# DIGITAL SIMULATION OF MAINTENANCE SERVICE OPERATIONS IN THE COMPUTER INDUSTRY

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## Abstract

The increased complexity of computer-communication hardware, the wide dispersion of remotely linked computer terminals, and the strict requirements of operational efficiency of direct-access information systems place a great deal of strain on the EDP maintenance organization. It is no longer possible to maintain a profitable position while managing EDP maintenance with the "rule of thumb" decision making process. The generalized model presented in this paper provides an approach to effective utilization of both field maintenance work-force and redundant EDP equipment. The model handles field technician dispatching and service facility allocation so as to meet the requirements of the EDP customer population at a predefined level of service satisfaction.

## INTRODUCTION

### Formulation of the Problem

The study of the complex service systems has been an important research area in the production and transportation management field for some fifteen years. The earliest works centered upon abstractions of certain job-shop type production sequencing problems as static and deterministic problems. Dissatisfaction with the static and deterministic nature of the combinatorial sequencing approach led some researchers to the formulation of dynamic queueing models for studying job-shop production systems. A number of problems involving queues can be solved mathematically. However, most of the solutions obtained are limited to problems of a single activity servicing exogenous arrivals into a queue. Most activities in a real life situation receive their input from the output of other activities and the conditions of a mathematical solution are not applicable unless considerable simplifying assumptions are made.

A majority of the work, to date, has been directed toward deterministic demand service systems, such as the classical job-shop scheduling problem. This paper will be directed toward complex stochastic demand service systems such as transportation systems, large-scale production systems or hospital service systems. Because of many recent advances in its theory and applications, digital simulation is well established as one of the more powerful techniques of operations research. The complexity of large-scale maintenance service operations involving a great number of service men, machinery and customers and the many problems confronting managers of these operations suggests the desirability of intensive use of computer-aided simulation analyses.

However, simulation of maintenance service systems is not utilized as frequently as could be expected. The literature on the subject is rather limited and appears to predominantly cover maintenance operations of aircraft and of complex weapon systems. There are no studies, as far as the author could ascertain, in the field of maintenance of complex systems such as electronic data processing equipment. The sustained growth of computers, which in the continental United States has reached, to date, a population of over 60,000 systems, the increased complexity of computer-communication hardware, the wide dispersion of remotely linked computer terminals, and the strict requirements of operational efficiency of real-time management information and control systems, place a great deal of strain on the EDP maintenance organization.

Operations management of EDP maintenance will no longer be able to maintain a profitable position while operating with the "rule of thumb" decision making process. EDP maintenance service, which is often a subject of user complaint, because it is the most visible aspect of the supplier-customer relationship, will continue to worsen unless something is done to appreciably improve prevailing conditions.

The only advisable way by which this can be accomplished is by the design and control of the large-scale EDP maintenance organization so as to make effective utilization of the resources available while continuing to meet customer specified service response time and quality of service.

The paper, therefore, aims at developing a methodology that would make it feasible to use digital simulation techniques in the design of maintenance organizations and in the control of existing maintenance operations.

## ANALYSIS OF COMPLEX MAINTENANCE SERVICE SYSTEMS

Maintenance of computer systems presents a whole range of special problems. Complexity of the system is accompanied by the digital nature of the devices which accounts for their special character. The normal attitude toward data processing equipment is that it must behave like a "perfect" machine. The contribution of complexity, from a maintenance viewpoint, may be principally one of reduced reliability, because of the large number of parts that can fail, as well as the difficulty of understanding the total system structure on the part of the user and maintenance personnel.

A second factor reflecting the nature and process of EDP maintenance is that the typical data processing system is actually a large configuration of many distinct subsystems interconnected to form a single system. Units such as central processors, tape drives, printers, typewriters, drums, disk files, communication interfaces and terminals, are often of distinct manufacture and employ different technologies. These devices have their own maintenance problems, which for medium and large scale equipment, are characterized by a large incidence of electro-mechanical failures. The electro-mechanical content of the "typical" data processing system delivered today represents the most sizeable portion of the investment made by all parties, particularly the maintenance function.

From a management viewpoint, the organization objectives of a Field Engineering Department (FED), i.e., the field organization, are to provide efficient and effective maintenance service for EDP equipment users served by the company, and maintain pre-set profit objectives and equipment performance goals.

The analytical approach used in this paper includes a thorough study of most common EDP maintenance organization structures, remedial (emergency) maintenance practices from a management viewpoint, functions of repair message handling operations, dispatching practices for assignment of field personnel and logistics aspects of deployment of field technicians.

## FORMULATION OF A DESCRIPTIVE MODEL

The formulation of a descriptive model of large-scale EDP maintenance operations stipulates system parameters that provide the operating mode of the maintenance service system, and describes means for developing the system organization. The service system that is explicitly modeled interacts with what can be termed a network of EDP installation sites. It becomes then mandatory to study the customer site environment and the various forms, requirements, and service time responses that this environment requires.

The EDP installation site is described, for reasons of simulation, as to type and number of devices installed, its geographical location, its proximity to other sites, the clustering effect of sites placed in areas of varying density, or whether it belongs to service areas far remote from the service points serving the region considered. Sites with multiple installations are also considered, as well as availability of spare devices (redundancy of equipment) at specific sites. Figure 1 illustrates a possible configuration of sites, clusters and service points of a typical region.

The structure of the maintenance service organization must be designed not only to respond to the user environment requirements but also to be sensitive to such planning variables as forecasts of equipment delivery to the field, probable type and class of installations and type of service response class. The latter is forecasted according to the type of user, company, or business expected to operate in predetermined industrial and business areas of the urban region examined by the model.

The service organization modeled also accepts such aspects as initial deployment of service men, criteria of dynamic dispatching of men in the field, and standards of field work performance. Tracking of each team of field technicians is performed by the model during normal day-shift operations, overtime periods or second and third shifts of work. Daily schedules also consider lunch periods, week-end periods, and variability in travelling segments of the field work, due to different traffic conditions that may prevail at specific times during the day. EDP maintenance operations and relative dispatching of men revolve primarily around emergency or remedial maintenance work. It is the purpose of emergency maintenance to keep EDP equipment at a high level of performance and customer satisfaction. Figure 2 shows the general system model diagram for equipment emergency maintenance.

## GENERALIZED MODEL OF THE EDP MAINTENANCE SYSTEM

On the basis of the formulation of the descriptive model, a generalized simulation model for EDP maintenance service can thus be organized. The basic field engineering philosophy is on-call maintenance, i.e., fast response or reaction to a customer call for service.

Exogenous calls coming into the system, originating from a population of customer sites, are transmitted through public telephone facilities to an <u>Emergency Message Receiving Center</u>. The times at which repair calls originate or breakdown events occur during simulation are specified in the model and determined by one of the following processes:

1. Deterministic Schedules
2. Deterministic Schedules with superimposed random variations
3. Stochastic originations

Looking at Figure 3, a time and sequence diagram traces the chain of events occurring between equipment breakdown and departure of maintenance man after the malfunction has been repaired.

After calls are accepted, going through the first service queue, they are channelled to the dispatcher station where they wait to be assigned. Various decision rules can be utilized in dispatching the men to the sites requiring repair service. For example, first-come-first-served discipline and priority disciplines can be applied.

<u>The Logistic and Servicing Subsystem</u> takes into consideration, by explicit modelling, all field operations that have to do with routing rules and travel of men from site to site or two-way travel from service center to site. Operating schedules of service facilities may also be included covering both the queue and server elements of the components in the subsystem. Eligibility conditions resulting from the interfacing of the servicing subsystem with the customer site may apply, such as whether customer site is accessible after normal work hours or whether repair work cannot be done because of a spare part or replacement part not available at site.

Among the system operating rules, repair service times represent a significant portion of the model dynamics. The simulator is capable of utilizing either

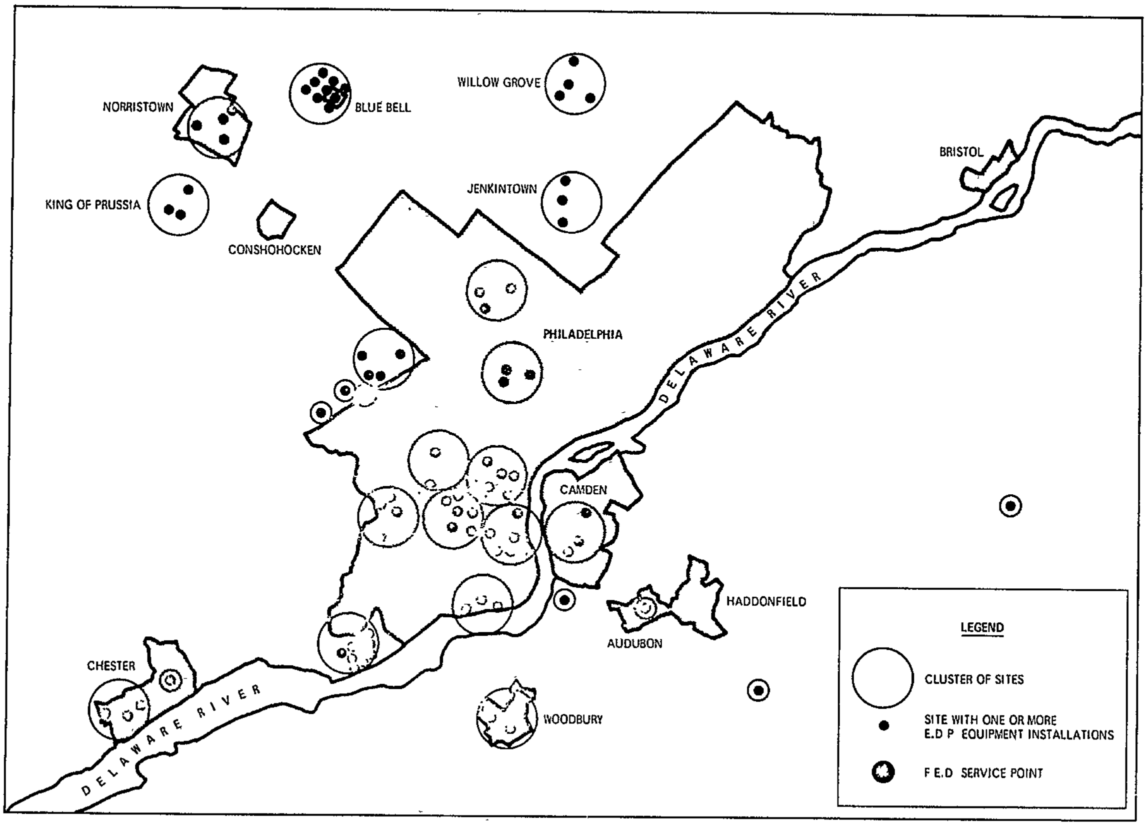

Figure 1. Equipment Maintenance Simulation Model Logistic Diagram

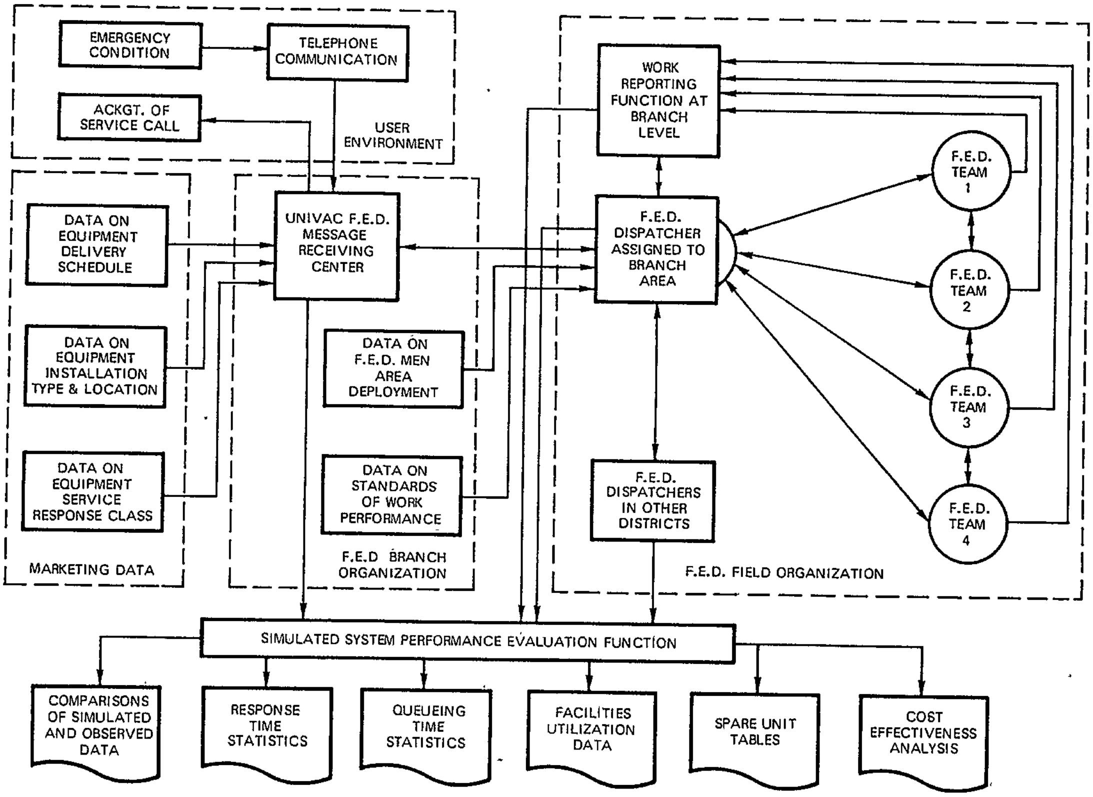

Figure 2. General System Model Diagram for Equipment Emergency Maintenance

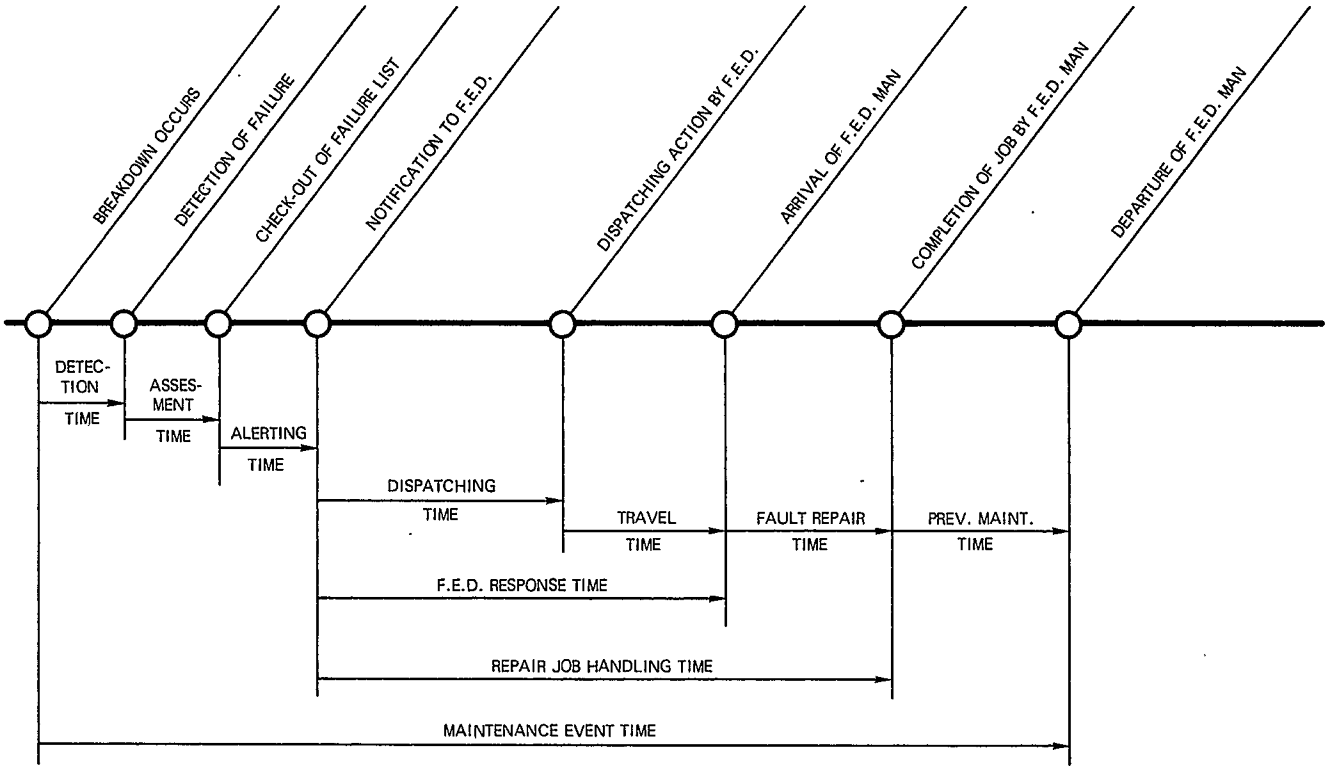

Figure 3. Equipment Maintenance Service Model Time and Sequence Diagram of Maintenance Event

deterministic service times or stochastic times obtained from specified probability distributions by Monte Carlo sampling. Whether deterministic or stochastic, the service times may be expressed as parametric functions of system or non-system variables if required to realistically represent the performance of the system.

The simulator can accept input data on EDP sites in any of the following forms: (1) Estimates, obtained from experienced EDP maintenance personnel or obtained from engineering estimates; (2) Empirical Data, obtained from historical records available in FED organizations, or obtained by field measurement sampling actual performance; (3) a combination of the above sources.

The generalized model of the EDP maintenance function represents the physical flow of repair call messages through the service system and movement of field service men, parts support logistics and service center operations. Its output provides measures of performance, such as service response times, degree of congestion at service points, duration of delays, utilization of facilities, et cetera.

Determining the typical performance of a system is of fundamental importance in any analysis, as there can be no rational planning, operation or control of the system unless the physical performance is known. This knowledge is required to evaluate the effect of changes in system design, policies, operating rules, and so on.

In large-scale systems such as those providing maintenance service for complex EDP equipment, the physical performance of the system is not sufficient. It has to be complemented by an economic analysis to provide an adequate basis for managerial decision making. Therefore, a simulation methodology such as the one treated by this paper, which provides for both physical performance and economic analyses of a system, is applicable to a large range of problems and becomes a more powerful Operations Research tool.

A Cost-Effectiveness Analysis Module of the Simulator processes economic information as the simulation of physical operations progresses. It aims at translating physical operations into dollar values of cost. Cost may be labeled as variable, semi-variable or fixed. The model treats variable costs in relation to unit-by-unit, service-by-service performance of the EDP maintenance organization. The semi-variable and fixed costs are usually applied to the aggregate performance of the system and its components.

A partial classification of costs analyzed by the model includes costs of waiting for service, costs incurred by providing for service, and costs of being in the system while service is performed. The cost effectiveness analysis involves the determination of these cost values to provide a good framework for the study and heuristic improvement of the service system.

As to the specific structure of the cost effectiveness analysis module, an important consideration to make is that the model can analyze costs of different system components at different levels of detail, not necessarily similar to the levels used in simulation of physical performance. The costs handled will relate to the operation and ownership of facilities, cost of labor and costs which are a function of time elapsed or a function of amount of use.

Other costs that could be handled with extensions to the model include cost increases in expediting and supervision when there are FED manpower units idle in the system or facilities not used. Deterioration in customer relations and consequent lost revenue from EDP equipment rentals and services, because of slow response time in providing maintenance, can also be evaluated.

The tabular and graphical displays that can be produced by the model cover comparisons of simulated and observed performance data, response time statistics of services rendered, queueing time statistics, data on utilization of system resources, tables of spare unit deployment (system redundancy versus allocation of services) and cost effectiveness analysis data.

Summary reports are also produced at any specific time during the simulation to present a concise picture of the system and its components. The reports are optional and may be produced at any desired time and as frequently as necessary during the simulation. The user of the model can specify whether the summary report is to cover the performance of any or all of the system components as required by the analytical objectives.

Output data can be during simulation accumulated to cover (partial list):

1. Time period(s) of simulation in work-days and work-weeks.
2. Number of service calls entering the system.
3. Average number of service calls waiting in queue (at any one of the service points).
4. Maximum and minimum number of service calls waiting in queue over simulated period.
5. Cumulative number of service calls that have waited in queue.
6. Average time spent in queue by those service calls that had to wait.
7. Cumulative total time spent in queue for all calls.
8. Number of FED men or operators in service.
9. Average time spent on travel by FED men.
10. Average time spent on repair (emergency) work by FED men.
11. Average time spent on preventive maintenance work by FED men.
12. Average utilization of each FED man and of each service facility.
13. Total loading levels at each FED service center.
14. Total service capacity levels at each FED service center.
15. Total number of service calls accepted by system and completed.

The model can track performance from the very first event at the start of the simulation to show the initial conditions of the system. Alternatively, it can start measurement when possible transient conditions are overcome and steady state behavior of the simulation process has been achieved.

## DECOMPOSED HEURISTIC METHODOLOGY

Up to this point the author has developed a "classical" simulation model — classical in the sense that one has to perform a number of intuitive trial and error simulation runs in order to hopefully arrive at a "satisficing" solution to the problem. There is no intention made here, by the author, in any way to debase current simulation practices. On the other hand, the author believes that coupled with the development of more sophisticated and powerful simulation languages should be equally powerful and sophisticated operational simulation methodologies. For, when the number of variables within a simulated system is large, it becomes extremely costly to test various points of the sample space consisting of feasible alternatives. In fact, as the number of variables increases linearly, the possible combinations in the solution space increases geometrically. Therefore, if our model consists of n discrete variables which are bounded by all integer values between $q_i$ and $r_i$ ($i = 1, 2, 3, \ldots n$) inclusive, $\prod^{n} (r_i - q_i + 1)$ possible legitimate combinations of system variables exist.

For example, 1000 variables, each having 5 possible states, would produce $5^{1000}$ permutations of alternative solutions.

The methodology employed in this model, which is similar to the decomposition principle in linear programming, isolates each subsystem of the model through the process of environmental decoupling. Each subsystem, therefore, tries to individually optimize its own objective function while operating under a common simulated environment. Following a computer run, the model heuristically chooses the minimum cost (or maximum profit) state of each subsystem; readjusts all system parameters to conform to the current feasible solution; and then proceeds to again simulate, using the newly defined system configuration as the next common environment. This iterative procedure continues until the (N+1) st solution is no longer statistically an improvement over the Nth solution. Employment of this technique drastically reduces the number of simulation runs necessary to arrive at an acceptable problem solution. Instead of $\prod^{n} (r_i - q_i + 1)$ simulations, one need only have a single run, as a result of the isolation objective function criterion, which evaluates $\sum^{n} (r_i - q_i + 1)$ alternatives.

Although one may intuit that this decoupling procedure would lead to unrealistic results, this is not the case. Classical simulation testing about the vicinity of the heuristically obtained solution yields less than one percent improvement in the overall objective function.

Another interesting fact is that the final system configuration is almost independent of the initial model loading. Regardless of the extreme conditions imposed upon the initial system environment, the model tends to rapidly converge to a near-common solution. The number of iterations can be somewhat reduced by using statistical approximations in statically loading the model. Figure 4 illustrates various rates of cost convergence based upon different initialization values (each link represents a single heuristic iteration).

## CONCLUSIONS

With the increasing complexities encountered in current system design and control, classical simulation procedures are rapidly becoming useless in arriving at satisfactory solutions to management problems. As a result of the cost of computing facilities, the manager must be satisfied with evaluating a very small fraction of the possible solution space and choosing the "best" alternative, from what could possibly be a very poorly chosen representative sample. This is not the fault of the system analyst. It is impossible for him to be cognizant of all interrelationships and trade-offs among the masses of variables present in any system of a reasonable size. He therefore simulates; alleviates new problem areas which may or may not have been caused by his corrections to the system on the previous simulation; resimulates; until he is constrained by either the project budget or the time limit imposed by the manager's need to make a decision.

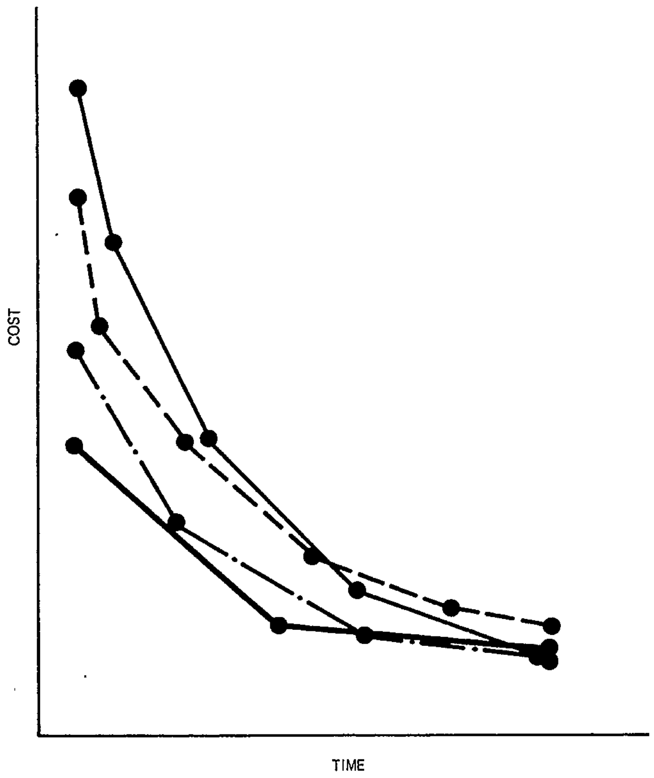

Figure 4. Heuristic Convergence

Summarizing, the author has presented in this paper, in conjunction with a complex maintenance simulator, a methodology for enumerating a significantly larger portion of the solution sample space, which has to date only been utilized for simple job-shop and network flow problems, at a low cost of computer facilities employment.

## THE AUTHOR

Mr. Dzubow received his Bachelor of Science degree in Commerce and Engineering Sciences from Drexel University in 1966 and the Master of Arts degree in Business and Applied Economics from the University of Pennsylvania in 1967. He is currently working on his Ph.D. dissertation at the University of Pennsylvania in the area of Logistics Design and Control of Maintenance Service Systems.

At Univac, as an Operations Research Analyst, he is mostly concerned with the application of management science techniques, especially digital simulation, to the solution of organization, tactical and operational problems.

Mr. Dzubow has published papers on simulation of manufacturing processes and inventory control. He is also an Adjunct Assistant Professor in the department of Information Sciences at Temple University where he instructs in the areas of computer languages, management information systems, and computer simulation.