ASSESSMENT OF SERVER LOCATION ON SYSTEM AVAILABILITY BY COMPUTER SIMULATION

by

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The author dedicates this book to the memory of his father, Gerd F. Weissmann.

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I. INTRODUCTION

An important characteristic of all systems is availability. Availability is the probability that a system or piece of equipment will operate in a prescribed manner when used under specified conditions. It is primarily a design dependent parameter.

Availability derives from a systems reliability and maintainability. Reliability is the probability that a system will operate for a specified time under specified operating conditions. It is commonly measured by the mean-time-between-failure (MTBF). Maintainability is the ability of an system to be maintained. For this report, maintainability is measured by the mean maintenance down time (MDT).[1]

The MDT is a function of several variables, including the mean-time-to-repair (MTTR) and Logistics Delay Time (LDT). MTTR is the time that active maintenance is being performed. The LDT is the time delay due to spare part availability, transportation, repair facility availability, traveling to the location of the malfunction, etc. LDT is a major portion of the MDT.[2]

In order to meet a requirement of improved system availability, the MTBF and/or the MDT must be improved. Decreasing the distance between the repair organization and the location of the failure may have a significant impact on LDT, assuming that the system's LDT is positively correlated to the distance traveled. An improvement in the LDT corresponds to an improvement in the MDT, hence the availability. For a situation where the repair function (referred to as the repair unit) travels to the location of the failed component, the deployment location may have a critical impact on a system's availability.

In a system where the operating components are located over a wide area and the repair organization must travel to the component to effect a repair, there are numerous ways to deploy the servicing units. The systems maintenance concept addresses this issue. The deployment of the repair units is the central focus of this report.

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[1] Blanchard, Benjamin S., *Logistics Engineering and Management*, 4th Edition, Prentice Hall, Englewood Cliffs, NJ, 1992

[2] Blanchard, Benjamin S. and Fabrycky, Wolter J., *Systems Engineering and Analysis*, 2nd Edition, Prentice Hall, Englewood Cliffs, NJ, 1990

The system considered in this report uses a two-level maintenance concept. The repair servers of the system are located at dispatch centers. From these centers they are dispatched to a system component upon its failure. A failed component cannot be repaired at the organizational level, it requires a repair unit. The distance needed to travel to the component comprises the LDT in this report. Different configurations for the location and number of servers assigned to each dispatch centers will be examined to estimate the effect on system availability.

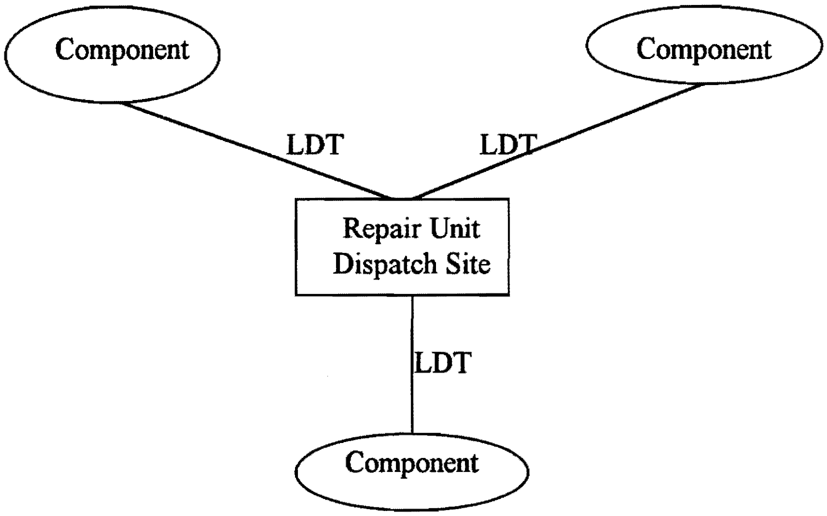

Figure 1-1 Basic System Concept

Repair units are not limited in any traveling distance, even with multiple dispatch locations. The nearest idle repair unit (one that is at a dispatch site) is dispatched to the location of the failed component. If there are no idle repair units then the nearest unit traveling back to its dispatch site is diverted to the location of the failure. In this report, a failure refers to a component in the system that has malfunction.

Different configurations for the home location of the repair units will have different mean distance between the repair server and the system's components. Assuming that LDT is positively correlated with the distance traveled by the repairer units, the smaller the mean distance required for a server to transit, the smaller the LDT. This translates into an improvement in the MDT and hence, the availability.

It is conjectured that the expected improvements in a systems performance will not be realized. Randomness in the performance of components, both failure rates and repair rates, may negate the effects of reducing the mean distance between repair units and components.

The reason for the conjectured lack of improvement is due to some service areas having more failures that other areas. This situation requires that repair units from other areas travel longer distances than if all servers were dispatched from a centralized location. An indication of this occurring in a system would be a large variance for the distance travel by a repair server.

This behavior in the system emphasizes the importance of considering the distribution of input factors on system performance. Mean values of systems characteristics do not provide a good indication of how the characteristic is behaving. The variance is an importance descriptor of a distribution's properties.

By using the variance, a better description is obtained of a system characteristic. A mean value for performance data does not indicate the range of values or its grouping. The variance of the mean identifies whether the values are about equal or are very different from one value to the next.

Because of the many interactions of various components, the use of analytic engineering methods is very difficult and may produce arguable results.[3] For many complex systems, analytic solutions are not possible, or are impractical to solve. Most analytic methods to queuing type problems usually require ambiguous assumptions, such as exponential behavior in time between arrivals and servicing times. Accordingly, a computer simulation was developed and its results compared with results from analytic models.

Computer simulation models yield an estimate of the system's actual characteristics. Deterministic models result in exact solutions.[4] Computer simulation models may be developed to study complex designs that cannot be solve by analytic methods.

Another reason for the preference for simulation methods over analytic methods is the ability of simulation to adapt to different distributions of parameters. The use of distributions as oppose to

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[3] Law, Averill M. and Kelton, W. David, *Simulation Modeling and Analysis*, 2nd Edition, McGraw Hill, Inc., New York, NY, 1991

[4] Ib. Id.

just mean values (as in *mean*-time-between-failure, *mean*-time-to-repair, etc.) is the consideration of the effect of variance on inputs and responses. An example of the importance of variance is given by Law and Kelton (pg. 293)[5]

> Consider a manufacturing system consisting of a single machine tool. Suppose that parts arrive to the machine with an exponential mean of one minute and that processing times are exponentially distributes with a mean of 0.99 minutes. Thus the system is a M/M/1 queue with utilization factor of ρ=0.99. Further more it can be shown that the average delay in queue of a part in the long run is 98.01 minutes. If we replace each distribution by its corresponding mean (i.e., if customers arrive at times 1 minute, 2 minutes...and each part has a processing time of exactly 0.99 minutes), then no part is ever delayed in the queue. In general, the variances as well as the means of the input distribution determine the output measures for queuing type systems.

This report will examine the effects on system availability of different configurations of dispersed servers, where the time required for a server to get to a component is a significant portion of the total repair time. The objective is to compare the availability forecast by computer simulations and analytic predictions. Four different server dispatch configurations will be tested.

The system under consideration is a generic and hypothetical system that does not accurately reflect a particular "real world " system, but has characteristics that may be used by many existing systems. It could be applicable to a service organization like police or cable installation in a municipal setting or to a system where the components are deployed worldwide. The basic concept is that the server must travel to the location where a component has failed. What will the impact on availability be by adjusting the location from which a server begins a servicing operation? Do analytic and simulation analysis concur?

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[5] Ib. Id.

II. OBJECTIVE AND METHODOLOGY

An evaluation of how the disposition of repair units would effect a systems availability is performed. Demonstration of sensitivity of system availability to different parameter distributions and variable Logistic Delay Time (LDT) is evaluated.

2.1 Objective

The objective of this experiment is to compare the system availability for different configurations of dispersed server dispatch locations. Changes in the systems maintainability will be effected by the different configurations. Evaluation of the changes in availability due to alterations in maintainability will be performed.

The system under analysis is a general system consisting of 144 identical components with a repair organization of sixteen servicing channels. The system and its components are assumed to be in continuous operation.

2.2 Terminology

For this report the following definitions apply. While some have broader context in systems engineering, they are limited here to improve description of this project.

- Availability : the probability that a system will be functioning when called upon.[6] For this project the system will be assumed to be on call at all times. For this report, availability is measured as the percentage of time that the system has a specified number of functioning components.
- LDT : Logistics Delay Time - time required for a repair units to travel to the location of a failure and return.
- MTTR : Mean-Time-To-Repair - refers to actual time of on site time repairing the failure
- MDT : Mean Maintenance-Down-Time - total time that component is out of service; consists of MTTR and LDT
- Length : Distance between two nodes
- Dispersal : Used to describe configuration of server dispatch locations
- Server : Organization element that accomplishes a repair action

[6] Blanchard, Benjamin S., *Logistics Engineering and Management*, 4th Edition, Prentice Hall, Englewood Cliffs, NJ, 1992

2.3 Assumptions

Several assumptions were made to simplify the problem:

- No administrative or other delays
- Instant detection of failures
- Continuous server operation
- All failures are repairable by one server

2.4 Experiment Description

A computer simulation was developed to model a system of widely spread components. The simulation examines the effects of different dispersal situations on system availability. The mean reliability of the components comprising the system is held constant. Thus, the major factor effecting the availability is the maintainability of the system's components.

The system under consideration consists of a population of 144 identical components uniformly distributed across a service area. There are sixteen identical servers available to repair components as they fail. Four different dispersal configurations are selected that gave each dispatch location an equal number of servers assigned. The configurations were for one, two, four, and sixteen dispatch sites. The site locations were established to minimized the mean distance from site to the components location in a servers' specified zone.

For conceptual and programming purposes, the system resembles an urban area as in Figure 2.1. It is a 12 by 12 grid. Each node in the grid represents a component in the system. Dispatch locations are also located at a node. Travel of the server is on the x and y axis on the lines connecting the nodes.

Once a component has failed, a server is dispatched from the nearest dispatch site to perform a repair action. Upon completion of the repair action, the server proceeds to any failed component that does not have a server assigned. If there are no other failed components, the server starts its return to its home dispatch location.

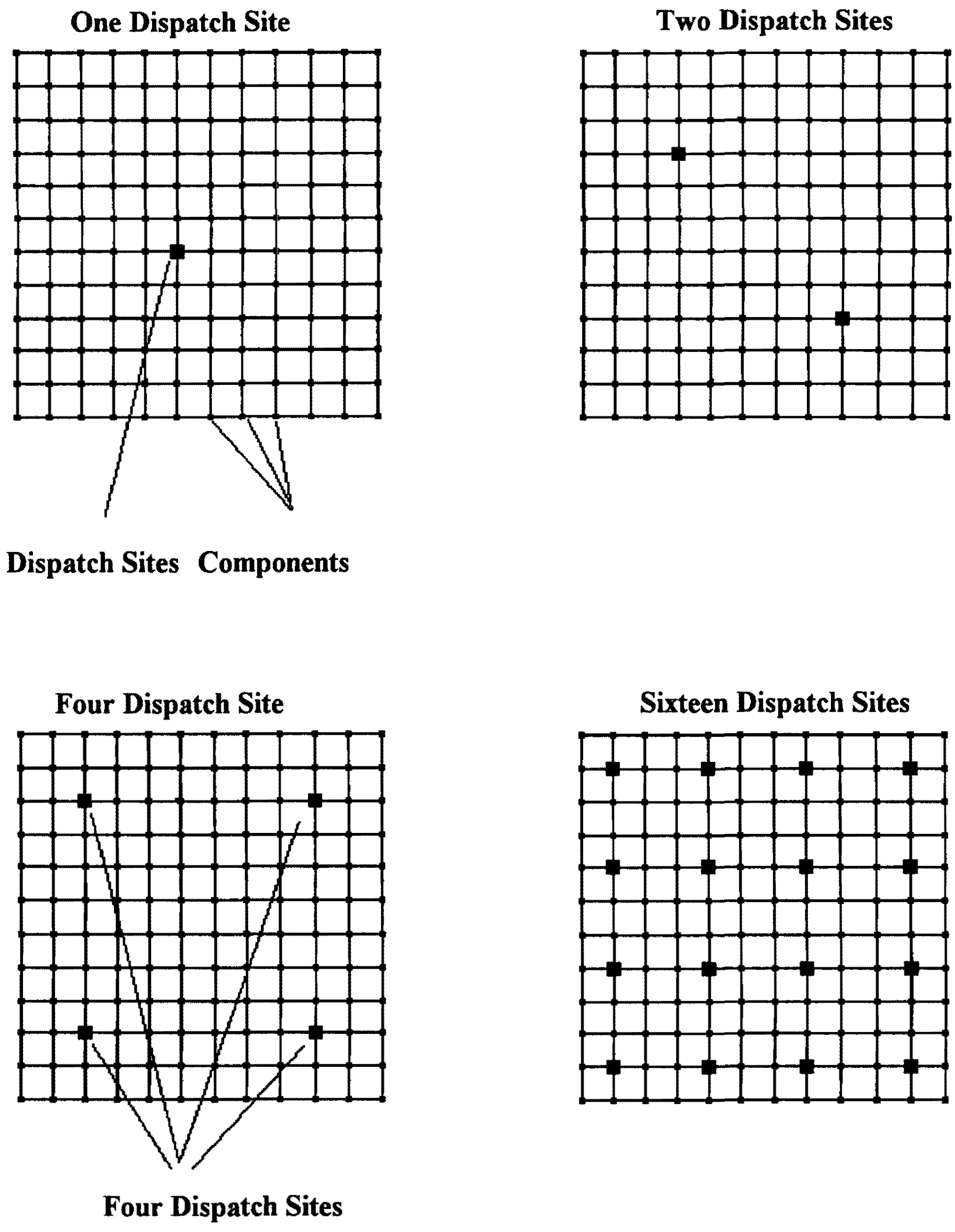


Figure 2.1 - System Conceptual Design

A server is not required to return to the dispatch site. It is assumed that the server has an unlimited supply of all material and equipment needed to complete a repair action. No breakdowns or downtime are incurred by a server. They may remain in continuous operation. Once a particular server is assigned to a failed component, it is not diverted or replaced, even if a much closer server becomes available. A server may be diverted on its return to the dispatch site at a node, not while it is traveling between nodes.

Essentially this system could be modeled as a basic queuing system with sixteen servers. The MDT is a function of LDT and the MTTR. The time to repair is exponentially distributed, with constant mean. The LDT is an exponential distribution with a mean that is dependent upon the distance on the customers' (components) and the servers location. If a queue starts to form, the mean repair time is also effected, the distance the server must travel is dependent on both the current and previous location of failed components.

If more than sixteen components are not functional at one time, the system is said to be unavailable. Sixteen was selected as the threshold of unavailability and is an arbitrary figure. If more than sixteen components are failed at one time, the system is inoperative or unavailable. Regardless of the systems status, all operational components continue to operate until failure.

The system has a first-in-first-out queue function for failed components. The first component in the queue is assigned the first server available, even if another server completes a repair and is closer to the failed component.

There are two parameters to be considered in the system: reliability and maintainability. Maintainability consists of the on site MTTR and the LDT. The reliability is measured by the MTBF. There are three items that are random variables: MTTR, LDT and MTBF.

For a baseline configuration, the mean time to travel between one node was one time unit (TU). The mean repair time (time at the failure location) was set at 24 TUs. For a single, centralized dispatch site, the mean distance of a component from the site was six. This equates to a mean LDT of six TUs. The total MDT = LDT + MTTR = 24 + 6 = 30 TUs. The individual components set at mean MTBF was 400 TUs for all configurations. The base case was modeled by sampling exponential distributions only.

Additional experiments were performed with different random variable distributions . The time-between-failures was sampled from a lognormal distribution[7]. Its mean remained the same at 400 TU. It had a variance of 200. The LDT remained exponentially distributed with a mean of one. The MTTR was an Erlang random variable with a shape parameter of two.

The simulation is allowed to run for an initial warm-up phase before statistical data was recorded. This eliminates the bias caused by all the servers starting from their dispatch sites. After the warm-up period, many servers are sent directly from one failure to another.

The sensitivity of the system was tested by varying the MTTR. For each of the four dispersal configurations, the MTTR was varied between 12 and 45 TUs, using 3 TU increments. A total of 12 different mean repair times were used. This results in 48 data points. Each data point was sampled twenty five times. This was done in order to reduce the variance in the sampling.

Additional sensitivity testing was done by varying the LDT mean. The mean to travel between nodes was incremented from 0.5 to 3.25 in 0.25 increments. The Repair Time mean was set at 24 TUs for this experiment.

Seven system characteristics were monitored in the experiment; component system MDT, system MTBF, system availability, server utilization, distance traveled to failure, LDT, and component MDT.

2.5 Analytic Calculations for the MTTR

The mean distance of a dispatch site to a component is measured from the nearest dispatch site.

Assumptions

MTBF = LDT = 1 TU/length
MTTR = 24 TU
400 TU

[7] *AT&T Reliability Manual*, 1983, Bell Systems Information Publication IP 10475

The Repairable Equipment Population System (REPS) was used for analytic calculations to compare with the simulation output. For the calculations, λ was the inverse of the repair time plus the mean distance from dispatch site to the component times the LDT.[8]

For the single dispatch site with mean distance equal to six lengths:

$$\lambda = MTTR + 6 * LDT$$
$$\lambda = 24. \ + \ 6. = 30.$$

For the two dispatch sites with mean distance equal to 4.82 lengths:

$$\lambda = MTTR + 4.8 * LDT$$
$$\lambda = 24. \ + \ 4.8 = 28.8$$

For the four dispatch sites with mean distance equal to 3 lengths:

$$\lambda = MTTR + 3. * LDT$$
$$\lambda = 24. \ + \ 3. = 27.$$

For the sixteen dispatch sites with mean distance equal to 1.3 lengths:

$$\lambda = MTTR + 1.3 * LDT$$
$$\lambda = 24. \ + \ 1.33 = 25.3$$

2.6 Experiment Procedure

Significant differences between analytic and simulation predictions of system availability occurs at relatively high server utilization rates. The selection of the experimental means was driven by the desire to force this situation. At low utilization rates, servers would always be available from the closes dispatch site. The shorter distance to travel would reduce the LDT and hence the MDT. This would correspond into improved availability.

[8] Fabrycky, Wolter J. and Blanchard, Benjamin S., *Life-Cycle Costs and Economic Analysis*, Prentice Hall, Inc., Englewood Cliffs, NJ, 1991

Verification and validation of the model was performed to the extent possible. Since the simulation modeled a nonexistent system. No validation was possible.

The mean distance for a server to travel from a central dispatch site was calculated as six. The simulation was run with very high MTBF of the components. This resulted in a very low server utilization rate. With a server always available for dispatch , the distance traveled output would result in approximately six lengths. This matched the simulation results within statistically significant tolerances. Tests were performed on four and sixteen site configurations, with positive results.

In order to evaluate the diversion of returning servers to failures, write statements were inserted in the appropriate algorithms. When a diversion occurred, listings of the locations of the servers were outputted. This output showed that the algorithms were performing as desired.

In order to verify that repair servers were sent from the nearest dispatch site with an available server, output was obtained by verification methods similar to the diversion testing methods.

This method would not be sufficient for validation of real world simulations. The methods used for verification in this report is satisfactory because this is a relatively simple, straight forward simulation.

Standard statistical methods were used to analyze the output. The differences in the availability compared one dispatch site against the three dispersed dispatch site configurations. The sample size was sufficiently for valid assumption of the Central Limit Theorem. Statistical testing was a two tailed, t-distribution test. An α-level of 0.05 was used.

MathCad was used to perform REPS and the statistical calculations.

III. COMPUTER SIMULATION

A computer simulation model was developed to evaluate the effect of server dispersal on system availability.

3.1 Simulation Software

The simulation was developed using Simulation Language for Alternative Modeling (SLAM). It was selected due to the author's familiarity with it, its availability in PC and mainframe computer systems and its ability to accomplish the desired simulation.

The original model was developed on SLAMSYS for PCs, however it soon outgrew the limitations and was transferred to the Virginia Tech mainframe. The mainframe version lacks the Windows graphic capabilities and forces the programmer to increasingly rely on user-defined inserts. These inserts are written in FORTRAN and make use of numerous SLAM subroutines. The final version of the model relies heavily on the user inserts, except for creation of entities and scheduling of events. This is done in the network portion of SLAM. The SLAM and FORTRAN code is in APPENDIX 1.

3.2 Program Description

The simulation program developed modeled both the components and servers using entities. Each entity consisted of 10 attributes. These attributes stored the following values:

Attribute 1 : time
Attribute 2 : component ID
Attribute 3 : x coordinate of component
Attribute 4 : y coordinate of component
Attribute 5 : current x position of server
Attribute 6 : current y position of server
Attribute 7 : x coordinate of dispatch site
Attribute 8 : y coordinate of dispatch site
Attribute 9 : server ID
Attribute 10 : Distance from current location to failed component

When a component failed, a file of idle servers was searched. The nearest server was selected and it entered a traveling procedure utilizing Attributes 3-6. If there were no idle servers, a search was made for any servers returning from a repair operation. If available, the closest available one was identified and the failed component is placed in a file until its server is diverted. If there were no servers available, the component was placed in a waiting file.

When a repair action was completed, the component's next failure time was sampled from the MTBF distribution. The server searches the waiting file for failed components. If one was found, the Attributes with the components location and ID are copied into the servers attributes. It then begins a repair cycle. If there are no failed components waiting for a server to become available, it loads its ID and current location (held in its Attributes 5 and 6) and starts the trip to go its home dispatch site.

Every time a returning server reaches a node, it checks to see if it is to divert to a failed component, if it is not required at a failure, it updates its current location and proceeds to the next node. Travel occurs in an x then y then x axis manner. When the server reaches its home dispatch site, it is placed in an idle server file.

Figure 3.1 is the flow chart of the simulation.

3.3 Operation and Verification

Checks were performed to ensure that a steady state condition was achieved in the simulation. Response variables were sampled at short intervals for multiple runs and different configurations. Results indicated that the system had achieved a relatively stable condition after 500 TUs.

Additionally, the initial failure times for the components were generated from exponential, Erlang and uniform distributions. This was done to see that no cycle in the component failures was induced by the initial system conditions. The output from the different runs showed no significant difference in the response variables. This indicates that the system has warmed-up. The bias caused by the initial start-up period has been reduced.

Each of the 48 different configurations was run for 125,000 TUs. Sampling was performed every 5000 TU and the statistical arrays were cleared every 2500 TU. This resulted in 25 sampling operations per configuration.

Output was written to a separate file for use by MathCad.

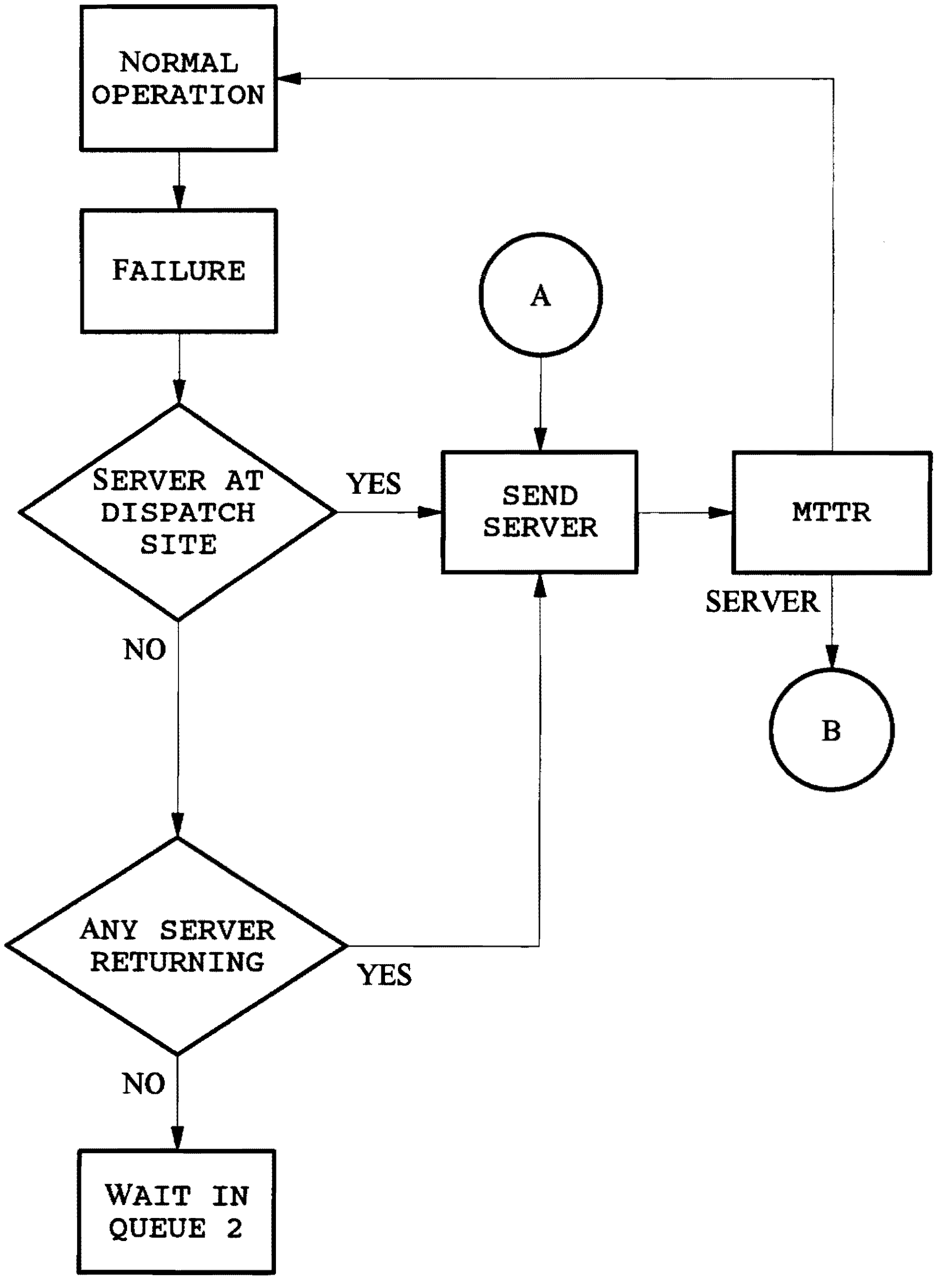


Figure 3.1a : Logic Flow Chart

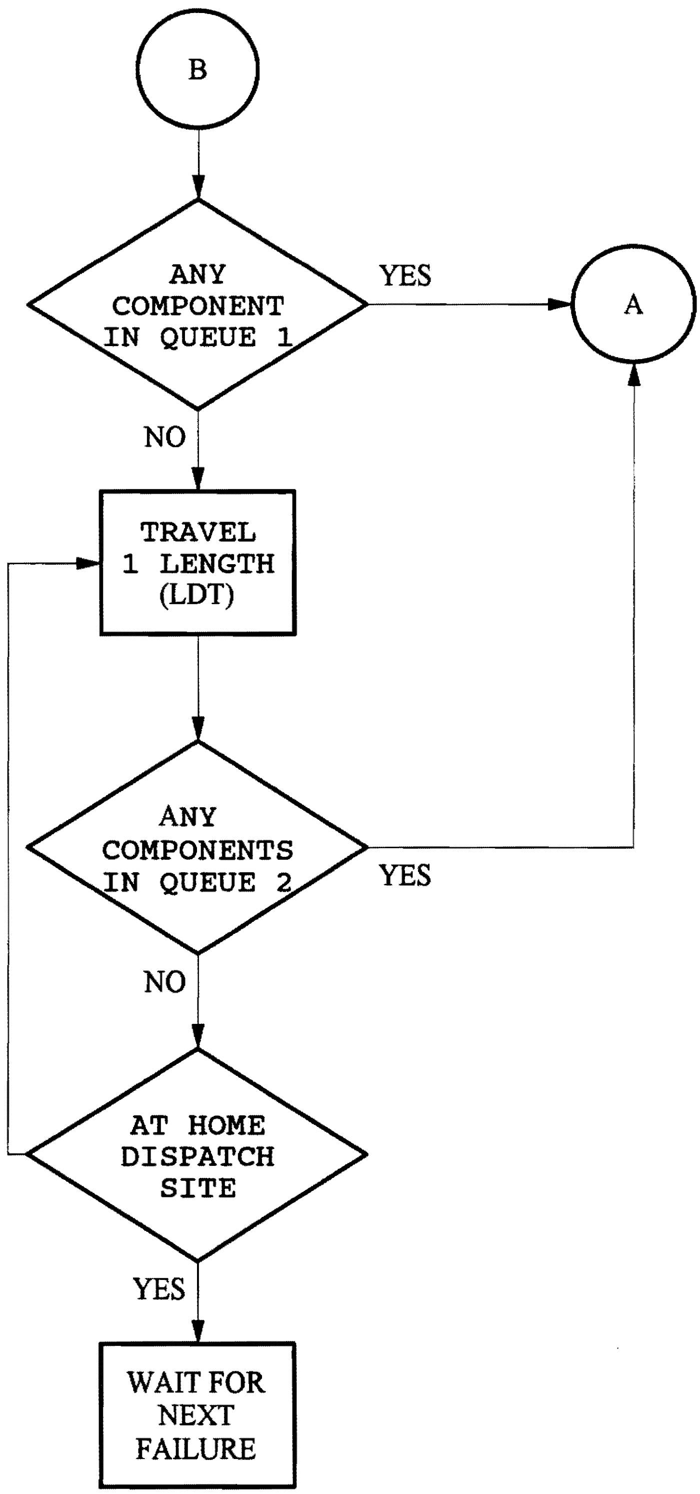


Figure 3.1b - Logic Flow Chart

IV. EXPERIMENTAL RESULTS AND ANALYSIS

The experimental data did not conclusively support the contention that dispersal of server dispatch sites would have detrimental effect on system availability. The results gave some evidence of improved availability by using dispersed server dispatch sites. The most important result was the lack of improvement in system availability for all the dispersed configurations. The system availability was significantly effected by varying the MTTR, varying the LDT and using different MTTR and MTBF distributions.

4.1 Base Case

The base case did not indicate any significant change in availability for pair-wise comparisons of the means for each dispatch site configuration with the same MTTR distribution. Figure 4.1 This figure is shown to emphasis the lack of significant change in system availability.

Only one data point had significant increase in availability. This was for sixteen dispatch sites and a mean repair time of 24 TU. Twelve different mean repair times for each of three pair wise combinations, 36 total comparisons, resulted in only one significant difference. Increasing the level to 0.20 only yielded three additional points of increased availability. Decreasing the α level to 0.025 resulted in no data points of change in the availability. The threshold selection of sixteen, results in availability 100% when the mean repair times is less than 18 TU.

Systems availability was sensitive to the changes in the mean repair time, not the dispersal of servers throughout the system. The plot of system availability in Figure 4.2 has relatively horizontal lines. This indicates that availability is sensitive to changes in mean repair time, not dispatch site configuration. The change in shade on the y-axis shows the change in availability with changing mean repair times.

Variance for the availability increases with the repair time as shown on Figure 4.3. The increase indicates chaos in the system. For repair times of 30 and greater, the variance is large enough to reduce confidence in conclusions drawn. The variance does not appear to vary widely for different configurations.

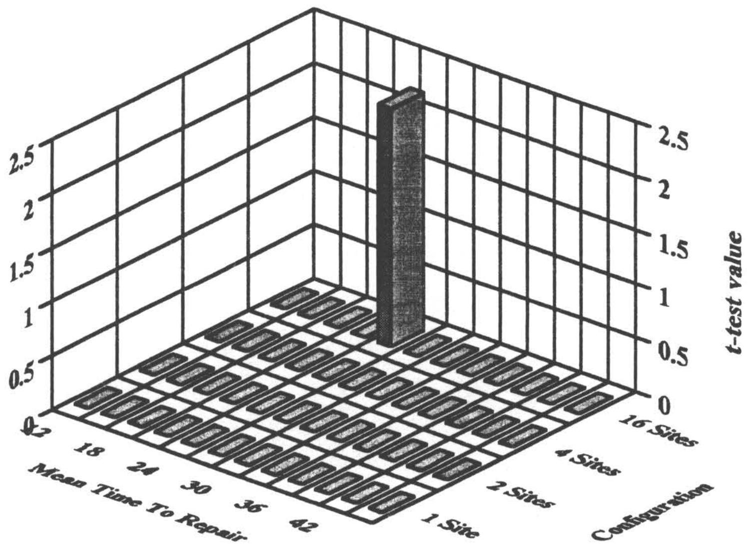


Figure 4.1 - Significant Differences in Availability

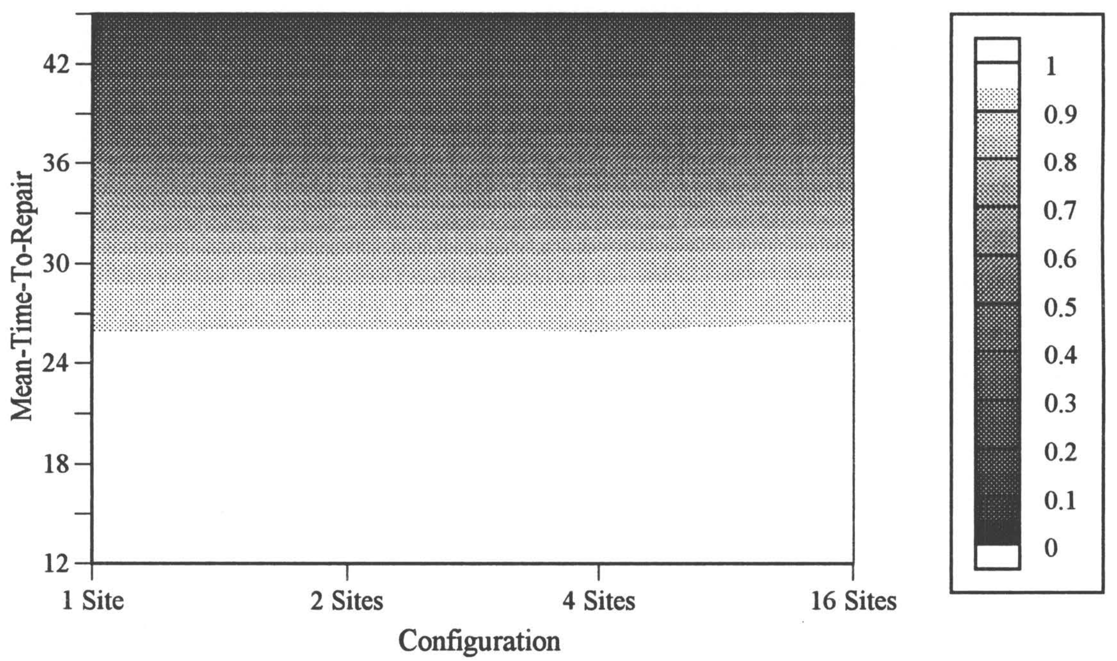


Figure 4.2 - System Availability : Base Case

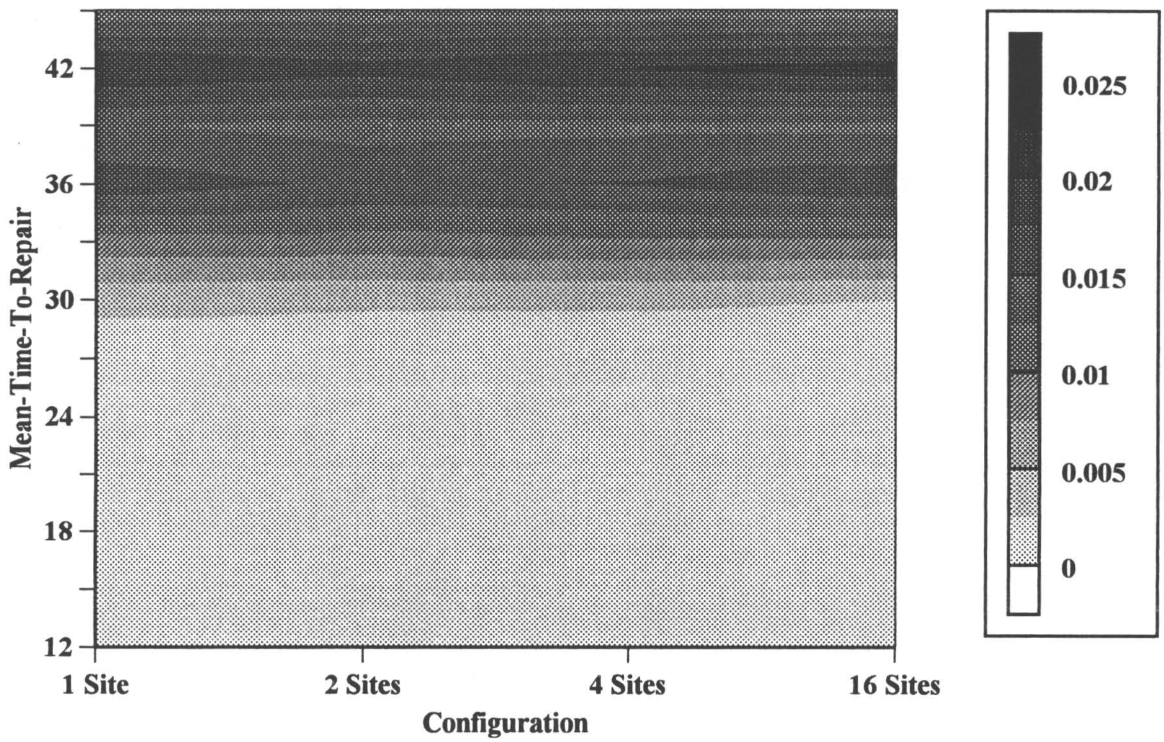
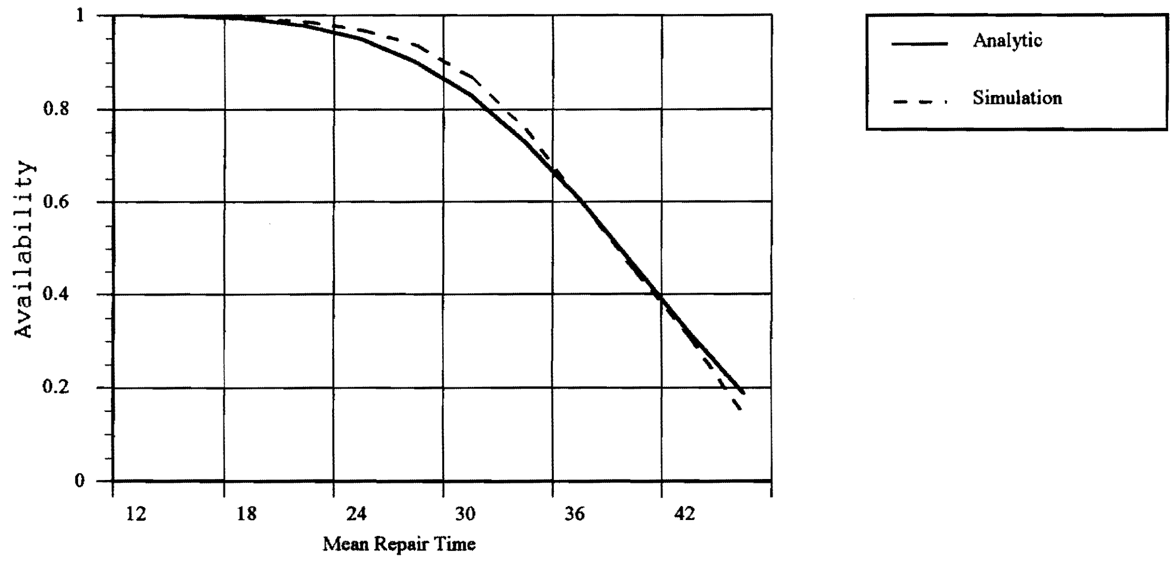


Figure 4.3 - Variance of Availability

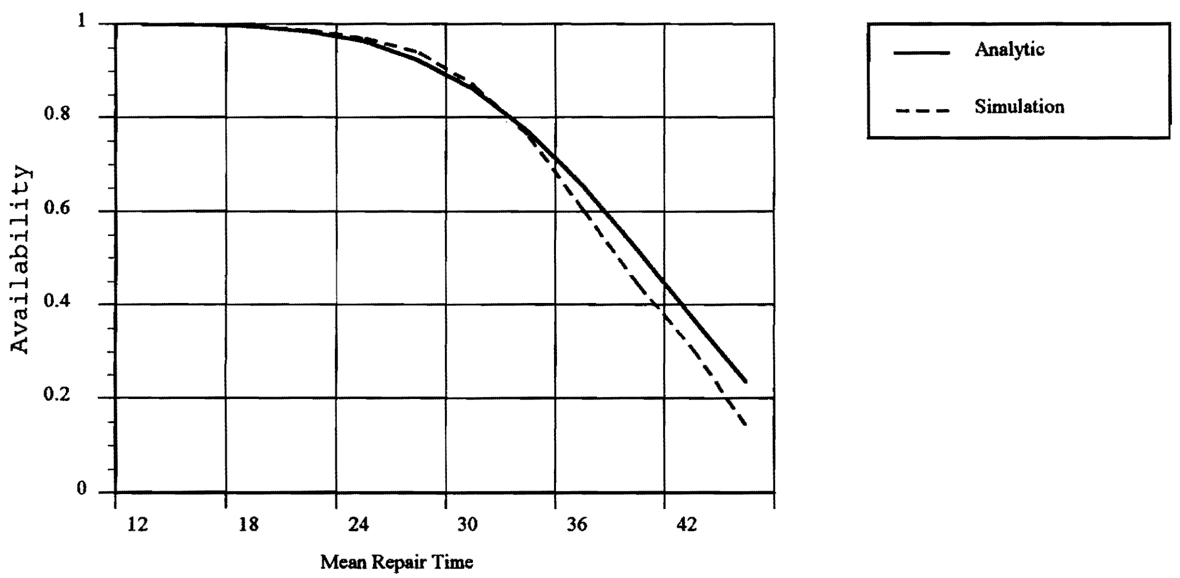
Predicted analytic availability versus the simulation availability is shown in Figures 4.4a and 4.4b. For one site, the availabilities are nearly identical. There is one point where the simulation results are better than the analytic, however this point is not statistically significant. For two sites the results are also almost identical except at high mean repair times.

Figure 4.4b shows where there are significant discrepancies between the analytic and simulation availability for four and sixteen dispatch sites. Both the analytic and simulation predictions match relatively well until the mean repair time was 27, then the simulation availability results decrease quicker than the analytic predictions.

Plots of the predicted analytic availability (Figure 4.5) show that the more dispersed configurations

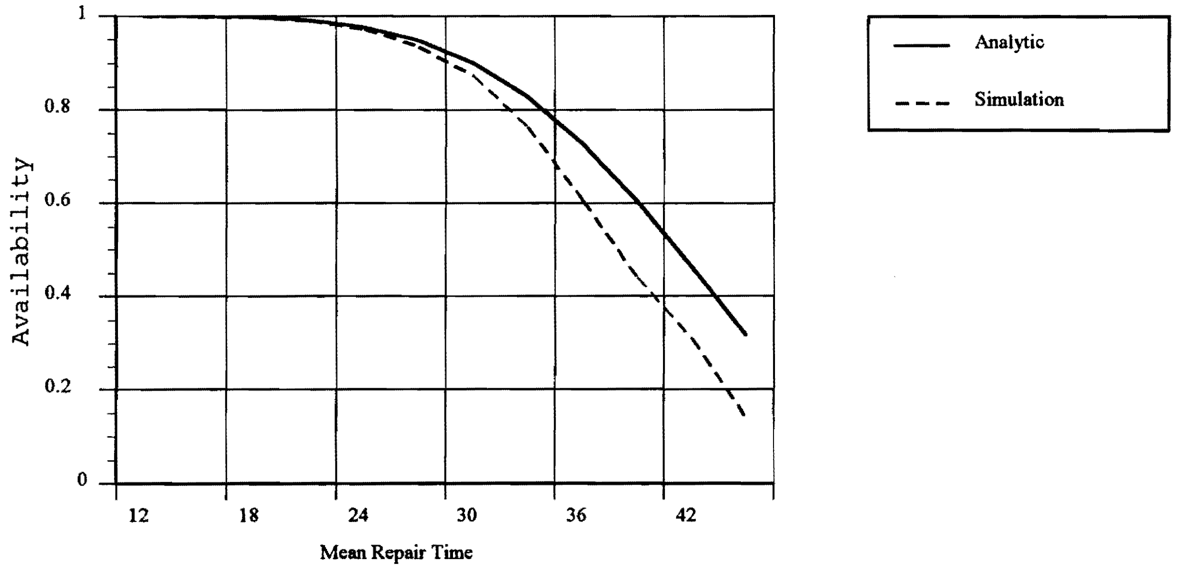


One Site

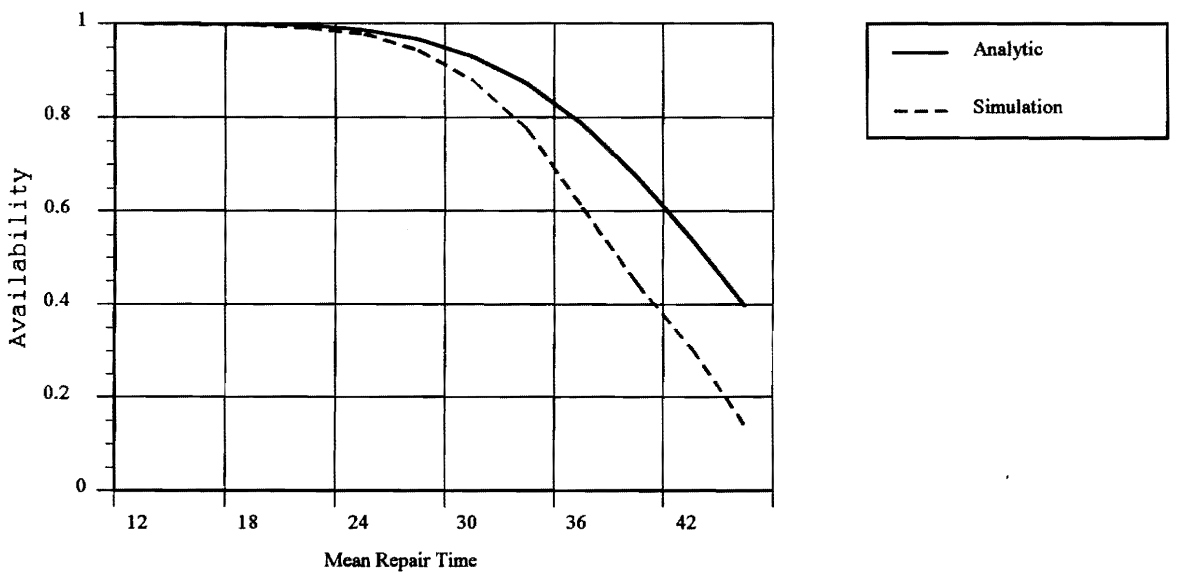


Two Sites

Figure 4.4a - Analytic vs. Simulation Availability



Four Sites



Sixteen Sites

Figure 4.4b - Analytic vs. Simulation Availability have higher availability.

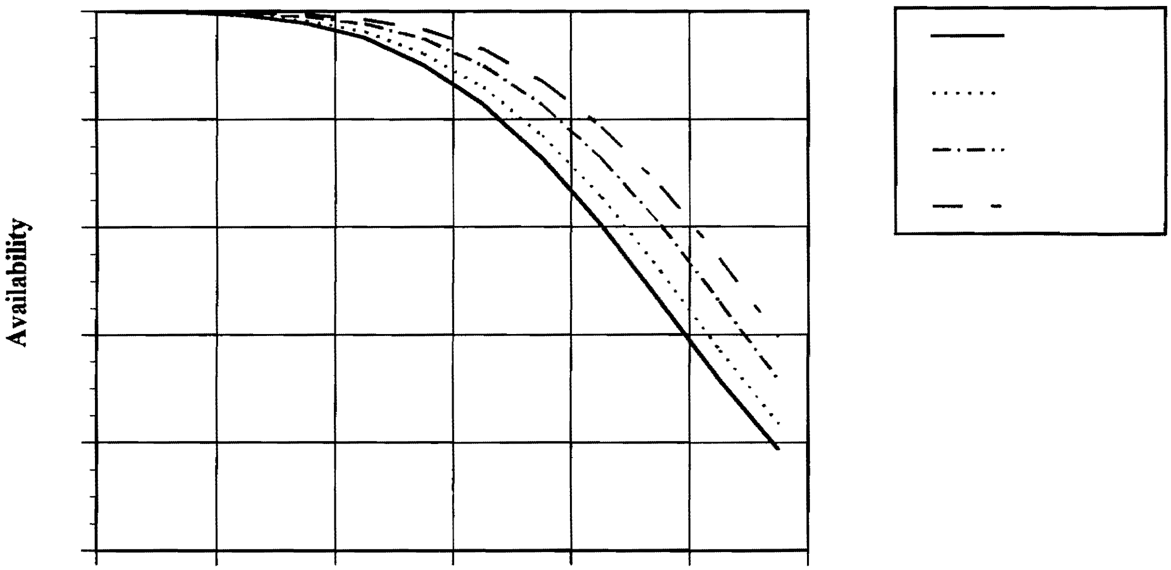


Figure 4.5 - Predicted Availability (Analytic)

By analyzing the mean distance traveled and its variance, the difference between the analytic and simulated results may be explained. Larger variance indicates a chaotic system, where servers are traveling wide ranges of distance to get to a failure. This translates into increased LDT and hence MDT.

Increases in the distance traveled by a server occur more significantly for dispersed dispatch configurations than for the single site is seen in Figure 4.6 The dark area in the lower left corner of the plot of the t-test values shows where is a lot of difference for the different configurations. The increases in travel distance variance is seen in the bottom plot. The more dispersed configurations have higher variance for higher mean repair times.

As more time is required for a repair action, the variance for dispersed configurations increases, especially four and sixteen sites. The travel distance variance is high for mean repair times between 27 and 36 TU. When the servers are utilized near 100%, they usually will travel either be diverted on a return or travel directly from one repair action to another. This causes the differences in the mean distance traveled to diminish. The mean travel time continues to increase pass 7.5 lengths for all configurations. This translates into higher MDT and decreased availability. This is part of the explanation why the experimental availability is lower than the predicted availability. See Figure 4.7 Additionally, the large queue of failed components may invalidate the REPS assumption of finite queuing.

Even though there is significant improvement for the MDT, when MTTR is 12 and 15 TUs, this does not translate into a significant improvement in system availability. There is some very small improvement, but it is not statistically significant.

There is some rough correspondence between the significant differences in Figures 4.6 and Figure 4.7. As the distance the server is required to travel increases, so does the MDT.

As the MDT increases, a queue of waiting failures build-up. Servers proceed from one failure to another without returning to their home dispatch site. This minimizes the effect of dispersal. The reduced variance in the distance traveled is due to the fact that the servers in the one site

configuration head for a centralized point. Other configuration servers, especially for four and sixteen sites, are traveling to points that are almost any point on the system.

Comparing the server utilization rate against the mean distance travel, Figure 4.8, shows that as the server utilization approaches 100%, the mean distance traveled by a server is the same for all dispatch configurations. This is caused by servers traveling directly from one component to another without attempting to return to the dispatch site. At a steady state near 100% server utilization, the different configurations have no effect.

The system MDT and MTBF had a very large variance for several data points. This precluded the performance of any valid analysis of these parameters.

The data from the experiment supports the contention that disperse sites might have detrimental effects on availability by increasing the MDT. The high variance means that some servers are traveling long distances. The effect conjectured did occur on availability, although not to the

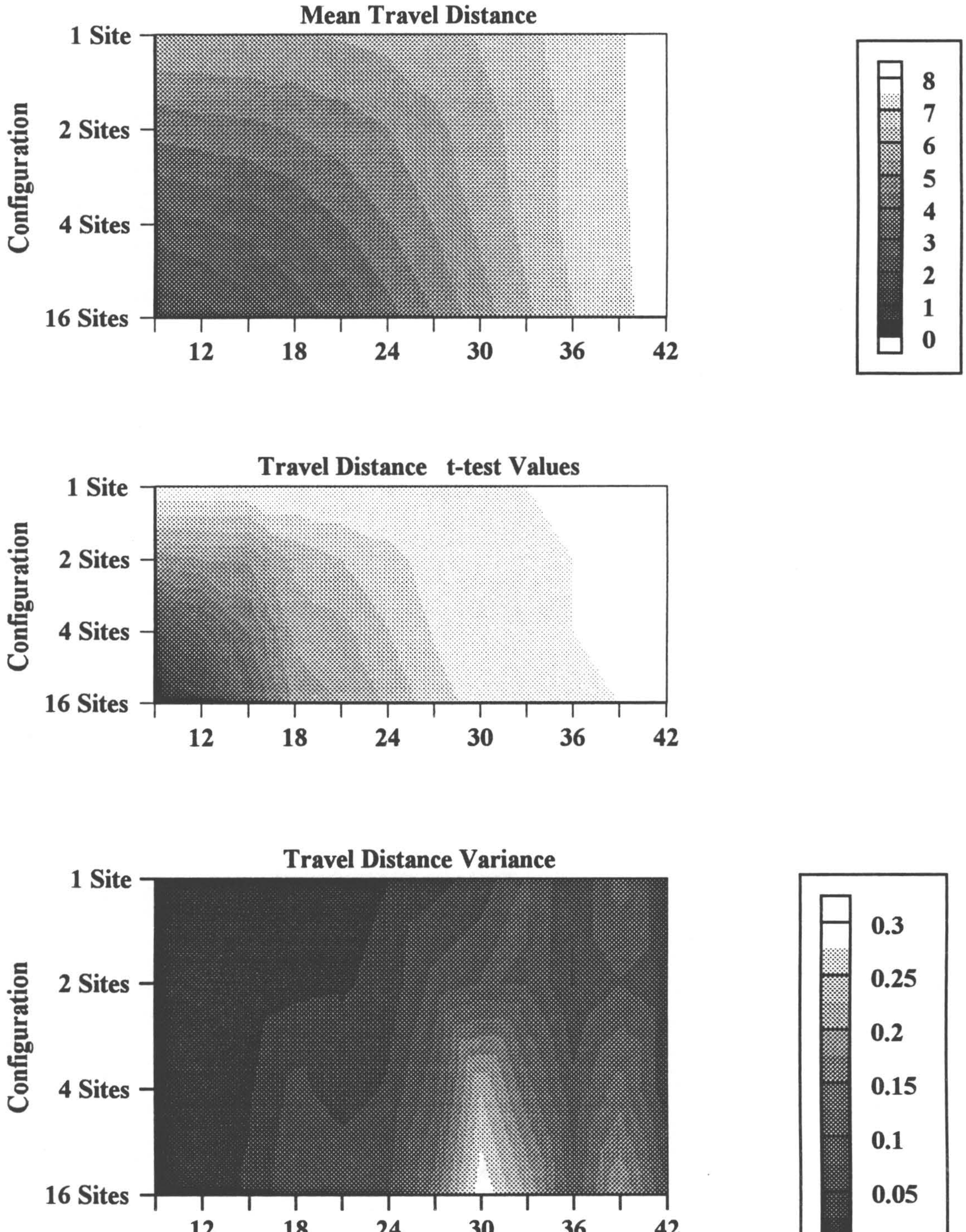


Figure 4.6 - Travel Distance Output

magnitude expected. There is no difference in availability for dispersed dispatch sites. The dispersed sites are predicted by analytic means to have improved availability. This did not occur.

4.2 Multiple Types of Distributions

A second experimental was run with different distributions. The repair time was sampled from an Erlang distribution with a shape parameter of two. The time between failures distribution was lognormal with a variance of 200. The LDT sampling continued from an exponential distribution. All means remained the same.

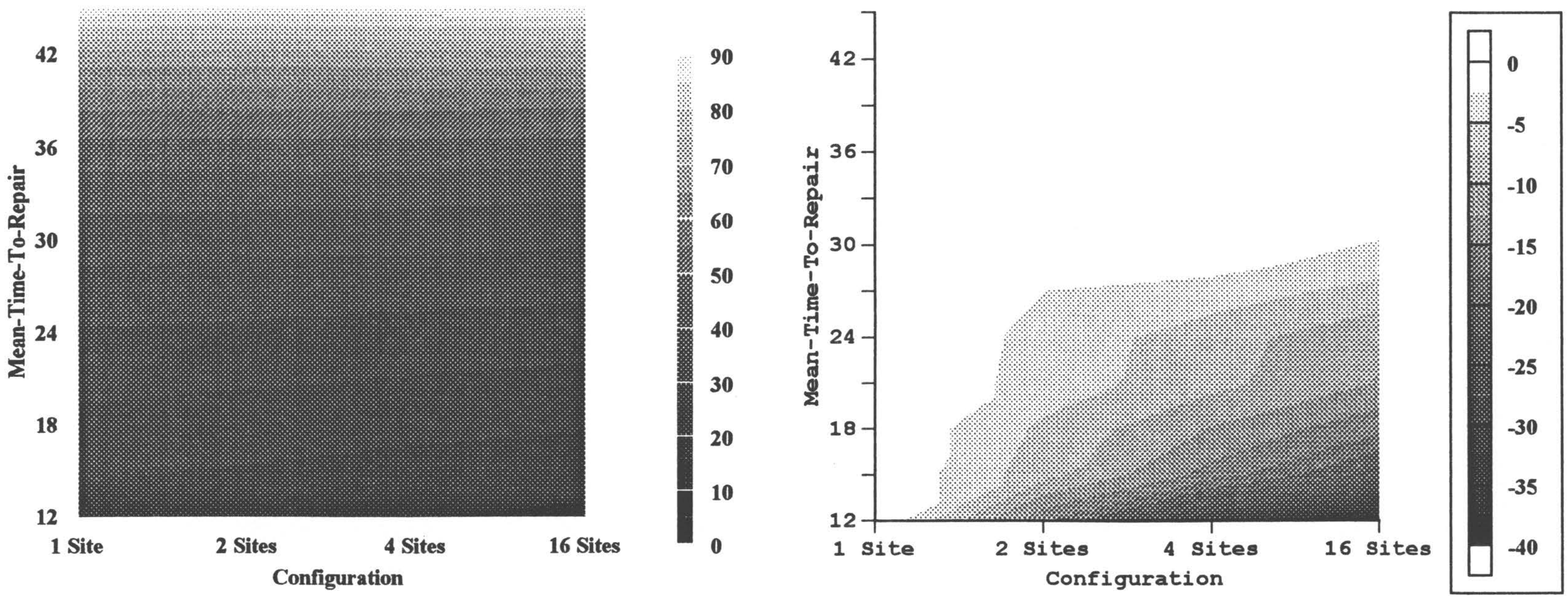
Figure 4.9 shows that the availability for both this case and the base case. For this case, the 80% availability level is reached with a MTTR of 12, as opposed to 30 for the base case.

In this experiment, the availability decreases very rapidly to zero. (more than sixteen simultaneous failed components) The variance of the repair and failure rates is very important to the system's performance. The same mean has yielded dramatically different results.

Comparisons of the actual versus the simulation predictions show the effect of changing the distributions. Figure 4.10a/b The actual availability is rapidly decreasing, while the predict decreases in an exponential shape curve. This comparison emphasizes the important of considering the distribution and variance, in addition to the mean, when evaluating a systems parameters.

There are only two points that have significantly improvement in availability in a pair-wise comparison against one dispatch site. These occurred for four and sixteen sites with a mean repair time of 12 TU. Evaluation of smaller mean repair times would yield more significant changes in availability. The low server utilization rate would allow the closes site to have a server ready to be sent. The dispersal configurations would lower the mean travel distance , hence the LDT and MDT.

As the mean repair time grows above 24 TU, there are no significant improvements in component MDT. Availability is in the 90-95% range. The variance in the data above a mean repair time of 18 makes analysis inconclusive. Figure 4.11



MDT

Significant Differences in MDT
t-test of MDT

Figure 4.7 Maintainability Results : Base Case

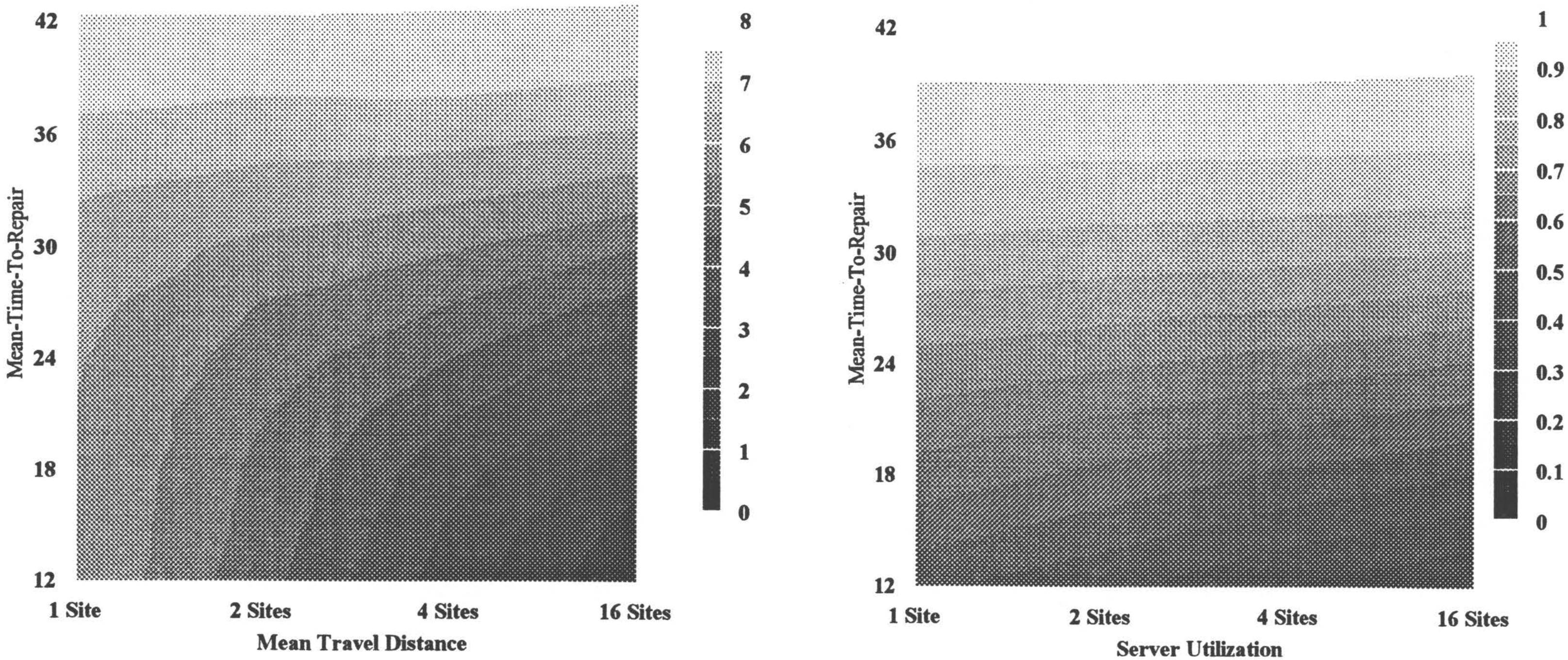


Figure 4.8 - Server Performance Results

The mean travel distance levels off at 8 lengths for all configurations when the mean repair time is greater than 21 TU. The variance is very small, implying a relatively ordered system, except for 16 dispatch sites configuration as shown in Figure 4.12. This could be a Type I error in the pair-wise comparisons.

The main difference between this experiment and the base case is the mean repair time that the availability decrease rapidly. The plots of the data were similar to the plot in the base case. The experiment showed that the mean used to calculate a systems parameters does not take into account the effects of different distributions on its performance.

4.3 LDT Sensitivity Analysis

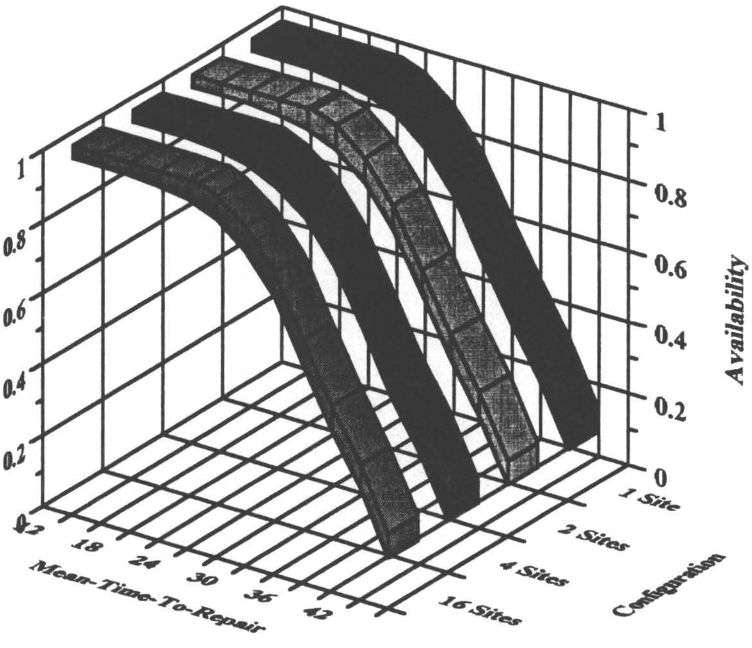
Sensitivity of the systems parameters to different LDT means was examined. The MTTR was set at 24 TU and the LDT varied. The results in Figure 4.13 show that availability is not effected by different configurations. The system's availability is sensitive to changes in the LDT.

The variance of the availability, in Figure 4.13, grows with increases in the mean LDT. For mean LDT 2.0 TU / length, the large variance reduces confidence in the results of the analysis. With an α-level of 0.05, there is only one point of significant improvement in availability. The point is a four site configuration with mean LDT of 1.25.

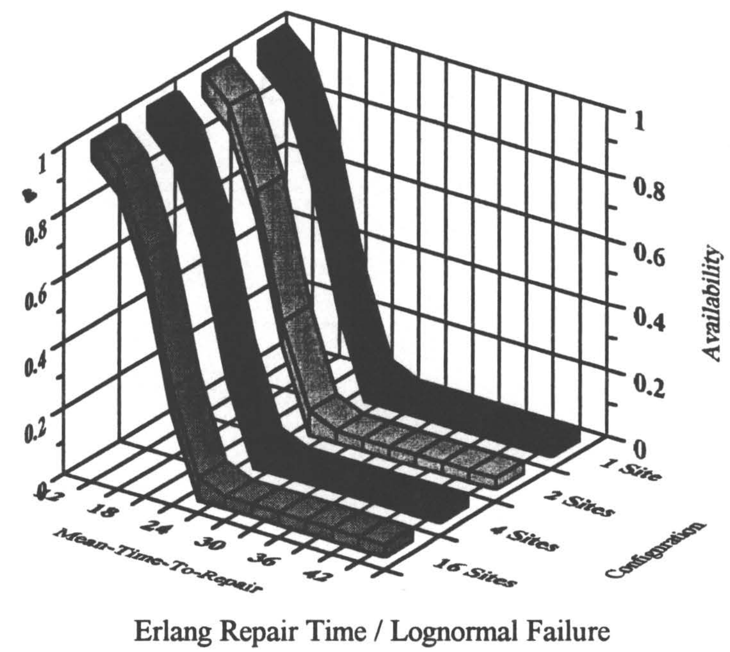
The actual availability is always less than the predicted. Its rate of decrease is greater also. The predicted and experimental availability for a single centralized configuration showed some correlation. The two site configuration, Figure 4.14a/b, also had some correlation, but to a lesser extent.

The MDT was significantly better for the dispersed sites for mean LDT in the 0.5 to 1.5 range. For larger values of LDT the significant differences drop-off, Figure 4.15 This improvement in the MDT for dispersed configurations does not translate into improved system availability because the difference between the availabilities was small.

Comparison of the varying the repair time and the LDT showed little significant differences in availability. The case where the mean LDT is varied, the availability decreases slower. This is due to the smaller time increments used.

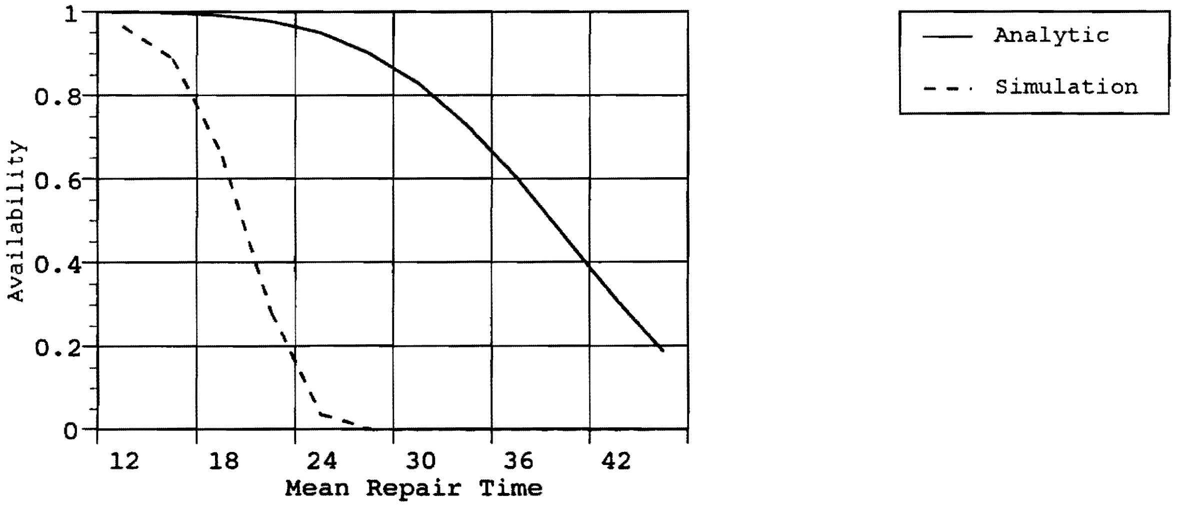


Exponential Distribution

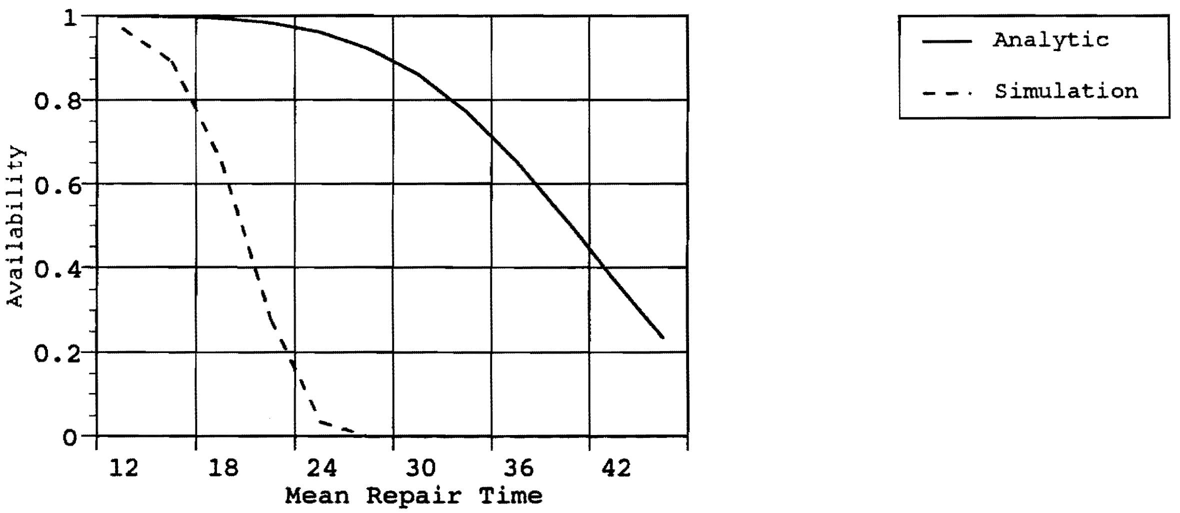


Erlang Repair Time / Lognormal Failure

Figure 4.9 - Base Case vs. Multiple Distribution Availability

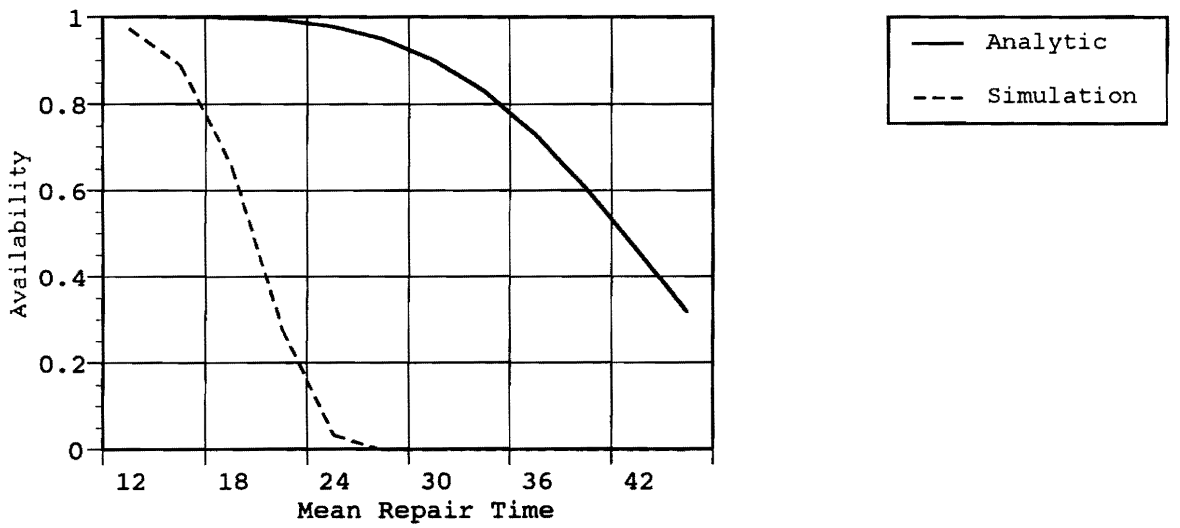


One Site

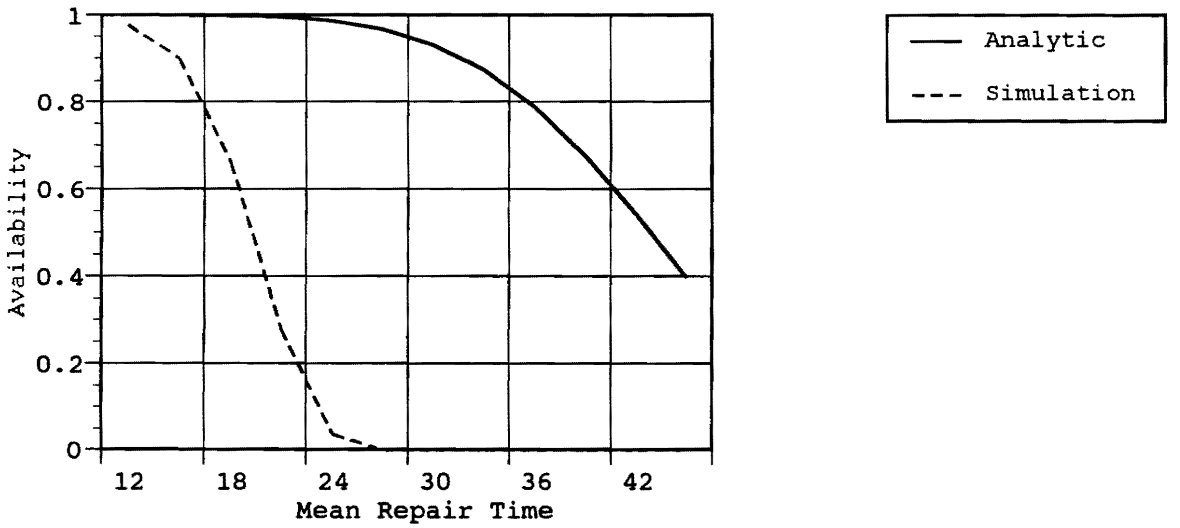


Two Sites

Figure 4.10a - Availability Results : Multiple Distribution

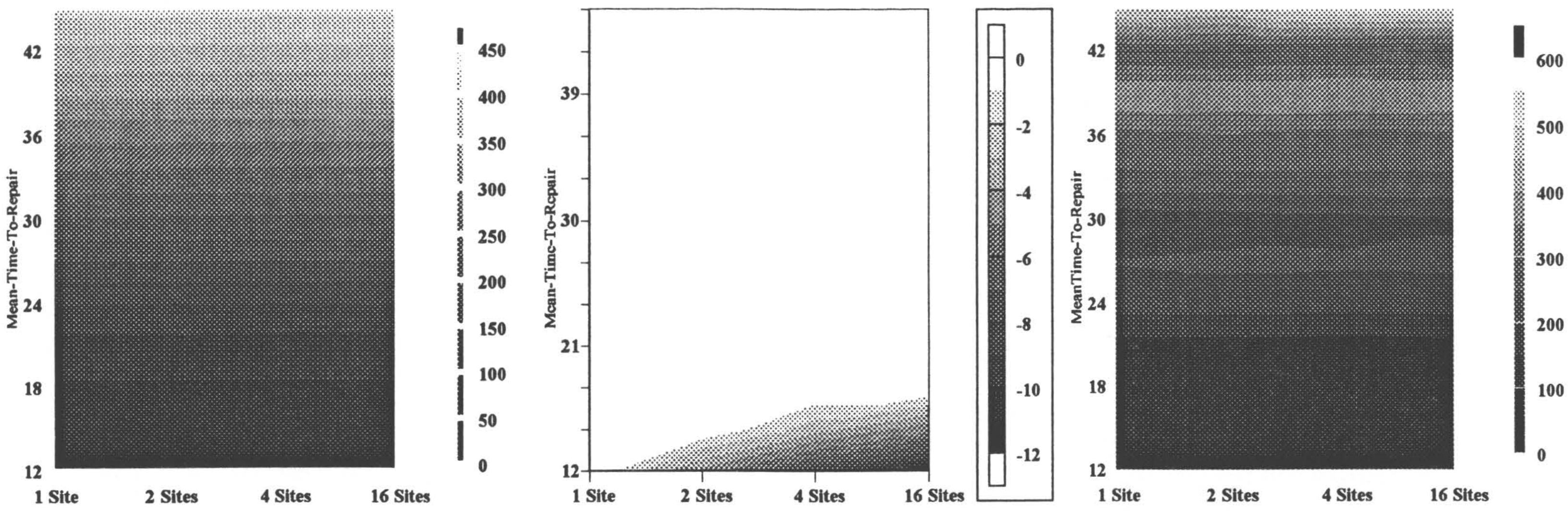


Four Sites



Sixteen Sites

Figure 4.10b - Availability Results : Multiple Distribution

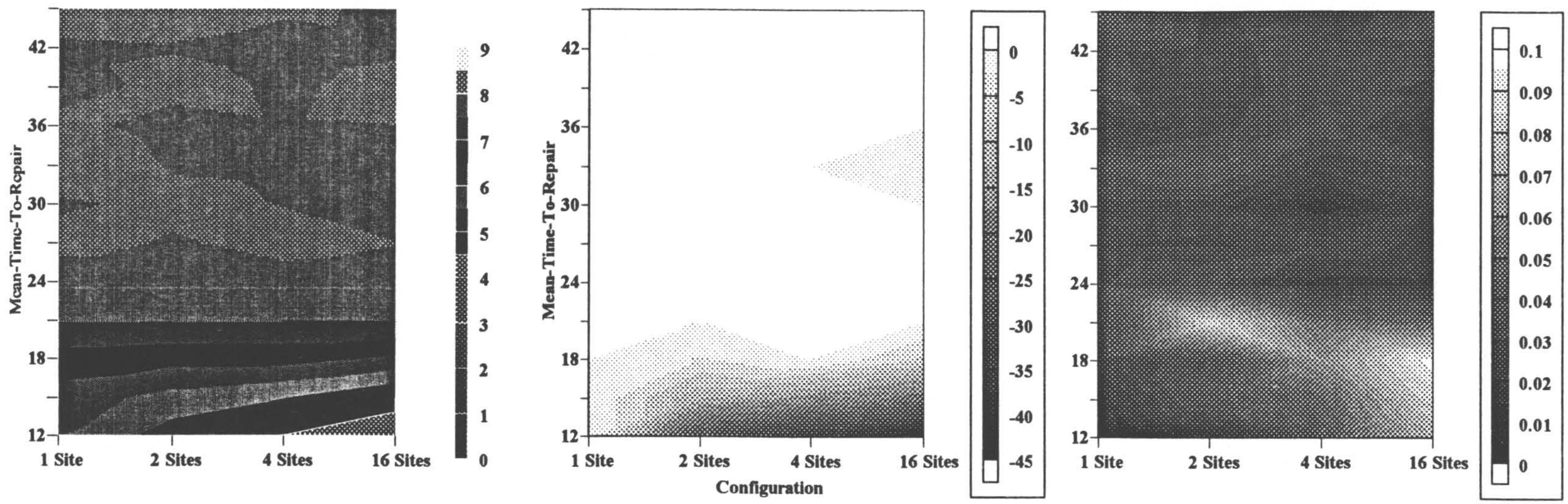


Mean Maintenance Down Time

Significant MDT Differences

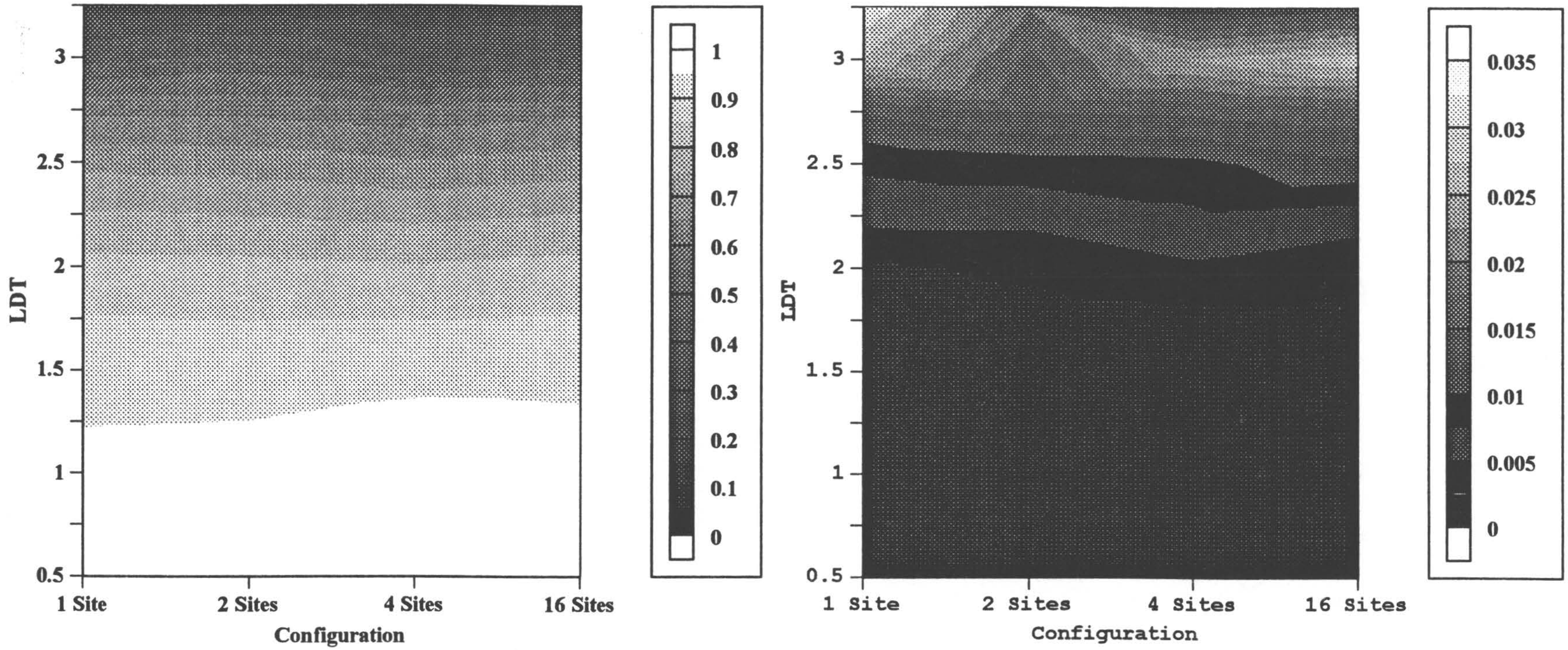
Variance of MDT

Figure 4.11 - Maintainability Results



Mean Travel Distance | Significant Difference | Travel Distance Variance

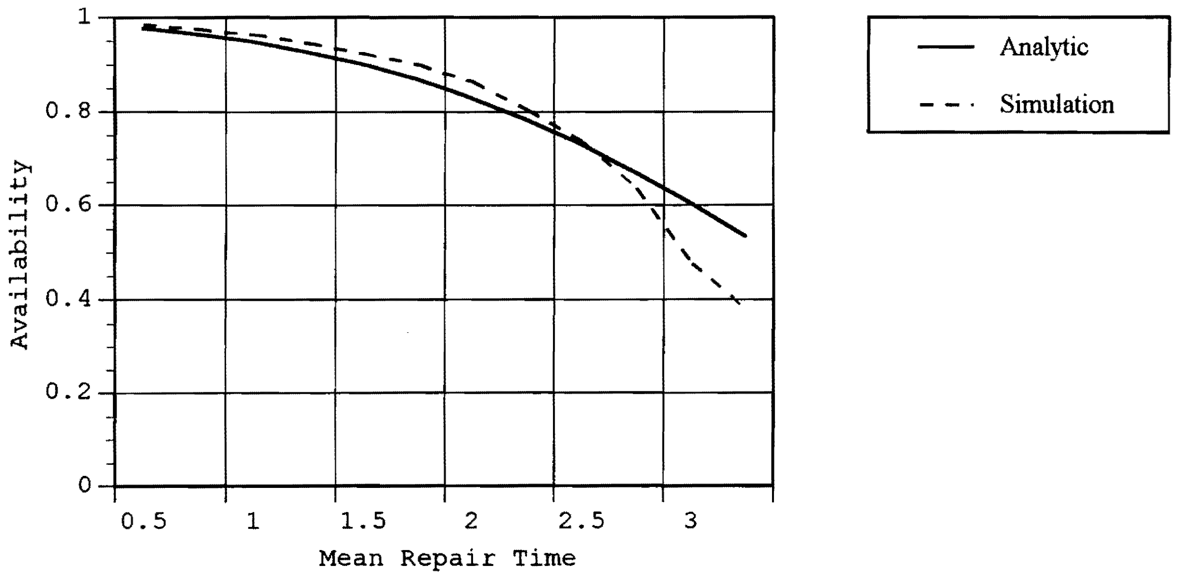
Figure 4.12 - Server Performance Results



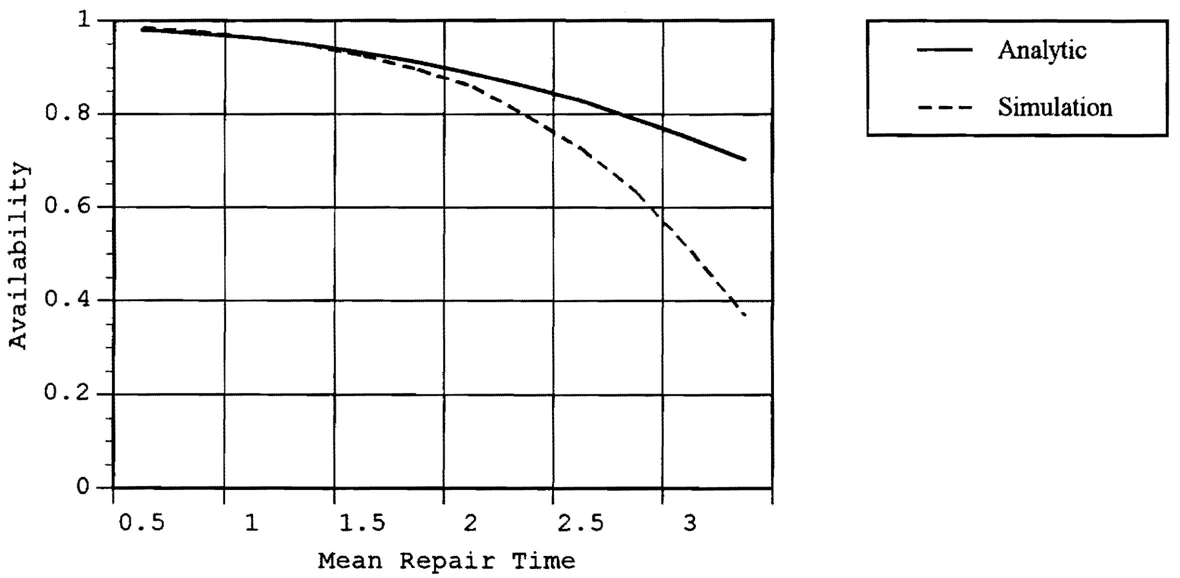
Mean Availability

Variance of Availability

Figure 4.13 - Availability Results : variable LDT

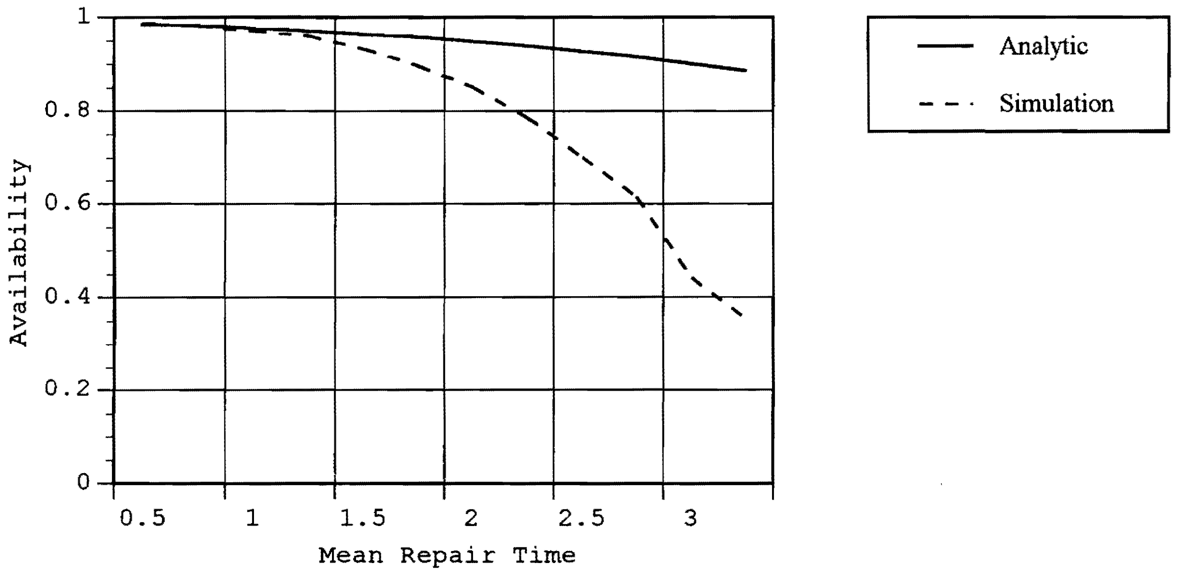


One Site

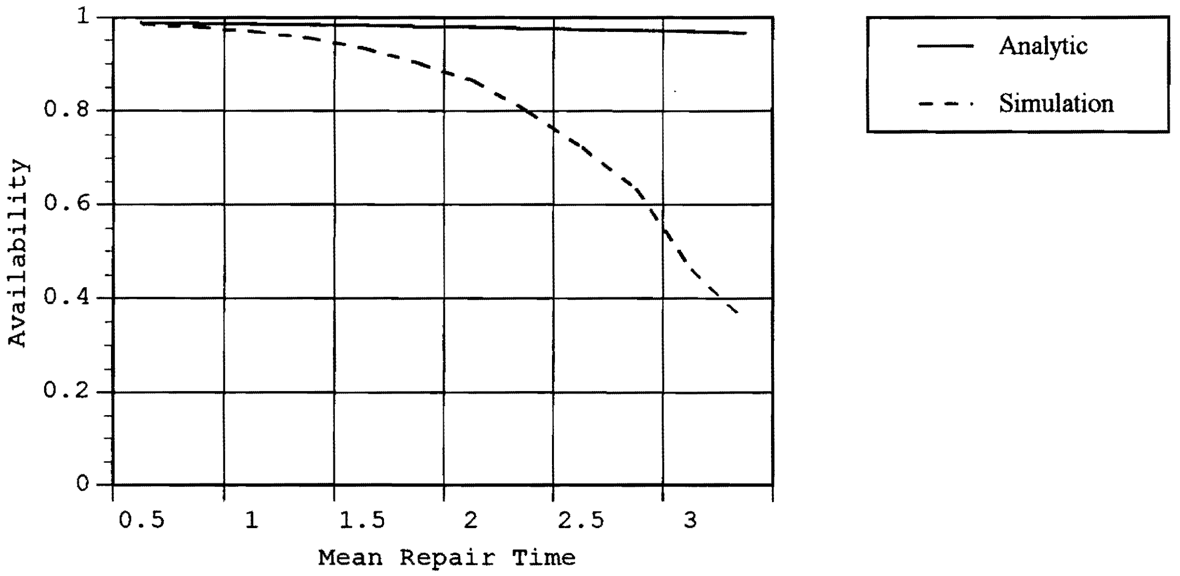


Two Sites

Figure 4.14a - Analytic vs. Simulation Availability : LDT

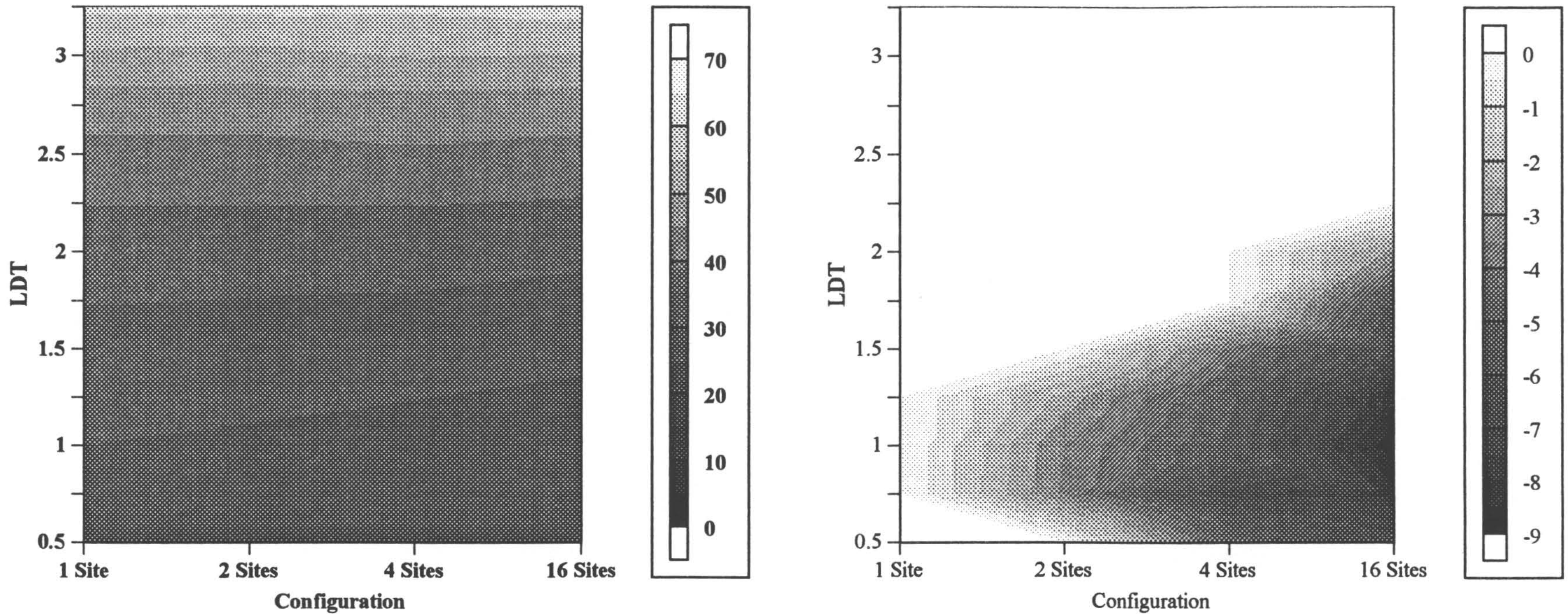


Four Sites



Sixteen Sites

Figure 4.14b - Analytic vs. Simulation Availability : LDT



Mean MDT

Significant Differences in MDT
t-test

Figure 4.15 - Maintainability Results : variable LDT

V. SUMMARY AND CONCLUSIONS

An evaluation of the effect of repair server location on a system's availability was performed using computer simulation. Four different configurations for the dispersal of the repair servers were analyzed. The population of components requiring repair actions were distributed over a large service area. Different time-to-repair and time-to-failure distributions were used.

Dispersal of server dispatch sites did not effect system availability, in either a positive or negative manner. The hypothesis that there would be some decrease was not supported. The reason explaining the absence of improvement in the availability is the variance. The higher variance for the distance traveled by the servers in the disperse configurations indicates that some servers are being sent far across the grid. This increases their total LDT and hence there MDT. This is why the smaller mean distance for the dispersed cases did not induce improvements in the systems availability.

For the range of values, the system was sensitive to changes in components of the MDT. This sensitivity resulted whether the LDT or MTTR was varied. Under the conditions of this experiment, dispersal played an insignificant role in effecting the availability.

Some of the cause for the increased MDT is that queues of failed components formed. They had to wait for a server to finish, when the system had more than sixteen simultaneous failures.

This experiment is limited in its applications because of the many system variables that were held constant. Further experiments that analyzed the systems sensitivity to the number of units that has to fail before the system became unavailable would be insightful. The number of servers could be varied also. The main reason that sixteen servers was select was to allow equal number of servers at dispatch sites.

There are numerous restrictions that could be place on the servers actions. One is that a server would have to return to a dispatch site after a given number of repair actions or time. The effects of shutting down working components when the system was unavailable would be realistic for many systems. Different means, depending on the direction traveling, could simulate the effects of traffic flow. Servers could be susceptible to malfunctions.

The variety of data available from a simulation makes it a very valuable tool. It should be used to refine preliminary designs of systems. It cannot replace analytic practice in system design. When possible, analytic methods are preferred, however most real world systems are too complicated and cannot be solved using solely analytic calculations. The reliance of most analytic methods on the assumption of exponential behavior limits the number of situations that they may be successfully used.

For a logistics support type system, the results of this project should be considered when deciding on a maintenance concept. Not only should costs and performance means be considered, the effects on the variance of the factors needs to be analyzed when developing a system.

Future investigations into the effects of different input distributions should be performed. Evaluation of a system's sensitivity to the variance of a distributions is inorder.

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Hillier, Fredrick S., Lieberman, Gerald J., *Introduction to Operations Research* ,5th Edition, McGraw Hill, Inc., New York, NY, 1990

Pritsker, A. Alan B., Sigal, C. Elliott, Hammesfahr, R.D. Jack, *SLAM II : Network Models For Decision Support*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1989

Pritsker, A. Alan B., *Introduction to Simulation and SLAM II*, 3rd Edition, Halsted Press Books, New York, NY, 1986

Warpole, Ronald E., Myers, Raymond H., *Probability and Statistics for Engineers and Scientists*, 4th Edition, Macmillan Publishing Company, New York, NY, 1989

APPENDIX

```
//LD1 JOB 32769,WEISSMANN,TIME=60,REGION=4M
/*PRIORITY IDLE
/*ROUTE PRINT VTVM1.ISE154
/*JOBPARM LINES=99
//STEP1 EXEC SLAMCG
//FORT.SYSIN DD *
      PROGRAM MAIN
      DIMENSION NSET(20000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(20000)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=20000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      STOP
      END

      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)

      GO TO(1,2,3,4,5,6,7,8),I

1     CALL FAILURE
      RETURN
2     CALL REPARED
      RETURN
3     CALL XMOVE
      RETURN
4     CALL YMOVE
      RETURN
5     CALL WORKERS
      RETURN
6     CALL PARTS
      RETURN
7     CALL CLEAN
      RETURN
8     CALL OPUT
      RETURN
      END
```

```
C***********************************************************************
C
C     FAILURE : ASSIGNS SERVER TO COMPONENT WHEN IT FAILS OR IF
C           NO SERVER IS AVAILABLE, PUTS COMPONENT IN A
C           WAITING FILE
C
C***********************************************************************

      SUBROUTINE FAILURE
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      EQUIVALENCE (XX(10),ID),(XX(12),POSY)
      EQUIVALENCE (XX(13),POSX),(XX(14),SERVER),(XX(15),SUM)
      EQUIVALENCE (XX(16),TSUM)

      ATRIB(1)=TNOW
      CALL FILEM(1,ATRIB)
      ID=ATRIB(2)
      POSX=ATRIB(3)
      POSY=ATRIB(4)


C     SEARCHING FOR AVAILABLE SERVERS AT DISPATCH SITES

      IF(NNQ(2).GT.0) THEN
        NEXT=MMFE(2)
        NTEMP=NEXT
        SUM=100000.
10       IF(NEXT.EQ.0) GO TO 100
          CALL COPY(-NEXT,2,ATRIB)
          TSUM=ABS(POSX-ATRIB(5))+ABS(POSY-ATRIB(6))
          IF(TSUM.LT.SUM) THEN
            NTEMP=NEXT
            SUM=TSUM
          ENDIF
          NEXT=NSUCR(NEXT)
          GO TO 10
100     CALL RMOVE(-NTEMP,2,ATRIB)
        ATRIB(1)=TNOW
        ATRIB(2)=ID
        ATRIB(3)=POSX
        ATRIB(4)=POSY
        ATRIB(10)=SUM
        CALL ENTER(1,ATRIB)
      ELSE
```

```
C    SEARCH FOR NEAREST RETURNING SERVER

      IF(NNQ(3).GT.0) THEN
        NEXT=MMFE(3)
        NTEMP=NEXT
        SUM=100000.
20        IF(NEXT.EQ.0) GOTO 200
          CALL COPY(-NEXT,3,ATRIB)
          TSUM=ABS(POSX-ATRIB(5))+ABS(POSY-ATRIB(6))
          IF(TSUM.LT.SUM) THEN
            NTEMP=NEXT
            SUM=TSUM
          END IF
          NEXT=NSUCR(NEXT)
          GO TO 20
200       CALL RMOVE(-NTEMP,3,ATRIB)
        ATRIB(1)=TNOW
        ATRIB(2)=ID
        ATRIB(3)=POSX
        ATRIB(4)=POSY
        ATRIB(10)=SUM
        CALL FILEM(4,ATRIB)
      ELSE

C PLACES FAILED COMPONENT IN FILE TO WAIT FOR NEXT AVAILABLE SERVER

        CALL FILEM(5,ATRIB)
      ENDIF
    ENDIF


C    IF MORE THAN 16 COMPONENTS HAVE FAILED, DECLARES SYSTEM
C    UNAVAILABLE

      IF((NNQ(1).GT.16).AND.(XX(88).EQ.0.0)) THEN
        CALL CLOSX(1)
        XX(89)=0.00001
        XX(87)=TNOW-XX(86)
        CALL COLCT(XX(87),2)
        XX(87)=TNOW
        XX(88)=1.0
      ENDIF

    RETURN
    END
```

```
C*******************************************************************
C
C     REPARED : PERFORMES REQUIRED ACTIONS WHEN SERVER HAS
C              COMPLETED A REPAIR ACTION
C
C*******************************************************************


      SUBROUTINE REPARED
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      EQUIVALENCE (XX(10),ID),(XX(12),POSY),(XX(13),POSX),(XX(14),TIME)

      ID=ATRIB(2)
      ATRIB(1)=ATRIB(1)+1.


C     HOLDING CURRENT ENTITY'S ATTRIBUTES IN FILE 6
C     FILE 6 IS A FILE FOR TEMPORY HOLDING DATA

      CALL FILEM(6,ATRIB)
      NEXT=MMFE(1)
10    CALL COPY(-NEXT,1,ATRIB)
      IF(ID.EQ.ATRIB(2)) GOTO 100
        NEXT=NSUCR(NEXT)
        GOTO 10


100   CALL RMOVE(-NEXT,1,ATRIB)
      CALL ENTER(4,ATRIB)

      IF(NNQ(5).GT.0) THEN
        CALL RMOVE(1,5,ATRIB)
        TIME=ATRIB(1)
        ID=ATRIB(2)
        POSX=ATRIB(3)
        POSY=ATRIB(4)
        CALL RMOVE(1,6,ATRIB)
        ATRIB(1)=TIME
        ATRIB(2)=ID
        ATRIB(3)=POSX
        ATRIB(4)=POSY
        ATRIB(10)=ABS(POSX-ATRIB(5))+ABS(POSY-ATRIB(6))
        CALL ENTER(1,ATRIB)
```

```
ELSE
      CALL RMOVE(1,6,ATRIB)
      CALL FILEM(3,ATRIB)
      CALL ENTER(5,ATRIB)
   ENDIF

C  CHECKING TO SEE IF SYSTEM HAS MORE THAN 16 FAILED COMPONENTS

      IF((NNQ(1).LE.16).AND.(XX(88).EQ.1.0))THEN
        CALL OPEN(1)
        XX(89)=1.0
        XX(88)=0.0
        XX(86)=TNOW-XX(87)
        CALL COLCT(XX(86),1)
        XX(86)=TNOW
      ENDIF
   RETURN
   END
```

```
C*************************************************************************
C
C   XMOVE :  AT COMPLETION OF MOVE ON X-AXIS, CHECKS IF SERVER IS
C            DIVERTED TO FAILED COMPONENT, OTHERWISE UPDATES
C            POSITION AND PROCEEDS ON TRIP ON Y-AXIS
C
C*************************************************************************


      SUBROUTINE XMOVE
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      EQUIVALENCE (XX(10),ID),(XX(12),POSY),(XX(13),POSX),
     *(XX(14),SERVER),(XX(15),SUM),(XX(16),TSUM)


      CALL FILEM(6,ATRIB)
      POSX=ATRIB(5)
      POSY=ATRIB(6)
      SERVER=ATRIB(9)
      NEXT=MMFE(4)
10    IF(NEXT.EQ.0) GOTO 100


        CALL COPY(-NEXT,4,ATRIB)

        IF((SERVER.LT.(ATRIB(9)+0.1)).AND.(SERVER.GT.(ATRIB(9)-0.1)))
     *THEN
          CALL RMOVE(-NEXT,4,ATRIB)
          ATRIB(5)=POSX
          ATRIB(6)=POSY


          CALL ENTER(1,ATRIB)
          CALL RMOVE(1,6,ATRIB)
          GOTO 888
        ELSE
          NEXT=NSUCR(NEXT)
          GO TO 10
        ENDIF
```

```
100  NEXT=MMFE(3)
101  IF(NEXT.EQ.0) GOTO 770
       CALL COPY(-NEXT,3,ATRIB)
       IF((SERVER.LT.(ATRIB(9)+0.1)).AND.(SERVER.GT.(ATRIB(9)-0.1)))
    *THEN
       CALL RMOVE(-NEXT,3,ATRIB)
     ELSE
       NEXT=NSUCR(NEXT)
       GOTO 101
     ENDIF

770  CALL RMOVE(1,6,ATRIB)
     IF((ATRIB(6).LT.(ATRIB(8)+0.1)).AND.(ATRIB(6).GT.(ATRIB(8)-0.1)))
    *GOTO 700
       IF(ATRIB(6).GT.(ATRIB(8)+0.1)) ATRIB(6)=ATRIB(6)-1.0
       IF(ATRIB(6).LT.(ATRIB(8)-0.1)) ATRIB(6)=ATRIB(6)+1.0
       CALL FILEM(3,ATRIB)
       CALL ENTER(3,ATRIB)
       GOTO 888
700  IF((ATRIB(5).LT.(ATRIB(7)+0.1)).AND.(ATRIB(5).GT.(ATRIB(7)-0.1)))
    *GOTO 701
       IF(ATRIB(5).GT.(ATRIB(7)+0.1)) ATRIB(5)=ATRIB(5)-1.0
       IF(ATRIB(5).LT.(ATRIB(7)-0.1)) ATRIB(5)=ATRIB(5)+1.0
       CALL FILEM(3,ATRIB)
       CALL ENTER(2,ATRIB)
       GOTO 888
701  CALL FILEM(2,ATRIB)
888  RETURN
     END
```

```
C*************************************************************************
C
C   YMOVE :  AT COMPLETION OF MOVE ON Y-AXIS, CHECKS IF SERVER IS
C            DIVERTED TO FAILED COMPONENT, OTHERWISE UPDATES
C            POSITION AND PROCEEDS ON TRIP ON Y-AXIS
C
C*************************************************************************

      SUBROUTINE YMOVE
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      EQUIVALENCE (XX(10),ID),(XX(12),POSY),(XX(13),POSX),
     *(XX(14),SERVER),(XX(15),SUM),(XX(16),TSUM)

      CALL FILEM(6,ATRIB)
      POSX=ATRIB(5)
      POSY=ATRIB(6)
      SERVER=ATRIB(9)
      NEXT=MMFE(4)
10    IF(NEXT.EQ.0) GOTO 100

        CALL COPY(-NEXT,4,ATRIB)
        IF((SERVER.LT.(ATRIB(9)+0.1)).AND.(SERVER.GT.(ATRIB(9)-0.1)))
     *THEN
          CALL RMOVE(-NEXT,4,ATRIB)
          ATRIB(5)=POSX
          ATRIB(6)=POSY
          CALL ENTER(1,ATRIB)
          CALL RMOVE(1,6,ATRIB)
          GO TO 888
        ELSE
          NEXT=NSUCR(NEXT)
          GO TO 10
        ENDIF
```

```
100  NEXT=MMFE(3)
101  IF(NEXT.EQ.0) GO TO 999
      CALL COPY(-NEXT,3,ATRIB)

      IF((SERVER.LT.(ATRIB(9)+0.1)).AND.(SERVER.GT.(ATRIB(9)-0.1)))
    *THEN
      CALL RMOVE(-NEXT,3,ATRIB)
     ELSE
      NEXT=NSUCR(NEXT)
      GO TO 101
     ENDIF

999  CALL RMOVE(1,6,ATRIB)

     IF((ATRIB(5).LT.(ATRIB(7)+0.1)).AND.(ATRIB(5).GT.(ATRIB(7)-0.1)))
    *GOTO 700
      IF(ATRIB(5).GT.(ATRIB(7)+0.1)) ATRIB(5)=ATRIB(5)-1.0
      IF(ATRIB(5).LT.(ATRIB(7)-0.1)) ATRIB(5)=ATRIB(5)+1.0
      CALL FILEM(3,ATRIB)
      CALL ENTER(2,ATRIB)


      GOTO 888
700  IF((ATRIB(6).LT.(ATRIB(8)+0.1)).AND.(ATRIB(6).GT.(ATRIB(8)-0.1)))
    *GOTO 701
      IF(ATRIB(6).GT.(ATRIB(8)+0.1)) ATRIB(6)=ATRIB(6)-1.0
      IF(ATRIB(6).LT.(ATRIB(8)-0.1)) ATRIB(6)=ATRIB(6)+1.0
      CALL FILEM(3,ATRIB)
      CALL ENTER(3,ATRIB)
      GOTO 888
701  CALL FILEM(2,ATRIB)


888  RETURN
     END
```

```
C***************************************************************************
C
C      WORKERS :   INITIALIZES ATTRIBUTES OF THE SERVERS
C
C***************************************************************************

      SUBROUTINE WORKERS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      ATRIB(9)=XX(6)
      XX(6)=XX(6)+1.
      ATRIB(5)=ATRIB(7)
      ATRIB(6)=ATRIB(8)
      CALL FILEM(2,ATRIB)
      RETURN
      END


C***************************************************************************
C
C      PARTS -       INITIALIZES ATTRIBUTE VALUES FOR COMPONENTS
C
C***************************************************************************

      SUBROUTINE PARTS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      ATRIB(2)=XX(5)
      IF(XX(3).GE.12.)THEN
       XX(3)=0.
       XX(4)=XX(4)+1.
      ENDIF
      XX(3)=XX(3)+1.
      ATRIB(3)=XX(3)
      ATRIB(4)=XX(4)
      XX(5)=XX(5)+1.
      RETURN
      END
```

```
C***************************************************************************
C
C      CLEAN -       CLEARS STATISTICAL ARRAYS WHEN CALLED BY NETWORK
C
C***************************************************************************

      SUBROUTINE CLEAN
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      CALL CLEAR
      RETURN
      END

C***************************************************************************
C
C      OPUT -        WRITES DATA TO FILE FOR ANALYSIS
C
C***************************************************************************

      SUBROUTINE OPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
     *MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,
     *SS(100),SSL(100),TNEXT,TNOW,XX(100)
      WRITE(88,10)FFAWT(1),FFAVG(2),CCAVG(4),CCAVG(2),CCNUM(6),CCNUM(5)
     *,CCAVG(1),GGOPN(1),CCAVG(3),FFAVG(1)

C      FFAWT(1) -    COMPONENT REPAIR TIME
C      CCAVG(4) -    SERVER UTILIZATION
C      CCAVG(2) -    DISTANCE TRAVELED BY SEVER TO COMPONENT
C      CCAVG(2) -    AVERAGE WAIT IN FILE 2
C      CCNUM(6) -    NUMBER OF FAILURES GREATER THAN 16
C      CCNUM(5) -    TOTAL NUMBER OF COMPONENT FAILURES
C      CCAVG(1) -    SYSTEM MTTR
C      GGOPN(1) -    PERCENT TIME GATE OPEN , MEASURES AVAILABILITY
C      FFAVG(1) -    TIME FOR SERVER TO TRAVEL FROM DISPATCH SITE OR
C                    DIVERSION POINT TO FAILED COMPONENT

10    FORMAT(2X,' ',10F8.2)
      RETURN
      END
//GO.SYSIN DD *
```

```
; NETWORK
GEN,WEISSMANN,PR,1/1/1993,12;
LIMITS,7,10,1000;
; INITIALIZING VALUES
INTLC,XX(2)=0.,XX(3)=0.,XX(4)=1.,XX(5)=1.,XX(6)=1.,XX(89)=1.,XX(88)=0.;
INTLC,XX(50)=0.5,XX(86)=0.0;

SEEDS,7111111(1),7222222(2),7333333(3);
INITIALIZE,,125000;

;INITIAL VALUES FOR RANDOM VARIABLES
; THESE WERE ALTERED FOR DIFFERENT CASES
EQUIVALENCE/EXPON(XX(50),2),LDT;
EQUIVALENCE/EXPON(400,1),MTBF/EXPON(9,3),REPAIRING;

EQUIVALENCE/XX(98),MTTR/30,MAINT;
STAT,1,SYS MTTR;
STAT,2,SYS MTBF;
NETWORK;
;
    GATE/AVAILABLE,OPEN,7;

; CREATES THE COMPONENT ENTITIES
    CREATE,0,0,1,144,1;
    EVENT,6,1;
    ACTIVITY,ATRIB(1);
BREA EVENT,1,1;
    TERMINATE;
;
    ENTER,4,1;
    ACTIVITY,MTBF,,BREA;
    ACT,,,BREA;
;
GBAK ENTER,2,1;
    ACTIVITY,LDT;
ZAAC EVENT,3;
    TERMINATE;
    ENTER,5,1;
    ACT,,,ZAAC;
;
    ENTER,3,1;
    ACTIVITY,LDT;
ZAAE EVENT,4;
    TERMINATE;
```

```
START ENTER,1,1;
    ACTIVITY;
ZAAH  GOON,1;
    ACTIVITY,0,ATRIB(5).EQ.ATRIB(3),ZAAG;
    ACTIVITY,0,ATRIB(5).LT.ATRIB(3),ZAAK;
    ACTIVITY,0,ATRIB(5).GT.ATRIB(3);
    ASSIGN,ATRIB(5)=ATRIB(5)-1.0;
    ACTIVITY,LDT;
ZAAG  GOON,1;
    ACTIVITY,,ATRIB(6).GT.ATRIB(4);
    ACTIVITY,,ATRIB(6).EQ.ATRIB(4),ZAAI;
    ACTIVITY,,ATRIB(6).LT.ATRIB(4),ZAAJ;
    ASSIGN,ATRIB(6)=ATRIB(6)-1.0;
    ACTIVITY,LDT;
ZAAI  GOON,1;
    ACTIVITY,,ATRIB(5).EQ.ATRIB(3);
    ACTIVITY,,ATRIB(3).NE.ATRIB(5),ZAAH;
    GOON,1;
    ACTIVITY,,ATRIB(4).NE.ATRIB(6),ZAAG;
    ACTIVITY,,ATRIB(6).EQ.ATRIB(4);
    GOON,1;
    ACT;
    COLCT,INT(1),DISPATCH TIME;
    ACTIVITY,REPAIRING;
FIXD  ASSIGN,MTTR=TNOW-ATRIB(1);
    COLCT,ATRIB(10),TRAVEL DISTANCE,,1;
    ACT;
    COLCT,INT(1),MTTR,,1;
    ACT,,MTTR.GT.MAINT,OVER;
    ACT,,MTTR.LE.MAINT,UNDR;
UNDR  EVENT,2,1;
    TERMINATE;
OVER  COLCT,INT(1),EX MAINTENACE,,1;
    ACT,,,UNDR;
ZAAJ  ASSIGN,ATRIB(6)=ATRIB(6)+1.0;
    ACTIVITY,LDT,,ZAAI;
ZAAK  ASSIGN,ATRIB(5)=ATRIB(5)+1.0;
    ACTIVITY,LDT,,ZAAG;
;
;
;
```

```
;SIXTEEN SERVERS ARE CREATED
;       EACH GETS ASSIGNED A HOME POSITION IN ATRIB(7) AND ATRIB(8)
;       THESE VALUES ARE CHANED FOR EACH DIFFERENT DISPATCH
;       CONFIGURATION
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;

    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
```

```
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
;
    CREATE,0,,1,1,1;
    ACTIVITY;
    ASSIGN,ATRIB(8)=6.0,ATRIB(7)=6.0;
    ACTIVITY,,,HOME;
HOME EVENT,5,1;
    TERMINATE;
```

```
;       TRIGGERS STATISTICS SAMPLING DATA TO OUTPUT FILE
;       EVERY 5000 TIME UNITS
    CREATE,5000,5000,,,1;
    ACT;
    EVENT,8,1
    ACT;
    TERM;
;
;
;       TRIGGERS CLEARING OF STATISTICS ARRAYS 2500 TIME UNITS
;       AFTER START OF EACH RUN
;
    CREATE,5000,2500,,,1;
    ACT;
MANI EVENT,7,1
    ACT;
    AWAIT(7),AVAILABLE,,1
    ACT;
    TERM;
    ENDNETWORK;

;       EACH SIMULATE STATEMENT INCREMENTS EITHER LDT OR REPAIR TIME
;       THIS PROGRAM SHOWS INCREMENTING LDT
;       TO INCREMENT REPAIR TIME INSTEAD OF LDT, USE XX(50) IN REPAIRING
;       RANDOM VARIABLE INSTEAD OF LDT RANDOM VARIABLE


SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=0.75;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=1.0;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=1.25;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=1.5;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
```

```
INTLC,XX(50)=1.75;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=2.0;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=2.25;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=2.5;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=2.75;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=3.0;
;
SIMULATE;
SEEDS,7111111(1),7222222(2),7333333(3);
INTLC,XX(50)=3.25;
;
FIN;
//FT88F001 DD SYSOUT=C,DCB=LRECL=123
/*
//
```