SAN FRANCISCO, CALIFORNIA USA
1984 January 24-26

ISSN 0149-144X

1984 PROCEEDINGS ANNUAL RELIABILITY AND MAINTAINABILITY SYMPOSIUM

THE Forum for the Assurance Technologies

Sparing Criteria. Clear Management Approach

Z. Bluvband; Israel Aircraft Industries; Lod

S. Shahaf; Israel Aircraft Industries; Lod

Key Words: Spares, Back Order Probability, Logistic System, Availability, Complement Cost, Total Cost, Operational Readiness.

Abstract

Reference is made in this paper to the possibility of defining logistic system parameters, allowing the Logistics Sensitive Operational Availability (LSOA) usage. To this end, a parameter of Back Order Probability (BOP) was introduced, allowing calculation of the Average Wait Time per Order (TWAIT), which, together with the Weighted Demand Rate (WDR) expresses the Mean Logistic Down Time (MLDT). The mechanism of the effect of spares quantities on the Availability was analyzed, taking into account different Indenture Levels (IL) and different Levels Of Repair (LOR) in a multi-echelon case. Algorithms for calculation of BOP, TWAIT, LSOA and Operational Readiness (OR) were developed with consideration of the Poisson Distribution of demands.
In addition, a proper technique for total cost constraints calculation, adequate for sparing application, was established.

Introduction

The ability to optimize high-level logistics management decisions, depends on clearly defined top criteria which comprehensively reflect the end effect.
The existence of a link between top criterion (such as OR) and spares quantities allocation, provides management with an effective view of the impact on the logistics system from a top-down aspect. This approach preserves the main principle that the management level (making the decisions) must define top level requirements only rather than having to go into details at lower levels. The objective of this present research was to link spares allocation to definition of Availability and OR as top criteria with the aid of convenient and clear logistics parameters.
The paper is composed of the following:

- An analysis of parameters customary in logistic systems with integration of the proposed parameters (BOP, TWAIT).
- A method for calculation of average wait time for spares orders is proposed, and integration of the parameters in Availability or OR calculations, and an analysis of the mechanism of the effects on logistic systems.

Finally, the total financial aspects of the system, as possible cost constraints in optimization/decision process, are reviewed.

I. Investigation of Commonly Used and Proposed Criteria

In this framework the definitions, relationships and interdependencies, advantages and disadvantages of each of the customary and proposed criteria (logistic system parameters) are investigated.

Confidence Level (CL)

Definition:

$$CL(SPQ_j , \lambda_j , T) = \sum_{i=0}^{SPQ_j} P(i/\lambda_j , T). \quad (1)$$

CL is the probability of less than or equal to SPQ_j demands of item j during time interval T.
Thus the statistical meaning of CL is the ratio

$$CL = \frac{\text{The number of "T" time intervals without lack of stocks of item j}}{\text{The total number of "T" time intervals}} \quad (2)$$

For systems with large quantities m of various items, total probability CL_Σ of the system working without any (from the m types) item spare shortage could be defined as (Ref. 2,3)

$$CL_\Sigma = \prod_{j=1}^{m} CL(SPQ_j , \lambda_j , T) . \quad (3)$$

Implications

1. From definitions (2) and (3) it is obvious, that in a large logistic system, the "number of periods without any spare parts (SP) shortage" → 0 with the growth of m (always, in every significant time interval observed there is a shortage of spare part for some item). Thus, the numbers obtained for CL_Σ are usually very small, and approach zero, despite the fact that for every item its CL approaches 1.
2. The criterion CL may at times mislead the user in various types of applications, when a derived parameter must be calculated. For instance: "mean turn around time" (T) is calculated in Ref. 1
$$T = CL \cdot t + (1 - CL) \cdot T_{cs} , \quad (4)$$
where wait time equals t, assuming spares available at operational site; T_{cs}, assuming no spares. Formula (4) is not accurate since the relative quantity of missing spares in relation to the number of orders for which no spares are missing, rather than the relative number of time intervals with missing spares dictate the relative number of T_{cs} as compared to t (see section BOP).
3. In view of the above significance, it is claimed that: The number of back orders rather than the number of time intervals in which there is shortage of spares, determines the quality of performance of the logistic system (system response times etc.). The next criterion (EBO), accepted as a criterion for many models, including "MODMETRIC", is analysed in the sub-chapter below.

Expected Back Orders (EBO)

Definition:

$$EBO(SPQ_j , \lambda_j , T) = \sum_{i=SPQ_j+1}^{\infty} (i-SPQ_j)\cdot P(i/\lambda_j , T). \quad (5)$$

Formula (5) expresses the average number of logistic failures per item j (demands for which no immediate answer can be found) for time interval T, if the initial stock is SPQ_j.
The statistical significance of the EBO is:

$$EBO = \frac{\text{number of logistic failures in observed periods}}{\text{total number of observed periods}} \quad (6)$$

The characteristic of an entire logistic system is the sum of all EBO's for all items of the system:

$$EBO_{\Sigma} = \sum_{j=1}^{m} EBO(SPQ_j \ , \ \lambda_j \ , \ T) \qquad (7)$$

Implications

1. The advantage of the EBO is that it gives the average number of logistic failures, allowing as a result:
   - Calculation of total wait time for logistic failures in a time interval T
   - A possibility to calculate economic penalty as a result of BO "complimentary funding" for certain processes (see Chapter IV).
2. The drawback of the EBO is due to its size increasing with time interval, and calls therefore for normalization. (Sometimes the EBO proper is insignificant, for instance, is EBO=0.0014, or EBO=7, high or low?)
3. In the end, the logistics system is characterized by the average wait time for every demand (similar to (4)). Thus, the normalization of BO per total number of demands must be investigated.

Back Order Probability (BOP)

Definition:

The criterion we propose is defined as the probability of a logistic failure (BO) in the system given a demand (order) for spare parts, i.e.

$$Prob(BO/order) = \frac{Prob(BO, Order)}{Prob(Order)} \qquad (8)$$

where

$$Prob(Order) = \sum_{i=1}^{\infty} P(i/\lambda \ , \ T) \ , \qquad (9)$$

$$Prob_j(BO, \ Order) = \sum_{i=1}^{\infty} P_j(BO/i) \cdot P(i/\lambda_j,T) \ , \qquad (10)$$

where $P_j(BO/i)$ is the conditional probability of BO given i orders will occur, meaning that a priori if within a time interval "T" i orders occur and the stock is SPQ_j, and every order is handled without priorities, then:

$$P_j(BO/i) = \begin{cases} 0, & \text{when } 0 \le i \le SPQ_j \ , \\ (i-SPQ_j)/i, & \text{when } i > SPQ_j \end{cases} \qquad (11)$$

Note that $BOP_j = Prob_j(BO/Order)$. Then from formulas (8), (10), (11) it follows that:

$$BOP_j = \Big(\sum_{i=SPQ_j+1}^{\infty} P(i/\lambda_j,T) - $$

$$- SPQ_j \cdot \sum_{i=SPQ_j+1}^{\infty} P(i/\lambda_j,T)/i) \Big/ \sum_{i=1}^{\infty} P(i/\lambda_j,T). \qquad (12)$$

The statistical significance of BOP_j is the ratio of

$$BOP_j = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{\text{number of orders for item j not filled in period i}}{\text{total number of orders for item j in period i}} , \qquad (13)$$

where n = the total number of observed periods.

Implications

1. The advantage of BOP is that it provides an answer to the average number of BO in relation to one order (average ratio).
2. It is evident that the use of BOP instead of CL for calculation of logistics system response time in formula (4) is correct, since the number of waits T_{cs} per order and the number of wait t per order relate to one another on the average as BOP to (1-BOP).

That is (4) must be expressed in the form:

$$T = (1 - BOP) \cdot t + BOP \cdot T_{cs}$$

3. Let a period during which some logistic failures occur enter the "black" category, and a period : which there are no logistic failures the "white' category. Then CL is the average ratio between "white" and the total sum of "black + white", wh BOP indicates any period in a "wide spectrum of colours", meaning that it does not lose the info mation available from the "black" period (number BO, Orders).
4. The advantage of the BOP criterion (in additior the aforementioned advantages) is in its clear r ing from the logistic point of view for the deci maker. The decision maker in his reference to e item will correctly evaluate the significance o: ratio of the number of BO to the number of order For example, 6 lacking parts per 10 orders and c lacking part per 100 orders, and the average wai time per order for a given time.

II. BOP Application

Remark: In this chapter the Poisson distribution w be used. Let denote:

$$P(i/\lambda \ , \ T) = \frac{(\lambda T)^i \ e^{-\lambda T}}{i!} \equiv q_i(\lambda T),$$

$$F(S \ , \ \lambda T) \equiv \sum_{i=S}^{\infty} q_i(\lambda T).$$

Average Wait Time Per Order - TWAIT

In this section we propose a general application o: for calculation of average wait time per order, TWA This time will clearly reflect the relationship bet the maintenance levels, the maintenance policy and stock management mechanisms.

We will deal with two generally accepted policies:

(I) - For discard items, policy, s,S

(II) - For repairable items, policy S-1,S

Case (I) - two processes cause BO:

(I1) - BO occurring in the internal resupply proces from the central warehouse to the station, w a given lead time interval (T_{RS}) as a result a number of orders within this interval whic exceeds s. It is assumed that the average r ponse time to a logistic failure (BO) in thi process equals T_{IN} (internal Emergency Resup Time).

(I2) - BO occuring in an external process, from the point of view of the central warehouse, as a result of stock depletion S_W in the central house and at the station, and additional ord taking the provisioning cycle (prediction ti TPRED) into account. It is assumed that eve order issued by the base to the central ware when empty waits an average time of T_{EX}. Then, analogously to (14), the average wait per order in the provisioning cycle TPRED is

$$TWAIT_j = (1-BOP_j(TPRED)) \cdot BOP_j(T_{RS}) \cdot T_{IN} + BOP_j(TPRED) \cdot T_{EX},$$

where $BOP_j(T_{RS}) =$

$$= (F(s+1,\lambda_j T_{RS}) - s \sum_{i=s+1}^{\infty} q_i(\lambda_j T_{RS})/i \ )/F(1,\lambda_j T_{RS}$$

and $BOP_j(TPRED)$ analogous to (18) but with TPRED in: of T_{RS} and the total spare part quantity in the lo tic inventory system S_W instead of s.

An approach to BOP calculation with the aid of Pois Distribution Table is presented in Appendix 1.

Case II
Wait times for orders for repair parts originate in the repair part supply process proper, as for discard parts. However, these parts call for special handling, since their wait times are a function of the wait times for orders for their spare parts. Every part "j" having a failure is sent to its repair level station. It is assumed that the repair time includes handling time TPR_{oj} (repair, delivery, administrative, etc.). This time TPR_{oj} does not include delay times because of logistic failures, such as lack of spares designated for repair at the station. Every one of the items of which it is composed and which are defined as "Kj" spares may be missing when ordered - logistic failure of item "Kj".
Let us assume an average order wait time of item "Kj" equal to $TWAIT_{Kj}$. Since the average ΔTPR_j time of the delay must be obtained, while taking the order for every item defined as spare parts (for item "j") into account, the following calculation is applicable:

$$\Delta TPR_j = \frac{\sum_{Kj=1}^{m_j} \lambda_{Kj} \cdot TWAIT_{Kj}}{\sum_{Kj=1}^{m_j} \lambda_{Kj}} , \quad (19)$$

where:
m_j - total number of spare part types of part "j",
λ_{Kj} - failure rate of item "Kj" as spare part within part "j".
Now the time interval TPR_j required for repair of item "j" is composed of:

$$TPR_j = TPR_{oj} + \Delta TPR_j . \quad (20)$$

In formula (19) the term $TWAIT_{Kj}$ is extracted as follows:
- If the "Kj" part is discard as per formula (17), with "Kj" instead of "j",
- If part "Kj" is repairable, then

$$TWAIT_{Kj} = BOP_{Kj}(TPR_{Kj}) \cdot BOWAIT_{Kj} , \quad (21)$$

where for $BOWAIT_{Kj}$ calculation see Appendix 2.
$BOP_j(TPR_j)$ calculation is performed according to (18), substituting TPR_j for T_{RS} and S for s.

Availability
The purpose of parameter calculations such as BOP, TWAIT, etc. was twofold:
- To establish criteria having themselves logistic meaning
- To establish a method to integrate them in a top criterion sensitive to both equipment inherent failures and logistic failures.
One of the known and accepted options for such a criterion is availability.
In practice, a good estimate of operational availability as the probability of an operational system (aircraft, for instance) to perform its missions whenever required, is expressed as the ratio between the average available time of the aircraft for a required period of time and this period itself (Up Time Ratio)

$$A = \frac{MTBM}{MTBM + MDT} , \quad (22)$$

where:
MTBM - Mean Time Between Maintenance
MDT - Mean Down Time reflecting the mean maintenance task time and the duration of logistic delays.
Equation (22) can be expressed in final form as:

$$A = (1+MRSDT+WDR(MTTR+MLDT))^{-1} \cong LSOA \quad (23)$$

where:
MRSDT - Mean Relative Scheduled Down Time
LSOA - Logistic Sensitive Operational Availability.
The MLDT term in equation (23) reflects the impact of the logistic system on aircraft availability by means of the wait times for parts. It is important to emphasize that the intent here is to LRU's only, i.e.:
MLDT = TWAIT(LRU).
TWAIT(LRU) is obviously a function of the BOP's and of the BO wait times for all LRU elements (defined as SP) at all indenture levels in consideration of the levels of maintenance and stocks of spare parts allocated to every level. The relationship between every indenture level and maintenance levels and their effect on availability through TWAIT(LRU) will be analyzed in the next chapter.
It can be seen, that in the ideal case LSOA coincides with inherent availability: MTBF/(MTBF+MTTR).
Therefore, LSOA will be sensitive enough to both inherent and logistic failures and it directly reflects the Organization-level back-order possibilities.

Operational Readiness
A top criterion in the operational system is defined by the command/management level as the readiness goal of the operational system.

$$OR = \frac{N_{av}}{N_{ac}} , \quad (24)$$

where:
OR - Operational Readiness,
N_{av} - Number of available aircraft demanded,
N_{ac} - Fleet size.
In this section it is assumed that there is a given LSOA, and a demand to establish the nature of the link between it and the readiness goal.
Since every aircraft is available at any time with a probability LSOA, the probability that at least N_{av} of aircraft will be available out of the fleet size N_{ac} has a binomial distribution:

$$P(\geq N_{av}) = \sum_{i=N_{av}}^{N_{ac}} \binom{N_{ac}}{i} (LSOA)^i (1-LSOA)^{N_{ac}-i} . \quad (25)$$

For a given LSOA a certain level of confidence is obtained, assuring the required OR goal. If the obtained level does not meet anticipations and a β level of confidence is required higher than obtained in equation (25), this may be defined as an additional request complementing the request for the OR goal, and an LSOA value is required from equation (25), yielding:

$$\beta \leq P(\geq N_{av}), \quad (26)$$

for any β, OR and N_{ac} data. A calculated solution can be found for minimum LSOA valid for (26), with the aid of known tables.

III The Reciprocal Effect Mechanism In a Logistic System

This chapter does not take into consideration all effects and aspects existing in the logistic system, but only those points concerning the subject of this paper. The aspect of interest to us is the effect of the size of the stock at the D, S and O-maintenance levels.
Fig. 2 schematically presents the LSOA calculation method relating to:
- Indenture Level (IL) (B & P, LRU/SRU/SSRU),
- Maintenance Levels (ML) (Org. (O), Interm. (S), Depot (D)),
- Level Of Repair (LOR) (Repairable, Discard).
The aircraft is defined as the top indenture level (Top IL). In most customary maintenance policies for on-board systems at the Organizational level (operational site) maintenance is performed at LRU level only

i.e. failed LRU is replaced by a new one from the stores. If repairable, the unit is sent to one of the higher ML. Thus, the aircraft Availability (LSOA) is directly affected only by <u>availability/non-availability</u> of the LRU as spare parts at the stores when ordered. It is therefore clear why the LRU as spare part is allocated only at the O-level stores or at the central stores supplying the O-level with equipment.
It should be noted that every repairable LRU item has a movement in the logistic system, made up of two main routes (see Fig. 3).

(a) From the aircraft to the shop or depot (as maintenance level) - in unserviceable condition ($\alpha_{ik}^{①}$, $\alpha_{ik}^{②}$), .
(b) to the aircraft from O-level (as spare part stores) - in serviceable condition ($\alpha_{ik}^{⓪}$).

The movement of the LRU as a repairable unit in route (a) may be defined as Depot only, Shop only or Split between both. In all cases there is a need to prepare spare parts for the repairable unit as a function of failure rates (λ), which is derived from the split ($\alpha_{ik}^{⓪}$) where "i" is the number of the operational site and "k" the number of stores at the appropriate maintenance level M. These spare parts may be repairable or discard, and defined in accordance with the maintenance policy as SRU.
<u>Availability/non-availability</u> of SRU as spare parts of the appropriate maintenance level (S, D or Split) when demanded <u>directly affects</u> the delay time of the LRU in the non-serviceable status and delays their referral to the O-level (or central) stores, i.e. to be ready to move along route (b), and this way non-availability of SRU for the repairable route of the LRU indirectly affects aircraft availability (LSOA).
For the SRU received for repair at one of the maintenance levels (S, D or Split) the same mechanism of reciprocal effects of spare parts exists. <u>Availability/non-availability</u> of SSRU's as spares in the stores when ordered for the SRU directly affects SRU delay as spare parts for the LRU, i.e. indirectly it affects the availability of the LRU as spares for the aircraft and as a result, also aircraft availability (LSOA).
This inductive analytical process is easy to continue for the SSRU, constituting a discard item.
<u>Availability/non-availability</u> of that discard item at the stores is only dependent on similar ones in the stores. Thus, the chain is broken (it is obvious that the chain could also be interrupted if the LRU or SRU would have been discard).
The method of calculation of TWAIT (LRU) thus ensures the capability to include the quantities of spare parts at the stores at all maintenance levels in the context of the indenture level and LOR.
This way we arrive at the conclusion that LSOA is sensitive to logistic failures at all possible multi-echelon and multi-indenture levels in Fig. 2.
The calculation process is erected bottom-up, starting with discards such as B & P via SSRU, SRU, and LRU up to LSOA as aircraft availability. The calculation process is focused on calculation of TWAIT(LRU), with calculation of LSOA and/or OR at the top.
TWAIT(LRU) is calculated analogously to ΔTPR (19):

$$\mathrm{TWAIT(LRU)} = \Big(\sum_{\substack{\text{over}\\ \text{all LRU's}}} \lambda_{LRU} \cdot \mathrm{TWAIT}_{LRU} \Big) \Big/ \sum_{\substack{\text{over}\\ \text{all LRU's}}} \lambda_{LRU} . \quad (27)$$

For a detailed explanation of the process, see the flow chart in Fig. 4.

IV. Total Cost Constraints Analysis

Every selection of spares stock allocation requires a trade-off of time versus financial expenditure.
The trade-off in terms of time is reflected in LSOA through BOP and TWAIT as the wait time for the ordered spares. The effect of the quantities of spare time interval was analyzed in the previous cha while the expenditure, having a clear effect c availability through the quantities of spares, for a parallel analysis.
The actual allocation of stocks of spare part a provisioning time interval TPRED by purchase payment (stock funding C_S) results in a certai LSOA. However, it cannot be said that the LSC equation (23) is achieved as a result of inves only. Indeed, for a correct operation of a system, the demand is always supplied by procu lacking quantity (BO) from external supply sou For every j item discarded, that spares are re the various maintenance levels (O, S, D), the tion of anticipated shortages in the logistic may be calculated by $EBO_{EXT\,j}$ (TPRED) from (5) tuting T for TPRED and SPQ_j for S_{Wj}.
Considering the cost C_j for item j the cost e tion required $C_{c\Sigma}$ (complementary funding) for nance of the logistic system at a given LSOA l taking in account the exclusive need to supply for discard items only, is

$$C_{c\Sigma} = \sum_{\substack{\text{discard}\\ \text{items "j"}}} EBO_{EXTj}\,(\mathrm{TPRED}) \cdot C_j \, .$$

The total cost expectation supporting a certai level, considering also the allocated stock an BO's, will be: (m-total number of spare types

$$C_\Sigma = C_{S\Sigma} + C_{c\Sigma} = \sum_{i=1}^{m} S_{Wi} \cdot C_i + \sum_{\substack{\text{discard}\\ \text{"j"}}} EBO_{EXTj}(\mathrm{TPRED})$$

A smaller investment in a pre-allocated stock provisioning of spares ($C_{S\Sigma}$) entails a higher ment in procurement of the complementary stock results in a penalty of a longer wait time, ad affecting the LSOA, and vice versa. A sample in Fig. 1 of the relationship between $C_{c\Sigma}$ and for a given system. The objective of the best cation within cost constraints is, of course, such a spare parts package that LSOA (or OR) wi maximum for a total cost constraint C_Σ or, conv minimization of the total cost of required LSO required OR). In Fig. 1 a minimum total cost also given, C_Σ, as a function of LSOA.
The total minimum cost C_ΣMIN which permits achi the required LSOA (or OR) permits the best poss decisions on total cost allocation and stock cc the point of the "Total Cost - LSOA" couple. F stance, point B is better than point A in absol fashion, and at point C it is worthwhile to sto ting money in stocks (from the point of total c because the large investment does not result in nificant growth in LSOA, while point C may be s according to the best combination of:

- Readiness goals,
- Selection of the size of the aircraft fleet,
- Flight hour/sortie potential.

Conclusions

1. It is recommended to use the Back Order Prob (BOP) as having clear logistic significance decision makers, and TWAIT - Average Wait Ti Order as parameters, quantitatively emphasiz important sides of the logistic system. The meters are preferable to others in use at pr
2. The use of these parameters allows to combine criteria such as LSOA - Logistic Sensitive O tional Availability <u>or</u> Operational Readiness allowing clear and optimal decisions of spare allocations, with consideration of Indenture Maintenance Levels, and Repair Levels.

3. Optimization shall be effected in such a manner that budget constraints C_Σ takes into account the pre-allocated cost for stocks $C_{S\Sigma}$ (initial provisioning) as well as complementary cost $C_{c\Sigma}$.
4. Future efforts will focus on expanding the application of this paper to find decision points (lower and upper thresholds) for total budget allocation, which includes the dependency on LSOA (or OR).

Appendix 1

It is evident that:

$$BOP = \frac{1}{F(1,\lambda)}\left(F(S+1,\lambda) - \frac{S}{\lambda} F(S+2,\lambda) - S \sum_{i=S+1}^{\infty} \frac{q_i(\lambda)}{i(i+1)}\right) .$$

$F(x,\lambda)$ and $q_i(\lambda)$ are tabulated. The "problematic" expression is:

$$S \sum_{i=S+1}^{\infty} \frac{q_i(\lambda)}{i(i+1)} = S \sum_{i=S+1}^{S_\Delta} \frac{q_i(\lambda)}{i(i+1)} + S \sum_{i=S_\Delta+1}^{\infty} \frac{q_i(\lambda)}{i(i+1)} .$$

Since:

$$S \sum_{i=S_\Delta+1}^{\infty} \frac{q_i(\lambda)}{i(i+1)} \le \frac{S}{(S_\Delta+1)(S_\Delta+2)} F(S_\Delta+1,\lambda),$$

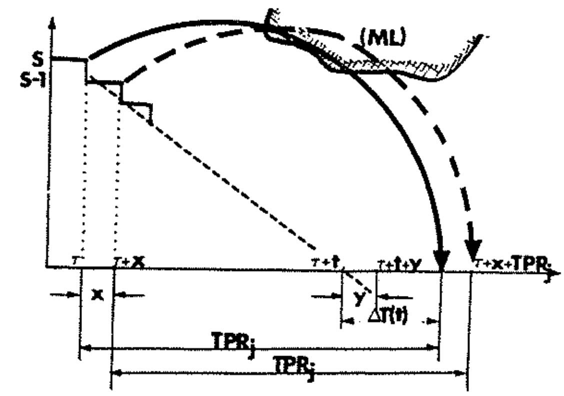
for demanded accuracy Δ, may be found S_Δ that

$$\frac{S}{(S_\Delta+1)(S_\Delta+2)} F(S_\Delta+1,\lambda) \le \Delta ,$$

then:

$$BOP \approx \frac{1}{F(1,\lambda)} \left(F(S+1,\lambda) - \frac{S}{\lambda} \cdot \left(F(S+2,\lambda) + \sum_{i=S+1}^{S_\Delta} \frac{q_{i+1}(\lambda)}{i}\right)\right).$$

Appendix 2



Assuming that the order was received at a time τ and reduced stocks to S-1, the repairable part j returns after TPR_j. A logistic failure occurs at point $\tau+t$, when demand number S+1 arrives. If the probability of this occurring in interval $(\tau+t, \tau+t+dt)$ is

$$f_S(t)dt = \lambda \frac{(\lambda t)^{S-1} e^{-\lambda t}}{(S-1)!} dt$$, then the mean BO wait time

$$BOWAIT_j = \int_0^{TPR_j} (TPR_j - t) f_S(t)dt,$$ or finally

$$BOWAIT_j = TPR_j \cdot F(S, \lambda_j \cdot TPR_j) - \frac{S}{\lambda_j} F(S+1, \lambda_j \cdot TPR_j) .$$

It can be observed that for every other BO (such as point $\tau+t+y$) the average wait time is the same, since a response to the BO at point $\tau+t+y$ arrives at point $\tau+t+x+TPR_j$ (from the point $\tau+x$), and $E(x)=E(y)=1/\lambda_j$, i.e. the average rate of "stock depletion" equals the average recovery rate. Thus, it is seen that the average wait time for every BO is $BOWAIT_j$.

The result is in correlation with the result of a similar case (Ref. 6), which was derived by another method.

References

1. F.J. O'Neil, "A Two-Level Sparing Approach For Plug-In Modules", 1983 Proceedings Annual RAM Symposium, pp. 388-393.
2. H.L. Platzer, "Sparing For Repairable Redundant System", 1983 Proceedings Annual RAM Symposium, pp. 394-397.
3. J.G. RAU, "Optimization and Probability in Systems Engineering", 1970, Van Nostrand Reinhold Co., N.Y.
4. J.B. Abell, J.E. Lengel, F.M. Slay, "Toward Improved Initial Provisioning Strategies: The F-16 Case", Logistics Management Institute Report # ML108 (Washington, D.C.), April, 1982.
5. J.E. Arsenault & J.A. Roberts (Editors), "Reliability and Maintainability of Electronic Systems", Computer Science Press, 1980.
6. G.B. Rubalsky, "Inventory Control with Random Demands", Sovietskoye Radio, Moscow, 1977.

Biographies

Zigmund Bluvband, Ph.D.
Israel Aircraft Industries Ltd., Dept. 4540
Ben Gurion International Airport, Lod, Israel

Zigmund Bluvband is a Senior Reliability engineer and analyst in the IAI Reliability and Product Assurance Department. He is an electronic engineer, graduated from the Polytechnic Institute of Lvov, USSR (1969). He received his MSc in Mathematics from the University of Lvov (1974), and his Ph.D. from the Polytechnic Institute of Lvov (1974). Dr. Zigmund Bluvband has accrued 14 years of experience in reliability and quality engineering. He has published more than 20 papers and reports in technical journals, technical conference proceedings, etc. He is a member of IEEE, Reliability Society, ASQC, and is an ASQC Certified Reliability engineer.

Shimon Sahaf
Israel Aircraft Industries Ltd., Dept. 9680
Ben Gurion International Airport, Lod, Israel

Shimon Sahaf is the Head of Sparing Design Department since 1980. From 1968 he completed 12 years of active duty as officer in the IAF. From 1977 to 1980 he was head of a project in the IAF dealing with design of a new logistic system. He is a mechanical engineer, graduated from the Technion of Haifa.