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EVALUATION OF A METRIC INVENTORY SYSTEM USING SIMULATION

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Traditional measures obtained from the application of theoretical inventory models do not provide detailed information on the ability of multi-echelon, reparable item inventory systems to maintain their supported machines in an operational status. Monte Carlo simulation techniques are applied to obtain estimates of the operational status actually attained. An advantage of the simulation techniques is that they do not require all the strict assumptions of the theoretical models. The SLAM simulation language developed by Pritsker and Pegden is used for this analysis.

1. INTRODUCTION

The objective of this paper is to determine the operational status of a large-scale reparable item inventory system where the spare levels are established by the Multi-Echelon Technique for Recoverable Item Control (METRIC). The use of the METRIC to establish the level of spares needed does not assure that the number of supported machines remains at the established level. The traditional measures provided in inventory analysis (expected shortages, etc.) are indices of supply behavior and do not directly answer how well the maintained machines are supported. Additionally, certain assumptions required by METRIC models are not met in operational systems. Monte Carlo simulation is applied to estimate the operational status actually attained within an operational inventory and repair system and to determine the effects on the operational status of relaxing strict assumptions of the theoretical models.

The paper consists of four sections. In the first section, the conceptual model of the system is presented and analyzed using the theoretical models cited in the literature. Based on the conceptual model, a network simulation model is developed and used to analyze the operational status of the system. Next, the results of the simulation analysis are analyzed to test the hypothetical effects of relaxing theoretical assumptions. The final section presents conclusions and suggestions for future research.

2. CONCEPTUAL MODEL

The system used as the basis for this study supports the inventory and repair of the missile guidance sets (MGSs) for the Minuteman III missile force. The MGSs are characteristic of reparable items -- they may be repaired upon failure[1] and returned to a serviceable condition. In fact, this is a closed system since no new MGSs are being purchased. The system is illustrated in Figure 1 as a hierarchical maintenance and supply support system where defined locations have both repair and stockage capabilities.

The lower echelon in Figure 1 represents Strategic Missile Wings, which will also be referred to as base-level facilities. Each wing is normally composed of three squadrons, with each squadron containing 50 missiles. The operations of a base-level facility are detailed in Figure 2. Note that only one of the three squadrons is depicted. The other squadrons have identical operations.

The monitoring of the MGSs is performed at a squadron launch facility. When a failure is detected within a MGS, a maintenance crew is dispatched for on-site inspection of the missile. Ten percent of the failed MGSs are returned to operational status within one to two and a half hours. Ninety percent of the failed MGSs require replacement with an operational unit. Operational MGSs are obtained from base supply and the defective unit is removed from the missile and sent to base maintenance. The total time necessary to requisition, replace and transport defective units ranges from ten to eighteen hours.

At the base maintenance facility, defective MGSs are inspected. Minor repair can be performed at the base-level facility, with the MGS returned to supply within 1 to 1.5 days. However, 97 percent of the MGSs cannot be repaired at the base-level, and must be forwarded to depot-level maintenance facilities where more sophisticated equipment and highly specialized technicians are available. The time for storing and transporting inspected MGSs to the depot ranges from ten to twenty-five days. When a MGS must be sent to the depot for

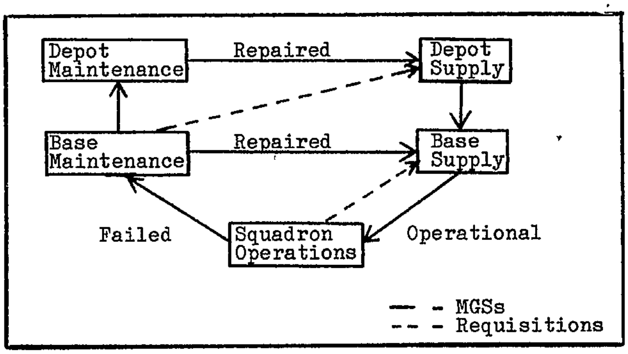

Figure 1. General Flow of Missile Guidance Sets Through the Multi-Echelon Maintenance and Supply Support System.

[1]The term "failure" includes degraded performance.

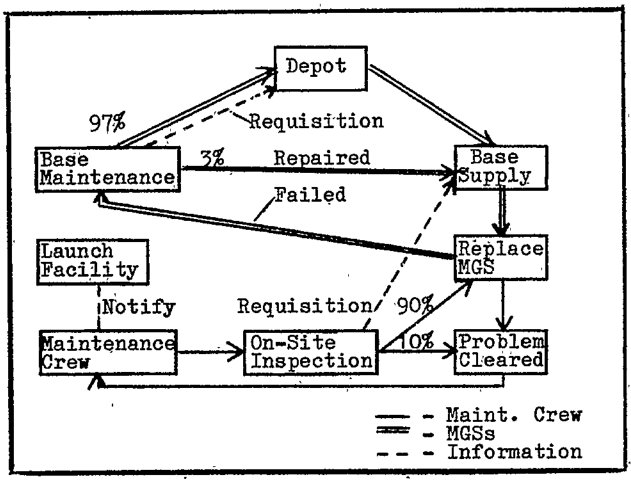

Figure 2. Detailed Operations in Lower Echelon of Maintenance and Supply Support System.

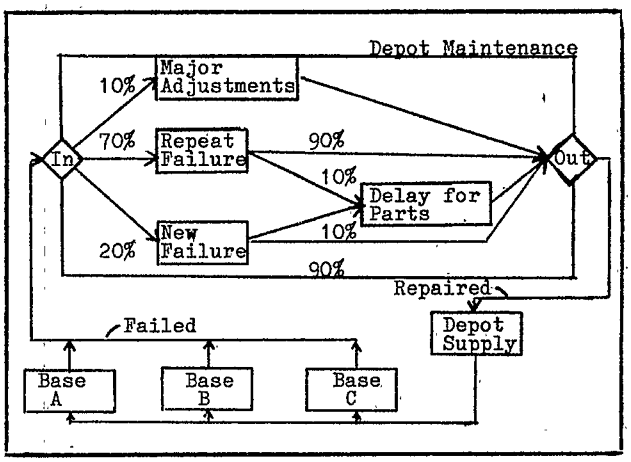

Figure 3. Detailed Flow of MGSs in Upper Echelon of Maintenance and Supply Support System.

repair, a replacement unit is requisitioned from the depot-level supply facility. Approximately five to ten days are required to ship the replacement MGS to the base supply facility.

The upper echelon in Figure 1 represents the depot-level maintenance and supply facilities. The operations of the depot-level facilities are depicted in Figure 3. Approximately ten percent of the defective MGSs may be returned to operational status after major adjustments requiring three to seven days. Seventy percent of the MGSs are classified as "repeat failures", requiring ten to fourteen days repair time. Ten percent of the MGSs are new or infrequent problems, and require fourteen to twenty-one days repair time. The repair times for the later categories assume that replacement parts are in stock. If one or more parts are not available, an extra repair time of fifteen to twenty days is required to order and receive the parts. Approximately ten percent of the MGSs requiring repair incur the extra repair time. Since the depot maintenance facility and the depot supply facility are geographically separated, an additional ten to fourteen days is required to ship the adjusted and repaired MGSs to supply.

Each missile squadron is required to maintain 49 missiles in an operational mode to maintain its operational status. Hence, the measure of effectiveness for this system is the operational status of the squadrons. The inventory problem is to determine the minimum stock levels for spare MGSs at each base supply facility and at the depot supply facility that maintains a status of 49 operational missiles.

The METRIC provides a methodology for computing optimal stock levels in a two-echelon inventory and repair system. The METRIC was originally developed by Sherbrooke and is discussed extensively in the literature.[2] This model requires the following assumptions:

a. The demand for MGSs at base "j" follows a compound poisson process with rate λ_j. The demand at each base is assumed to be independently and identically distributed according to a compounding distribution with mean f_j.

b. The probability that a defective MGS can be repaired at the base facility is r_j. Hence, the probability that a defective MGS must be sent to the depot facility for repair is $(1-r_j)$.

c. A_j is the expected repair time for the base-level repair facility.

d. D is the expected repair time for the depot-level repair facility, and includes the time for (1) shipping from the base to depot maintenance, (2) repairing the item at the depot, and (3) shipping from depot maintenance to depot supply.

e. O_j is the expected order-and-ship time from the depot supply facility to the base supply facility. The demand requests are filled by the depot in the same order received.

f. All MGSs can be repaired.

g. Lateral supply between base-level supply facilities is not allowed.

h. Successive repair times are independent identically distributed random variables. An infinite number of servers are available at both base and depot repair facilities. Hence, queuing does not exist at the repair facilities.

Table 1 summarizes the necessary equations and expected parameter values for applying METRIC to the conceptual system. A hypothetical mean-time-between-failure (MTBF) rate of fifteen days at the squadron-level will used throughout this analysis. The expected backorders at the depot and at each base for a random point in time for increasing stock levels are presented in Figure 4. Note that these results do not provide any insight as to the ability to maintain a 98 percent operational level.

Clark (1981) has introduced the concept of Optimal A_o Inventory Models which allow derivation of an expected operational availability of equipment. Conceptually, the operational availability is defined as the up-time divided by the sum of the up-time and the down-time. Clark suggests that up-time can be measured by the MTBF and the down-time by the sum of the mean-time-to-repair (MTTR) and the mean-supply-response-time (MSRT). The MTTR derivations are also presented in Table 1. The MSRT is calculated as the expected backorders at base "j" divided by the MTBF for base "j".

The results of applying Clark's methodology to this system are presented in Figure 5. This data suggests that a 98 percent operational level cannot be maintained in this system. The MSRT of .6225 days limits the operational availability to 96 percent, or 48 missiles.

A final inventory model applied to this conceptual system is the Logistics Management Institute (LMI) Procurement Model discussed by Demmy and Pressuti. Under the assumption that

[2]See Clark, 1972; Clark and Scarf, 1960; Demmy and Pressuti; and Nahmias.

A : Base Repair Time

Item	Avg.	E(x)
Travel to site	.075	.075
On-Site Inspection	.075	.075
Requisition MGS	.095	.095
MGS Replacement	.430	.430
Return Travel	.075	.075
Base Repair Time	1.250	1.250
Estimated Base Repair Time		2.000

D : Depot Repair Time

Item	Prob	Avg.	E(x)
Major Adjustments	.10	5.0	.500
Repeat Failures	.70	12.0	7.560
New Failures	.07	29.5	2.065
New Failures	.18	17.5	3.150
New with Parts Delay	.02	35.0	.700
Depot Maintenance Time			13.975
Travel to Depot			17.500
Travel to Depot Supply			12.000
Estimated Depot Repair Time			43.475

O_j : Order and Ship Time at Base j 7.500

MTTR : Mean-Time-To-Repair at Squadron

Item	Prob	Avg.	E(x)
Travel to Site	1.00	.075	.0750
Inspect MGS	1.00	.075	.0750
Requisition MGS	.90	.095	.0855
MGS Replacement	.90	.430	.3870
Estimated MTTR			.6225

B(So|λo D) : Expected Backorders at Depot with Stock Level So

$$= \sum_{x>So} (x-So)\ p(x|\lambda o\ D)$$

δ(So)D : Expected Waiting Time per Demand

$$= [\ B(So|\lambda o\ D) * D\ ]\ /\ B(\emptyset|\lambda o\ D)$$

Tj(So) : Expected Lead Time at Base j

$$= rj\ Aj + (1-rj)(Oj + \delta(So)\ D)$$

Bj(So,Sj) : Expected Backorders at Base j

$$= \sum_{x>Sj} (x-Sj)\ p(x|\lambda j\ Tj(So))$$

Table 1. **METRIC** Equations for Calculating Expected Backorders.

all bases are identical, this methodology produces a probability that a randomly selected missile at a randomly determined point in time is not missing any stocked inventory components. With only one component in the inventory system, this derivation reduces to the compliment of the expected backorders at base "j". The results of applying the LMI procurement model are also presented in Figure 5. Since this model does not include the time to inspect and replace defective parts, a 100 percent operational status can be attained.

The theoretical inventory models discussed above may be used to establish stock levels in reparable item inventory systems. However, such models do not consider all relevant aspects of the system under study. Specifically:

a. The theoretical models assume that an infinite number of servers are always available. In the conceptual system, this condition does not exist. There are a limited number of repair crews per squadron (two) and a limited number of

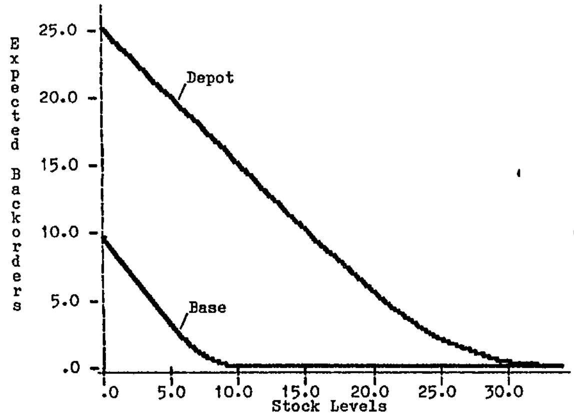

Figure 4. Expected number of backordered missile guidance sets per stock level.

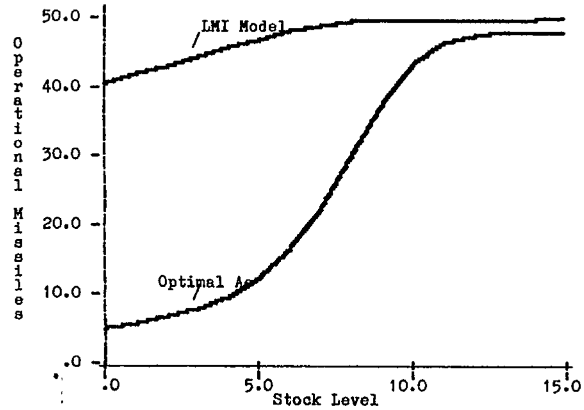

Figure 5. Expected Number of Operation Missiles Per Stock Level Using Optimal Ao and LMI Models.

MGSs that may be concurrently served at the depot maintenance facility (nine).

b. The theoretical models do not allow priorities in the requisition and resupply process. In the conceptual system, priorities are allowed between the depot and base supply facilities. When backorders exist at the depot, repaired MGSs are shipped to the base with the lowest stock level.

These deficiencies in the theoretical models may affect the operational status that can be maintained. In the next section, a network simulation model of the conceptual system will be developed and used to assess the operational status attained using actual stock levels of twelve MGSs per supply facility. The effect of imposing realistic limits on the number of servers and of allowing resupply priorities will also be analyzed.

3. NETWORK SIMULATION MODEL

3.1 Description of the Model

The network simulation model is depicted in Figure 6. The failed MGSs are emulated as transactions that flow through a series of service activities. Resources are used to model operational missiles, squadron maintenance crews, base stock levels of MGSs, depot stock levels of MGSs, and depot service channels. Fifty missile resources are allocated to each squadron, and twelve MGS resources are allocated to each supply facility. Maintenance crew and depot service channel resources are controlled variables.

The missile resource availability at each squadron is used to measure the operational status maintained. If the number of non-operational missiles (NOR) increases above one at any squadron, then the desired 98 percent

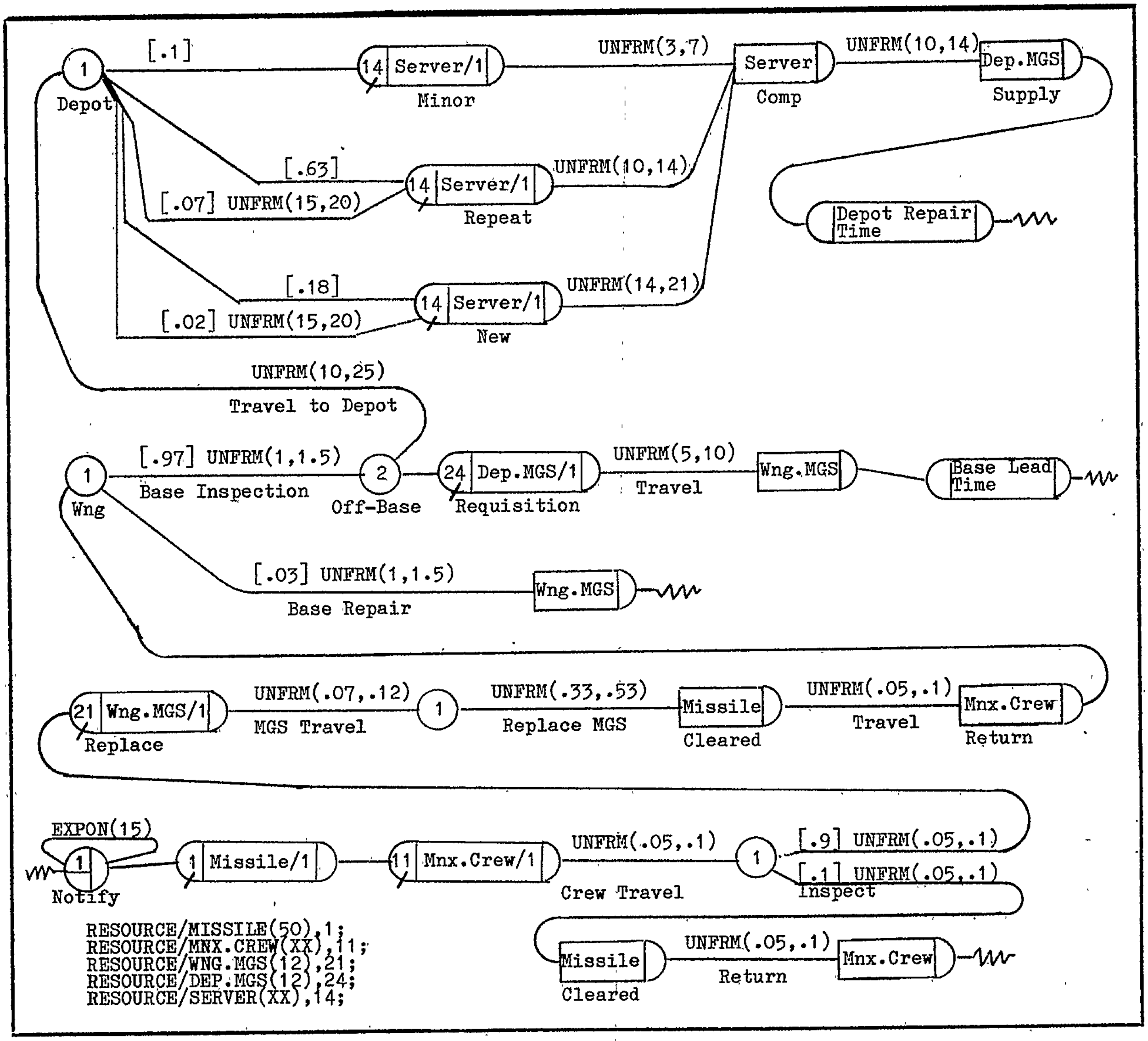

Figure 6. SLAM Network Model of Maintenance Supply and Support System

operational status has not been maintained. Two surrogate measures are used to assess operational status: (a) NOR time, which is the time weighted average of the number of days in which each of the squadrons had less than 49 operational missiles, and (b) NOR count, which is the total number of missiles included in the NOR time.

Other surrogate measures are used to provide insight into the flow of MGSs through the system and to allow comparison of the simulation model to the theoretical models. These include: (a) server wait time, which is the waiting time at the depot for a service channel, (b) depot repair time, which is the average time to repair a failed MGS at the depot and ship it to the depot supply facility, (c) the average waiting time at the depot for requisitioned MGSs to be shipped, (d) the average backorders at depot supply, (e) the MGS stock levels at each base, and (f) base lead time, which is the average lead time for each base to obtain a replacement MGS from depot supply.

3.2 Experimental Design

A randomized block factorial design was used to test the effects of the controlled treatments on the surrogate measures of effectiveness. Three treatments were controlled in the parametric model.

Priorities Priorities were either used or not used in the resupply process between the depot and base supply facilities. It is expected that the use of priorities will reduce the NOR time and base lead times. Altering the resupply process should not affect the depot repair cycle, the number of backorders, or the depot waiting time. The base stock levels will be affected only when one base has a lower stock level than the other bases. Since the bases are expected to have similiar stock levels, the use of priorities should not significantly impact base stock levels. The NOR count will be reduced only in those situations when the NOR status of the missiles is extended due to stockouts at base supply.

Depot Servers The number of MGS that may be concurrently serviced at the depot maintenance facility may be unrestricted or restricted to nine. Restricting the depot servers should increase the number of MGSs queued for depot maintenance, thereby increasing the depot repair cycle. This, in turn, should produce increases in the base lead times, the number of backorders, and the depot waiting time while decreasing the base stock levels. The NOR count should not be affected and the NOR time would increase only if base stockouts increase.

Maintenance Crews The number of maintenance crews assigned to each squadron may be unrestricted or restricted to two crews on duty

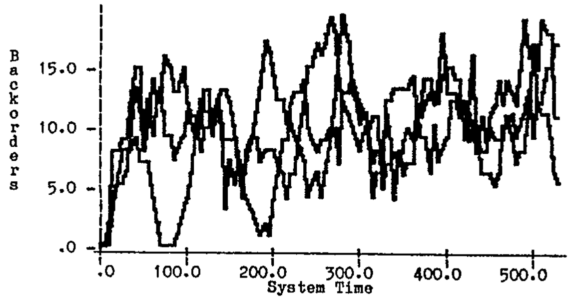

Figure 7. Plot Showing Variation in Measured Backorders Over System Time.

Item	Expected	Measured	Sigma
Depot Repair Time	43.475	43.260	6.3527
Base Repair Time	2.000	2.000	0
MTTR	.623	.646	.1393
P(On-Site Repair)	.100	.073	.0072
P(On-Base Repair)	.030	.029	.0007
Depot Backorders	13.304	12.027	4.0141
Depot Wait Time	21.045	19.921	1.1860
Base Lead Time	29.500	29.601	1.3311

Table 2. Comparison of Expected Values Derived from Theoretical Models to Measured Values Obtained from Network Simulation Model.

at any point in time. Restricting the number of maintenance crews should increase the mean-time-to-repair at the squadron level. This, in turn, should increase the NOR time, depot repair cycle, depot wait time and the number of backorders. Base lead times should also increase resulting in lower base stock levels. The NOR count would be affected only if the above changes result in increased stockouts at the base level.

3.3 Model Verification

Internal verification of the model was performed with the trace option, permitting a step by step analysis of the program. The trace was continued until all branches within the model were taken at least once. External verification was performed by running 500 transactions through the system to check transaction passages through those nodes requiring probabilistic branching. The percentage of total transactions passing through the nodes approximated the probabilities associated with the node.

3.4 Model Validation

Validation of the simulation model was also accomplished. This process involved using constant values equal to the expected durations in lieu of actual distributions. Since the simulation model replicates the theoretical model, similiar results should be obtained. A comparison of the theoretical and simulated results are presented in Table 2. All simulated results were within one standard deviation of the expected theoretical results except for the probability that the defective MGS is repaired on-site. This discrepancy is attributed to the relatively small number of failed MGSs which were generated at each squadron during the validation run.

3.5 Starting Conditions

Starting conditions are especially important since a continuous steady state system is being modeled. It is not reasonable to begin measuring the operational status until the simulation model achieves a steady state condition. Starting conditons were determined by making simulation runs of increasing time durations, with five replications per run, and assessing the stability of the variance in the number of backorders. The number of backorders is sensitive to fluctuations in squadron, base and depot operations. Hence, stability in this measurement is a good indicator of achieving system steady state. The number of backorders from three simulation runs are plotted in Figure 7. These results confirm that relative stability is achieved after 300 time units. Hence, collection of statistical data will be delayed until the simulation model has run 300 days.

3.6 Sample Size

The duration and number of simulation runs was calculated using the sample size derivations presented in Hicks. An initial pilot run was made to obtain an estimate of the variance associated with the NOR time (0.1798) and the NOR count (38.875). Alpha risk was set at five percent and beta risk was set at thirty percent for all calculations. Using these specifications, at least 52 MGSs must be processed through each squadron to be 95 percent confident of detecting a shift of two missiles in the NOR count. With a squadron MTBF of fifteen days, it will require approximately 780 days to model the failure of 52 units at the squadron level. This equates to over two years of simulated activities after the system has attained steady state conditions. Ten replications of each simulation run must be performed to be 95 percent confident that a deviation in the NOR time of 0.25 will be detected as statistically significant in the randomized block factorial model.

3.7 Variance Reduction Techniques

Common random number streams were used for each combination of treatment levels (blocks). A different seed was applied to each of the random number streams used across all replications within each block. Across blocks, the same seeds for the random number streams were used. The application of common random number streams across blocks should reduce the total variance for each surrogate measure.

To further reduce variation in the simulation model, a separate random number stream was used to generate durations within each squadron. This produces the same sequence of MGS failures across the blocks for each of the ten replications. Comparisons across the blocks are enhanced by limiting the source of variation to treatment effects.

4. ANALYSIS OF RESULTS

The results of the network simulation model were analyzed using multivariate analysis of variance (MANOVA). Bartlett's test for homogeneity of variance indicates that the variance due to experimental error within each treatment population is homogeneous. It is also assumed that the errors are normally distributed for each treatment population.

A three-way MANOVA model was applied to the surrogate measures of effectiveness. Each of the three base lead times and base stock levels were tested jointly to determine if the treatments had similiar effects on all three of the independent measurements. All measurements were tested both separately and jointly to determine overall treatment effects. The results of the MANOVA are presented in Table 3. Table 4 standardizes the averaged measurements within each block, and provides the overall average and standard deviation for each surrogate measure of effectiveness. Table 3 provides the statistical significance of trends in the data resulting from each treatment effect, while Table 4 provides an indication of the direction of the trends. Each hypothesis test listed in Table 3 will be discussed below.

4.1 Effect of Depot Priority

Allowing the use of priorities between depot and base supply facilities should reduce the occurrence of stockouts at the base level. This treatment will only have an effect during cyclic periods of high demand at a particular base. The possibility that all three bases experience high demand simultaneously is low. The results presented in Table 3 indicate that only NOR time and base lead time are significantly affected by

Surrogate Measures of Effectiveness	Ho: No Effect from Treatments			Ho: No Interaction Between Treatments			
	Depot Priority	Depot Servers	Maint. Crews	Priority by Servers	Priority by Mnx Crew	Servers by Mnx Crew	Priority by Servers by Mnx Crew
NOR Time	Reject	Not Rej.	Not Rej.	Reject	Reject	Not Rej.	Not Rej.
NOR Count	Not Rej.	Not Rej.	Not Rej.	Not Rej.	Reject	Reject	Reject
Server Wait Time	Not Rej.	Not Rej.	Reject	Not Rej.	Not Rej.	Not Rej.	Not Rej.
Depot Repair Time	Not Rej.	Reject	Reject	Not Rej.	Reject	Reject	Reject
Depot Wait Time	Not Rej.	Reject	Reject	Not Rej.	Reject	Reject	Reject
Depot Backorders	Not Rej.	Reject	Reject **	Not Rej.	Reject	Reject	Reject
Base Lead Time	Reject	Reject	Not Rej.	Not Rej.	Reject	Reject	Reject
Base Stock Levels	Not Rej.	Reject	Not Rej.	Not Rej.	Reject	Reject	Reject
Joint Effect	Reject	Reject	Not Rej.	Not Rej.	Reject	Reject	Reject

Reject at p=.05
** - Reject at p=.10

Table 3. Statistical Significance of Treatments on Surrograte Measures of Effectiveness

Priorities	Not Used				Used				Overall Average	Std. Dev.
Depot Servers . . .	∞		9		∞		9			
Maintenance Crews.	∞	2	∞	2	∞	2	∞	2		
Surrogate Measures of Effectiveness										
NOR Time	.005	.005	1.033	.531	-.380	-.380	-.408	-.415	.532	.424
NOR Count	-.203	-.203	.669	.441	-.190	-.190	-.350	.025	28.513	7.456
Server Waiting Time	-.875	-.875	1.146	.839	-.875	-.875	.789	.719	.414	.473
Depot Repair Time	-.686	-.686	1.197	.593	-.756	-.756	.822	.255	43.925	.636
Depot Wait Time	-.558	-.588	.795	.367	-.281	-.281	.158	.359	20.547	1.117
Depot Backorders	-.484	-.484	.595	.247	-.104	-.104	-.029	.370	10.955	.955
Base Lead Time	.238	.238	.807	.521	-.607	-.607	-.177	-.414	29.118	2.621
Base Stock Level	.548	.548	-.361	-.295	-.043	-.043	-.025	-.323	6.760	.440

Table 4. Standardized Measurements Within Each Treatment Block

allowing the use of priorities. NOR time would be reduced since the likelihood of stockouts are reduced. Base lead time is reduced during periods of high demand, and the aggregrate effect of this reduction is significant.

4.2 Effect of Restricting Depot Servers

Limiting the number of concurrent parallel servers at the depot maintenance facility increases the waiting time for servers at the depot. As a result, the depot repair time is increased, thereby increasing the depot waiting time and depot backorders. This, in turn, increases the lead time for satisfying base requisitions resulting in lower base stock levels. Lower base stock levels increase the occurrence of stockouts.

The NOR time and NOR count will only be affected during stockouts at the base supply facility. Restricting depot servers should increase the likelihood that stockouts will occur. Plots of base stock levels over a 200 day period are presented in Figure 8. This data verifys that stockouts do occur when depot servers are restricted. However, the aggregrate effect of base stockouts on NOR time and NOR count is not significant.

4.3 Effect of Limiting Maintenance Crews

Restricting the number of maintenance crews available at the squadron level should increase the amount of time required to service missiles when more than two MGSs malfunction simultaneously. Within the modeled system, this occurs only when base stockouts cause a delay in the MGS replacement time. In these situations, the mean-time-to-repair (MTTR) should increase. Increasing MTTR delays the transfer of failed MGSs to the depot. Since it takes longer for failed MGSs to arrive at the depot, the queue for depot servers is decreased, thereby decreasing the depot server waiting time. As a result, the depot repair time is decreased.

The waiting time to satisfy base requisitions at depot supply also appears reduced. An increase in MTTR delays the submissions of requisitions, which reduces the number of backorders and the delay in satisfying backorders. Since total system time from MGS failure to satisfying base requisitions remains constant, increasing MTTR produces a reduction in both the depot waiting time and base lead time. The reductions in base lead time were not statistically significant. Since restricting the number of maintenance crews did not significantly descrease the base stock levels, the NOR count should not increase (NOR count is only affected by stockouts at the base level).

4.4 Effect of Priority by Depot Server Interaction

Significant changes occur in the trends of NOR time from the combined effect of using priorities and limiting depot servers. When priorities are not used, restricting depot servers causes an increase in base stockouts and a subsequent increase in NOR time. When priorities are used, the likelihood of base stockouts are reduced thereby causing a decrease in NOR time. Reference to Figure 8 confirms that the use of priorities reduces the likelihood of stockouts.

4.5 Effect of Priority by Maintenance Crew Interaction

The combined effect of using priorities and restricting the number of maintenance crews causes significant changes in the trends for all surrogate measures, except waiting time for depot servers. Table 4 reveals that the maintenance crew treatment has no effect when the number of depot servers remains unrestricted. The significance of this treatment is attributed to

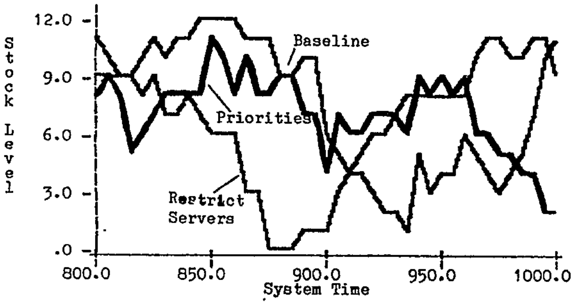

Figure 8. Plot of Base Stock Levels Varying Priority and Depot Server Treatment Levels.

the changes in trends when depot servers are restricted. When priorities are not used, restricting maintenance crews increases the MTTR. As discussed in section 4.3 above, increasing MTTR delays arrivals of MGSs to the depot which subsequentially decreases the queue for depot servers, the waiting time for depot servers, the depot repair time, the waiting time from delayed submission of requisitions to satisfying requests, and the base lead time for spares. When priorities are used, the same sequence of events decreases the depot repair time. However, since priority is given to filling requisitions from bases with the lowest stock levels, the lower priority requisitions spend additional time waiting to be filled. Base lead time decreases since the lower priority requisitions remain in backorders status and are not filled. Hence, the lead time statistic is downward biased. Base stock levels decrease as a result of increased backorders.

4.6 Effect of Depot Server by Maintenance Crew Interaction

When depot servers are not restricted, there is no change across the maintenance crew treatment. When depot servers are restricted, restricting maintenance crews produces different trends across the two priority levels -- that is, a significant three-way interaction occurs. Averaging the effect of changing priority levels still produces a significant trend in all measures except NOR time and server wait time.[3]

4.7 Three-Way Interaction Effect

The three-way interaction effect is discussed in section 4.6.

5 CONCLUSIONS AND RECOMMENDATIONS

This analysis indicates that within the modeled multi-echelon inventory system, squadrons drop into a NOR status approximately 13.43 (+ 7.0) times per year. The average duration of this NOR status is 8.5 hours (+ 7.4).[4] Thus, operational status is maintained, on average, for 78,726 of the 78,840 available hours per year. This suggests that the 96 percent limitation of operational status derived from the optimal A_o inventory model is quite conservative. In fact, the goal of maintaining 98 percent of all squadron missiles in an operational status is achieved 99.86 percent of the time.

The major cause of the NOR status appears to be the MTTR at the squadron level. Note that the MTTR would be decreased by over 2 hours, on average, if the maintenance crews could carry the spare MGSs when they are dispatched to inspect a malfunctioning missile. The network simulation model was modified to eliminate separate MGS travel. The travel time for the maintenance crew was increased to account for the additional time needed to pick up the MGS prior to departing for the missile site. The operational system was simulated, meaning that priorities at the depot were allowed and that both depot servers and maintenance crews were restricted in number. Ten replications of this revised model produced an average NOR time of 7.85 hours and an average NOR count of 12.22 missiles per year. The total NOR time for a year was reduced from 114.16 hours to 95.93 hours per year by eliminating separate travel for the replacement MGSs.

To confirm that increasing the MGS stock levels has little effect on NOR status, both the basic and revised (eliminating separate MGS travel) were executed with fourteen MGSs per supply facility. This produced total NOR times of 107.87 and 88.87, respectively. Eliminating separate MGS travel and increasing MGS stock levels to 14 produces an average NOR count of 11.39 and NOR time of 7.81. Hence, the system appears relatively insensitive to increases in the MGS stock levels.

The network simulation model could be extended by adding cost data, and comparing alternatives of stocking additional MGSs, adding additional servers at the depot repair facility, or increasing the number of maintenance crews. These extensions were not performed due to the non-availability of cost data.

In summary, this paper has demonstrated the use of a network simulation model to evaluate a multi-echelon inventory system. Theoretical models do offer a good starting point for evaluating such systems. However, they do not provide a detailed analysis of the operations which occur within the system. The use of a simulation model does provide this form of analysis to the decision maker, offering insights into the synergistic effects of varying system parameters. Also, the simulation model may be extended to evaluate expected changes in system performance from the introduction of new policies.

[3]The two-way interaction between depot servers and maintenance crews is analyzed by collapsing the data in Table 4 around the priority treatment -- averaging the four cells across the two priority levels.

[4]95 percent confidence intervals.

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