Queueing Theory Applied to Data Processing Networks
Author(s): Bruce E. Krell and Maria Arminio
Source: *Interfaces*, Vol. 12, No. 4 (Aug., 1982), pp. 21-33
Published by: INFORMS
Stable URL: http://www.jstor.org/stable/25060282
Accessed: 11/04/2010 06:25

INTERFACES
Vol. 12, No. 4, August 1982

0092-2102/82/1204/0021$01.25

QUEUEING THEORY APPLIED TO DATA PROCESSING NETWORKS

Bruce E. Krell

Hughes Aircraft Company, P.O. Box 92919, Los Angeles, California 90009

and

Maria Arminio

ICS Group, Inc., 3848 Carson, Torrance, California 90503

ABSTRACT. Wyle Data Services is a California-based company which operates a computer communications network for several clients. Using transaction count and message size data provided by Wyle, a cost-effectiveness exercise is performed to investigate alternative network architectures and capabilities. The foundation of the network analysis uses the steady state queueing delay formulas for a single-server queue. A cost/delay analysis shows that considerable savings may be accrued with minimal damage to delay times from changing network processing speeds across the communications links.

OBJECTIVE AND DEFINITION

The objective of this analysis is to apply a queueing methodology to the problem of sizing and constructing a data processing network by testing cost/effectiveness factors of various communications network parameters. The transaction volume of the organization selected is examined in relation to the processing time for transaction completion to determine the effectiveness of the network structure in terms of message delays. Alternative data processing architectures and link capacities are also examined for comparative analysis of system cost/effectiveness.

The most expedient and efficient means to perform the analysis for this study was to select a data processing organization that had a network structure currently in operation. (The analysis could also be performed by establishing projected transaction volume traffic logs within an organization and subsequently designing a network structure based upon projected transaction count.) Wyle Data Services, a data processing service corporation, was selected for the analysis based upon the following factors:

- The size of the network structure facilitated the mathematical calculations entailed in the analysis.
- An automated system for record tracking of transaction volumes provided actual and accurate data for the analysis.

Analyzing the network structure of the data processing architecture requires a definition of some basic terminology. The basic network structure of any data processing configuration consists of nodes and links (with varying capacities). The customer terminals referred to previously are nodes in the architectural structure. The

QUEUES—APPLICATIONS; NETWORKS/GRAPHS

central processing unit, located in Huntington Beach, relays all the messages to the various terminals and is considered the primary source node. Links can be defined as the lines of communication between nodes. Links, depending upon their capacity, can accommodate variable message sizes and speeds. The messages which can be sent over the communication links are controlled by a variable switch modem, which can vary the speed of the traffic relayed from 1200 to 9600 bits/second depending upon transaction volume. The communication links can be classified as dedicated (allowing messages to be sent directly from one node to another) or multidrop (relaying messages to an ultimate destination node via a number of nodes).

METHODOLOGY

The methodology used in this analysis begins with a network specification which examines the network structure, external traffic generation, and traffic proportions between, and retained at, the nodes. Node traffic is then determined and converted to link traffic. Finally, delay computations are calculated, including queueing delays and transfer delays, and an analysis of the results is formulated. Appendix A, Mathematical Description of Methodology, includes a complete description of all computational processes performed.

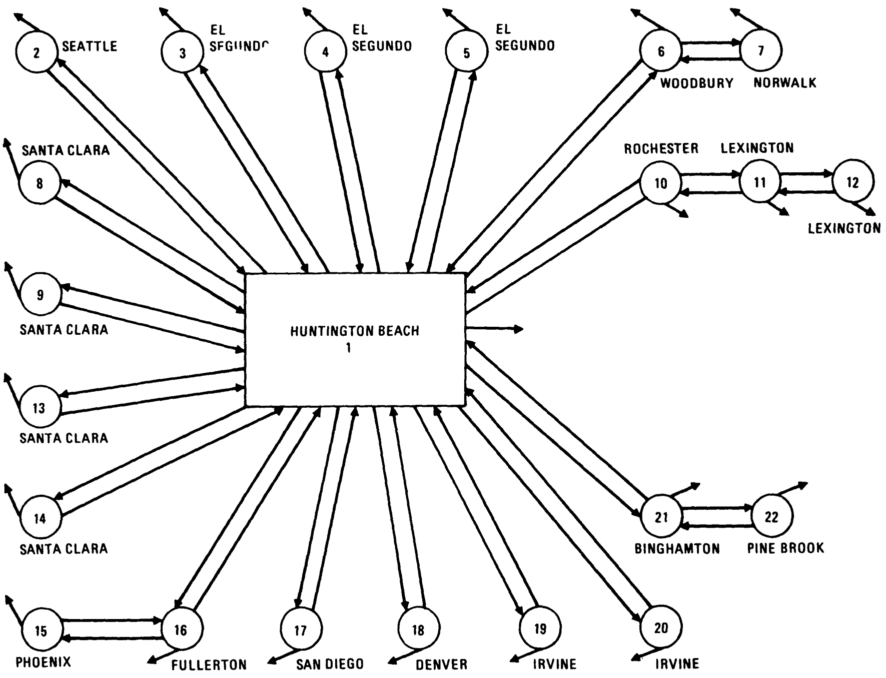
Network Specification

The network structure is basically designed as a star configuration, with 21 nodes connected to the source node by dedicated and multidrop lines (see Figure 1). Each of the terminal locations has been assigned a numeric code. Traffic direction paths from source node to destination node can be traced by following the arrows representing the communication links. Links without destination nodes indicate traffic retained at the source node.

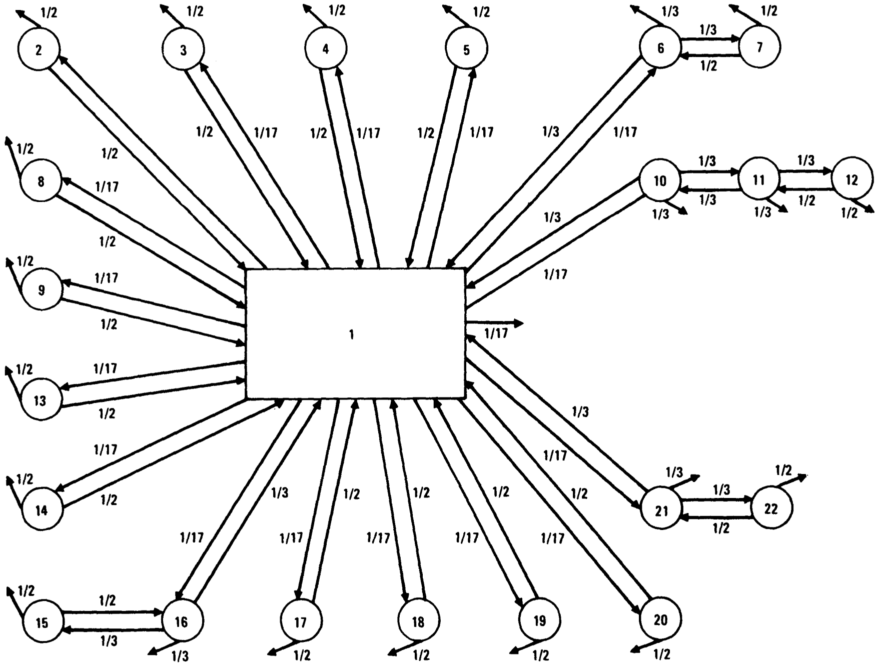
External Traffic Generated. The transaction count for two groups of Wyle customers was recorded over a three-month period and charted in Table 1. For reference purposes, each terminal location corresponds to the numeric code designated in Figure 1. From these transaction counts, an average monthly transaction volume is determined. For terminal locations with more than one node (indicated in parenthesis in Table 1), the average monthly transaction count is divided by the number of nodes specific to that terminal location. The number of messages per month, bits per second, and bits per message are calculated for each location in the network structure (Table 2).

Proportion of Traffic. Proportions have been assigned to each link in Figure 1 in accordance with the number of links drawn from the source, with one link selected to represent the proportion of the message retained at each node. For example, node 2 has two links emitting from this source node — one link transferring messages back to the primary node 1 and one link for retaining messages at node 2. Therefore, 50% of outgoing messages were designated to each link. Node 11, however, has three links emanating from this source, one transferring messages to node 12, one transferring messages to node 10, and one retaining messages. Hence, each link received 33% of the traffic.

FIGURE 1. NETWORK STRUCTURE AND TRAFFIC PROPORTIONS.



NETWORK STRUCTURE



TRAFFIC PROPORTIONS

TABLE 1. TRANSACTION HISTORY.
(Number in parentheses indicates number of terminal locations.)

Terminal Location	September	August	July
WYLE TRANSACTION COUNT			
Santa Clara (4)	693,194	684,561	721,546
El Segundo (3)	400,699	377,918	412,551
Denver (1)	109,876	101,882	110,317
San Diego (1)	147,858	152,943	165,682
Seattle (1)	115,986	104,345	117,109
Phoenix (2)	109,876	106,480	125,807
Irvine (2)	234,943	216,710	232,478
WDS (misc.)	2,487	1,701	2,735
Wyle total	1,820,146	1,746,540	1,858,225
HARVEY TRANSACTION COUNT			
Binghamton (1)	90,129	67,804	81,112
Lexington (1)	120,306	101,842	111,531
Norwalk (1)	88,424	73,873	89,851
Pine Brook (1)	93,110	79,930	92,904
Rochester (1)	55,143	56,006	52,717
Woodbury (1)	130,324	119,809	123,424
Harvey total	577,436	499,264	551,539

TABLE 2. LOCATION OF TRAFFIC COMPUTATIONS.
(Average number of characters per message is 390, bits per character is 8, seconds per month is 25.92×10^5.)

Location	(1) Destination Node No.	(2) Total Average Message per Month	(3) Bits per Second (α)	(4) Bits per Message $1/\mu_j$
Huntington Beach	1	$23.53(10^5)$	2832.31	3119.99
Seattle	2	$1.12(10^5)$	134.81	3119.88
El Segundo	3-5	$3.97(10^5)$	158.88	3119.82
Woodbury	6	$1.24(10^5)$	149.25	3119.80
Norwalk	7	$0.840(10^5)$	101.11	3119.96
Santa Clara	8-9	$6.94(10^5)$	280.46	3119.96
Rochester	10	$0.54(10^5)$	64.99	3119.52
Lexington	11-12	$1.11(10^5)$	66.20	3119.92
Santa Clara	13-14	$2.33(10^5)$	280.46	3119.96
Phoenix	15-16	$1.14(10^5)$	68.61	3119.94
San Diego	17	$1.55(10^5)$	186.57	3119.93
Denver	18	$1.07(10^5)$	128.79	3119.84
Irvine	19-20	$2.28(10^5)$	137.22	3119.94
Birmingham	21	$0.79(10^5)$	95.09	3119.91
Pine Brook	22	$0.88(10^5)$	105.92	3119.92

Node Traffic Determination

The next step in the methodology entails using matrix inversion to solve for the total, steady-state message traffic generated at each node; that is, the traffic relayed through one node to all other nodes. This total message traffic must be calculated for each node in the network structure, so that the total link traffic may be determined.

To compute the solution, the external traffic must be determined. This represents the average number of bits per second going through a node based upon the traffic initiated at the node. The initial constant must then be adjusted by factoring the probability that the message is relayed.

Steady state conditions dictate that all traffic entering a node exactly equals all traffic exiting a node (including retained messages). Implementation of these conditions results in a system of balance equations (see Appendix A) which are a function of the external traffic generated at the node and the traffic proportions of the links exiting the node.

Figure 2 is a matrix (R) of proportions of messages traveling from source to destination. The vector of external transaction counts, $\underline{\alpha}$, is column 3 of Table 2, with values repeated where there are multiple nodes at one location. To find the values for the vector, $\underline{\lambda}$, of total traffic at each node, form $(I-R)\underline{\lambda} = \underline{\alpha}$, then $\underline{\lambda} = (I-R)^{-1}\underline{\alpha}$, which is [5427, 2848, 2872, 2872, 2872, 2364, 1283, 2994, 2994, 2174, 965, 549, 2994, 2994, 1196, 2254, 2900, 2842, 2851, 2851, 2301, 1256].

Nodal to Link Traffic Conversion. Node traffic is converted to link traffic by multiplying the total traffic at a source node by the proportion of traffic emanating from the node across the destination link (Table 3).

TABLE 3. LINK TRAFFIC AND DELAY COMPUTATIONS, WYLE DATA SERVICES.

Source Node	λ_j	Link No.	Proportion	Link Traffic θ_j	Bits/Message	Queue Delay $1/(\mu_j C_j - \mu_j \theta_j)$ (sec)	Total Delay[a]
1	5427	L1	1/17	319.23	3119.99	0.336	2.336
7	1282.9	L19	1/2	641	3119.88	0.348	2.348
11	964.7	L31	1/2	482	3119.96	0.342	2.342
⋮				(Repeat for each link in the network.)			

C_j = 9600 bits/sec or 4800 bits/sec (baud rate).

[a] Includes 2 seconds for message transfer/printout.

Delay Computation. Queueing delays track the time which elapses in waiting for a message to be sent across a communication link (as a function of link capacity). The queueing delay is calculated by standard queueing theory formulas reflecting arrivals (θ_j) and services (μ_j). A transfer delay must be computed for each communication link. This transfer factor is especially important in terms of delays incurred on the multidrop lines, as transfer delays represent additional time elapsed in sending a message from one node to another. Transfer delays are derived as a function of the number of transfers (including destination node off-loading). An average of 2 seconds/transfer is assumed in Table 3.

FIGURE 2. MATRIX (R) SHOWING PROPORTION OF MESSAGES TRAVELING FROM SOURCE TO DESTINATION.

$$\left[\begin{array}{cccccccccccccccccccccc}
0 & 1/17 & 1/17 & 1/17 & 1/17 & 1/17 & 0 & 1/17 & 1/17 & 1/17 & 0 & 0 & 1/17 & 1/17 & 0 & 1/17 & 1/17 & 1/17 & 1/17 & 1/17 & 1/17 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/3 & 0 & 0 & 0 & 0 & 0 & 1/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/3 & 0 & 1/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/2 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/3 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/2 & 0
\end{array}\right]$$

Analysis of Results. The summation of the queueing delay and transfer delay for each of the links in the network structure results in the total processing time entailed in message transfer across each link. These results for each link can also be found in Table 3.

Assumptions. There are a number of assumptions which must be considered in the analysis of the results. First, the size of the characters per message ranged from 120 to 680 characters; the average number of characters in a message is calculated at 390. Second, the three-month tracking period of transactions is assumed to reflect the average transaction rate for Wyle and Harvey customers within any random month. Peak load traffic would probably alter the numerical results. Third, as arbitrarily selected, an equal proportion of the messages is retained at each node and an equal proportion of messages is transferred over the lines with multiple nodes in the same location. Fourth, the average transfer time is approximated as 2 seconds, as Wyle Data Services has a transfer time ranging from 1 to 3 seconds. Fifth, each character transmitted requires eight bits of data. Finally, equal proportions of traffic are assumed to exit on each link from a node.

ALTERNATIVE DESCRIPTIONS

For comparative analysis, alternative link constructions must be examined and compared to the network structure utilized to determine the variations which can occur in the average message delay. The Wyle Data Services network structure consists of an IBM System 370/3033 Central Processing Unit (CPU) and 3705 Controller with 29 available ports. Dedicated lines connect all branches to the CPU, with the exception of the Phoenix branch, which is a multidrop line. The dedicated lines have a link capacity of 9600 bits/second. All Harvey branches (locations 6, 7, 10, 11, 12, 21, and 22 in Figure 3) are multidrop lines, as this type of configuration is more cost effective for the needs of Harvey customers. The multidrop lines (including Phoenix) have a link capacity of 4800 bits/second.

Alternative No. 1 is defined as the same network structure as the baseline case computed in Table 3, using dedicated and multidrop lines, but the link capacity is limited to 4800 bits/second (Figure 3). The variation in this link capacity should increase the delay time for messages traveling across the network, as compared to the base network structure. Alternative No. 2 (Figure 3) is defined as a network configuration structured with dedicated lines only. The link capacity for all communications in Alternative No. 2 is 9600 bits/second. The usage of completely dedicated lines should decrease the delay time for messages traveling across the network because the transfer delay incurred with multidrop lines is eliminated. The link capacity of 9600 bits/second should also aid in decreasing message delay time. All calculations described above were performed for Alternatives No. 1 and 2. Details are omitted for the sake of brevity.

ANALYSIS

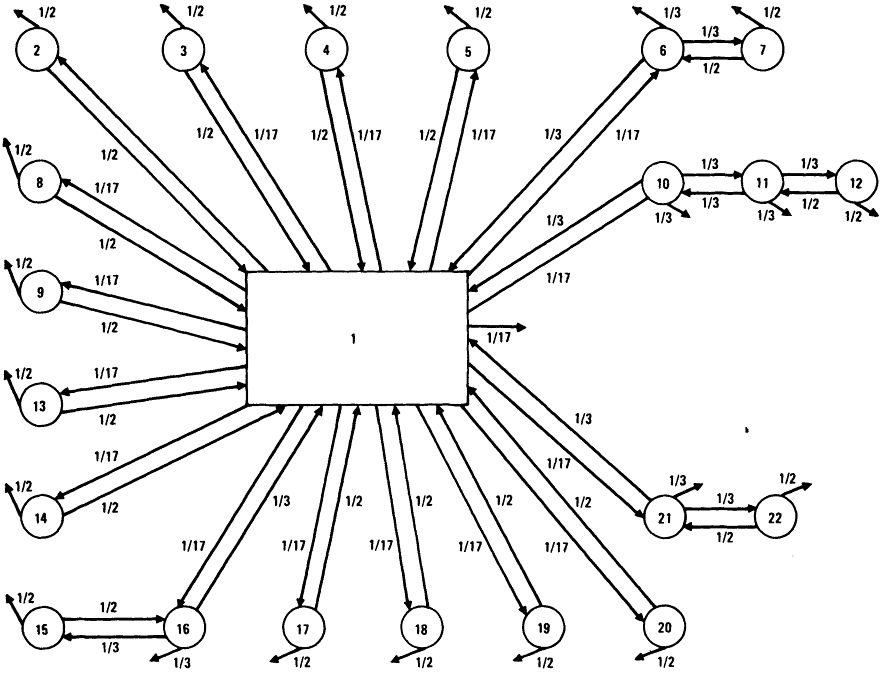
Using the prescribed methodology, the message delay time was calculated for each of the links in the current Wyle network structure, Alternative No. 1, and Alternative No. 2. Subsequently, the average message delay time was determined for each of the architectures by dividing the sum of the message delays (queueing and transfer) within each structure by the total number of links in the structure:

Network Structure	$\dfrac{\text{Transfer + Queueing Delay}}{\text{Total Number of Links}} =$	Average Message Delay Time
Wyle Data Services	$\dfrac{162.816 \text{ seconds}}{64 \text{ links}} =$	2.544 seconds/link
Alternative No. 1	$\dfrac{178.688 \text{ seconds}}{64 \text{ links}} =$	2.792 seconds/link
Alternative No. 2	$\dfrac{151.360 \text{ seconds}}{64 \text{ links}} =$	2.365 seconds/link

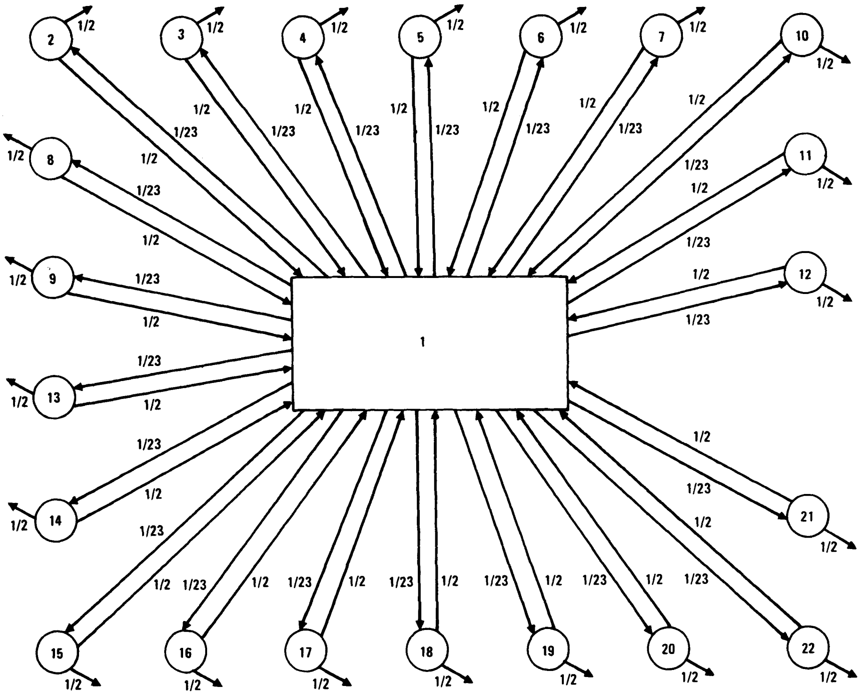
This assumes that the average message traverses only one link. Most messages simply travel to or emanate from Node 1 (see R), so that this is a realistic assumption.

Ostensibly, the results indicate that the shortest message delay time occurs in Alternative No. 2, which utilizes all dedicated lines, with a link capacity of 9600 bits/second. Alternative No. 1, using both multidrop and dedicated lines, with a link capacity of 4800 bits/second for all links, results in the longest message delay time, recorded at 2.792 seconds.

FIGURE 3. NETWORK STRUCTURE/TRAFFIC PROPORTIONS, ALTERNATIVES 1 AND 2.



ALTERNATIVE NO. 1



ALTERNATIVE NO. 2

A comparison of the current Wyle network and Alternative No. 1 network structure indicates that the use of 4800 bits/second link capacity for all links in the structure, as opposed to 9600 bits/second link capacity (and 4800 bits/second Phoenix drop), will increase the average message delay time by 0.248 second per message. The use of all dedicated lines, at 9600 bits/second (Alternative No. 2), as opposed to the dedicated multidrop structure found at Wyle Data Services, could decrease the average message delay time by 0.179 second per message.

The cost/effectiveness of each of the network structures was then determined by comparing the monthly service costs associated with each of the network configurations, as charged by the General Telephone Company. Table 4 shows the monthly service charges for each of the terminal locations in the Wyle Data Services network structure, given dedicated and multidrop lines. To estimate cost/effectiveness for all dedicated lines, the charges for dedicated lines to each terminal location are also accumulated. Additionally, the price of 9600 and 4800 bits/second modems are recorded, as charged on a monthly basis. The cost data, provided by General Telephone Company, is listed in Table 4.

TABLE 4. MONTHLY SERVICE CHARGE PER TERMINAL LOCATION.

	Monthly Charge		
Rate Center	Dedicated Line from Huntington Beach, CA	Dedicated and Multipoint[a] from Huntington Beach, CA	Comments
El Segundo, CA	233.18	233.18	
San Diego, CA	301.34	301.34	
Irvine, CA	143.03	143.03	
Santa Clara, CA	491.53	491.53	
Phoenix, AZ	497.37	620.28[a]	Includes Fullerton, CA
Seattle, WA	1,047.11	1,047.11	
Denver, CO	930.86	930.86	
Fullerton, CA	152.75	—	
Binghamton, NY	1,641.18	—	
Lexington, MA	1,748.98	2,131.94[a]	Includes Rochester, NY and another drop in Lexington
Norwalk, CT	1,701.90	1,866.56[a]	Includes Woodbury
Pine Brook, NJ	1,682.54	2,015.64[a]	Includes Binghamton
Rochester, NY	1,605.98	—	
Woodbury, NY	1,699.76	—	
Total Cost/Month	$13,877.51	$9,781.47	

[a] Modem 9600 bits/second = $200 per month; 4800 bits/second = $135 per month.

Given the monthly service charges for each of the communication lines and modem usage, the total monthly cost for each network structure can be determined. This information is displayed in Table 5. Intuitively, the monthly service cost of the network should increase in direct proportion to the increase in the number of dedicated lines in the structure and the increased capacity of links in the network. As indicated in Table 5, the total line charge per month for Alternative No. 2 is greater than charges for the current sizing or for Alternative No. 1, because Alternative No.

2 has more dedicated lines. Also, the capacity cost of the links in the network is greatest for Alternative No. 2 which uses all 9600 bits/second, as compared to Alternative No. 1 which uses all 4800 bits/second, or as compared to the current structure which uses a combination of both capacities.

TABLE 5. COST/EFFICIENCY ANALYSIS.

Parameter	Wyle Data Services	Alternative No. 1	Alternative No. 2
Total line charges per month	$ 9,781.47	$ 9,781.47	$13,877.51
Total model costs per month			
9600 bits/second at $200 each	4,000.00	—	4,400.00
4800 bits/second at $135 each	270.00	2,970.00	—
Total costs	$14,051.47	$12,751.47	$18,277.51
Average message delay, sec	2.544	2.792	2.365
Link construction	$9.6 \times 10^3/4.8 \times 10^3$ dedicated and multidrop	All 4.8×10^3 dedicated and multidrop	9.6×10^3 all dedicated

Additionally, the monthly service cost is indirectly proportional to the average message delay. That is, as the monthly cost of the network structure increases the delay time for relaying messages should decrease. For example, Alternative No. 2 has the highest total cost per month for line charges and network capacity, averaging $18,277.51 per month. The average message delay associated with this network is 2.365 seconds. Comparatively, Wyle Data Services currently has monthly charges averaging $14,051.47 with an average message delay of 2.544 seconds; Alternative No. 1 has monthly charges averaging $12,751.47 with an average message delay of 2.792 seconds.

The analysis results indicate that the methodology proposed in this study can be successfully used to assess data processing architectures and is effective in determining message delay times. As reflected in the cost/efficiency analysis, the most timely network configuration in terms of processing time is Alternative No. 2, where transfer delay time incurred is substantially reduced with the use of all dedicated lines in comparison to the Wyle Data network. The costing exercise, however, indicates a significant increase in price (specifically $4,226.04 per month) associated with the 0.179 second decrease in processing time.

Alternatively, dropping to 4800 bits/second lines, as reflected in Alternative No. 1, can result in a decrease in monthly service costs by $1,300 per month, as compared to the current Data Services' network. This decrease in cost has a minor impact on the average message delay, decreasing the average message delay by 0.248 second. If forecasts show that business has stabilized, the costs could be reduced and passed on to the users with negligible degradation in delay times.

This information can be valuable to Wyle Data Services in terms of the product-offering available for their customer base. The trade-offs associated with the variety of link capacity, message relay, and line configuration in relation to the costs for these accommodations should be reviewed not only in terms of the overall network capabilities, but also for the individual needs for the customers.

REFERENCE

Kleinrock, Leonard, 1976, *Queueing Systems, Volume II: Computer Applications,* John Wiley, New York, p. 214.

APPENDIX A. MATHEMATICAL DESCRIPTION OF METHODOLOGY

Notation Employed

r_{ij} = proportion of messages traveling from node i to node j ($r_{jj} = 0.0$)
α_i = traffic initialized from node i (bits/second)
λ_i = total traffic passing through node i (bits/second)
N = number of nodes
I = an ($N \times N$) identity array
$R = \left[r_{ij}\right]$
$\underline{\alpha} = \left[\alpha_i \dots \alpha_N\right]^t$
$\underline{\lambda} = \left[\lambda_i \dots \lambda_N\right]^t$
θ_j = traffic across channel/link j (bits/second)
C_j = link capacity (bits/second)
μ_j = message traffic (messages/bit)
Q_j = queueing delay on link j (seconds)
TR_j = transfer delay at end of link j (seconds)
T_j = total delay across link j (seconds)

Network Structure

The central processing unit in Huntington Beach is designated as the primary source node, No. 1. Each of the terminal locations is also assigned a numeric code ranging from 2 to 22. The legend for these codes is found in Figure 1. Traffic flow is indicated by directional arrows including one link for each node representing retained messages.

External Traffic Generated

(1) Determine the average number of messages per month per terminal location.
(2) For those cities which have more than one destination node from the source node, divide that monthly transaction volume by the number of destination nodes. (This assumes that equal volumes of transactions are incurred at each node for those terminal locations with more than one node.)
(3) Bits per second are calculated as follows:

$$\frac{\text{(characters/message) (messages/month) (bits/character)}}{\text{(seconds/month)}}$$

(4) Bits per message ($1/\mu_j$) are then calculated by another simple equation:

$$\frac{\text{(bits/second) (seconds/month)}}{\text{(messages/month)}}$$

Proportion of Traffic

The proportion of traffic between nodes and the proportion retained at each node (initially assumed equal) is calculated by examining the source node, determining the number of paths for message traffic emanating from that node to any destination and the proportion of traffic retained at each node, and dividing the paths from the source node into equal proportions.

Node Traffic Determination

The total traffic across each node can be found by solving the following system of balance equations for $\underline{\lambda}$:

$$\left[I-R\right]\underline{\lambda} = \underline{\alpha}.$$

(See Kleinrock [1976].)

Node-to-Link Traffic Conversion

(1) A link number is arbitrarily assigned to all links within the network structure. For each network structure (current Wyle Data Services, Alternative No. 1, and Alternative No. 2), there are a total of 64 links.

(2) The node traffic is then converted to channel/link traffic by multiplying the total traffic at node i by the proportion of traffic emanating from the node across link j, i.e.,

$$\theta_j = \lambda_i \, r_{ij}.$$

Delay Computation

(1) The messages per bit (μ_j) can be determined by taking the reciprocal of bits per message, $1/\mu_j$.

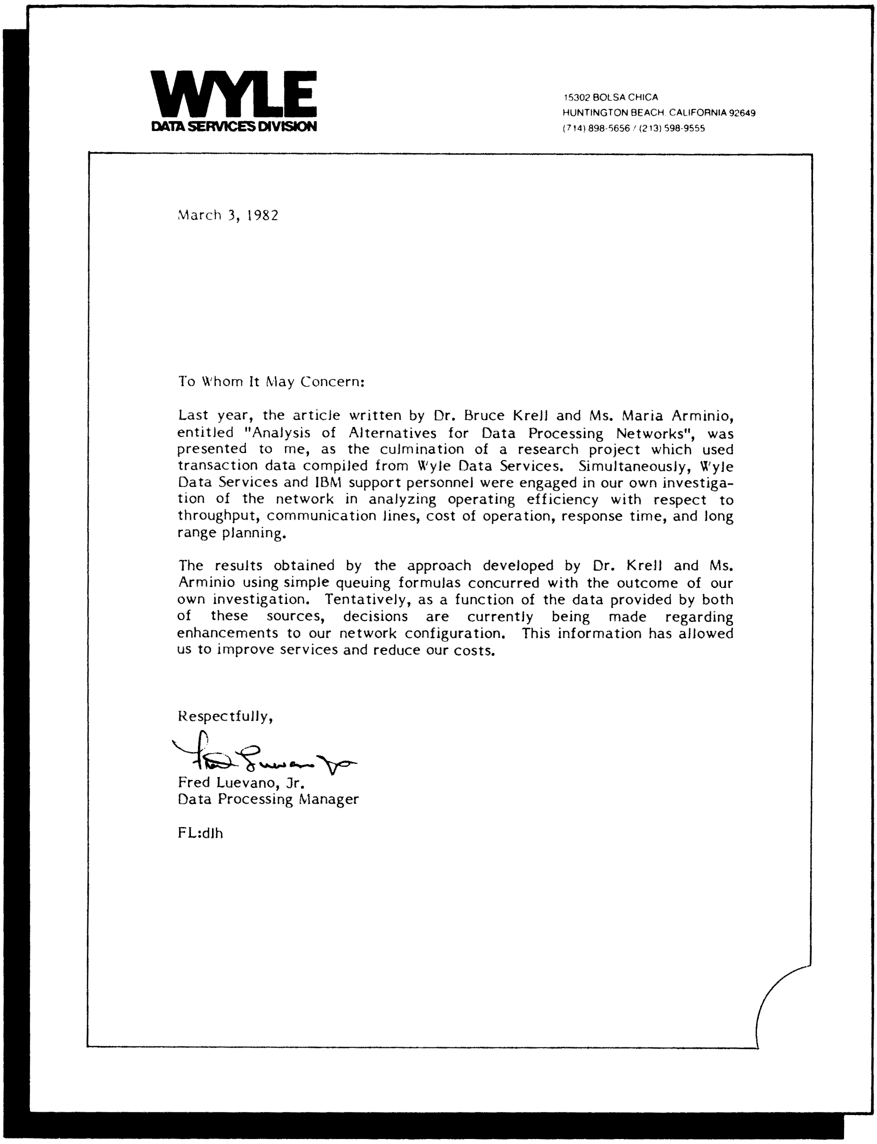
(2) Link capacity varies depending upon the architecture being examined. For this problem, each link capacity could vary from 1200 to 4800 or 9600 bits/second. The link capacities selected for the baseline analysis are a mix of 9600 bits/second and 4800 bits/second. For Alternative No. 1, all link capacities are limited to unit speed of 4800 bits/second. Alternative No. 2 operates all links at a unit speed of 9600 bits/second.

(3) To find the queueing delay across each link, compute

$$Q_j = \frac{1}{\mu_j C_j - \mu_j \, \theta_j}.$$

(4) Total processing time across each link is determined by adding the queueing delay and the transfer delay as follows:

$$T_j = Q_j + TR_j.$$



WYLE
DATA SERVICES DIVISION

15302 BOLSA CHICA
HUNTINGTON BEACH, CALIFORNIA 92649
(714) 898-5656 / (213) 598-9555

March 3, 1982

To Whom It May Concern:

Last year, the article written by Dr. Bruce Krell and Ms. Maria Arminio, entitled "Analysis of Alternatives for Data Processing Networks", was presented to me, as the culmination of a research project which used transaction data compiled from Wyle Data Services. Simultaneously, Wyle Data Services and IBM support personnel were engaged in our own investigation of the network in analyzing operating efficiency with respect to throughput, communication lines, cost of operation, response time, and long range planning.

The results obtained by the approach developed by Dr. Krell and Ms. Arminio using simple queuing formulas concurred with the outcome of our own investigation. Tentatively, as a function of the data provided by both of these sources, decisions are currently being made regarding enhancements to our network configuration. This information has allowed us to improve services and reduce our costs.

Respectfully,

Fred Luevano, Jr.
Data Processing Manager

FL:dlh