DYNAMIC SIMULATION OF A NATIONAL RESOURCE SHARING COMPUTER NETWORK●

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ABSTRACT

A national computer network for research and educational institutions has frequently been proposed as a means for meeting selected computing needs in an effective manner. Although many technical problems remain, it is generally believed that the most difficult issues facing such a network revolve around economic, political, and organizational considerations. In order to investigate these issues, a model of a computer network was developed to test a variety of networking alternatives, and to evaluate the ways in which a network would impact its member institutions.

This paper describes the use of the simulation model in a three day gaming exercise by sixteen institutional teams who made decisions about their likely participation in a network that "progressed" through several years of simulated time. Participants were able to interact dynamically with the decisions and actions of other participants, to deal with a variety of network issues, and to explore the relative advantages and disadvantages of various modes and levels of network participation.

This project represented an unusual and different application of a simulation game in that it concentrated on the policy and behavioral aspects (i.e., people concerns) of what is usually considered to be a technical design problem. The players were real decision makers, playing themselves as they relate to their own institutions, rather than students. Consequently, it was possible to focus on learning about the implications of national networking, rather than merely demonstrate or teach known principles.

● This research was supported by the National Science Foundation under Grant #MCS75-03634, "A Simulation and Gaming Project for Inter-Institutional Computer Networking." The viewpoints presented here are those of the authors and not necessarily those of the NSF. This study would not have been possible without the assistance and cooperation of the participating institutions.

I. INTRODUCTION

Decision makers at research and educational institutions are currently exploring ways to meet their computing needs in a cost-effective manner, while still satisfying the requirements for high quality service. A national computer network for such institutions has the potential to meet selected needs by making available specialized computing resources, minimizing duplicate software development, and making more efficient use of the nation's total computing resources (1). (In fact, a prototype national network, EDUNET, is now in operation (2).) Although such a network is technically feasible today, its ramifications have not been established.

Two previous papers (5,6) summarized the rationale behind the decision to use a simulation model as a basis for studying these issues, the characteristics of the model developed, and several simulation experiments performed by the project staff. However, no simulation model could completely encompass the many possible behavior patterns that could occur in the real world. The only way to observe the full dynamic, competitive aspects of networking is to include real decision makers in a man-machine simulation. Thus, in addition to the previously reported technical studies that required no human interaction, the simulation model has now been used in a gaming mode to investigate situations in which institutional behaviors and politics are important. In a gaming environment, the policy and behavioral portions of the model can be controlled by real decision makers, reflecting the many diverse sources of influence that affect computing in their respective organizations.

The three day gaming exercise, referred to as the "Live Game," involved sixteen institutional teams who made decisions about their likely participation in a network that "progressed" through several years of simulated time. Each institutional team consisted of a senior administrator, the computer center director, and a representative of the institutional user community.

It is interesting to note that, unlike most gaming exercises, the participants represented their own real-life roles and made decisions with full awareness of the motivations and constraints that existed at their home institutions. From the institution's perspective, the explorations focused on the institutional profile and its effect on participation in a national network, the economic impact of network purchases and sales, budgetary constraints, the provision of special services, and the evolution of behavior patterns as a result of network participation.

In parallel with the investigations of institutional involvement, an examination of the role of a network facilitating organization provided information about the services such an organization might offer and the ways in which it might be supported. This was accomplished by adding a pseudo network organization and staff to the gaming environment. Reacting to the needs of individual institutions, and the directives of the Network Board of Directors (the senior administrators of the participating institutions), this facilitating organization dealt with such issues as network organization and management, network composition, financing, network service offerings, site specialization, and network growth and evolution.

The gaming environment made it possible to place control of many of the key model elements in the hands of human decision makers. In addition, externalities such as the organization and operation of the network facilitating organization could be modified as required. Consequently, the exercise has been referred to as a "dynamic simulation," to describe the continuous changes in decision rules, behavior patterns, and model components.

Game attendees were given a broad exposure to key issues relevant to network participation. This experience will be extremely useful in the future as opportunities for network participation are made available to them. Unfortunately, the nature of the gaming exercise, and the complexity of the real world, makes it impossible to provide prescriptive statements describing how individual institutions should act in a networking environment. However, much was learned about the desirable and likely characteristics of a national network for higher education and research.

II. SIMULATION MODEL

DESIGN GOAL

The basic design goal was to provide a highly parameterized and flexible model that would permit the examination of a variety of institutional and network policy rules. This model, in conjunction with data representing the computing requirements, resources, policies, and facilities of the individual institutions, could then be used to explore a variety of possible network implementations.

STRUCTURE

The model was programmed in FORTRAN IV and implemented in a top-down structured manner. The full system presently consists of about 35,000 lines of code, and runs in 700,000 bytes of memory. The system includes the simulation model; a series of data files describing the network institutions; and an interactive interface used to update the data files, define the network configuration, describe simulation runs, and browse the output reports and other data from the runs. Output reports can also be produced on a high speed printer. The model operates with a basic time unit of one week. This 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 simulation model is designed to handle up to 25 sites. In addition to the representation of the site's hardware, software, and use of computing services, the description of each site contains all necessary policy specifications and decision rules. The decision rules deal with such areas as pricing, hardware changes, budget allocations, user support levels, and computer scheduling and priority setting.

The model has three basic conceptual elements: the "supply" of computing services, the "demand" for these services, and the balancing of desired demand with available supply ("market"). The "supply" of services offered by a site consists of a list of available software offerings (selected from a master list of possible types); the hardware capabilities (such as CPU speed, memory size, unit record equipment speeds, channel capacity, number of on-line ports, and communications bandwidth) available to process requests for these offerings; and the conditions associated with the offerings (prices, level of support, restrictions etc.). Determination of hardware and services to be supplied is based on such factors as prior offerings and existing equipment, perceived local and remote user demand, budget constraints, and overall institutional profile or image.

User "demand" for the available computing services is generated at each site based on built-in rules. The rules take into account previous demand, available supply offerings, policy decisions, human behavioral patterns, and the status of the network during the previous time interval (e.g., response time at each site, cost of each service, communications volume, etc.). The aggregate demand placed on a given installation depends on the demand throughout the network, local policy constraints on remote service and usage, communications capacity, and the attractiveness of the site relative to other potential sources of supply.

Recognizing that the network capacity at any point in time will not precisely match the demand for services, the "market" model segment has been incorporated to match capacity against demand. This module determines what work actually is successfully completed and where it is done, subject to the institutional rules that govern the completion of computational work.

Because of its modular design, the simulation model can be easily modified to incorporate new policies, procedures, facilities, or reports. In this way the model can be tailored to meet the needs of a particular application or research effort.

INSTITUTIONAL REPRESENTATIONS

There is, within the simulation model, a representation of each of the participating institutions and algorithms for predicting what happens at each site. These algorithms simulate the financial aspects of computing, the computing resources available, the nature and cost of the computing services provided, the nature and magnitude of demand for computing services by the various categories of users, and the policies and procedures for allocating computing resources. To a significant degree, these site models can be used to explore the implications of alternative financial, technical, and policy options within the site itself, independent of the larger networking context. In addition, policy and behavioral data describe the permissible and likely interactions of the institution with any network organization.

NETWORK REPRESENTATIONS

A network, as defined for simulation purposes, is viewed as a collection of sites (or institutions) capable of sharing computer resources under a specified set of conditions. The model predicts the interrelationships among these sites in terms of the flow of services, the flow of funds, and the contractual and financial interactions between institutions. To accomplish this, it is necessary to simulate what happens within each institution as well as what happens among institutions.

The organization of the particular network to be simulated can be varied in several ways. The most obvious variation is in the number of sites and their characteristics (for example, large, small, public, or private institutions). Other network descriptions that can be changed include communications costs and capacities, financing of the network organization, and constraints on work flow.

III. DATA COLLECTION FOR THE SITE REPRESENTATIONS

As with many simulation projects, the collection of data to support the model was a formidable task. In addition to all of the usual problems of unavailable, inaccurate, and obsolete data, there were vast differences in hardware, accounting systems, definitions of workload and jobs, and philosophy of computing. The major approaches and problems are summarized below.

TECHNICAL DATA

As mentioned, each node on the network was represented as having a given computing capability, a demand for computing services, and rules and policies governing the interaction between the two. In order to minimize the problems of representing diverse hardware, the computing capacity was measured in terms of the hourly capacity of eight specified "critical resources" such as CPU seconds, printer lines, and connect hours. (Each institution could also define additional critical resources that were of particular concern at its site.) The maximum available weekly capacity was then based on the hourly capacity of each resource and the uptime of the computing facility (a function of schedule and reliability). With this approach, only the hourly capacities of the critical resources had to be collected.

Although there is little standardization among individual sites as to how "work" is described, it was necessary to get a consistent work description for model purposes. This was done by developing a list of standard job ("service") types. After several unsuccessful attempts to collect data on much longer lists, the service types were aggregated into a list of 20. Each service type was then described in terms of its usage of the critical resources. Most sites were able to provide weekly data at this level of aggregation. Overall system performance was then determined by summing resource requirements over all jobs and comparing this with the total system capacity.

No attempt was made to model individual users. The basic unit in this context is the "user category." A user category is a group of users having a describable set of demand characteristics (in the aggregate) and an identifiable aggregate budget (i.e., an institutional budget line item). In addition, university policy should be consistent for any given user category. Sites were given complete freedom to name and describe their unique user categories (e.g., "research users," "students," "administrative data processing," etc.). This approach made it possible to examine the impact of widely varying institutional policies with regard to various groups of users.

The technical data describing the present supply of, and demand for, computing services were obtained through two lengthy questionnaires that were filled out by each institution, plus numerous telephone and letter interactions.

POLICY AND BEHAVIOR DATA

These data were obtained through direct interviews with key people at each institution. These interviews concentrated on institutional postures toward such areas as increasing or decreasing computing facilities in response to usage, reactions to overloads, adjustments to pricing algorithms, restrictions on the use of computing services, and attitudes towards external users.

DATA CLEAN-UP AND VALIDATION

Preliminary data clean-up and validation was performed in traditional ways: programmed reasonableness and consistency checks, manual comparison of data files and model inputs with source data, and matching of model outputs with known historical data. However, the availability of a working interactive model that could be operated remotely by users presented a unique opportunity. In particular, each institution was asked to run its internal data through the model as a "single site" network. As such, the model represented the current status of computing at their institution before any new network work flows. Each institution was requested to experiment with the model in order to learn its possibilities and limitations, and also to work with its own data representation to bring it closer to perceived reality. A series of questions was provided to guide the institutions through this process. This was an iterative process, with sites being able to make changes, run the model, and look at results until they were satisfied with their overall representations. Note that besides data clean-up, this approach was an excellent way to keep participants involved in the model design and implementation process.

Although each institution refined its own representation so that it would more closely approximate its actual computing situation, there were still a number of anomalies when data across sites were compared. The hardware and service offerings represented on the network encompassed a wide range, and some consistency had to be imposed. This was a joint process between project staff and the participating institutions.

IV. LIVE GAME

OVERVIEW

Since real decision makers provide the only mechanism for reflecting the full richness and complexity of institutional behavior in a networking environment, the live game represented a focal point in the conduct of the project. University administrators, computer center directors, and computer users were brought together to make decisions similar to those they make in real life. The simulation model was the tool used to help integrate the data and decisions and to reflect the impact of decisions on network participation and operation.

The live game thus provided the institutions participating in the project an opportunity to explore many of the key organizational, economic, and behavioral issues involved in networking. Although most of these issues had been identified through the course of the project, they had never been presented in terms of the specific decisions that must be made at each individual institution and the impact of those decisions on the institution. In addition to decision making and policy formulation in a networking context, the participants were able to explore some operational aspects of network participation and the possible impacts that a network might have on their own computing facility. In both these areas, the live game represented a learning experience that could not easily be duplicated. The intensive three day session was sufficiently realistic so that participants were "seduced by the game," as one team member said, and reacted as if the simulated situations were real. The dynamic development of the network allowed them to experiment with alternate network participation profiles and to investigate the impact of particular choices. In addition, the institutional teams were able to discuss a number of side issues, both among themselves and with their counterparts at other institutions.

Typical decisions faced by an institution at the gaming exercise included the general management of computing at the institution, financing the provision and use of computer services for both internal and external users, pricing of computing services, and reaction to network issues such as the financing of a facilitating organization.

The information learned in this three day exercise supplemented that gained through analytical studies, interviews, simulation experiments with the model, and participation in the design, implementation, and operation of real networks.

GAME ACTIVITIES

The three day exercise held in Princeton, New Jersey, on April 3-5, 1978, offered a variety of activities.

The gaming sessions provided the institutional teams an opportunity to consider the general management of institutional computing in situations that were realistic, even if not real. In addition to this general management, specific scenarios were presented at the beginning of each gaming session. Each established a particular situation that might occur in a networking environment. The institutions were asked to focus on the long term implications of these situations and take appropriate actions if necessary. After going through this exercise, the institutions might well have different viewpoints and might reevaluate many of their attitudes towards networking.

There were many different "scenarios" that could be posed, and those chosen were selected from a much larger list. There were two major groupings of scenarios, so that the individual sessions could pursue the questions raised through several years of simulated time. One group of scenarios focused on encouraging local users to access network services. A second group looked at two different types of specialized services: software packages as represented by bibliographic retrieval services, and hardware offerings represented by very inexpensive, large capacity hardware. This latter capability was provided by a new institution, controlled by project staff, that joined the network. This new institution was presented as having considerable excess hardware capacity and having decided to pursue an aggressive price strategy in order to generate revenue from external users.

Each gaming session had a specific sequence of activities. First, the current situation was presented and relevant announcements were made. These announcements included items such as changes in the network financing procedures, descriptions of new service offerings, a federal directive governing computing, and modifications to the network composition. Each team was asked to analyze the potential impact of these announcements on its long term plans and to develop strategies to guide its institutional decision making. Most of each session was reserved for the institutional teams to review previous results, to gather information, to discuss their status, and to decide on the next actions to take. At the end of the session, each team submitted a list of actions taken and data to be changed (capacity modifications, improved usage estimates, policy revisions, budget modifications, etc.). They were also asked to document their desired strategies and their success in implementing those strategies. After each session, data changes were entered and the model was run to represent from six to twelve months of simulated time. The results were distributed at the beginning of the next gaming session.

The simulated network during the live game was composed of fifteen universities and colleges and one research institute.** The mix included both large and small organizations, public and private. Most institutions had their own computing facilities, but several did not. Some had had a great deal of experience with campus, regional, or state networking, while others were getting their first exposure to such an environment. Thus the gaming sessions and other activities had to appeal to a wide range of interests and experiences.

** Institutions participating in the live game were: Bryn Mawr, Carnegie-Mellon University, University of Chicago, Dartmouth College, University of Georgia, Harvard University, University of Iowa, Lehigh University, Massachusetts Institute of Technology, Ohio State University, Saint Olaf College, SRI International, Stanford University, University of Texas, Texas Tech University, and Vassar College.

ROLES AND GAME PLAYING

The live game represented an unusual situation for a gaming exercise -- instead of playing artificial roles the participants "played" themselves. Not only did the nodes on the network represent actual institutions, they represented the participants' own institutions. This brought a level of realism and involvement to the game that it might not otherwise have had. In addition, it presented a major challenge for the simulation model. Not only did the results have to be both reasonable and consistent, they had to agree with the situation as perceived by the institution itself.

The administrative role was typically filled by a person such as a vice president or provost that had administrative responsibility for reviewing computing activities and expenditures. In this situation he or she represented the entire institutional administration and, as such, assumed the level of involvement that the administration actually took at the institution in areas such as the resolution of policy issues, the financing of computing, and approval of the computer center budget.

The computer center director's role was most often assumed by its real-life counterpart. As such, this was the most natural role of the three and the computer center director's participation was fairly straightforward and intense.

The user representative had no real-life equivalent. Instead, he or she had to represent the whole gamut of institutional users, ranging from students taking a beginning programming course, to faculty doing research, to members of the administration running payroll applications. The person in this role was expected to take different stances to express the concerns of the different users rather than to express a consistent consensus. On some teams this role was played by a member of the computing center staff who was responsible for user services. On others it was filled by a faculty member or other campus user active in computing activities.

To supplement this role differentiation, not all reports were given to each team member. The administrator received the financial reports, the user representative received reports dealing with computer usage, while the computer center director received nearly all information (with an emphasis on operational data). This distribution was intended to focus on specific areas and to reduce the volume of paper for any one person. During discussions, team members were free to share reports that had not been distributed to all three.

NETWORK FACILITATING ORGANIZATION

In parallel with the investigations of institutional involvement, an examination of the role of a network facilitating organization provided insights about the services such an organization might offer and the ways in which it might be supported. This was accomplished by adding a simulated organization (SIMUNET) and staff to the gaming environment. The major artificial factor in the game was that all participants had to be members of SIMUNET (although they could elect not to sell to or buy from other members). As members, they were required to accept certain responsibilities to the organization, such as participating in determining its policies, membership, financing, and services. The facilitating organization staff encouraged and promoted the exchange of information, and helped the teams evaluate various modes of network participation.

The costs and many of the services associated with a facilitating organization were synthesized into the simulation model. However, many of the services are people oriented and difficult to describe in a complex model. The physical participation of persons representing this organization supplemented the modeled services with a human element of personal contact. To support these functions, the SIMUNET staff received weekly network summary reports comparing current prices, turnaround, reliability, usage volume, and user services at the different institutions. Hence they served as a central source of information and a focus for network activities. To keep the participants up-to-date with network happenings, the SIMUNET staff produced periodic newsletters and made announcements during the gaming sessions.

Many of the other information exchange functions that such an organization would have provided were carried out by the participants themselves due to their physical proximity. Despite this reduction in tangible services provided, the presence of this group focused attention on a goal of the project, i.e., to evaluate such an organization and to indicate its possible duties, responsibilities, and support.

NON-GAMING ACTIVITIES

The gaming sessions alternated with plenary sessions and workshops. These could be categorized into those oriented towards institutional concerns and the impact of a network on institutions, and those oriented towards network-wide issues. The topics discussed were closely related to the questions raised in the gaming sessions. In most cases they either preceded a session to provide background information for that session or followed a session so that the participants might pursue the issues in more depth.

In addition to providing participants with an opportunity to exchange ideas and experiences, these non-gaming activities allowed the project staff to enter data, run the model, and organize the results for distribution.

V. GAMING EXPERIENCES

PLAYER EXPECTATIONS

Attitudes toward the game were serious, and many participants did a great deal of preparation in advance. They arrived with a wide variety of expectations. Some merely wanted to learn more about possible approaches towards national networking. Others wanted to examine the implications of some well thought out and carefully planned strategies. Even though they had used the model to experiment with their own institutional representations, none of the institutions had had an opportunity to test their strategies and offerings in a true "competitive" situation with each institution seeking to optimize its own position. Most of them, for example, expected to be suppliers, i.e., to sell some services over the network; and most expected, on balance, to sell more than they purchased. Even the smallest institutions that had computing facilities had some unique resources that they felt would be attractive to others.

PLAYER APPROACHES

Strategies

Most of the participants came to the game with specific goals in mind. These goals fell into two general categories: to test the viability of existing institutional constraints, objectives, and strategies in a network environment; and to explore experimental objectives that did not necessarily parallel actual situations (i.e., "what if ?" questions). Although most institutions had some goals in each category, most of them emphasized one of the two approaches at any given session. For example, some schools followed actual constraints fairly closely during the first set of gaming sessions, and experimented during the second set. A few institutions had two different computing facilities modelled, and took a different approach with each facility.

It had been anticipated by project staff that specific scenarios or artificial problems would be required to force the institutions to consider new networking issues and to keep them actively occupied. Instead, there was enough game playing and experimentation generated by the institutions that such dramatic scenarios were, in retrospect, not necessary. Most institutions put so much energy into the management of their facilities in a networking environment, that the scenarios were often glossed over.

On the other hand, since the scenarios pushed some institutions to extreme experimentation that they might not have done otherwise, perhaps the dramatization was useful. One scenario, in which a supplier with very low prices joined the network, emphasizes this. In reaction, two sites decided to phase out their local facilities and to purchase all services over the network, while several others decided to compete aggressively. The rest combined protective trade barriers with taking advantage of these new opportunities. Although some of the dramatic actions taken by the sites might be considered unrealistic, they did provide a great deal of useful information. The capability to do this type of experimentation was one of the major reasons a simulation approach was chosen at the inception of the project.

Interactions

Three basic types of interaction took place during the three days. At the gaming sessions, most of the discussions were at an institutional level. For some of the teams, this was a natural extension (although intensive) of the methods that prevailed at home. Other institutions did not normally have such close communication, particularly between the administrator and the other two team members. In these cases, the exercises played a particularly valuable role in that all three team members were exposed to issues and problems about which they previously had had only a very superficial perspective.

Although the intense activity during the gaming sessions did not allow much time for interaction between institutions (other than bargaining and negotiations), this was a major feature of the workshop sessions. These discussions enabled participants to share their experiences with their peers at other institutions and to discuss issues with persons from a variety of backgrounds.

A final type of interaction occurred between the institutions and the simulated facilitating organization, SIMUNET. During the gaming sessions, this organization provided network information in areas such as comparative services, price, and turnaround. Outside the gaming environment, discussions were held on the role such an organization should play, what services it should provide, and how it should be financed.

IMPACT ON PLAYERS

Players left the live game with as wide a range of reactions and experiences as they had had expectations before arrival. One often expressed opinion was that the game provided valuable insight into the participant's own institution and computing facility, particularly for the administrator and the user representative. One administrator, who in the past had not been involved in the operation of the computer center (except for budgeting and other financial purposes), found that the game provided his "first real introduction to our own computer center operations." Another administrator remarked that he had made "more major decisions about computing services at his institution in three days than had been made in the last five years." Users were able to understand more about the decision making processes within the university by this close interaction with administrators and computer center directors.

In addition to individual insights into the local facility, the game provided a good opportunity for members of an institution to interact in decisions about computing for their institution. One attendee noted that the game "stimulated discussion within our group." Many of the issues had never been discussed by the group as a whole, even by teams who had been working together for many years. This brought a new perspective to institutional planning that is likely to continue after the game.

The major learning experience for most participants was a new awareness of networking issues. As one administrator commented, "The gaming format was very useful in providing a much better idea of the behavior of a network and the implications for our institution. It raised many policy issues that need to be examined." All participants found themselves dealing with unanticipated dimensions. Those that had not had any networking experience were exposed to a major new operating environment; those that had been dealing with networks on a local or regional level discovered that national networking presents many problems and opportunities that they had not considered before. Almost every institution found that the game provided a mechanism for learning, planning, and policy formulation in an area that is likely to be of major importance in future years.

One useful aspect of the game had not been fully anticipated -- i.e., the opportunity for comparison of offerings, strategies, and management approaches between teams. Many institutions found that when subjected to objective comparisons, they "weren't as good as they had thought they were." Others found that they had unexpected strong points. There was much to be compared and learned when similar problems were subjected to different approaches.

VI. SUMMARY AND CONCLUSIONS

This project represented an unusual and different application of a simulation game in several ways:

- It concentrated on the policy and behavioral aspects (i.e., people concerns) of what is usually considered to be a technical design problem.
- It used real decison makers playing themselves as they relate to their own institutions.
- A major focus was on learning rather than teaching. In this game the staff endeavored to learn how decision makers do act, as compared to usual games in which an experienced staff tries to teach students about how they should act in the real world.

One benefit that this gaming exercise did have in common with most others was that players learned to function in a new environment.

As is usually the case with simulation experiments, the richness of the exercise to individuals was proportional to the amount of preparation time and effort that preceded the game. Those with well thought out strategies and a good understanding of the model were able to look at rather sophisticated and subtle issues. Those with only minimal preparation spent most of their time examining technical and operational details. Throughout the sessions, the players demonstrated a strong level of personal involvement and took the game quite seriously. This provides an indication of the success of the game and demonstrates that the players perceived it as being a credible experience.

Although the nature of the gaming exercise makes it difficult to draw prescriptive conclusions about how individual institutions should act in a network environment, much was learned about the critical issues and the available options for dealing with them. The simulation model provided a useful tool for the examination of proposed policies and strategies in terms of the impact of institutional decisions on the network, as well as the impact of network actions on the individual institutions. Thus, although the specific learning experiences depended on the background and needs of the individual participants, each was able to derive useful knowledge from the game. In addition, as reported elsewhere (4,7), the requirements and major unresolved issues relative to the design and implications of a national network were better defined in a global sense.

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