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THE USE OF MODELLING IN LONG-RANGE COMPUTER COMMUNICATIONS NETWORK PLANNING

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ABSTRACT

There has been an incredible expansion and proliferation of computer communications networks in the last 10 years, most of them proprietary. Furthermore, the use of these networks has changed from a business operations tool to a strategic weapon for corporations. In order to better coordinate and control the growth of these networks, as well as add functionality, communications architecture plans are being developed for the corporate networks of the nineties. Cost/benefits analyses of these architectures have to be played against the proposed strategic plans of the corporation. Also, it is desirable to test these architectures for a number of scenarios involving future variations of regulatory, technology and standards projections that vitally effect the networks. All of this analysis is aggravated considerably by a lack of operations data for the current networks along with incomplete data on future computer communications protocols, services and loads.

The purpose of this paper is to present a methodology involving modelling on several levels that will not only quickly present very high-level, cost-benefit analyses for proposed architectures, but will continue to refine these analyses as all future data gathering and modelling work is prioritized and refined on an ongoing basis. The result will be an up-to-date repository for all communications planning tools and data.

I. INTRODUCTION

The last ten years have seen enormous growth in corporate communication networks. Not only is the investment in computer communications significantly greater, but the importance of the networks as the lifeblood of the corporations has, in some cases, become almost frightening. The increase in the number of networks has also primarily been in proprietary architectures with the result that many of the networks in the same corporation will not communicate with each other. One result of this has been the attempt in recent years to develop a common communications architecture for planning the future corporate networks. (Architecture will be used here to simply mean the technical rules for building the network.)

Another significant development in the area of corporate networks is in their use as a strategic tool. This tool and architecture are examined in Sullivan, 1988. Several classical examples of instances of this are Reuters in financial services, Federal Express in overnight delivery, The Wall Street Journal in newspaper publishing, and others as cited in Keen, 1986. The result is that corporate strategic planning is now a direct input into the development of the corporate communications architecture.

U S WEST is a Regional Bell Operating Company (RBOC) that was created in 1984 at the time of the AT&T divestiture. It has a very large corporate network with thousands of terminals, hundreds of mini and mainframe computers and, unfortunately, many different data communications networks connecting them. Although the proliferation of unlike networks has been a problem for most large corporations, the fact that U S WEST was formed from three historically separate Bell Operating Companies in 1984 aggravated this situation.

For U S WEST, as most other corporations, it became apparent that a process had to be developed to meet the challenge described above. For this and several other reasons, the Computer Communications Architecture Group, CAG, was formed as part of an overall Information Management (IM) architectural organization and was located in U S WEST Advanced Technologies. This group has the responsibility for developing a common computer communications architecture for the whole corporation that will be implemented in the 1990s.

Figure One shows the planning process that has as its primary product the Communications Architecture. The top string of boxes portrays the primary planning route. The business drivers from Corporate initiate the process. These drivers and other factors are used to develop the Communications Strategic Plan. The next box, the Architecture, reflects the requirements on the network to accomplish the objectives contained in the Strategic Plan (along with, of course, all of the current work that is to be continued) and the "rules" by which the computer communications network is to be engineered. The last box represents the hand off of the architecture plan to the Tactical Planners and Implementors. All of the boxes in the diagram below the top line in the figure represent support activities for the development of the architecture. The subject of this paper is the box labelled "Cost/Performance/Functional Modelling".

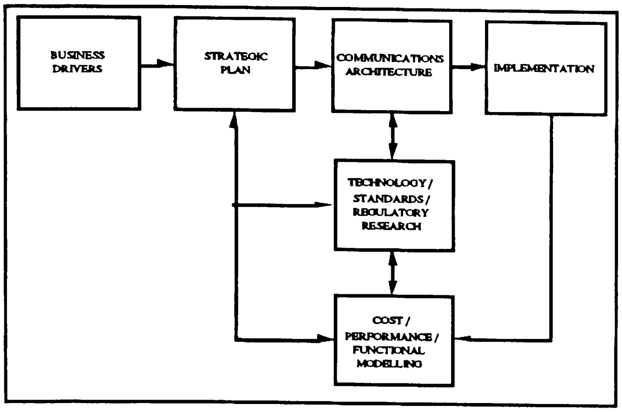

Figure 1: Planning Process

2. COMMUNICATIONS PLANNING REQUIREMENTS / PROBLEMS / OPPORTUNITIES

This section will develop the requirements for the entire cost and performance modelling system. The problems and opportunities that effect these requirements will be discussed.

2.1 Requirements

The primary requirement for communications planning, and most IM planning efforts, is that the plan should be evaluated on a cost, performance and functional basis, and to accomplish this evaluation well before major design and implementation decisions are made. Bell, 1988, elaborates on this for modelling large projects and the arguments are as appropriate here. The use of cost and performance factors should be fairly obvious. It is very easy to install a communications network that is relatively inexpensive but that has inferior performance. The opposite is also true. One obviously cannot be considered without the other. The third factor, function, must also be considered. Automatic Logon would be an example; this added function would of course entail extra expense, and should be accounted for both in cost and benefit.

Comparing network proposals in the area of cost and performance is made easier if it is possible to normalize the networks to a given cost or performance level. Probably the most useful technique is to normalize performance to an agreed upon or required performance service level (e.g., 90% of the interactive transactions must be completed within four seconds). Therefore a requirement of this system is to be able to make iterations of the cost and performance models relatively easily until a given level of performance is reached.

There are a number of variables encountered in computer communications that are not encountered in the planning of the rest of the Information Management System. First, there is the projection of cost and functional effects from regulatory changes; this can be very important and is the most difficult to assess because it can be a political issue. Another factor is the progress of the development and implementation of international computer communications standards. This factor is much more significant in the communications areas than other IM parts, and the widespread user and vendor acceptance or rejection of these standards may vitally affect the architecture. A third factor which can cause uncertainty in the architecture area are changes in the other IM architectures. The best example of this is the data architecture. A significant change in the distributed database architecture will greatly effect the communications architecture requirements. The effect of all of these variables, along with projecting technology advances, requires the ability to make a number of iterations of the models easily and inexpensively. The requirement of being able to examine many scenarios quickly and easily is common to other industries as shown in Anderson, 1988.

2.2 Lack of Communications Operations Data

There is a surprising lack of operations data in computer communication systems, including infrastructure data. This may be possibly due to the rapid growth of these networks in the last few years, which in turn has led to poor data collection and documentation procedures. Also, where there is data, it comes in many flavors unlike, for example, the predominantly used IBM-SMF data seen in mainframe computers. Circuit utilization in one vendor's measurement system is not necessarily equivalent to utilization in another vendor's system. A third problem is the lack of hardware performance data in communications equipment. The condition of insufficient computer communications planning data is true in much of the industry.

The requirement generated for this system then is to use the methodology to isolate and prioritize the collection and refinement of the subset of operations data that is required. One of the strengths of modelling is that these priorities can be established through techniques such as sensitivity testing. Instead of a massive data gathering effort (and another massive failure), it is possible to concentrate on only the most important data, and to call for careful validation of the data where necessary.

2.3 Early and Phased Reporting of Results

There are good reasons to organize a project like this in a top-down approach, starting with the best data and models that can be obtained quickly, running iterations, and determining which data or models should be refined next. See Suri, 1988, for similar time requirement problems with modelling in manufacturing.

The means of doing this with operations data is discussed immediately above and the same techniques can be applied directly to the level of detail that goes into the performance models.

Another reason for doing this is that the risk of having a project terminated by management is increased as the duration goes on without showing usable results. There are many unstarted but worthwhile projects that compete for resources, not to mention the inevitable fires to fight. Therefore a requirement for this project is to organize it on a top-down basis, such that early results are reported with the best data and models available, and then that data is used to determine the priorities for the second refinement phase. Also, these early results should be consciously used to show the value of the project.

A complicating factor is the large number of work loads and communication protocols which have to be modelled. Given that a detailed model of a communications function or protocol may take from two weeks to two months to model and study, it is obvious that detailed studies are not likely. However this problem can also be alleviated with the methodology mentioned above.

2.4 Opportunities

This brings us to the opportunities that exist. The necessity of many modelling efforts mentioned above can be minimized by the international communications standards that are now being developed. In short, eliminating most of the proprietary communication systems means that there are less protocols to worry about. Also, functions have been defined and assigned in the OSI reference model and this has simplified the task of the performance analyst. More importantly, with the standardization comes a focusing of independent performance studies that are being published. The bottlenecks are being defined and reported on. For example, performance problems with the transport layer (layer four in the OSI reference model) have been reported for several years as pointed out in Strauss, 1987, and Weaver, 1988. Furthermore, the effects of performing certain functions such as segmenting and check-summing (in software) are well documented. This enables us to prioritize our modelling efforts if not to actually obtain models or results. The advantage of being able to use the work of others is significant.

3. THE MODEL SYSTEM

This section will discuss the overall modelling solution to the basic problems posed, i.e., finding a way to "test" the proposed architecture for an optimized cost/performance system. It will also discuss a methodology for handling the secondary problems posed, the lack of communications data and the need for early and top-down reporting of results.

The overall system consists of two processes. The first process is the macro-level, cost/performance modelling system which has been written for a spreadsheet (Symphony). Initially it is using coarse estimates for the cost and infrastructure of the communication networks, and whatever analytic models or "Rules of Thumb", (ROTS), that can be obtained easily for the performance portion. It has the ability to run many scenarios quickly (manually for now), thereby satisfying the requirements posed in sections 2.1 and 2.3.

The second process is one of overall control of the refinement process. This process determines which data to collect next and which analytic model to refine next, this being the requirement in section 2.2.

It should be emphasized that this effort is the first step in modelling a very large and complicated system. The refinement process referred to above will be a key factor in evolving the model and methodology. Also, an overall validation and examination process will lead to further evolution of the cost and performance factors now used.

3.1 Description of Macro-level Cost/Performance Model System

Figure Two shows the macro-level modelling system for the current computer communications network (present method of operation - PMO). A similar system of models will be available for each proposed architecture/scenario. The following is a description of this modelling system.

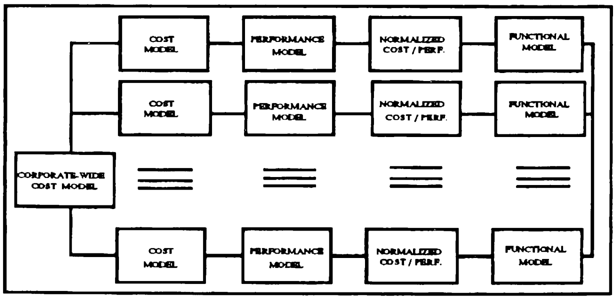

Figure 2: Modelling System

The single block on the left, labeled Corporate-wide Cost Model, pertains to the overall computer communications network. Like all of the other models in the spreadsheet, it is constructed on a macro-level basis, the criteria being that it cover over 80% of the total costs on a detailed per unit device level. There are some arbitrary categories that have to be covered regardless of cost though. These are the portion of the host utilized for communications applications, the terminals, the circuits, the major communications devices and the operations costs (people, etc.). This is very similar to the categories used in Treacy, 1988.

More detail will be given in Section 4. Also other cost categories will be added as the cost model is refined as suggested in Allen, 1989.

This overall cost model is then broken into the major individual networks, by type, that exist. The number of networks in this breakdown is also guided by an 80-20 rule, with at least 80% of the total network cost represented by the networks in the breakdown. Examples of these networks are the IBM SNA network, the BANCS network (a proprietary Bell synchronous network), a X.25 network, etc. The first block in each set of individual network models is a cost model, identical in construction to the overall cost model, but containing the cost elements for that particular network. The second block in each individual set of network models is a performance model of a typical user configuration in that network. This is an analytical model that is embedded in the spreadsheet with the cost model, and its infrastructure attributes are keyed directly to the infrastructure defined in the cost model. For example, if the network loads are interactive transactions across a set of tail circuits, then the total volume of transactions defined for this network are divided by the total number of tail circuits defined in the infrastructure in the cost model (and costed there), multiplied by a definable factor accounting for variance of load. In these directly coupled cost and performance models, the number of circuits (for example) can be varied and the new cost and performance figures computed directly.

The next two blocks of Figure Two define processes that are obtained from the spreadsheet models but are not in the spreadsheet itself (although they could be). From the results of iterating the cost and performance models, a cost/performance value can be obtained, normalized to the negotiated or contractual performance service level for the type of communications service performed by this network. In the case of interactive processing, for example, that value would have the units of cost per transaction for, say, an average five second response time. The last part of the analysis pertains to applying the cost/performance values to the functions performed in the network. The functional model is a carefully defined statement and description of these functions. It should be noted that unless the functions of one network architecture are a subset or congruent to another, the comparison of the cost of functions becomes labored.

Even without projecting models of new architectures, this analysis is immediately useful for comparing the cost/performance of the current networks. The breakdown will also be used for developing transition strategies for the individual networks. Finally very high level analysis of the cost of communication per employee can be otained. Some industries such as the Financial use this figure regularly to test the cost/performance of the corporate communications systems.

3.2 Comparing Communications Architectures

Figure Three shows the work flow for developing comparisons between architectural plans that have in turn been developed from the strategic plan. The first block on the left is essentially the set of models referred to in Figure Two for the PMO. The second block refers to the process of developing the communications loads for some point in the future. This process has three components. The first is to simply use the natural forecasting units (NFUs) of the capacity planning process to project the current loads, if these loads will exist in the time frame being investigated. The second part is to project the loads of currently scheduled new projects. The implication here is that any replaced projects, or portions of projects, have their loads removed. This too is standard capacity planning methodology. The third part is to project new loads that were defined in the strategic plan. Most of these loads will be developed by the detailed models in the second process.

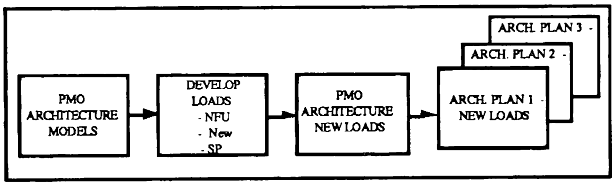

Figure 3: Comparisons Between Architecture

The third block refers to running iterations using the PMO architecture to determine the infrastructure required to run the new loads and to cost it. The fourth column of blocks refers to following the same process with various proposed architectures to again determine the infrastructure required to run the new loads and again to cost them. In both the PMO and the proposed new architectures, the costing would be done using the normalized cost/performance procedures.

3.3 The Control and Refinement Process

There are several operational procedures that relate to the process of determining the priority in which data elements are to be validated/refined, or in models that are to be refined. In the macro-level set of cost and performance models, each input data element and model has two attributes attached to it. The first is the importance of that data element or model to the overall results. This value can be determined either through observation of the results and/or sensitivity tests on the model. The second attribute is the confidence level of the data or model itself. This value is subjective and is assigned by the provider. The importance here is in the methodology, which causes the overall set of input data or models to be continually upgraded. This technique also provides input to the confidence level in the overall results. It should be noted that techniques have been suggested for modelling "in the absence of data", as in

Law, 1982. The methodology extends the suggested assumptions to a method for refining them.

3.4 The Use of "Simple" Models

The requirement in Section 2.3 in part has to do with either using analytic models or developing discrete event simulation (DES) models quickly and reasonably accurate. The contention of this paper is that it is possible to model, in a simple fashion, either the infrastructure or loads, and still derive data that will be useful for this type of a study. This section explores the accuracy of these models relative to the purpose of this methodology, the availability of operations data, and some of the considerations and problems which are encountered.

It should be noted that this section also confronts the eternal simulation problem of spending enough time to develop a fairly complete and sophisticated model versus bending to the time realities of the situation and developing a series of tools quickly. The latter course of action was chosen with the primary criteria of success being only whether or not the methodology is useful. The examples below are meant to show how experience (not just arm-waving) might atone for some of the time not spent on more sophisticated modelling tools.

This first example explores the simplicity of a model as a function of the data available. In the performance model of the synchronous, interactive protocols, queueing is determined in the model using M/D/1 and M/M/1 models as best and worst cases. (From experience with a number of different computer communication applications, it is known that the amount of variance in service times almost always falls between that of deterministic and exponential distributions). A very simple extension of this would be to go to the Pollaczek-Khinchin (P-K) formulation where variance in service time is at least taken into consideration and which could be easily done in a spreadsheet. The reason for not doing this is simple; in a situation where getting expected message lengths is difficult, getting variance data of that same data element is almost impossible. In short, the data simply is not there. Furthermore, estimating the variance does not give as much useful information as the maximum/minimum data obtained as above. For the record, most commercial network design tools use some variation of the P-K formulation where with the proper values of variance, an M/M/l or M/D/l model may result.

The second example explores a problem in the possibility that simple models can lead to undesirable results if care is not taken. The protocol in this case is a bisynchronous (BSC) subset of the one above. For most simple interactive applications, over eighty percent of the response time can be calculated from the host time, the transmission time (a function of message lengths and circuit speed) and the queueing time on the line. The rest of the time is spent in the "handshaking" parts of the BSC protocols, and equipment delays, e.g., modem-pair-delay. Now if the 20% of time elements that were small for most applications were lumped together as a constant, the propagation times involved in the many "handshakes" of BSC would be eliminated as a physical process. This is what is done in the model. For terrestrial, wide-area networks, this is not a bad assumption. The worst case within this country, for example, is about 25 milliseconds. However, when satellites are used in the network, the propagation times begin reaching a quarter of a second. With a protocol like BSC, with a great deal of handshaking, this time becomes significant and cannot be ignored.

One of the assumptions that will almost always be made will be independence of queueing processes. This is certainly true of the two examples given above (and again is true in most commercial network design tools). To assure that this assumption will not result in gross errors in the cases where little experience and/or validating data is available, DES models will be constructed and the results compared to the analytical model results.

Another consideration in this methodology is that the results will always be comparisons of models of architectures and loads as opposed to the absolute results from one modelling system. As stated in Law (1982), the real usefulness in simulation is in the process of comparing implementations of systems. This is especially true if care is taken to keep the assumptions and detail the same and/or consistent across the architectures being analyzed. For example, the assumption of NFU growth mentioned above can have a relatively low precision if it is applied consistently across all architectures being analyzed.

It should be noted that not all of the performance tools used in the spreadsheet will take the form of a response time equation. In the case of local area networks (LANs) where the transmission time is small compared to other time elements, load limits will simply be analyzed to determine if a maximum or rule of thumb is exceeded. This would be especially true in the case of IEEE 802.3 (CSMA/CD) where instability occurs after a given limit is exceeded. Here, the load limit has been determined by DES results. Other simple results can also be used for LANs from publications such as Stallings (1988).

Finally, one type of DES modelling that is required is that of the new loads e.g., see Becker, 1989. The problems here are quite different from infrastructure modelling in that we are primarily modelling the effect of instruction path lengths (the load) impinging on one or more CPUs (the resource or server) along with the I/O that exists. The difficult part here involves determining the instruction path lengths. DASD I/O, for example, is easier to model and to obtain needed data.

Two techniques are used here. One involves finding the resource utilization of similar known functions on known processors. Care has to be taken in separating system overhead from application time. This technique is used where the application in question does not exist.

Where at least a prototype of the load exists, measurement of CPU cycles can be made, again attempting to separate out the system functions from those of the application. Although this sounds relatively simple, it usually is not. Also, some knowledge of the options and their effect on the CPU utilization is required. Finally, in the case of the software prototype, the "tightness" of the code, i.e., how much will it be improved in later versions, is always a question.

4. THE MACRO-LEVEL COST/PERFORMANCE MODEL

Figures Four and Five show the inputs being used for testing a sample network, and a summary of cost figure results, respectively. Figure Six shows the coupled performance data results. (It should be emphasized that all of the data shown are fictional). This system is now being used to produce baseline cost and performance estimates of the computer communications infrastructure, and will then be used to test various strategic and transition scenarios for cost and performance comparisons with the baseline.

5. THE "SIMPLE" MODELLING TOOLS

Validation of simplified models with measured data becomes even more important than the usual validation processes. Also the "loads" modelled require measurements to derive instruction path length information. In order to accomplish this and other tasks, CAG has available both simulation tools and a measurement lab. The simulation tools include a general purpose package (GPSS/PC) and a communications oriented system (CACI's Network II.5). The communications lab has two workstations, a Sun 4/260 and a DEC VAXstation 3500. Both have Unix operating systems. They are currently connected via an IEEE 802.3 local area network and some X.25 switching gear. We also have hardware monitors that can measure the LAN protocol along with a general protocol analyzer for the wide area network protocols such as X.25 and HDLC. ISDN equipment has also been installed. Communications software includes DOD's TCP/IP and a full suite of OSI software.

Significant communication work loads such as file transfer are now modeled. (Transaction processing workloads, e.g. ISO's TP, will be modelled in 1990). Discrete event models have been built of the current and future file transfer processes, FTP (DOD) and FTAM (OSI). The software systems have been installed in the lab and experiments have been run validating the models. Unfortunately, space does not allow the presentation of these results

6. SUMMARY

There is still much work to be done and some very pertinent questions to be answered. The most obvious has to do with the validation of the macro-level results. A means of doing this is being developed and will involve reasonableness tests, the test of existing rules of thumb as in Zimmer, 1988, and a walk-through of the results with knowledgeable people in the field. A similar question has to do with "typicalness" of the macro-level performance models. This is a critical measure in that the selection of the model influences the final, normalized cost/performance results.

However, this methodology now exists and is currently being populated with data and performance models. The ability to evaluate the current networks within the PMO is already available. Actual testing of proposed communications architectures should take place next year. Equally important, the methodology includes provisions for prioritizing the collection of the most pertinent computer communications data and the modelling/refining of the most important communications processes. At the same time useful results are already being demonstrated to management, thereby continually validating the project and ensuring its continuation. The most sophisticated program in the world is of no use if it goes uncompleted.

Finally there is now one central, up-to-date repository for computer communications planning information and tools that not only will be used in the communications architecture process, but that can be extended to the network implementation people when the implementation date comes. This procedure has never been available before.

ACKNOWLEDGMENTS

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ITEM	VARIABLE DESCRIPTION	INPUT VALUE
Term Calc	No. of Employees	10,000
	% of Employees Requiring Terminals	.75
	Single function factor terminal-on-desk	1.25
	Multifunction factor terminal-on-desk	1.00
	% Teleprocessing (TP) Based Terminal Req.	30%
	% non-TP Based Terminals (Async) Req.	45%
	% non-TP Based Terminals (Personal Computer - PC) Req.	5%
	Cost of TP-Based Terminal	$1,500
	Cost of non-TP Async Terminal	$1,000
	Cost of PC	$2,500
	Cost of TP monitors supported	$250,000
	No. of terms supported by TP monitors	4,000
Rem CC	No. of Devices on Cluster Controller	10
	Cost Per Cluster Controller	$15,000
Coax Wire	Cost of Teflon Connection per Terminal	$1,175
FEP	No. of terminal devices on Front End Processor (FEP)	500
	Cost per FEP ($M)	$0.25
Async Dev	% Intrabuilding Terminals needed	10%
	Cost of Async connection	$1,500
Host Power	On-line terminals supported by 1 MIPS (millions of instructions per second)	100
	% Computation power on mainframe	25%
	Computation power on mini-superminis	75%
	Cost per MIPS ($M)	$0.25
DASD	On-line term supported by 1 Gbyte Disk	1,000
	Cost per Gigabyte	$60,000
Data Comm	Average cost / Mile / Month for lines	$0.75
	Cost for access (2 ends)	$80
	LAN: initial cost per terminal	$1,250
	Yearly maintenance cost	$250
Lt 1	Length in miles for Intrabuilding Links	0
Lt 2	Length in miles for City-wide Links	5
Lt 3	Length in miles for LATA-wide links	30
Lt 4	Length in miles for State-Wide links	200
Lt 5	Length in miles for Nation-wide links	1,000
	% of Lt1 Required	10%
	% of Lt2 Required	20%
	% of Lt3 Required	30%
	% of Lt4 Required	39%
	% of Lt5 Required	1%
	No. of teminal per pt-to-pt TP lines	10
	Calculated Annualized cost factor	0.36

Figure 4: Input Data (Test)

ITEM	QUANTITY	COST ($M)	ANNUALIZED DATA COSTS ($M)
DATA COMMUNICATIONS			
Equipment			
Non-TP Terminals	3,375	3.37	1.21
PC Terminals	375	.93	2.2
TP Terminals	3,750	5.62	2.02
Remote Clusters	375	5.62	2.02
Coax Wiring	3,750	4.40	1.58
Local FEP's	7	1.87	.67
Async Hardware	3,750	5.62	2.02
Total		27.4	9.89
Recurring Costs			
Communications	--	--	1.95
Network Control (hardware, monitors)	19	.46	.16
Network Control (staff)	30	--	1.0
Total		.46	2.62
Total Data Communications		27.9	13.5
DATA PROCESSING			
Hosts (MIPS)	75	18.7	6.7
DASDs (GB)	37	.45	.16
Total		19.2	6.91
Total DP/DC Environment		47.1	20.4

Figure 5: Cost Summary (Test Data)

ITEM	VARIABLE DESCRIPTION (time in sec.)	VALUE
INFRA/ LOAD	Synchronous Terminals	11,133
	Total Volume Transactions - Peak Hr.	2,000,000
	Average Message Input Length (bytes)	100
	Average Message Output Length (bytes)	1,100
	Host Time - Sec.	.8
	Number of Tail Circuits	1,335
	Load Variance	1.2
	Typical Circuit Transmission Rate (bps)	9,600
PERF	Transmission Time	1.00
	Trans hr / circuit	1,798
	Line Utilization	.50
	m/d/l Wait Time	.50
	m/m/l Wait Time	1.00
	m/d/l Response Time	2.30
	m/m/l Response Time	2.80

Figure 6: Performance Data (Test Data)