THE USE OF A REPAIR CENTER SIMULATOR

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Summary

The model, written in GPS K, (General Purpose Simulator K is a discrete simulation software package offered by Honeywell Information Systems, Inc.) is in a generalized form from which any specific repair center can be simulated. A repair center is a depot from which service engineers of various skill and ability are dispatched to answer failures of computers and remote entry devices. The model is presently used to evaluate the impact of additional customers on the repair center, skill mix of service engineers, various dispatching algorithms, and reorganization feasibilities. In addition to being a working tool, a simulated typical repair center has been used as an experimental model. By varying the input to the simulated repair center (an impracticality in real life), a quantifiable relationship between workload, queue length, and utilization on both sides of the queue was developed.

Introduction

This paper will describe the use of a digital simulation model of a repair center in a computer repair service environment. A repair center can most simply be defined as a depot from which service engineers of varying skill and ability are dispatched to repair random failures of computers and remote entry devices. In order to objectively evaluate alternate operating procedures, it is essential to know the effect that parameters of demand maintenance have on operating costs and contractual performance requirements. Inefficient operating procedures may result in customer dissatisfaction or high cost. Either of these may lead to decreased profit. For this reason, it is very risky to "try-out" new procedures in an operating environment. Therefore, it is most important to evaluate the tradeoff between "good" service and low cost by other means.

A repair center is a very complex queuing situation. The customer base varies by time of day and day of week. There are different service engineers (servers) of varying skill (variable service rate) available at different times of day and days of the week. In addition, the dispatching algorithm (queue discipline) is extremely complicated. Simulation is the best approach to this problem because the number of variable parameters preclude an analytical approach.

Assumptions

All repair centers operate in the same general way to service unscheduled demand maintenance:

1. A customer's equipment fails, generating a demand call.
2. Several decisions must be made:
   a) Who is sent to repair the failure?
   b) In what order are failures repaired?
   c) When is assistance required?
3. A service engineer travels to the site, repairs the failure and either returns to the office or goes to another site.

It was possible to write a simulation model of a repair center in a skeletal form using common characteristics where possible and then input data on the specific repair center under study to initialize the model. The assumptions are that all similar devices (tape drives, disc drives, c.p.'s) have the same MTBF and all service engineers who have similar skills have the same MTTR's. Time and labor were saved by taking this approach since otherwise a different model for each repair center would have been required.

The repair center simulator was subdivided along the lines of the repair center operation on unscheduled demand maintenance as follows:

1. A subroutine whose output is random unscheduled failures generated according to the operating schedules of the customers and their system configuration.
2. A dispatcher simulator that assigns service engineers to answer the unscheduled failures generated in Subroutine 1. This section of the simulator is catalogued in "Standard" dis-

2\. (Cont.) patching routines but the ability to develop a new routine exists at all times. This subroutine also keeps track of the progress of service engineers on failures and sends additional men as required.

3\. The third subroutine simulates the service engineer traveling to the failure, repairing it, and then traveling to his next assigned location.

The repair center simulator accounts for only unscheduled demand maintenance. In addition, the service engineers perform preventive maintenance, install equipment, install field changes, and other direct and indirect work. By analyzing the demand workload only, one assumes that other work performed has no effect on mean response time (average queue time), utilization (for unscheduled work), and overtime for unscheduled work. As long as sufficient time remains for these other tasks, this approach should be valid. Essentially the repair center is a parallel channel queuing process with a variable number of channels; each with a different service rate. Consider the following queuing situation; a parallel channel queuing process with variable number of channels with a maximum fixed at M. If there are N customers in the queue an additional channel (up to M) is added to serve the first in line. The channel is removed when the number in queue is less than N. It can be shown that when N = 1 this situation is the same as a fixed multiple channel model.[1] In the repair center, response time is a critical parameter and almost always of very short duration. A unit in queue will only wait for a very short time before a service engineer interrupts another task and answers the demand call. In light of this, it is felt that the simulation of only demand maintenance is valid.

Language

The model was written in GPS K. (General Purpose Simulator K is a discrete simulation software package offered by Honeywell Information Systems, Inc.) This language was selected because of its suitability for simulating a queuing environment. Debugging was made easier due to the keyboard inquiry ability of the GPS K package. It is possible to examine the model while it is running (number of transactions in a queue, facility utilization, number of transactions in a block, variable value, contents of a savevalue, etc.) via the operator keyboard in order to find out if the model has a logical error without running to completion. Also the simulation run can be ended at any time with normal completion statistics. Repair center simulations are presently being run on a Honeywell 1250 with 131K of memory, but simulations of limited sized repair centers have been run on 65K. The basic unit of simulated time is one-half hour. Using a Honeywell 1250, a three month simulation requires about 30 minutes of machine time.

Description of Model

Input data required in order to simulate a given repair center originates in two places. Failure (MTBF) and repair (MTTR) statistics are from reports on all similar devices (tape drives, printers, central processors, etc.), installed in the U.S. Additional information is available from the local manager about his repair center. We found that having the manager supply data is also an effective way to help him develop an understanding of simulation and build his confidence in the model's accuracy.

We developed probability distributions of time of day a failure of a computer system may occur, given the system is in operation T hours per day and a failure occurred. For simplicity we limited T to (8, 10, 12, 16, 24). A typical distribution is shown in Figure 1. It is obvious that the failure rate is not constant during the interval (O, T) but is dependent on time from start-up.

We made the assumption that time between failure is exponentially distributed. The hyperexponential distribution[2] (1) fit our historic data equally well for the few devices it was tested on.

$$f(x) = p\theta_1 e^{-\theta_1 x} + (1-p)\theta_2 e^{-\theta_2 x} \quad (1)$$

The rationalization for the possible use of the hyperexponential distribution is that there are two types of repairs that

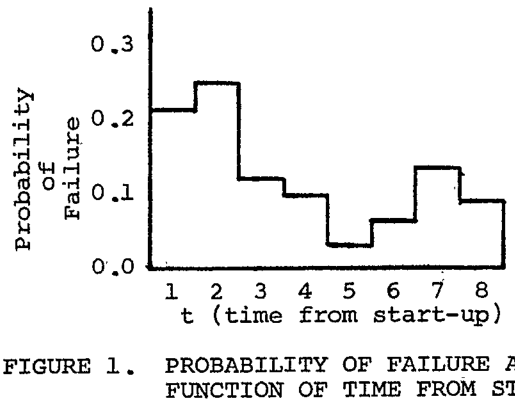

FIGURE 1. PROBABILITY OF FAILURE AS A FUNCTION OF TIME FROM START-UP

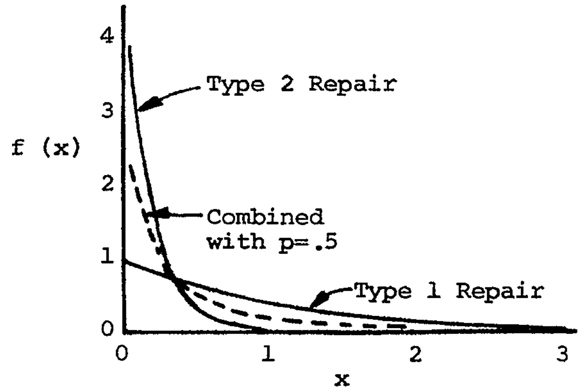

FIGURE 2. HYPEREXPONENTIAL DISTRIBUTION

can be made to correct the failure: the correct repair (Type 1) and a less reliable repair that also erases the failure (Type 2). (This can be thought of as generating a repeat call.) Thus a service engineer solves the problem with a Type 1 repair with probability p and with a Type 2 repair with probability (1-p). A Type 1 repair generates a mean time between failure of $1/\theta_1$, and a Type 2 repair generates an MTBF of $1/\theta_2$. This is shown in Figure 2. In order that we would not have to estimate p, θ_1 and θ_2 for all devices and skill levels, the exponential distribution was used for time between failures on all devices. In the near future we will use the hyperexponential distribution for time between failures which will allow us to utilize an additional variable, p.

Time between failure and time to repair distributions were compiled for each device and model (tape drive, disc drive, etc.). Similar devices and models were then combined to give approximately 26 different categories of devices. The repair center manager inputs the complement of each customer's system and the operating hours of the customer.

The information on system parameters and the probability distributions of time of day of failure and days between failure are combined in Subroutine 1. The output of this section of the repair center simulator is:

a failure
of device i
on system j
on day k
at time l
of apparent difficulty m

Difficulty is classified as easy, medium, or hard based on the device that failed. For example, it is more likely that a failure in the central processor will be classified as hard than a failure in a card reader.

The next step in the model is to decide who will repair this failure and when. The information required at this point is:

1. Which men are available?

2. What is their skill on this device?

3. How far are they from the failure?

The process of assigning men is called dispatching. The model makes no attempt to optimize the dispatching algorithm. A partial list of algorithms that can be used follows:

1. Closest man
2. "Best" man
3. Shortest job first
4. FCFS
5. FCFS within class of customer
6. Use minimum number of available men
7. Zone coverage

The output of this section of the repair center simulator is an assignment of a service engineer to answer a failure call. The service engineer then travels to the site and repairs the failure. This simulation is Subroutine 3.

The model handles repair times in a somewhat unusual manner. Because of the vast amount of detail data required and because more experienced personnel tend to be dispatched to the more difficult calls, we have not determined a statistically significant difference in mean time to repair of field personnel of different skills (time in field, ability, training). A basis for promotion of personnel is that ability increases with experience and intuitively one feels that experience leads to faster repair times. In line with this, the following method of assigning a repair time to a demand maintenance call was developed.

The time to repair is dependent on the skill of the repairer and the difficulty of the failure. Difficulty of call was classified into one of the three categories"

1. Easy

2. Medium

3. Hard

All personnel have a skill rating on each device:

1. Below average
2. Average
3. Above average

Table 1 shows how the resultant nine (9) combinations of skill and difficulty were classified into five (5) mean times to repair. (The distribution is exponential in all cases.)

TABLE 1

MEAN TIME TO REPAIR AS A FUNCTION OF SKILL AND DIFFICULTY OF CALL

		Skill of Repairer on Device		
		Below Average	Average	Above Average
Difficulty of Call on Device	Easy	3	2	1
	Medium	4	3	2
	Hard	5	4	3

The assumption is that the time to repair distribution for an average skill man on an easy call and an above average man on a call of medium difficulty (on the same device) is the same. (Case 2) The relationship between 1, 2, 3, 4, and 5 is:

$$x_j = a_j x_3 \qquad (2)$$

x_j = MTTR for Case j

j = 1, 2, 3, 4, 5

where x_3 is the historic MTTR and $a_3 = 1$. The time to repair is then picked randomly according to the appropriate distribution.

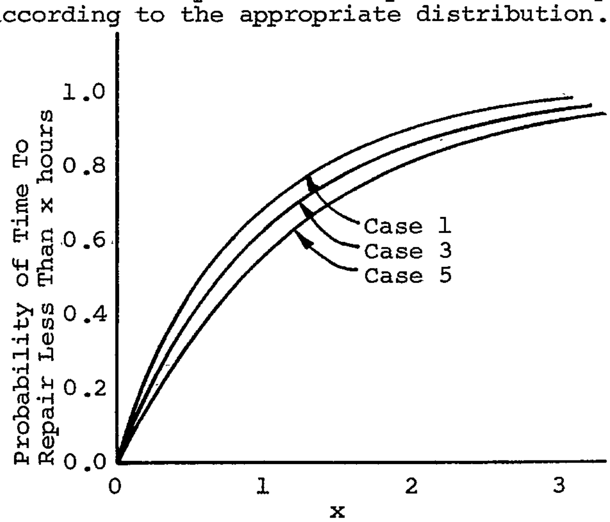

FIGURE 3. CUMULATIVE TIME TO REPAIR DISTRIBUTION

Figure 3 shows cumulative time-to-repair distributions for Cases 1, 3, and 5 for unit MTTR and a = (.8, .9, 1.0, 1.1, 1.2). This chart demonstrates that the better suited the service engineer is for the call, the lower the probability that the time to repair will exceed a fixed limit (say 2 hours).

Communication with Management

In order to make effective use of the model, a manager should understand what simulation is. Therefore, the repair center managers were instructed on how a computer model of the operations of a repair center is run over time (thereby simulation) and how the results indicate what the real life situation is likely to be. In addition, this procedure gave the manager confidence in the usefulness of the model. To use the repair center simulator, the existing situation is modeled to establish validity and then the model is run with altered parameters. The manager of the repair center is taught how to evaluate the differences between the two cases.

A listing of simulated unscheduled maintenance calls is one aspect of the output that has a strong effect on the acceptance of the results of the model. It is an encoded record of all unscheduled work that was performed in the simulated repair center. Figure 4 is a partial sample listing of this type of output from a repair center simulation run. It can be seen that the unscheduled workload for Tuesday, the 45th simulated day is:

a printer failure on system 3
a console failure on system 2
a card reader failure on system 2
a card reader failure on system 11

Review of this type of output enables the manager to see that the daily workload of the simulated organization is typical and that the simulation model operates similarly to actual operation.

Output

The output of a run of the simulation model of a specific repair center for a given length of time can be classified into four basic areas. (Additional output can be generated if requested by the local manager.)

1. Distribution of response time.
   a. Probability distribution
   b. Average response time
   c. 95% limit of response time

2. Service engineer statistics.
   a. Average utilization of the repair center on demand maintenance

b. Individual utilization on demand maintenance
c. Number of times a service engineer needed assistance
d. Number of times a service engineer assisted
e. Overtime

3. System statistics.
   a. Hours down
   b. Percent of scheduled time down
   c. Percent of scheduled time available (systems availability)
   d. Number of unscheduled demand maintenance calls

4. Type 3 call statistics.
   a. Summary of calls
      1. Day of week
      2. Shift
      3. Time of day
   b. Listing of all simulated demand maintenance calls (Figure 4)

Use of the Simulation Model

In order to properly evaluate a change in a maintenance strategy, the precise relationship between response time limit, manpower utilization, and systems availability must be known. The simulation model was used to develop quantifiable relationships between these major parameters of emergency maintenance. The critical factor is response time limit. Response time is defined as the time from failure to the time a service engineer arrives at the customer site. As utilization is increased, (by increasing customer base or decreasing manpower) the probability that all service engineers are occupied in demand maintenance is greater, and hence, the response times will be longer.

To determine the exact nature of this relationship, a study was performed by varying workload in a simulated repair center. Simulations were run for different workloads while all other factors (service engineer skill levels, repair times, and schedules) were kept constant. All customers were handled similarly in the model with no special priorities. A demand call was responded to by the available service engineer whose skill best matched the difficulty of the call according to the priority schedule shown in Table 2.

TABLE 2

PRIORITY OF SERVICE ENGINEER ASSIGNMENT

		Priority 1	Priority 2	Priority 3
Difficulty of Call	Easy	Below Avg.	Avg.	Above Avg.
	Medium	Avg.	Below Avg.	Above Avg.
	Hard	Above Avg.	Avg.	Below Avg.

Each simulation was run for a 13 week period and the call arrival rate ranged from 1/2 to 5 times normal.

Figure 5 shows the relationship between response time constraint and attainable utilization for unscheduled demand maintenance. Within a given response limit, the corresponding utilization for unscheduled demand maintenance can be attained only if sufficient time remains for the performance of other required tasks. If sufficient time does not exist, then additional manpower would be required, thereby lowering the attainable utilization (but surpassing the response constraint).

In addition this graph clarifies the meaning of response time constraint and its relationship to system availability. Systems availability is defined as follows:

$$SA = \frac{1 - N * (\bar{R} + MTTR)}{T} \qquad (3)$$

where, N = Number of failures
$\bar{R}$ = Mean response time
T = Scheduled operating time

At point A, 95% of the failures are responded to within 4 hours with an average response time of 1 hour. Thus if a customer's system fails he can expect it to be down for 1 hour plus MTTR. At point B the mean response time is 4 hours, and 95% of the calls are responded to within 12 hours. At this point a customer can expect his system to be down for 4 hours plus MTTR for each failure.

The expected increased utilization of the service engineers at a longer response time limit (point B) must be evaluated with the increased expected downtime (lower system availability) of the customer's systems. The importance of the response constraint is apparent. The limit of utilization for demand maintenance is determined by the response characteristics that are acceptable to the customer.

The repair center simulator has also been used to provide information to enable repair center managers to:

1. Decide on organization changes such as realignment of repair centers within a city.

2. Evaluate changes in response time characteristics and overtime caused by changing manpower or the customer base.

3. Evaluate benefits of various dispatching algorithms by trying several simulations of a specific repair center.

Conclusion

Continued development of the repair center simulator will expand its area of application. We anticipate using the repair center simulator to improve manpower scheduling. In addition, when we include additional variables in the model it will be possible to evaluate the impact of maintenance options in new products and to improve operations by simulating spare parts deployment.

We have been encouraged by the degree of acceptance that simulation has achieved in our organization. Those managers that have utilized the repair center simulator are very enthusiastic about it and its use is increasing. Repair center simulation has become an extremely valuable tool to evaluate alternate operating procedures.

References

1. Saaty, T.L., Elements of Queuing Theory, New York, McGraw Hill, 1961.

2. Ehrenfeld, S. and Littauer, S.B., Introduction to Statistical Method, New York, McGraw Hill, 1964.

Failure Number	Call Time	Answer Time	Compl. Time	S.E./ Assist	Difficulty/ Skill	Device/ System No.
135	19540	22540	26540	30	230	1018
136	27540	28540	29540	70	110	1906
137	48540	2641	2641	40	220	1515
138	17641	18641	21641	30	130	1905
139	22641	23641	23641	70	120	1004
140	2742	3742	10742	31	133	1620
141	9143	10143	11143	20	230	716
142	[illegible]	[illegible]	[illegible]	20	130	1003
143	244	[illegible]	[illegible]	70	[illegible]	[illegible]
144	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]
145	[illegible]	18244	21244	10	[illegible]	[illegible]
146	17244	19244	20244	30	[illegible]	1601
147	[illegible]	21244	21244	30	[illegible]	1502
148	[illegible]	22244	25244	[illegible]	[illegible]	[illegible]
149	15345	18345	19345	10	230	1003
150	17345	19345	20345	30	[illegible]	1202
151	21345	23345	26345	70	220	802
152	24345	25345	28345	30	130	611
153	18446	19446	19446	30	230	912
154	20446	[illegible]	[illegible]	10	230	1512
155					123	1106
156					213	1818
157						
158	[illegible]			71		
159	1648	[illegible]	[illegible]	40		
160	17648	19648	19648	30	[illegible]	
161	23648	24648	34648	71	223	804
162	25648	26648	26648	30	130	1509
163	17749	18749	22749	30	230	804
164	25749	26749	32749	31	133	106
165	32749	33749	45749	31	333	515
166	17251	18251	24251	31	233	1007
167	17251	18251	18251	10	230	1018
168	17251	19251	19251	10	230	1215
169	18251	20251	20251	10	130	518
170	24251	25251	26251	70	220	807
171	27251	28251	30251	30	230	1707
172	33251	35251	36251	70	120	1017
173	17352	18352	18352	30	130	1018
174	24352	25352	25352	70	120	716
175	27352	28352	29352	70	110	113
176	17453	18453	18453	30	230	718
177	17554	18554	20554	30	230	804

7 A.M.

Tues.

45th Simulated Day

Service Engineer No. 1

System No. 3

Printer

Skill of S.E. No. 1 on Printers (Above Average)

Symptom Difficulty (Medium)

FIGURE 4. SAMPLE LISTING OF ENCODED RECORD OF UNSCHEDULED MAINTENANCE PERFORMED IN A SIMULATED REPAIR CENTER

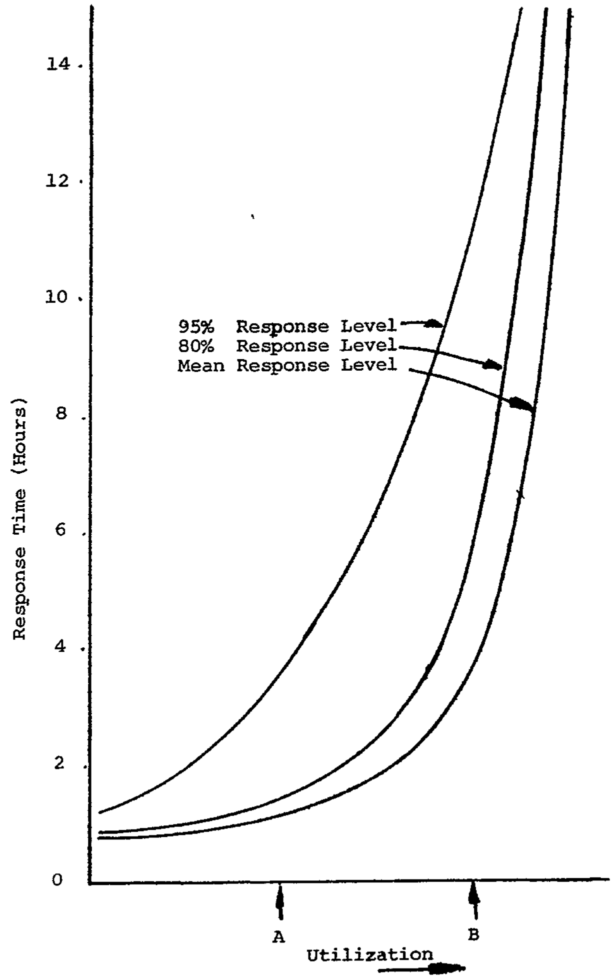

FIGURE 5. RESPONSE TIME VERSUS ATTAINABLE UTILIZATION