1 = C_1 + \frac{C2}{Q} + C_3\frac{\overline{D}}{Q}\left[E(D > R-1) - E(D > R)\right] \quad \text{------------- (1.9)}$$

The costs associated with the policy of not allowing inter location transfer include stock-out & holding cost, that are as given below

Stock-out Cost= C3 --------------- (1.10)

Holding Cost $= \frac{I}{K} C_4 \times C_5$ --------------(1.11)

Where

I = Current on hand inventory

K= Average annual demand

C4=cost of one unit

C5=annual inventory holding charge

I/K is the mean period of time a unit remains in inventory. Total associated cost of not following the practice of inter location transfer of spares is given by equation 1.12.

$$TC_2 = C_3 \frac{I}{K} C_4 \times C_5$$ -----------------(1.12)

Condition for inter location transfer of spare to occur is TC 1 < Tc2

$$C_1 + \frac{C2}{Q} + C_3 \frac{\overline{D}}{Q}\left[E(D > R - 1) - E(D > R)\right] < C_3 + \frac{I}{K} C_4 \times C_5$$ ---------- (1.13)

As the expected stock out quantity per cycle E (D > R) is extremely small as compared the order quantity (Tersine, 1994) and with the assumption that E (D>R-1) - E (D>R) is negligible, equation 1.13 reduces to

$$I > \frac{K}{C_4 \times C_5}\left(\frac{C2}{Q} + C_1 - C_3\right) = I_C$$ ---- (1.14)

For the condition that order quantity "Q" is based on Economic Order Quantity "Ico" equation 6.14 becomes

$$I > \frac{Q_0}{2} + \frac{K}{C_4 \times C_5}\left(C_1 - C_3\right) = I_{C0}$$ ---------- (1.15)

The above equation gives the minimum level of spares inventory "Ic0" at the donor location, above which inter location transfer of single unit is justified. In case the on hand inventory is lower than "Ico" requests for emergency transfer of spares have to be declined. Generalizing the model for situations when more than one unit are transferred, in case of transfer of multiple units (m>1) of spares, equation 1.9 becomes.

$$TC_1 = C_{1m} + \frac{C_2}{Q} m + C_3 \frac{\overline{D - 1 + m}}{Q}\left[E(D > R - 1) - E(D > R)\right]$$ ----------------- (1.16)

Since "m>1" number of units are transferred, the donor location faces increased possibility of stock-out in case its inventory falls below reorder level after transfer is effected. The duration of the period for this possibility to occur is (-D-1+m)/Q

Also E(D> R —m)—E(D > R) cannot be assumed to be negligible for more than one number of units to be transferred (Evers, 2001) [39].

Costs associated with not making the transfer of "m" units becomes:

$$TC_2 = C_3 m + \left[\left(\frac{\frac{I}{K} + \frac{I - m}{K}}{2}\right)\right] C_4 C_5$$ ------------- (1.17)

The above equation considers that "m" units are carried in inventory for the duration averaging 1/K and (1-m)/K.

From equations 1.16 & 1.17 the condition for inter location transfer of "m" units to occur can be expressed below

$$I - \frac{m}{2} > \frac{K}{C_4 C_5}\left[\frac{\left(\overline{D} - 1 + m\right)\{(D > R - m) - E(D > R)\}}{Q} + C_1 - C_3\right]$$ ------------------ (1.18)

$$I - \frac{m}{2} > \frac{KC_3}{C_4 C_5 Q}\left[\frac{\left(\overline{D} - 1 + m\right)\{(D > R - m) - E(D > R)\}}{Q}\right] + \frac{K}{C_4 C_5}\left[\frac{C_2}{Q} + C_1 - C_3\right] = I_{C0}$$ (1.19)

The equation 1.19 gives the critical value of on hand inventory ICo corresponding to the shipment of "m" units from the location while minimizing overall expected costs.

III. ILLUSTRATION

To illustrate the analysis let's take the following historical data for a spare part needed to be stocked at a particular location of system usage.

Y = 0.09 failures per 1000 hrs, k = 10 parts

T = 3 months, P = 0.85

k Y t = 1.944

From equation 1.6 using spare part requirement nomograph as given an Appendix I (Blanchard, 2001), the optimum number of spares "So" for achieving 85% availability comes out to be

So = 3 units of spare

Following is the historical data about parameters affecting spares management policy.

K = 80 units annually,

C2 = Rs. 150 per order

C4 = Rs. 1000 per unit,

C3 = Rs. 120 per stockout

C5 = 20% of spare cost per year,

C1 = Rs. 120 per transfer

The order quantity for location is economic order

$$Q = \sqrt{\frac{2KC2}{C_4C_5}} = \sqrt{\frac{2\times80\times150}{1000\times2}} = 11Units = Q0$$

For a single spare transshipment, using quation 1.15 the value of inventory level "Ico" is given by

11 + 80
IC0= 2 10000.2(120 —120)

=5.5 Units= 6Units

Since ICo = 6 units > So (3 units) the transfer request for one unit should be accepted without compromising the system availability.

Analyzing the case of multiple unit transfer let's consider additional past data as being average demand during lead time D = 4 units & standard deviation of demand (assumed to be normally distributed) a = 2.15. For 99% possibility of no stock-out during lead time taking Z=2.33 (Safety factor for Normal distribution), results in safety stock of Z x α = 5 units = Ss, and a reorder point of quantity i.e.
5 + 4 = 9 units.

E(Z) = 0.0034 from the Normal table of unit normal loss integral (Nair, 1994)

E(D > R) = a.E(Z)= 0.00782

Equation 1.19 for this case can be expressed as
1> M/2+ 4.364[(3 + m){E(D > R — m)—0.00782}J+ 5.45 = Ico --- (1.20)

For emergency transfer of m=2 units, E (D>R-m) is computed on the basis of reduced safety stock of 3 units (i.e. 5 - 2) and safety factor

Z = 7 — 4 = 1.395
2.15

Corresponding partial expectation E(Z) from the normal table i0.037075

Therefore, E(D > R - m) = a E (Z) = 0.07971
& 'Co = 8.018 from equation 1.20.

The results are summarized in table 1.1 for various values of "m"

(1)	(2)	(3)	(4)	(5)	(6)	(7)
m	So	Ss	Z	E(Z)	E(D > R - m)	ICo
1	3	5	2.3300	0.003400	....	05.500
2	3	3	1.3950	0.037075	0.07971	08.018
3	3	2	0.9302	0.095030	0.20431	12.095
4	3	1	0.4650	0.208800	0.44890	20.924

TABLE — 1.1: Summary of the Results

IV. RESULTS & DISCUSSION

The following points are observed from the analysis of results shown in the table 1.1.

(i) The safety stock "Ss" (for a single unit transfer request) dictated by the distribution parameters of variable demand is more than the optimum level of inventory "So" obtained through availability consideration, the provision for interlocation transfer of spares is justified as it does not affect the system availability.

(ii) The critical value of inventory (Column 7) above which the transfer of spares in different quantities (for various values of "m") can be made, increases with increase in number of units requested.

The transfer of more than 3 units (i.e . .4 and above) is not feasible because the maximum on hand inventory level (safety stock and order quantity) is 16, whereas critical value of inventory "Ico" associated with the transfer of 4 units is 20.924, therefore placing the limit on the transfer quantity "m" equal to 3 as maximum.

(iii) For a given level of system availability (P= 0.85), availability consideration criteria stipulates a fixed value of optimum of spares (So=3) to be held at the location. The safety stock "Ss" based on distribution of variable demand (Normal in this case) is more than "So" for single unit and decreases with increase in "m" Although for "m = 3" cost considerations recommend the inter location transfer but safety stock (Ss=2) falls below the level stipulated by availability consideration (So=3).It seems that transfer of three units adversely affects system's availability but in essence the donor location is also benefited from transfer of spares from the other locations. Therefore the transfer of maximum of m=3 units retains its validity.

Moreover if the stock-out cost is higher than transportation cost, the formula yield a lower inventory level "Ico" highly recommending inter-location transfer & the reverse is true for higher transportation cost as compared to the cost of stock-outs. Further, lower annual demand and cost of placing an order suggest that the inter location transfer minimizes the overall costs. Higher values of these parameters entail higher values of "Ico" i.e. lesser economic ground for inter location transfer of spares.

V. Conclusion

This paper aims at addressing the two relevant aspects of spares management and provisioning in a logistic support system namely - system availability & minimizing relevant costs for a given demand variability. Development of the model in this chapter has considered only two locations for the sake of simplicity, but the generality and applicability of it has not been compromised. The proposed approach can be used in multiple types of spares used at multiple locations with the provision of inter-location emergency transfer. This model draws its authenticity & applicability from some practical conditions that the time required by a location to acquire a spare (or in fixed order quantity) from the central depot is much longer than the time taken to ship the spares between various locations.

Hence this model provides the much needed aid to spares management issues for logistic support system of an enterprise in two different dimensions i.e. sustaining system availability & overall cost reductions. The incorporation of time required to procure the spare from Central depot, that of inter location transfer & restore the system to operable status can help bring forward the research in this aspect of spares management.

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