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ABSTRACT

The high cost of computer network components, such as processors and circuits, resulted in the host-based computing model that dominated from the 1950s into the 1980s. Users shared the cost of expensive mainframe computers. Dramatic reductions in the price of these network components allowed for the emergence of personal computers and the client-based computing model during the 1980s. The drive to reduce the cost of communications among client computers in organizations contributed to the client-server architecture that currently dominates the market. This paper develops an economic location model of computer-communications networks calibrated with historic data. The model can be used to speculate on future trends.

Keywords: Network Computing, Location Cost, Optimal Design, System Economics

INTRODUCTION

Two issues that have attracted much current attention and which may impact the location of network components in the future are the high labor costs associated with current systems and the dramatic improvement in the speed and price of network communications. The issue of growing labor costs has been addressed in the context of the Total Cost of Ownership, with current estimates that 60 to 80 percent of the expense of operating a business computer network are associated with administration and support. At the same time, improvements in the price to performance ratio for data communications, processing, and storage over the past few years have dramatically changed the network environment.

Within the framework of the client-server model, the high cost of user support has already encouraged a movement to the thin client model. Technology companies are busy creating the technology that would move this trend forward to the network computer. Sun Microsystems, for example, has recently demonstrated a computer card that looks like a typical credit card, but which allows a computer user to carry his most recent desktop in his wallet. Silicon Graphics is working on technology for computing fabrics, a business model similar to the time sharing systems that were familiar in mainframe environments. The network computers in this model would not contain processors, but would connect through the Internet to share processing, storage, and software.

These new network models may succeed in changing the computing environment if they provide sufficient economic benefit to organizations and individual users. This paper proposes a model grounded in economic location theory and drawing on optimization tools that can be used to investigate network configurations.

At least two general areas of literature contribute to solutions of network modeling problems. The literature on network economics provides support for problems related to standards (2, 4, 7,

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12), scale economies (1, 15, 16, 17), and market structure (3, 10, 11, 14). The technical literature on networks examines the physical structure of networks (6, 8) and tools for numerical optimization (5, 9, 13, 18).

THE GENERAL MODEL

Consider a group of computer users (U) distributed over an area that can be connected by a single bus, represented by a line. Users may incur a cost in traveling to an input/output (I) device that allows for access to a processor (P) that is linked to memory (M) and storage (S). Bringing computer resources to users through a network involves costs related to transmission speed and distance. The labor costs required to support the system are related to the number of users and the complexity of the system. The optimal system design that minimizes total systems cost, C, subject to service and technical constraints is defined as:

$$\text{Minimize} \quad C = \sum_{u=1}^{U} \sum_{i=1}^{I} \sum_{p=1}^{P} \sum_{m=1}^{M} \sum_{s=1}^{S} (I_i + P_p + M_m + S_s + L_{u,i,p,m,s} + U_{u,i} + I_{i,p} + P_{p,p} + M_{m,p} + S_{s,p}) \quad (1)$$

where,

I_i the cost of input/output device i.

P_p the cost of processor p.

M_m the cost of memory at location m.

S_s the cost of storage at location s.

$L_{u,i,p,m,s}$ the labor cost to suppor user u, input/output device i, processr p, memory m, and storage s.

$U_{u,i}$ the cost to user u on the network to have access to input/output device i

$I_{i,p}$ the cost to network input/output device i with processor p.

$P_{p,p}$ the cost to network processors p

$M_{m,p}$ the cost to network memory at location m with processor p.

$S_{s,p}$ the cost to network storage at location s with processor p.

Figure 1 illustrates the basic model for a familiar situation of a single user sitting in front of an input/output device attached to a processor supported with memory and storage.

Figure 1: The General Model for u,i,p,m and $s = 1$
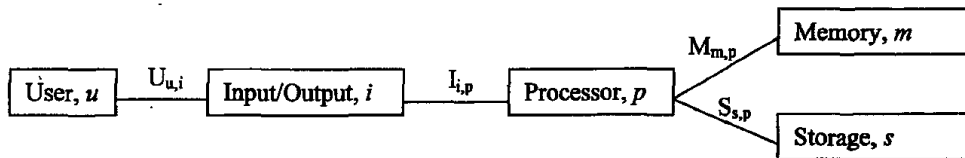
In Figure 2, the model is expanded to illustrate two users in a client/server architecture who share a printer. As the relationships that drive costs in the network model change over time, the optimal network configuration changes.

**Figure 2: The General Model for a Client/Server Network
with Two Users and a Shared Printer**
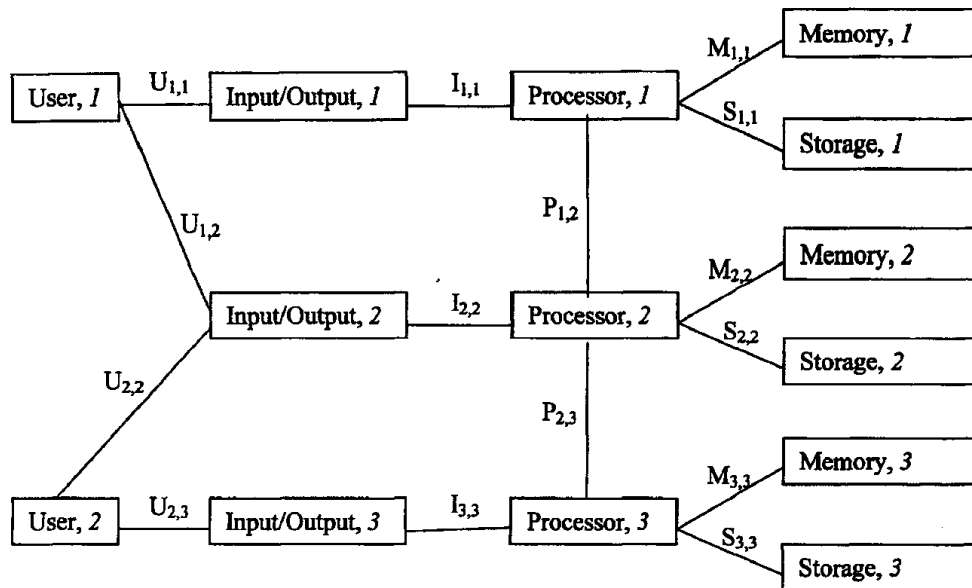
MODEL DETAILS AND DATA

The following section specifies details of the network cost elements following the activity based costing approach that ties cost to specific cost drivers. For each variable affecting system cost, the cost drivers are discussed and parameter estimates are provided.

Components Costs (I, P, M, S)

Prices for input/output (I), processing (P), memory (M), and storage (S) have generally declined over time while quality has improved. Representative prices appear in Table 1 for the 1970 to 2000 time frame. The price of an input/output device reflects the average configuration of either a terminal with keyboard or a printer. Processing prices include a CPU with necessary supporting hardware such as a printed circuit board. Memory and storage prices are for standard configurations in this example, but a more detailed version of the model would relate prices to speed and size.

Users' needs for processing, like their transport costs, will vary among individuals and can be approximated using a probability distribution. Processing resources come in discrete bundles, computer processor units. Measurement of processing unit resources is more complicated than elements like storage which are commonly measured in bytes. Instructions per second is perhaps the most commonly accepted measure. An approximation can be made as in the following equation that looks at the cost of a processor, p, and the number of users, k, which can be supported by a single processor. In the case of personal computers k = 1.

$$Pi = p_a(1/k_a) \tag{2}$$

where,

p_a is the cost of a central processing unit of architecture type a

k_a is the number of users that can be supported by a single processor of architecture type a, minimization of this cost element requires that k be an interger

The Users' Costs ($U_{u,i}$)

Users incur travel costs to processing facilities that include the users' time and the cost of transportation.

$$U_{u,i} = u_u D_{u,i} \tag{3}$$

where,

$U_{u,i}$ the cost to user u on the network to have access to the input/output device at location i.

u_i the estimated cost to user u for traveling each unit of distance to the input/output device a location i. Costs are distributed following the lognormal.

$D_{u,i}$ the distance in feet between user u and processing capacity at location p. Distances are assumed to be uniformly distributed.

Travel costs per unit distance will vary among users reflecting differences in the cost of time for different individual users. The simulations developed in this paper rely on a log-normal distribution of user cost, a common approach for estimating income and wage distributions. In this example users are assumed to be uniformly distributed over the network. The impact of alternative distance distributions is a common thread in the location literature.

The Network Cost ($I_{i,p}$, $P_{p,p}$, $M_{m,p}$, $S_{s,p}$)

Notations with two subscripts in this model indicate a network connection. For example, $I_{i,p}$ specifies the network cost for input/output device i to be connected to processor p. Memory and storage are both connected to processors, indicated respectively by $M_{m,p}$ or $S_{s,p}$. Network costs are typically a function of distance and speed measured commonly in bits per second. Some technical constraints require integer solutions, such as the limited number of speeds available in the market. For example, modems currently operate at 56kbps, 33 kbps, and 28 kbps. Users need for network speed will vary, with some users applications requiring higher speed network connections, and could be modeled with some distribution like the log-normal.

Equation 4 below makes the simplifying assumption that network connections operate at a standard speed so that the cost of the network connection is related to the cost per unit distance, n, separating the user u and processor p. Also that there is fixed cost of setting up the connections, a, including terminal equipment. In the case of wireless connections, which are often not cost sensitive to changes in distance over a certain range, all of the costs may be associated with the fixed cost.

$$I_{i,p} = a_{i,p} + n_{i,p}D_{i,p} \qquad (4)$$

where,

$I_{i,p}$	the cost to network input/output device i with the processor p.
$a_{i,p}$	the fixed cost of a network connection between input/output device i and processor p.
$n_{i,p}$	the cost of networking per unit distance from input/output device i to processor p
$D_{i,p}$	the distance in feet between input/output device i and processor p.

Following this same format, network cost equations are developed for processors ($P_{p,p}$), memory ($M_{m,p}$), and storage ($S_{s,p}$). The notation assumes that a processor can be linked to other processors ($P_{p,p}$) and that memory and storage are linked to processors ($M_{m,p}$ or $S_{s,p}$). The technical literature provides a lot a detail for expansion of the model in this area.

Table 1 contains estimates of historical values for network components and labor. Network connection and user access costs are described in Table 2. There are also technical and service constraints for many of the model parameters. Cost estimates and model equations are combined into a spreadsheet used to find the minimum network cost defined in Equation 1.

Table 1: Estimated Costs for Network Components and Labor
(in dollars, annual)

Parameter	I	P	M	S	L per User	L per Component
Year						
1970	325	10,000	10000	4000	1500	200
1980	250	3500	600	900	1500	250
1990	150	300	80	250	1500	300
2000	60	100	40	25	1500	400

Table 2: Estimated Costs for Network Connections and User Costs
(in dollars, annual, distance costs are per foot)

Parameter	$a_{i,p}$	$n_{i,p}$	$a_{p,p}$	$n_{p,p}$	$a_{m,p}$	$n_{m,p}$	$a_{s,p}$	$n_{s,p}$	$u_{u,i}$
Year									
1970	20	7	50	20	80	35	70	25	.001
1980	14	5	35	15	60	25	50	18	.002
1990	10	3	25	11	55	18	45	13	.003
2000	8	2	20	8	45	14	35	9	.004

CONCLUSION

Given the high cost of connecting network components during the early period of computing, a single processing unit located in the middle of a network is shared among users. As the cost of processing comes down, processors tend to be clumped among high cost users. With further reductions in processor cost, processors are distributed throughout the network, giving rise to the client/server model that is sensitive to high network costs. In the new model, with network costs coming down rapidly, labor costs begin to dominate leading to a more centralized network design (thin client) with fewer components.

The general model presented here can be used as a framework to evaluate alternative future network configurations. Better estimates of user and labor costs are two important improvements among the many that could be implemented to improve the reliability of model solutions.

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