SIMULATION OF INSTITUTIONAL BEHAVIOR IN A NATIONAL NETWORKING ENVIRONMENT

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ABSTRACT

Computer networking is often mentioned as being an attractive means for bringing a varied and economical mix of computing services to the nation's researchers. Technically, a national network linking major universities and research institutions is feasible today; however, the economic, political, and organizational implications of such a network have not been established.

To this end a computer simulation model has been constructed to permit investigation of the behavioral rather than the technical aspects of such a national network. Data for the study is being provided by 18 participating institutions around the country, permitting a realistic representation of the variety of capabilities, requirements, policies, and decision rules that exist at such institutions. The design goals and the operational characteristics of this network model are described in the first portion of the paper.

Using the simulation model, eleven areas of investigation pertaining to network performance and behavior have been identified. Five of these topic areas (standard performance, site specialization, network stability, network resource-sharing potential, and service pricing policies) are particularly relevant to questions of institutional behavior and impact and have been the subject of a pilot program of experimentation. The organization of these preliminary investigations and the experimental findings obtained to date are discussed in the last portion of the paper.

I. INTRODUCTION

Decision makers at educational and research institutions are grappling with difficult questions about how to best satisfy the expanding and increasingly varied demands for computing services. It is clear that, although user demands will continue to grow, the cost spiral must be controlled. Technological advances in micro- and mini- computers and in large-scale hardware facilities will not, in themselves, be sufficient to satisfy economically the requirements for access to a greater variety and sophistication of services.

Networks offer a very attractive means for improving the efficiency and effectiveness of computing (1). The report of the deliberations at a NSF-sponsored series of General Working Seminars on computer networking held in 1972 and 1973 (2) concluded that it is now technically feasible to create a network of computer facilities at colleges, universities, and research institutions around the country. Although some technological problems remain, the primary difficulties confronting such a network were viewed as being nontechnical in nature. In particular, economic, political, and organizational factors were considered likely to pace the development of a successful network. In order to deal with these issues, it is necessary to have a clear understanding of the potentials, limitations, and implications of networking.

Existing networks can provide an indication of the costs and technical characteristics that might be associated with a national network. They do not indicate, however, how a dynamic national networking environment would affect member institutions in terms of economic, organizational, political, and intellectual considerations. Nor is it known how these effects would vary with the particular computing philosophy, policies, and practices of each institution. For example, what changes would a network bring to instruction, research, science information, or administrative computing? What would be the impact of "balance of payments" problems? How would users be affected by the availability of multiple resources at a variety of prices? What changes would take place in the types of computing resources developed or maintained by an institution? What impact would a network have on established institutional policies?

The characteristics of a network and the ways it might evolve in the light of collective institutional choices also need to be examined. What policies relative to the network must be established by university resource managers, users, and top-level decision makers? To what extent and in what areas would centralized management of the network be required? What contractual arrangements should be made among buyers, suppliers, and network administrators? How should prices be set? How should invoices for services rendered be handled and accounts paid?

These questions can best be resolved in an environment in which the implications of such policy questions can be observed in concrete terms. Moreover, that environment should not be constrained by a priori solutions to these issues so that questions of network management and control could be subject to experiment and change.

No existing network has the necessary characteristics to examine all of these important issues. Further, using a real network to examine these issues, while providing concrete results, would pose a number of problems. Experimenting with an actual network would be extremely costly, would take several years to complete, would severely restrict the approaches and alternatives that could be investigated, would disrupt the normal operation of both the network and its institutions, and would require significant commitments of intellectual and other resources by each institution.

In recognition of these difficulties, a simulation approach was proposed for studying the behavioral and policy aspects of such a national computing network. The objective was to develop a model sufficiently detailed to represent the nontechnical conditions that might prevail in a real networking environment. The simulation approach would explore the potential impact of the network upon member institutions, as well as indicate the effects upon the network of decisions and policies of participating institutions. A simulation approach would also provide flexibility as to the types of networking situations considered and allow for the testing of a variety of alternatives at a relatively low cost.

Developing a large simulation model is a complex and difficult undertaking and must be carefully planned if it is to be effective. To do such planning, EDUCOM* brought together a group of eight individuals knowledgeable in the areas of model building, gaming, economics, resource administration, and educational computing. After an initial feasibility study, National Science Foundation support was secured for an intensive planning study (NSF grant GJ-41429). Over a six-month period, assisted by the EDUCOM staff, these individuals established the specific goals and objectives for such a simulation and gaming project, outlined the data to be collected, selected the initial participating institutions, determined the level of detail and framework of the basic network model, and prepared a detailed plan for the actual conduct of the project. This information is set forth in the project report (4) to the NSF.

EDUCOM subsequently submitted a proposal to NSF to implement that research plan over a three-year period. A grant was awarded (NSF grant DCR75-03634), and the project began in the spring of 1975. The first phase of the project included construction of the basic network model and an investigation of network performance in response to various operating environments and patterns of institutional behavior. This paper reports upon the simulation model that has been developed and upon the results achieved from the preliminary experiments utilizing that model.

The next section describes the basic objectives of the project, while the following section describes the characteristics and capabilities of the simulation model. Section IV describes the types of analyses that are planned, and Section V sets forth the results obtained to date from preliminary investigations employing the network model.

Further information about the simulation and the research results obtained may be found in the phase one project report (3) to the NSF.

II. OBJECTIVES

The project intends to provide a simulated environment in which two principal objectives can be pursued. The first objective is to explore the parameters that govern network behavior and to isolate and examine those elements critical to network success or failure. The second objective is to provide assistance to institutional decision makers in understanding the impact which a national network could have upon their internal process of resource allocation.

The first objective requires investigation of policy and structural issues critical to network behavior. Policy issues include pricing, funds flow, network standards, service guarantees, user support, marketing, and capacity adjustment responses. Network management structures can range from a loose set of bilateral agreements between individual institutions to a highly structured and centrally managed network. Each policy alternative will be examined in light of the various suggested network structures.

The second objective of the study is to improve institutional decision-making ability and establish policies pertaining to national networks. Some of the data already collected indicate that institution administrators often do not have sufficient contact with networks for the establishment of clear policies governing network situations. As a consequence, where policies exist, they are often incomplete or inconsistent and may contain unanticipated implications for the institution or the network.

Results of the model-based investigations should clarify for administrators the present intuition-based conceptions about the impact of their policy decisions. The model will also be employed to study institutional policy positions and to assess the likely advantages and disadvantages of various modes of network participation.

A clearer understanding of network behavior will be useful not only to policy makers at institutions affiliated with this project, but also to a wider audience interested in networks. For example, federal policy makers who are concerned with the effective utilization of the nation's computing resources are likely to benefit from a close scrutiny of network behavior. Similarly, computer scientists and other researchers can use the model to explore various hypotheses about network response characteristics.

* EDUCOM is a consortium of more than 200 colleges, universities, and non-profit organizations that serve higher education. It was founded to help its members make the most effective use of computer and communications technology.

III. NETWORK MODEL

DESIGN GOALS

The basic design goal is to provide a highly parameterized flexible model which permits the examination of a variety of institution and network policy rules in order to study their impact, given various network configurations, management structures, usage modes, and growth patterns.

All policies are represented programmatically as subroutines which are called whenever a policy decision or policy-influenced action is required. Users of the model can therefore describe their sites' practices parametrically by using any combination of policies from a stored policy library or, programmatically, by providing their own decision-making routines. In future project phases, users will be able to specify ad hoc representations by entering decisions on-line. Considerable flexibility is thus available in representing a given institution, and it is relatively easy to modify or expand the internal policy library on a continuous basis.

STRUCTURE

For purposes of design, the model network has been defined as having twenty initial sites. Eighteen of these have been set aside for detailed representations of the eighteen institutions participating in the project. (The actual number of sites to be used in any given run is, of course, an input variable.) One of the remaining two facilities has been designated the "background" site where all work originates that enters the network from other locations besides the eighteen member sites. This site also receives all work destined for non-member locations. This artificial site was introduced to permit representation of the characteristics of a full mature network. The second extra site, referred to as the "network" site, is an artificial site for assigning and relaying non-site-specific work to particular processing facilities. For example, requests to obtain a particular type of processing without designating a specific supplier (e.g., at "lowest cost" or with "fastest turnaround") will be sent to this site for allocation to an appropriate supplier.

The description of each network site contains all necessary policy specifications and decision rules. These deal with such matters as pricing, hardware changes, budget allocations, user support levels, and computer scheduling and priority setting.

The simulation model has three basic conceptual elements: supply offerings (capacity), user requirements (demand), and the balancing of desired demand with available supply (market). Each site on the network is viewed as having specified service offerings and available capacity measured in such terms as processor time, primary memory size, line printing potential, and communications bandwidth.

The demand for, and supply of, computing resources at each site is expressed in terms of computing categories called "service types." Each service type is presumed to include a reasonably homogeneous type of work. While the present forty-eight service types represent an over-simplification of the workload, they are sufficient to adequately represent the supply and demand of network resources. More service types could be added, but model memory requirements would be unnecessarily increased.

The model operates with a basic time unit of one week. Although a week-long time increment precludes use of the model for investigating hour-by-hour variations in the processing loads at individual facilities, this does not preclude the examination of service characteristics having a time aspect of less than one week, (e.g., shift differentials). The 2:00 - 4:00 PM afternoon peak period can still be examined; however, it will be examined on a weekly basis, i.e., the weekly supply and demand for service during that time period. The weekly time interval was selected as being small enough to reflect overall network dynamics, large enough to be computationally feasible, and compatible with typical weekly, monthly, quarterly, and annual decision cycles.

The main time-varying information about network service is stored in a three-dimensional matrix that contains the amount of each service type that each network site requests from every other network site.

CAPABILITIES AND REQUIREMENTS

Execution of the model is possible using but a single run command, with all loading specifications and file descriptions provided by executive procedures. However, the operation of the model depends upon the availability of a fairly large data base describing the characteristics of each network site. Currently, each site requires the input of approximately 300 card records for its specification, in addition to any policy subroutines that might be required. Thus, while operation of the prepared model is quite easy, the user must appreciate the difficulty of collecting and assembling the necessary set of meaningful and consistent data for input to the on-line files.

The model is programmed in FORTRAN IV and operates on IBM 370 series equipment. Currently the model consists of nearly 15,000 lines of Fortran code. The model's memory space and execution time requirements are dependent upon the number of sites to be included in the network and upon the number of services offered. For example, the present simulation of twenty network sites, each with up to forty-eight service offerings, requires a region of 600,000 bytes of main memory.

VALIDATION

DESIGN VALIDATION

One of the major problems in developing a large, complex simulation lies in validating that the model performs according to specifications. Use of a top-down approach, as described in the project report (3), permitted a continuous monitoring of the model from the earliest stages and helped to minimize this problem. For example, at the end of the second week of implementation, it was confirmed that the master module called all the top-level modules correctly, and that all variables and parameters were properly passed between these routines. Hence, the accuracy of the interactions between these modules was confirmed, and it was subsequently possible to treat the expansion of each of these modules separately. In addition, each module was tested to see that it performed according to specification. By continuing this process on a hierarchical basis, it was determined with reasonable confidence that the model was functioning according to design.

IMPLEMENTATION VALIDATION

A major difficulty in validating the simulation was that the network being modeled did not exist for comparison. Accordingly, a series of validating steps were performed. Once the model had passed simple plausibility tests, a single site was chosen as a test vehicle. The model was run as a "one-site network," and the results compared with actual data supplied by the test site. Once the one-site model was validated, the selected site was replicated several times as a multi-site network with identical sites. This permitted validation of the model without network flows. Next, this multiple identical site configuration was altered in a number of ways, in order to validate the areas of the model involved with network flows. First, site data was changed so that computing capacity at some sites was reduced to a fraction of its original value, and proportionate capacity increases were made at other sites. Demand levels were left unchanged. Similar tests were made with reduced prices at two sites to see if demand would gravitate to a site with extremely low prices. Other tests were made with modifications in turnaround and level of support.

The final model validation runs were performed with various site behavior patterns. For example, policies for one site were chosen to exhibit cost-conscious behavior, while those of another site were chosen to exhibit entrepreneurial behavior. A mixture of capacities and services offered at the different sites was also introduced. Following completion of these tests, the model was ready for testing with actual site data provided by the participating institutions.

IV. NETWORK ANALYSIS PLAN

In developing a plan for investigating the institutional behavior and policy aspects of a national computing network, the project team identified the following eleven topic areas as being of particular relevance and interest:

- Standard Performance
- Bilateral Agreements vs Central Network Organizations
- Site Specialization
- Network Stability
- Network Resource-Sharing Potential
- Communications Costs
- Service Pricing Policies
- Provision of Special Services
- Network Equilibrium Conditions
- Quality of Network Information Made Available to Users
- Network Growth Effects

For each of these areas, a series of simulation experiments was specified in order to produce the information required for investigation and analysis of that topic. The considerations underlying this experimental plan are further described in the project report (3).

In order to provide some preliminary information to guide the further specification and subsequent conduct of the network analysis portion of the project, a set of preliminary experiments was performed. Because of the pilot nature of these experiments, they were very limited in scope. Nevertheless, they provided some initial insights into the characteristics and implications of institutional behavior in a networking environment.

Each simulation run in the preliminary series was restricted to a length of 22 simulated weeks and modeled a network consisting of five sites. Investigations were conducted in five areas that are relevant to institutional behavior considerations (standard performance, site specialization, network stability, network resource-sharing potential, and service pricing policies). The results are given in this paper. The remainder of this section describes the tests which were performed, while the following section discusses the findings derived from those runs.

Each experiment was conducted by changing the appropriate data files for each of the five sites to reflect the policy areas or service offerings under investigation. Although it is expected that in a real network the stabilization of network flows will take a long time, it was possible in these experiments to select policies that hastened this process. Thus some measure of network stability was generally reached by the tenth simulated week. Several of the experiments required that changes be made in a stable network, so these alterations were introduced in the tenth week.

The initial configuration of each site used in the preliminary investigations was as follows:

SITE 1 -- IBM 370/158 medium load

SITE 2 -- IBM 370/145 heavily loaded

SITE 3 -- IBM 370/168 lightly loaded

SITE 4 -- No internal hardware. Only interactive demand which is currently satisfied externally from a non-network site.

SITE 5 -- H6180 - Large time-sharing system. Extremely I/O bound. Specialized user community that does not have any batch usage.

STANDARD PERFORMANCE

The major intent of this experiment was to determine a base performance level to serve as a standard of comparison for the performance data derived from subsequent experimental runs.

This base run reflected an idealized environment in which all work could be done at any network supplier. Hardware incompatibilities, conversion costs, delays, and network surcharges were ignored. The common preference for working "in-house" or staying with the current supplier was reflected by giving each site a 20% preference factor as compared with outside suppliers, and each present supplier a corresponding boost as compared with competing suppliers. In order to better examine the potential for network usage, no site was permitted to restrict where or how users spent available funds.

SITE SPECIALIZATION

The intent of this experiment is to investigate the impact of site specialization in such services as low price, high user support, or rapid turnaround. The viability of facilities that attempt such specialization and the subsequent user responses were examined. For example, if a site emphasized only those services that could be efficiently offered on its particular hardware, it could charge less for these services than a site with a comparable hardware configuration that offered a full range of service.

One implication of site specialization is the shifting of usage of some service types from one site to other network sites that can process them more efficiently. Just as in an international trade situation, where different countries have different comparative advantages, and hence trade between them becomes beneficial, so in in a networking situation one would anticipate certain service types to flow to particular sites which have a comparative advantage for that type of computing. Thus one might expect that the distribution of service types processed at a site would change over time, as users moved away from that site and onto the network for selected service types. At the same time, users from the network should, on balance, be expected to become users at that site for the services which it could provide more efficiently. If this phenomenon occurred, more total work could be performed on the network than could have been performed in aggregate at the sites individually.

NETWORK STABILITY

The major questions to be answered by this experiment concerned the conditions under which institutional behavior can become unstable and lead to wild swings in network usage. Typical factors that might lead to this condition include:

- lowered barriers to user switching of suppliers
- price competitiveness among network sites
- shifts in behavior patterns
- capacity shocks

Lowered barriers to the switching of suppliers can evolve from technological advances or from a central facilitating organization for the network. The model's momentum parameter governs the tendency of users to switch sites, and it is easily adjustable. As the users' willingness to switch sites increases, performance problems at one site can touch off a mass migration to other sites, causing overloading and the attendant degraded performance. This leads to even more user movement.

A variety of price-cutting situations could also cause abnormal network flows. Suppose, for example, an underutilized site is successful in attracting work by virtue of a series of price reductions. What will happen if varying numbers of other sites respond in kind? Similarly, shocks can be introduced by sites shifting to entrepreneurial behavior, to zero-net balancing behavior, or to cost minimization behavior. These shifts can create instability, that is, continually shifting demands, within the network.

A network in equilibrium may be vulnerable to a variety of perturbations in available capacity. Typical examples include the addition of a new network supplier offering a substantial portion of network capacity at reduced prices; the addition of a new network demand source having a demand equal to a significant portion of total network capacity; and the dropping of a major network service, whose supply to the network significantly exceeded his network demand.

NETWORK RESOURCE-SHARING POTENTIAL

The major topic of this investigation concerned the degree of sharing which can take place under various environmental conditions. The types of conditions to be tested include:

-- Situations in which there is a wide spread in the costs of service types offered by the different facilities, providing users with economic incentives to share resources.

-- Situations in which there is a wide spread in turnaround time between service types and between different sites on the network, providing users with service incentives to share resources.

-- Situations in which different sites specialize in different types of services, providing users with availability incentives to share resources.

-- Situations in which the external price of services is perceived by all users to be less on the network than it is at their local site, providing another type of economic incentive to move onto the network.

-- Situations in which there are no communications costs, reducing an economic barrier to sharing.

SERVICE PRICING POLICIES

The major purpose of this experiment was to investigate the impact which pricing policies could have upon network usage and the participating institutions. In a cooperative network such as the one being investigated, the member institutions would be independent organizations which normally retain the freedom to price the computing services they offer. If the network's administration does not place constraints upon the pricing policies of member institutions, what would be the result if an institution prices its services so as to maximize resource utilization, to maximize revenue, or only to recover cost?

V. PRELIMINARY RESULTS

The preceding section described the various topics investigated with the network simulation model. A limited number of experimental simulation runs, covering some of these topic areas as a pilot study, has now been completed. This section describes some results for those areas concerned with institutional behavior and the resulting impact of that behavior upon network service and other member institutions.

STANDARD PERFORMANCE

Performance data from the base run revealed that sites 1 and 2 quickly became heavy network users. Nearly 70% of site 2 computing expenditures went to the network. On the other hand, site 3 became a heavy recipient of network business. Site 5 raised its I/O charges, sending much of its I/O bound interactive work to site 3 and subsequently received a substantial amount of non-I/O bound interactive work from the network. The cumulative dollar flows for the first 20 weeks are shown in Table 1. It is interesting to note that over the 20-week period, more than 12% of all computing dollars were expended on network-supplied services.

TABLE 1

CUMULATIVE DOLLAR FLOWS (THOUSANDS)
BASE RUN (20 WEEKS)

SITE	TOTAL COMPUTING REVENUE	EXPENDITURES ON NETWORK SERVICES	REVENUE FROM NETWORK SERVICES	BALANCE OF TRADE
1	$ 546	$ 168	$ 58	$ -110
2	401	272	1	-271
3	1077	9	315	306
4	332	34	0	- 34
5	1673	29	138	109
	$4029	$ 512	$ 512	$ 0

SITE SPECIALIZATION

Separate experimental runs were not made for this area in the pilot study. However, observations on site specialization were taken from several runs made in connection with other experiments. Under the conditions of specialization, every installation had some users going onto the network for at least part of their needs, and every site that offered services found some outside buyers for some of their services.

These runs also revealed that the success of site specialization is critically dependent on user behavior and institutional policy decisions. Accordingly, further investigations in this area are being postponed until better user behavior and institutional behavior models have been developed.

NETWORK STABILITY

The findings of the network stability experiments were similar to those of the site specialization runs in that the results were very sensitive to user behavior patterns and site policies. Thus, more definitive results await a better definition of user and site behavior. However, most tests suggested for the pilot program were performed; the following discussion of one run is indicative of the results obtained.

In this run, a shock was introduced by making site 3 unavailable for one week on an unannounced, unscheduled basis. No outside users attempted to use the site that week, but many of the in-house users did attempt to do so. Most of the derivative results of the shock were as might be expected. However, there were some unusual problems.

The first problem developed when the in-house users at site 3 tried to move onto the network. The network communications at site 3 couldn't handle the desired volume of traffic, and approximately 50% of the user demand was unable even to reach the network.

Second, those interactive users that did reach the network completely flooded site 5. Site 5's original users, many of whom had moved to site 3, returned to find a quite different site 5 than they had expected. It was so overloaded that almost 20% of the attempted usage of site 5 could not be accommodated. The site 3 batch users had an easier time. That work which could be transmitted over the network was directed to site 1, which still had some excess capacity. All work was accommodated, albeit with degraded turnaround.

No oscillatory behavior developed from this particular shock. Most of the users returned to site 3 rather quickly after it returned to service since, on balance, its offerings were significantly more attractive than available alternatives.

A similar experiment was performed in which the supply of service at site 3 was unexpectedly reduced to a small percentage of normal, reflecting a week of excessive, unanticipated down-time. In this case, users still attempted to process their work at site 3, but there was a large amount of unsatisfied demand. In addition, site 3 turnaround times became intolerably high. As one would expect, in the weeks following the shock, many turnaround-sensitive users moved from site 3 to other sites on the network.

For the conditions tested, the network proved to be quite stable in response to induced changes in network state. A number of factors tended to dampen movement, including communications limits, increased turnaround times, site capacities, file locations and conversion costs.

NETWORK RESOURCE-SHARING POTENTIAL

All of the investigations proposed for this area were conducted during the pilot simulation experiments. Most of the results could be anticipated and will not be detailed in the limited space available here. However, there was a general shifting of workload from one site to another whenever there were major imbalances in either price, turnaround, or user support services.

SERVICE PRICING POLICIES

The pilot pricing policy experiments focused on the impact of those policies aimed toward maximizing overall utilization of facility resources. For this purpose, the odd-numbered sites were given a pricing policy that would both lower resource prices on significantly under-utilized resources and raise prices on significantly over-utilized resources. The findings were encouraging. For example, site 5 tripled its I/O prices over a span of 20 weeks causing I/O intensive jobs to migrate onto the network and permitting the facility to handle a greater overall workload. Similarly, site 3 lowered its I/O prices by 25% during the course of the run and was able to attract additional work to the facility.

The actual rate at which price adjustments and resulting workload shifts would take place in a real networking situation are likely to be much slower than in the pilot experiments because reaction times here were purposely shortened. The extent of the benefits which would be realized in practice must await the acquisition of further data on user behavior. However, the experiments that were performed did indicate movement toward a price-motivated exchange of workload that resulted in positive benefits for all parties.

VI. CONCLUSION

The experiments performed thus far are of a preliminary nature, and it is dangerous to draw many hard conclusions before a full set of institutional behaviors and policies can be incorporated into the experiments. However, several interesting trends have been observed.

The network and institutional arrangements investigated thus far indicate that equilibrium network behavior tends to be quite stable. Even the introduction of relatively large displacements did not result in unstable behavior. A number of stabilizing factors exist which appear to be sufficiently strong to dampen oscillatory movement quite rapidly.

The networks examined also revealed a substantial resource sharing potential. When there were large discrepancies between sites in the area of pricing, turnaround or user support (and the actual data indicate that such discrepancies do exist), there was a gradual shifting of workloads between the processing sites. Assuming that site hardware costs remain unchanged in the short run, these shifts should result in reduced job costs and improved turnarounds for the user community. The major inhibition to such network flows would be institutional policies restricting network usage in order to control cash flows. The problems posed by payment imbalances will be addressed in subsequent simulation runs when further institutional data are available.

Similarly, as further data are obtained on institutional policies and decision rules, the various experiments described in the analysis plan will be conducted. These simulation runs should yield a great deal of additional information about the implications of various institutional policies and behaviors upon network performance and upon other member institutions.

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