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AUG 81 A J KAPLAN

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report models the interaction between stockage of float end items, stock of essential repair parts/spares, and operational availability. The model is applied to a missile system to find the least cost mix of float and spares/repair parts to achieve a target operational availability. Limitations of the approach are pointed out.		

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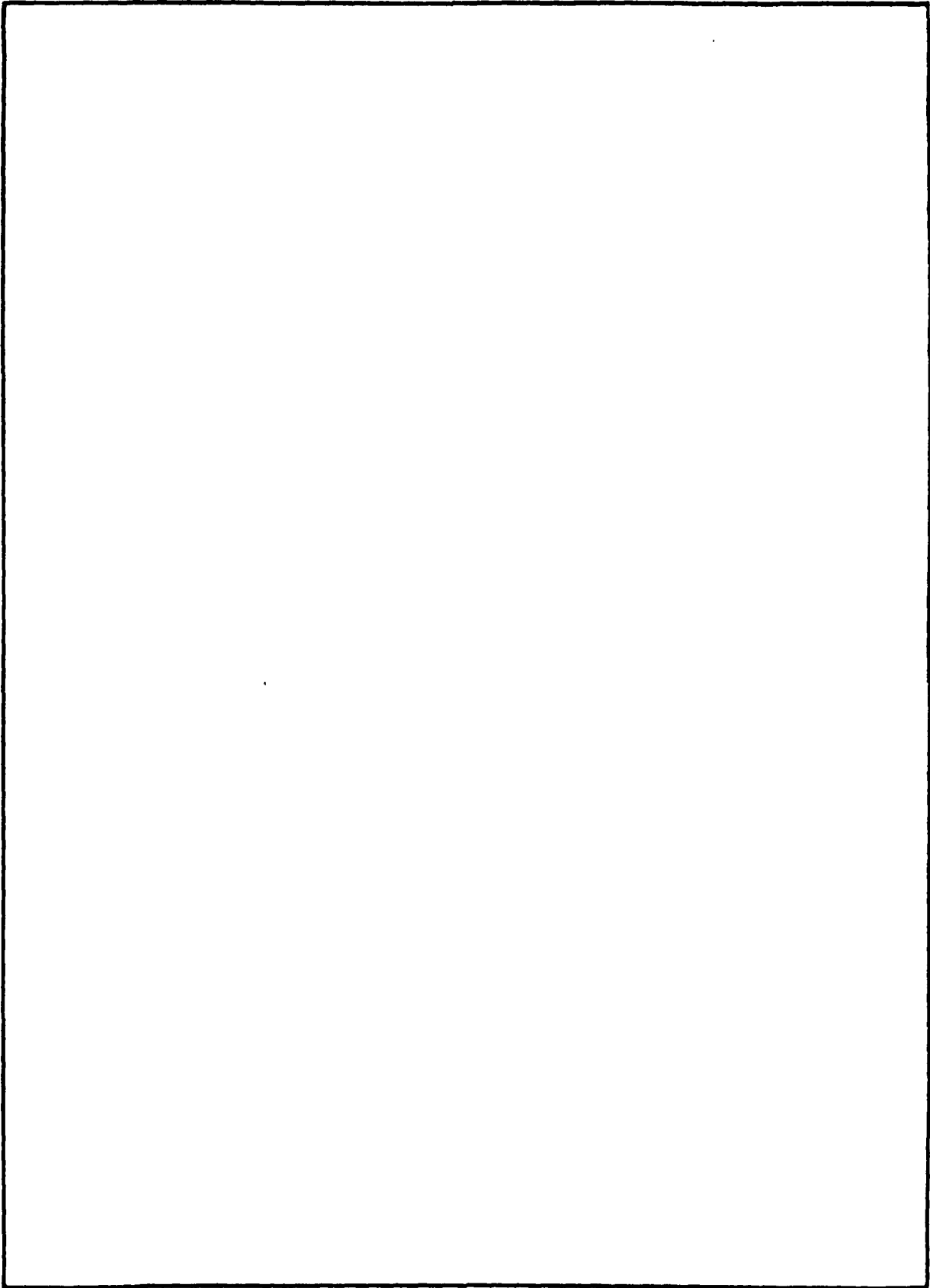
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Introduction

Operational Readiness Float (ORF) are end items stocked at Direct Support Units (DSU's) and issued to using units (ORG's) to replace like end items evacuated to the DSU for maintenance. By regulation [11,12], the float end item should not be issued if the evacuated item can be repaired within specified time limits.

Essential Repair Parts Stockage List (ERPSL) are spares and repair parts which are stocked at organizations, direct support units, and possibly other retail echelons to provide a specified degree of end item operational availability. Operational availability is usually defined as the expected percent of time an end item is capable of performing its primary mission. Without ERPSL repair and spare parts are stocked, but not in the same quantity or range.

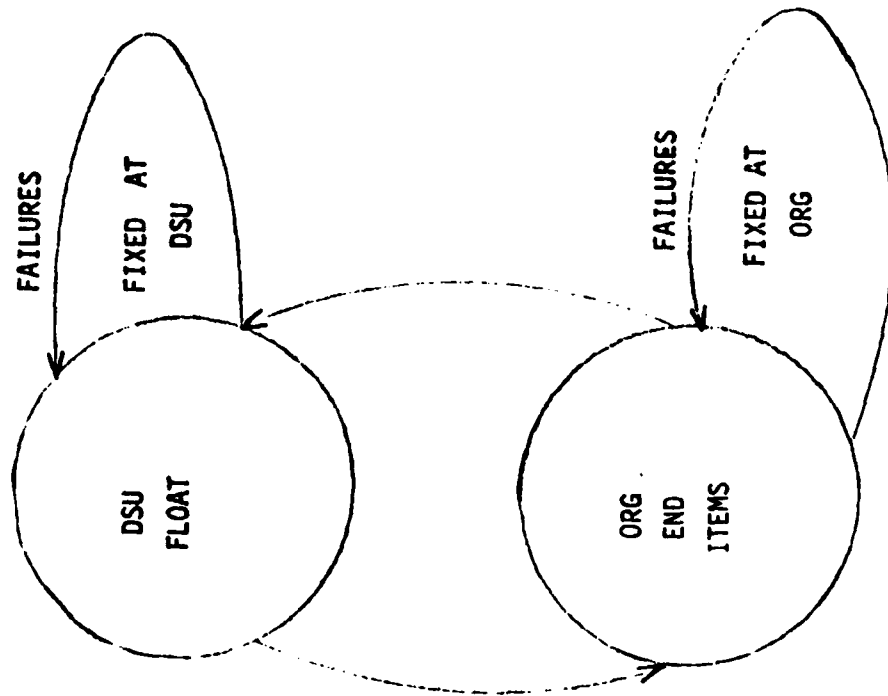
The interaction between ORF, ERPSL and operational availability is illustrated in Figure 1. When an end item fails, its downtime, if the failure is organization reparable, will depend solely on ORG repair part/spares support. If the end item is evacuated to the DSU, and conditions are met for float issue, then downtime will depend directly on whether a float is available, or on how long it will take to get one. Spare/repair part support at DSU affects operational availability in several ways: if there is no planned DSU float, the user must wait until his evacuated item is repaired; if there is planned float, availability of float for issue will depend on the time to repair evacuated end items as well as on the number of float; and, finally DSU parts support impacts spare/repair part availability to the ORG user.

Currently, ERPSL quantities are developed by computer models which determine the least cost mix of spares/repair parts which are expected to result in a target level of operational availability. The most commonly used model is SESAME [6,10]. Neither SESAME nor any of the other ERPSL models used within the Army allows evacuation of end items from ORG to DSU; hence, they do not model float. SESAME assumes that if a spare must be replaced by DSU-level personnel, a DSU "contact" team can bring the spare to the end item and do the work at ORG.

ORF is currently computed by multiplying specified factors by supported densities. While wartime quantities may be bought, only peacetime levels are actually stocked at DSU's. The peacetime quantity factors are keyed to

FIGURE 1

METHODOLOGY FLOAT MODEL BASIS



REPAIR LOOP =

(TIME TO RETURN UNIT)

+

(TIME TO GET SPARE)

+

(TIME TO INSTALL SPARE)

availability of float [11,12] when needed rather than directly to end item availability at the user. Wartime factors are supposed to be keyed to operational readiness, but the methodology has not been worked out. Repair part support is accepted as a given.

In this paper we discuss techniques for evaluating the operational availability which will be achieved from a given mix of ERPSL and float, and for determining what is the least cost mix to achieve the operational availability target. These techniques are applied to a missile system, which will not be identified since the inputs used were estimates, subject to change, and therefore no longer valid. For the missile system, the error SESAME makes by ignoring float is computed.

Major limitations of this study should be emphasized. The modelling is based on stationary, steady state conditions. Briefly, this means inputs such as densities and average failure rates are not changing over time, and operational availability reflects what will happen, on average, in such an environment. Battlefield surges, disruption of supply, loss of equipment or spares to enemy fire, and so on, are not modelled, nor is the relative vulnerability and mobility of alternative mixtures of ERPSL and ORF considered.

Finally, it should be noted that many of the systems with operational readiness float are not authorized ERPSL. For such systems, the techniques discussed could still be used to determine float quantities, but not to optimize the mix of end item float and spares/repair parts.

Notation

- S - Number of float end items per DSU
- MTBF - Mean Time Between (end item) Failures
- MTR - Mean Time to Repair
- MLDT - Mean Logistics Down Time
- W - Average Wait for a float to be available for issue
- T - Time to move a float from DSU to ORG
- PORG - Probability a failure can be repaired at ORG
- ORG,DSU - Used as subscripts; e.g. MTR_{ORG} is mean time to repair if repair is done at ORG
- OA - Operation Availability
- Ex() - Expected value of variable in parenthesis

MLDT and MTR are defined to be exclusive of each other; MTR assumes the spares/repair parts needed are available, while MLDT refers only to delays to repair caused by absence of parts. MTR_{DSU} includes the time to evacuate the end item to DSU. $MLDT_{DSU}$ refers only to the wait for a part used at DSU, and not to delay in satisfying an ORG requisition on the DSU.

Operational availability is defined as the percent of time an end item is up at ORG. In the event that an end item is evacuated, down time begins when it fails, and up time resumes when the replacement is received.

Modelling Approaches

Initially we will assume failures are stationary Poisson and successive down times are independently and identically distributed; all failures which cannot be fixed at ORG qualify for issue of a float; each failure requires exactly one spare/repair part to be fixed; there is no special treatment of NORS requisitions, i.e. requisitions for a part keeping an end item down at ORG; and there is no cannibalization.

Then

$$(1) \quad OA = \frac{\text{Ex(Up Time)}}{\text{Ex(Up Time)} + \text{Ex(Down Time)}}$$

$$= \frac{MTBF}{MTBF + (PORG)(MLDT_{ORG} + MTR_{ORG}) + (1-PORG)(T+W)}$$

Note in equation (1) that expected down time is conditional on whether the failure can be fixed at ORG, with probability PORG.

In equation (1), $MLDT_{ORG}$ depends on the ERPSL quantity, while W depends directly on the float stock, S, and indirectly on ERPSL via the impact of ERPSL on $MLDT_{DSU}$.

In particular, if the MLDT's are given, float availability can be modelled as a finite source queue (cf Gross and Harris) and W thereby determined. DSU repairable failures constitute arrivals, and repair constitutes service in queueing terminology. The queue is finite source if the total DSU repairable failure rate depends on the number of operating end items, decreasing as end items go out of service.

While Fox [2] suggested use of the finite source approach for the float problem, it becomes messy if the ORG repairable failures are considered - these

do not constitute demand for float, but do affect the total DSU - repairable failure rate by putting items out of service. Fox did not consider ORG repair. Gross et al [4] present results for a similar problem suggesting that use of an infinite source model is a good approximation. Kaplan [5] provides some sketchy results suggesting that if, in the infinite model, OA is factored into the total estimated failure rate, results improve:

$$(2) \text{ Yearly demand for float} = (OA)(\text{Number of Supported End Items})(1/MTBF)(1-PORG)$$

If there is an OA target, this is used in equation (2). If a given value of S is being evaluated, iteration is employed: assume OA is 85%, and using equation (2) to get the arrival rate, compute W. Use W in equation (1) to develop a new estimate of OA and iterate. The process was programmed to stop after 10 iterations, or when successive values of OA differed by less than 0.5%. The program never took as many as 10 iterations, and the whole process is very fast.

We have been taking MLDT as given. In the SESAME version which is widely distributed, the MLDT which is output is

$$MLDT = (PORG)(MLDT_{ORG}) + (1-PORG)(MLDT_{DSU})^*$$

A modification was made to print out $MLDT_{ORG}$ and $MLDT_{DSU}$ separately.

Relaxation of Assumptions

It was assumed that a float would be issued whenever one was needed and was available. However, policy states that a float should not be issued if the evacuated end item can be repaired in a specified number of days, where this number varies among major commands. Such a policy must degrade operational availability in the short run, but offers incentives to organizations to keep their own equipment in the best possible shape.

One method of modelling such a policy is to identify a priori DSU repairable failures which are not serious enough to warrant float issue. For such failures MTR would include time to move the end item to DSU and back, and MLDT would be

* If the same part is used at both ORG and DSU, only the ORG demands contribute to MLDT in the distributed version of SESAME.

based on wait for parts at the DSU. Down time would be the sum of MTR and $MLDT_{DSU}$ and would not depend on W (the wait for float).

In the missile analysis it was assumed normal resupply to the ORG from DSU was two days, but that if the part was needed for immediate use on a downed end item, i.e. if there was a NORS requisition, the part could be obtained in one day. Three alternative modifications to SESAME were examined which all gave comparable results. They are discussed in the Appendix.

Optimization

We state the optimization objective as achievement of a given OA target at least cost. The alternative - best possible OA under a given budget constraint - presents no additional difficulties.

The optimization problem was not investigated in the research reported here. A quick and dirty approach was sufficient to do the missile analysis as will be seen. Nevertheless, we would like to briefly discuss the state of the art and a promising approach.

The float problem is a special case of the MODMETRIC problem. The original MODMETRIC model [8] considered situations for which, in our terminology, float could be put at ORG as well as at DSU, but $MLDT_{DSU}$ was fixed and not a decision variable dependent on stockage. In fact, while there now exist a number of MODMETRIC computer programs, the only one which we know of which attempts to optimize $MLDT_{DSU}$ is Clark's [1].

Solution of the MODMETRIC model tends to be time consuming and so various approximate techniques have been developed. Actually no existing code guarantees "the" optimum solution; there are just various degrees of approximation. In the LMI approach to "original" MODMETRIC type problems [9], DSU float and ORG spares are equated in that they indirectly affect OA, while ORG float directly affects OA. (In our version of the problem, with no ORG float, DSU float and ORG spares directly affect OA, while DSU spares indirectly affect OA.)

In the approach to the original MODMETRIC problem most compatible with the SESAME ERPSL program, Kotkin [7] builds on the generalized Lagrangian approach. Given a Lagrangian, spare backorders at ORG are costed out as a weighted average of float cost and the Lagrangian (which is chosen equal to or greater than float cost). The spares problem is solved based on this cost, and then the float stockage problem is solved based on the Lagrangian value, and using the $MLDT_{ORG}$ just found by solving the spares problem. A simple

search routine can be programmed to find the Lagrangian which will produce the target OA.

The ultimate rationale for Kotkin's weighted average formula is that it worked quite well on test cases. However, it was based on a logical derivation. This derivation suggest that the same formula should work equally well in our problem in costing out those DSU backorders for spares which contribute to $MLDT_{DSU}$. (Some DSU backorders are backorders of replenishment requisitions from the ORG. These backorders are already implicitly and correctly costed out by SESAME as a function of ORG spare backorder cost). The Lagrangian is then used to cost out float and ORG spares backorders.

Analysis of Missile Data

Inputs to the analysis are given in Table I.

Table II evaluates various combinations of ERPSL and float in terms of total cost and operational availability. Float policy I was to stock 85% of the repair cycle quantity for float; the repair cycle quantity is defined as demand per day multiplied by repair time. Float policy II was to stock the entire repair cycle quantity. As it happened, with rounding these two policies gave the same result. Float policy III was to stock sufficient float to satisfy 85% of all demands for float without delay. These policies were based on AR750-1 [12]. Note that the repair cycle quantity depends on the policy for repair parts/spares since the latter impact $MLDT_{DSU}$.

Under the first policy for repair parts/spares, policy A, there is no ERPSL, but even without ERPSL, repair parts/spares costs, based on standard provisioning procedures, are \$11.6 million for each DSU and its supported ORGs. With zero float, OA = 72.7%, while with 2 float, costing \$2.77 million each, OA increases only to 76.0% and so on.

Note that float does not impact on down time caused by ORG level failures, so that even unlimited float quantities cannot guarantee high OA.

Under stockage policy B, ERPSL is run to achieve a SESAME reported availability of 84.1%. Actual availability without float is 83.4%, and with 1 float, 85.1% OA is achieved. Note that the error SESAME makes in ignoring end item evacuation is not great (84.1% vs 83.4%), nor is the error in ignoring float (84.1% vs 85.1% or 86.6% depending on float policy).*

* A similar analysis on a limited amount of tank data again showed small errors.

By increasing ERPSL dollars to \$13.0 million (Policy (c)) an OA of 85% is achieved without float, and at least total cost.

In Table III wartime failure rates were used. Still, no float was cost effective if the OA target were 85%. For a 92% OA target it is cheaper to have 1 float than to increase ERPSL sufficiently to achieve the target without float.

TABLE 1

DATA

MTBF

11.5 DAYS (PEACETIME)

4.75 DAYS (WARTIME)

PERCENT OF FAILURES REQUIRING EVACUATION TO DSU: 9.1%

MTTR

4 HOURS IF ORG REPAIRABLE

30.6 HOURS IF END ITEM IS EVACUATED TO DSU

OST'S

DSU → ORG: 2 DAYS (1 DAY FOR FLOAT OR MORS REQUISITIONS)

CONUS DEPOT → DSU: 32 DAYS

UNIT OF ANALYSIS

1 DSU SUPPORTING 4 ORGS WITH 9 END ITEMS EACH

END ITEM PRICE IS \$2.77 MILLION

TABLE 2

SPARE/FLOAT EVALUATION

(PEACETIME RATES)

POLICY	COST SPARES	#/COST FLOAT	TOTAL COST	FLOAT WAIT	OPERATIONAL AVAIL
A	11.6 MIL	0	11.6 MIL	10.7 DAYS	72.7%
(NO ERPSL) I } II }	"	2/5.5 MIL	17.1 MIL	3.7 DAYS	76.0%
III	"	5/13.9 MIL	25.5 MIL	0.3 DAYS	77.7%
B	12.6 MIL	0	12.6 MIL	5.3 DAYS	83.4%
(LIMIT I } NORS) II }	"	1/2.8 MIL	15.4 MIL	2.4 DAYS	85.1%
III	"	4/17.1 MIL	23.7 MIL	0.1 DAYS	86.6%
TRADEOFF DERIVED TO GET 85% OP AVAIL	13.0 MIL	0	13.0 MIL	4.4 DAYS	85.1%

TABLE 3

SPARE/FLOAT EVALUATION
(WARTIME RATES)

POLICY	COST SPARES	#/COST FLOAT	TOTAL COST	OPERATIONAL AVAIL
NO FLCAT	41.0 MIL	0	41.0 MIL	92.0%
TRADE OFF DERIVED TO GET 92% OP AVAIL	36.6 MIL	1/2.8 MIL	39.4 MIL	92.0%

12

COMMENTS:

OPERATIONAL AVAIL TARGET WAS RAISED TO 92% ONLY FOR ILLUSTRATION

WITH 85% TARGET, TRADE OFF POLICY SETS ORF TO 0

APPENDIX I

EXPEDITED RESUPPLY

Notation

ORGFILL - ORG fill rate, or fraction of demands filled from stock on hand.

DSUFILL - DSU fill rate.

t - routine supply time

e - expedited supply time

d = t-e

Modelling

SESAME was modified so that item stockage was computed assuming no expedited supply, but ORG LDT was calculated allowing for it. Three alternatives were compared on the missile date:

a. Reduce LDT by $(1-ORGFILL)(d)$

b. On items not stocked at ORG, reduce LDT by d. On other items, reduce LDT by

$$(1-ORGFILL)(1-DSUFILL)(d)$$

c. On items not stocked at ORG, reduce LDT by d. On other items reduce LDT by

$$(1-ORGFILL)(1-DSUFILL)(d) + (1-ORGFILL)(DSUFILL) \frac{d^2}{2t}$$

Rationale. Method c. will be explained, and the other alternatives should then be clear. If an item is not stocked at ORG, then a full d days are saved each time there is a demand. If the item is stocked, but there is no stock on hand, temporarily, there will be due-in. How much time is saved by expediting depends on the status of the due-in. If we could assume, as an approximation, that DSU and ORG on hand status are independent, then with probability $(1-DSUFILL)(1-ORGFILL)$ both ORG and DSU cannot fill a demand, and expediting will save a full d days. If the DSU can fill the demand, and there is one unit due-in uniformly distributed over the interval $(0,t)$, then with probability d/t time will be saved by expediting, and the average saving is $d/2$.

Comparison. Missile data was run without expedited supply and with the time saving estimated by each of the methods. Results are:

<u>Method</u>	<u>No Expediting</u>	<u>A</u>	<u>B</u>	<u>C</u>
LDT	1.8 day	1.47	1.57	1.54

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