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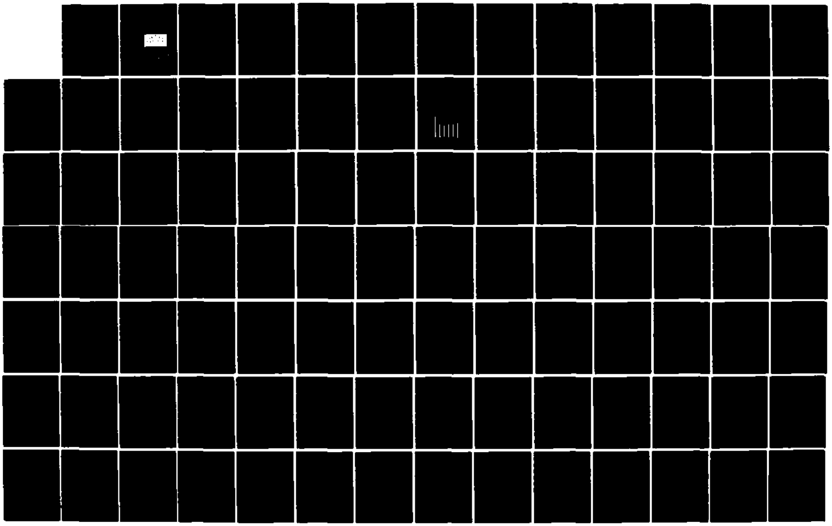

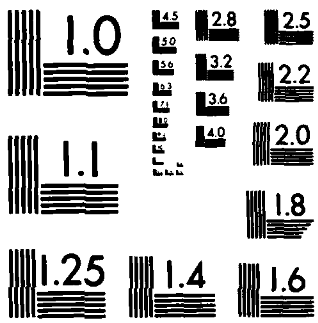

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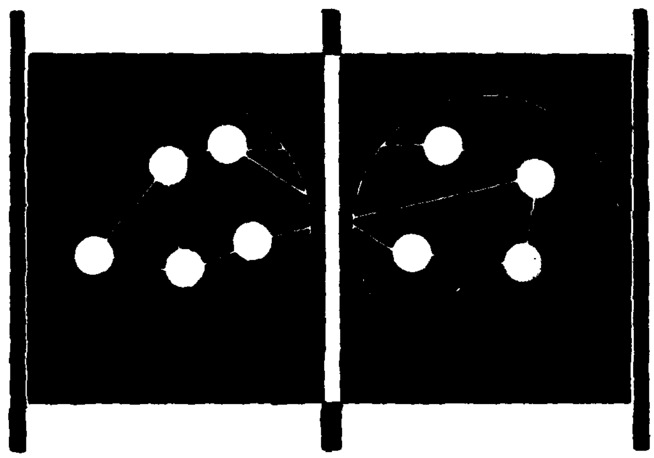
Alternative Network Strategies for Defense ADP Communications



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ALTERNATIVE NETWORK STRATEGIES
FOR
DEFENSE ADP COMMUNICATIONS

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ALTERNATIVE NETWORK STRATEGIES FOR DEFENSE ADP COMMUNICATIONS

EXECUTIVE SUMMARY

OBJECTIVE

This report presents the results of a cost-evaluation study of alternative Defense Communication network strategies. In this study, the terminal and traffic requirements of 35 ADP systems are considered, and the problems of designing the data networks which accommodate these requirements at minimum cost is addressed. The goal of the study is to identify the communications line and hardware costs associated with the array of feasible methods for implementing each system requirement.

SYSTEM OPTIONS CONSIDERED

The system options considered can be placed in two categories: systems without switching and integrated switched systems. Alternatives examined in each category are described below.

packet

Systems Without Switching

- Separate systems with terminals and hosts on dedicated lines. Such systems require no overall network optimization. For example, whenever new terminals are added to a system, separate dedicated lines are leased to the appropriate hosts.
- Separate systems with local line sharing. This approach requires a manager at each facility to coordinate the use of facility multiplexers and/or concentrators and the ordering of lines from a given location to reduce communication cost.
- Separate systems with local and regional line sharing. This approach requires a manager for each system who is responsible for optimizing each system network design.
- Limited system integration without switching. In this approach, several systems may share (via multiplexers) high speed lines. A coordinator with the ability to configure each of the systems and to combine requirements where appropriate is required.

Fully Integrated Packet-Switched Systems

The integrated packet-switched network approach allows the joint use of communication lines, communication equipment and host computers for resource and load sharing applications. Designs for three basic network approaches are developed.

- A fully integrated network with packet switches located at eight AUTODIN I store-and-forward switch sites.
- A fully integrated network in which switch locations are selected to minimize the overall communication line plus hardware cost without regard to the specific security issues at each site.

- Two independent packet-switched networks, one handling only the encrypted traffic generated by the twelve systems requiring encryption and the other handling all remaining traffic.

Each of the above system approaches requires an overall systems manager with knowledge of the individual system requirements and full control of the access and backbone network designs.

For each of the above alternatives, the cost impact of two different packet switch alternatives is assessed. These are:

- Use of "Pluribus" high speed, modular, multiprocessor IMP's currently under development.
- Clustering of currently available ARPANET IMP's at switching facilities to meet high bandwidth traffic requirements.

Also examined for each network strategy are link by link and end-to-end encryption alternatives.

ASSUMPTIONS

Assumptions include traffic volumes to be accommodated, component costs, message response times, reliability, and security requirements. The approach taken is to design each alternative so that it meets all system requirements. The costs associated with each alternative are then compared. A summary of the assumptions used in the study is given below.

System Size

- Number of host computers: 87
- Number of terminals: 1,103
- Total traffic: 1.26 Megabits/second

Data rates used for the study are, in some cases, best guess estimates that cannot, at present, be verified.

Cost Factors

Cost factors are based on current procurement estimates for tariffed communication lines and hardware. Communication line costs include mileage, termination and modem charges. Hardware cost factors include purchase price, installation, initial support, operations, maintenance, and amortization. Cost factors not considered are the host processor cycle time costs required to support various network connection schemes, network management costs, and the security costs of specially cleared switches and operating personnel required for link encrypted alternatives.

Reliability

- Availability greater than or equal to .99 for non-critical systems.
- Availability greater than or equal to .9995 for critical systems.
- The critical systems contain 34 host computers, 120 terminals, and 12.4% of the total system traffic.

Message Response Time

- For the independent, non-switched systems, the average end-to-end delay for a 500 bit transmission between terminal and host or host and host must be less than 1 second.
- For the integrated systems, the average delay for a 500 bit transmission must be:
  - Less than 1 second between terminal and backbone switch
  - Less than .25 second between host and backbone switch
  - Less than .1 second between any pair of backbone switches

The impact on response time and bandwidth of end-to-end, user specific protocols was not examined.

Security

- Twelve of the 35 systems require encryption.
- The 12 systems requiring encryption contain 56% of the total number of hosts, 6% of the total terminals, and generate 33% of the total network traffic.

CONCLUSIONS

Systems Without Switching

- More than seven million dollars per year can be saved, when compared to independent systems with hosts and terminals on dedicated lines, by introducing multiplexing at the facility level. This implies that each facility must have a manager to promote line and hardware sharing for the terminals and hosts at that location.
- An additional one million dollars per year can be saved by introducing regional multiplexing (or concentration) within each individual system. This implies that an overall network manager for each system is required to optimize the design of each configuration.
- If each system is separately optimized, little additional advantages are achieved by combining systems without adding intersystem switching.

Integrated Packet Switched Systems

- A preliminary packet-switched integrated network design yields a total system whose cost is within 13% of the best non-switched alternatives. This approach requires an overall system manager with control over the backbone and local access network configuration.
- Additional savings, using alternatives such as domestic satellites and new IMP minicomputers not studied in detail in this report, are achievable in a fully integrated network. Thus, resource and load sharing capabilities, inherent in a fully integrated system, can be achieved at no more than a small incremental cost when compared to the best non-switched system.
- Savings of over seven million dollars per year are achieved via an integrated network when compared to the strategy of independent systems with dedicated host and terminal communication lines.
- An alternative to handling all messages from all systems on a single integrated network is to construct two separate networks, one handling the messages which require

encryption, the other handling the remaining traffic. A two system approach was developed with the secure system having eight backbone switching nodes and with the system handling unencrypted traffic having 27 backbone nodes. The total cost of the two systems is approximately 7% higher than the cost of a single integrated system.

- If a two system approach were adopted, communications for current ARPANET users could be provided through the 27 backbone node system accommodating the unencrypted traffic. A feasible strategy would be to replace ARPANET IMP's by Very Distant Host Interfaces (VDH's) connected to ports on IMP's at military bases. VDH hardware plus access lines would cost less than one million dollars per year. The incremental backbone network cost to handle ARPANET traffic would be nominal. (As a point of comparison, ARPANET line cost alone will exceed 1.5 million dollars per year in the near future.)
- End-to-end encryption is more cost-effective than link encryption for all non-switched alternatives, even when the cost of the secure switches and operating personnel required for link encryption is ignored. For the switched systems, current annual costs for end-to-end encryption would range from $12,000 to $300,000 (1% to 45%) more than link encryption, when the switch factor is ignored. Since even gross estimates of the switch factor cost greatly exceed this difference, end-to-end encryption is the most cost-effective alternative.
- The number of switch locations in a single integrated network does not strongly influence the sum of the communication and hardware costs over the range of locations considered. However, the number of locations has a major influence on the strategy used to implement the packet switches. In addition, systems with few switch sites require a large number of Very Distant Host interfaces which may create excessive host CPU overhead.
- The major element of technological risk in the switched system approach is the development of the backbone switching facilities. If the integrated system contains a small number of backbone switches (e.g., eight), each switch must have a throughput capacity many times greater than that of the current ARPANET IMP. The highest risk strategy involves the development of high speed Pluribus IMP's.
- A low risk alternative is the modification of ARPANET IMP's by software changes and core expansion to handle DOD priority and preemption requirements. These IMP's would then be interconnected in "clusters" at the switch facility locations to handle the required traffic load. If a small number of backbone sites are utilized, then the IMP clusters at each site may contain as many as 16 IMP's, but are capable of handling the projected traffic requirements. While this approach appears to be "inelegent," it is shown to be feasible and the cost basis for comparing alternatives includes factors such as floor space and other major considerations.
- If IMP's are distributed to a larger number of facilities, the IMP clusters are considerably smaller. Thus, a 27-switch site system requires on the average four IMP's per site.
- The costs associated with the high speed Pluribus IMP and the modification of current ARPANET IMP's are approximately equal. However, the risks are substantially different.
- A third alternative, of intermediate risk, is to develop a second generation ARPANET IMP based on currently available proven minicomputers. This approach would require ARPANET software modifications for compatibility as well as for the addition of the required new software capabilities. The use of a new generation of ARPANET IMP's would reduce the IMP cost by at least a factor of two.

- If a new ARPANET IMP were developed, the 27-switch site system would be the most economical of all of the integrated packet-switched approaches examined, with a cost approximately 9% less than the comparable eight site system.
- If a new ARPANET IMP were developed, the two system approach, which segregates encrypted and unencrypted messages on different networks would be approximately equal in cost to that of the single integrated network with Pluribus message processors.
- The sensitivity of the study results to large increases in traffic over those used has not been examined. However, in this case, a major limiting factor would then be switch capacity. If, for example, switches were restricted to eight locations, the only way of handling the traffic would be to create clusters of high speed IMP's. A more flexible long range strategy would be to distribute packet switches to larger numbers of locations to meet long range growth requirements.
- Additional considerations for full comparison of alternatives include the management and organizational issues involved in implementing a fully distributed integrated network.

Chapter 1

INTRODUCTION

This report presents the results of a cost-evaluation study of alternative Defense Communications network strategies performed by Network Analysis Corporation. In this study, the terminal and traffic requirements of 35 ADP communications systems are considered, and the problem of designing the data networks which accommodate such requirements at minimum cost is addressed.

The report is organized as follows. Section 2 discusses basic assumptions and requirements. Included are summaries of element line cost and hardware and maintenance cost including applicable tariffs; tradeoff studies among tariffs; cost of modems, multiplexers, encryption devices, concentrators and packet switches. User requirements including traffic, reliability, and end-to-end delay are summarized. Requirements and unit costing information were supplied to Network Analysis Corporation by the Defense Communications Agency.

Chapters 3 and 4 summarize the results of a family of design studies of independent DOD computer communications systems. Individual designs for each system are developed based on the following strategies:

- Independent access lines for Hosts and terminals
- Clustering of terminals within the same facility via multiplexing to reduce communication cost
- Optimization of communication cost via the introduction of regional multiplexing.

These studies were performed for two reasons:

- To calibrate the results of the remaining studies with previous network designs developed by the Defense Communications Agency
- To identify the economies achievable by a unified approach to network optimization of each of the systems studied.

None of the design alternatives listed above and studied in Chapters 3 and 4 allow switching between systems, or resource sharing between Host computers of different systems. The results of the studies indicate that substantial economies of more than six million dollars per year are achievable by the introduction of new communications hardware and redesign of the network topologies. Network designs for the dedicated line and optimized systems are shown in Figures 1.1 and 1.2, respectively.

Chapter 5 discusses the introduction of limited system integration via time division multiplexing to allow high speed line sharing by different systems. No switching is allowed. Given that each independent system were optimized in line with the results of Chapter 4, little additonal advantages are achieved via this partial integration. Additional cost savings are negligible while the advantages of a fully integrated switch system are absent.

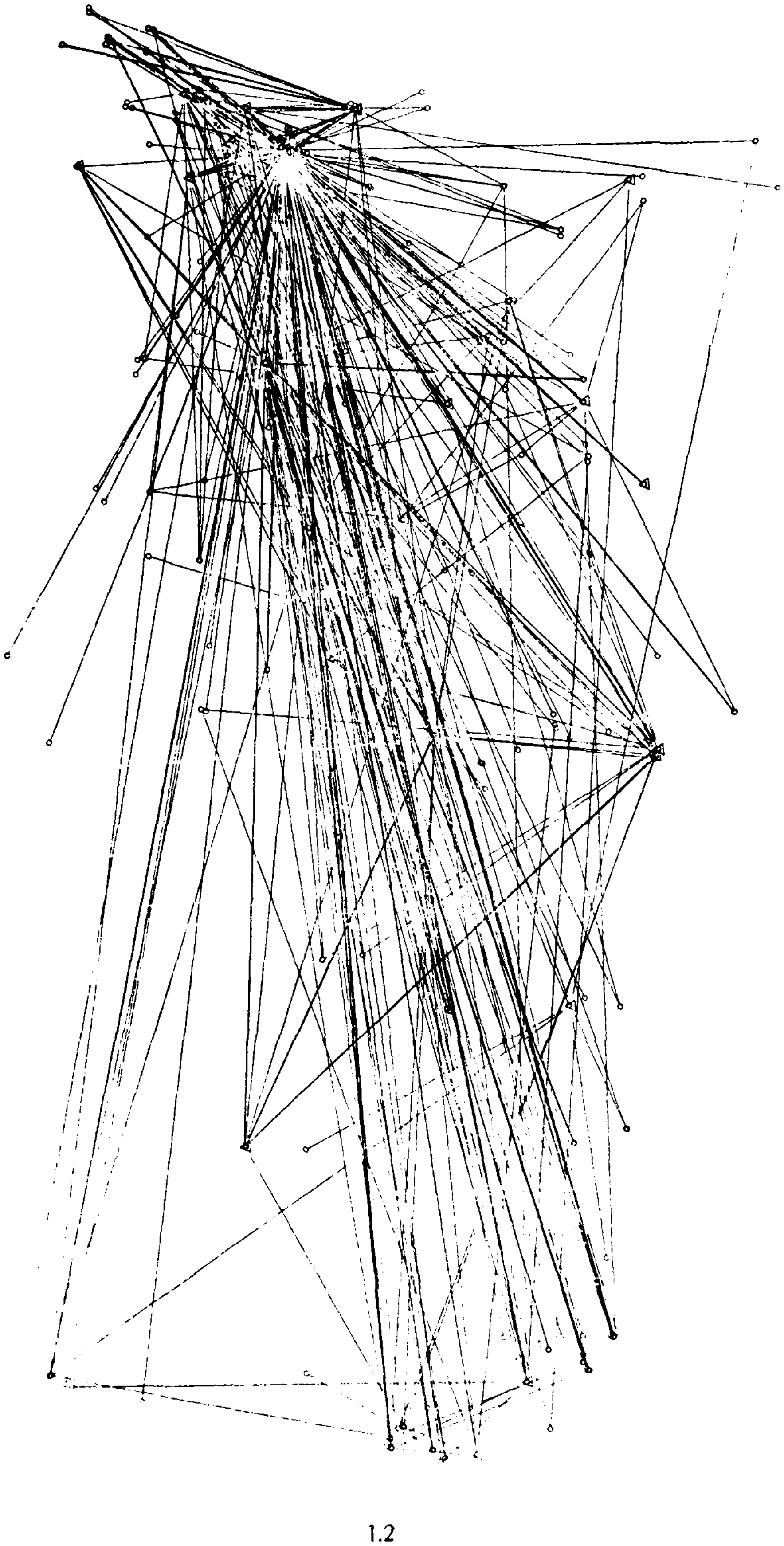


Figure 1.1: Superposition of 35 DOD Networks Based on Independent Access Lines for Hosts and Terminals

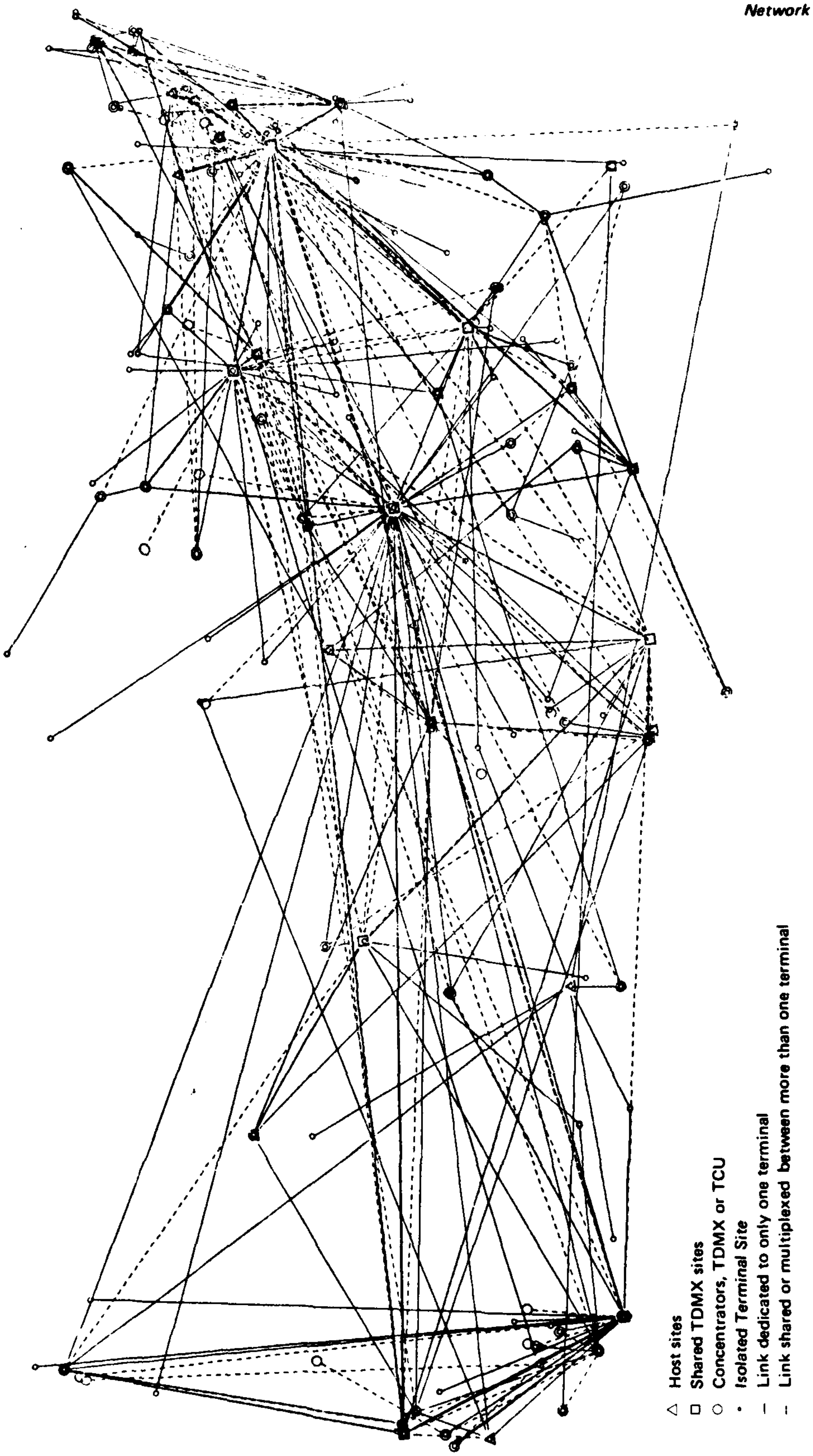


Figure 1.2: Optimized System Designs Using Local and Regional Multiplexers and Shared High Speed Lines Without Inter-System Switching

Chapter 6 investigates the use of a fully integrated packet-switched backbone system with switching processors at eight AUTODIN I store-and-forward sites. Designs for the local distribution systems and the backbone network are developed. The cost impact of two alternatives for the backbone switches are evaluated. The first involves the use of a "Pluribus" interface message processor (IMP) which is a high speed, modular, multi-microcomputer processor currently under development. The second involves the clustering of currently available ARPANET IMP's to meet high bandwidth traffic requirements. Costs for the two approaches are shown to be approximately equal. Thus, the careful study of the relative merits and shortcomings of each approach is recommended before selection of a particular nodal strategy.

The switched network approach yields costs within 13% of those of the best non-switched alternative. Moreover, other cost reduction techniques such as the use of domestic satellites, which were not considered during the time period of the current study, could lower the cost of the switched system. Thus, it appears that a fully integrated switched system could be introduced at small incremental cost when compared to the best non-switched system. A network design for the switched system is shown in Figure 1.3.

Chapter 7 discusses the use of a fully distributed packet-switched backbone system where packet switches are placed in locations to minimize the overall communications line plus hardware cost without regard to the security issues associated with each site. The fully distributed system has 27-switch locations with over 100 message processors. The configuration developed could be the result of relocating current ARPANET IMP's and TIP's. The results developed indicate that the cost of the distributed network is virtually identical to that of the network with the eight backbone nodes located at AUTODIN I sites. A network design for the distributed system is shown in Figure 1.4.

Chapter 8 studies the design of two independent networks: an eight-site backbone system handling traffic security requirements, and a 27-site distributed network handling traffic with no special security requirements. Total cost for the two networks is approximately 7% higher than the cost of a single integrated network.

Chapters 9 and 10 investigate specific security and reliability requirements for users identified as having special needs. The incremental costs for meeting these needs are calculated for each of the strategies discussed in Chapters 3 to 8.

Total costs for the strategies examined in this report are depicted in Figure 1.5. Figures 1.6 and 1.7 display the distribution of costs for the switched eight and 27-site systems, respectively. A detailed cost breakdown for each strategy is given in Table 1.1. The total cost is itemized in correspondence to the following network components:

- Computer access lines (Host-to-backbone node)
- Terminal access lines (from terminal, multiplexer, TCU, or concentrator to backbone node)
- Backbone lines
- Backbone switching processors (hardware and software)
- Backup lines to achieve the required system availability
- Encryption devices to achieve the required system security

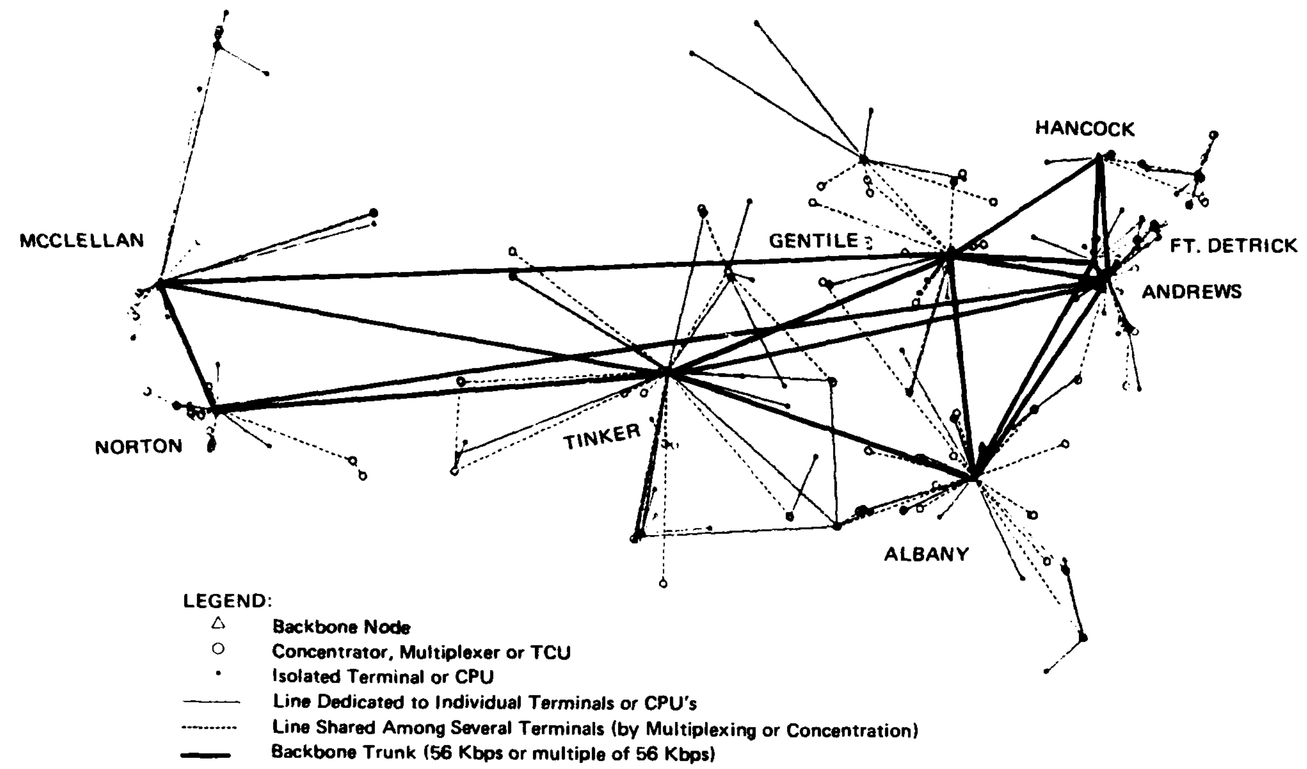


Figure 1.3: Packet Switched Integrated System with Switching Nodes Located at 8 AUTODIN I Sites

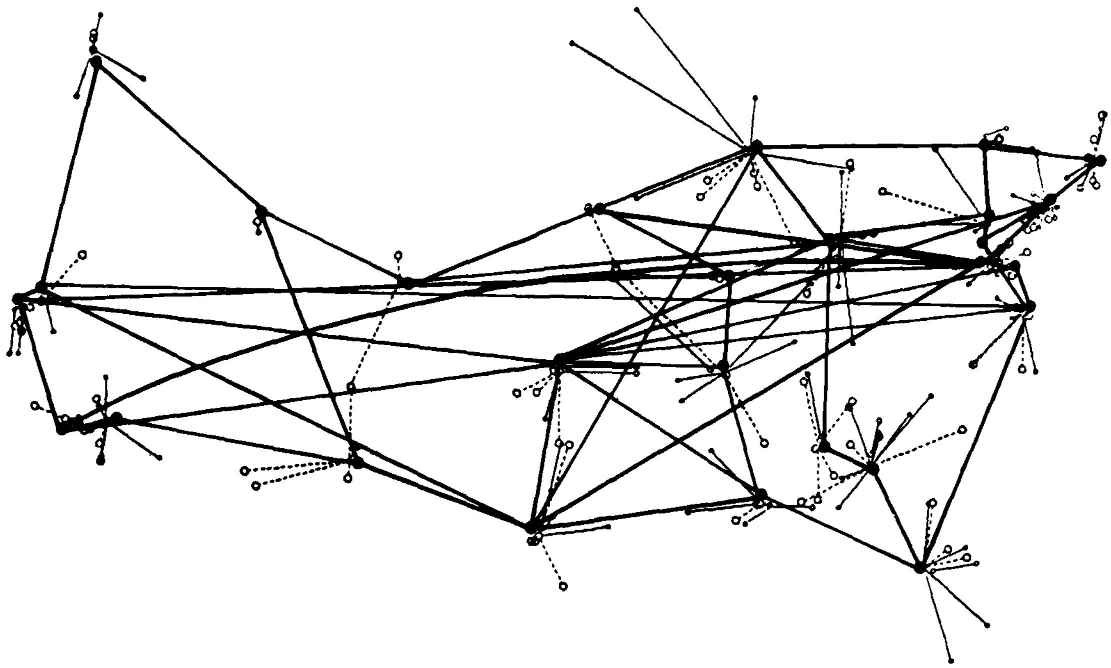


Figure 1.4: Fully Distributed Packet Switched Integrated System with Switching Nodes Located at 27 Sites

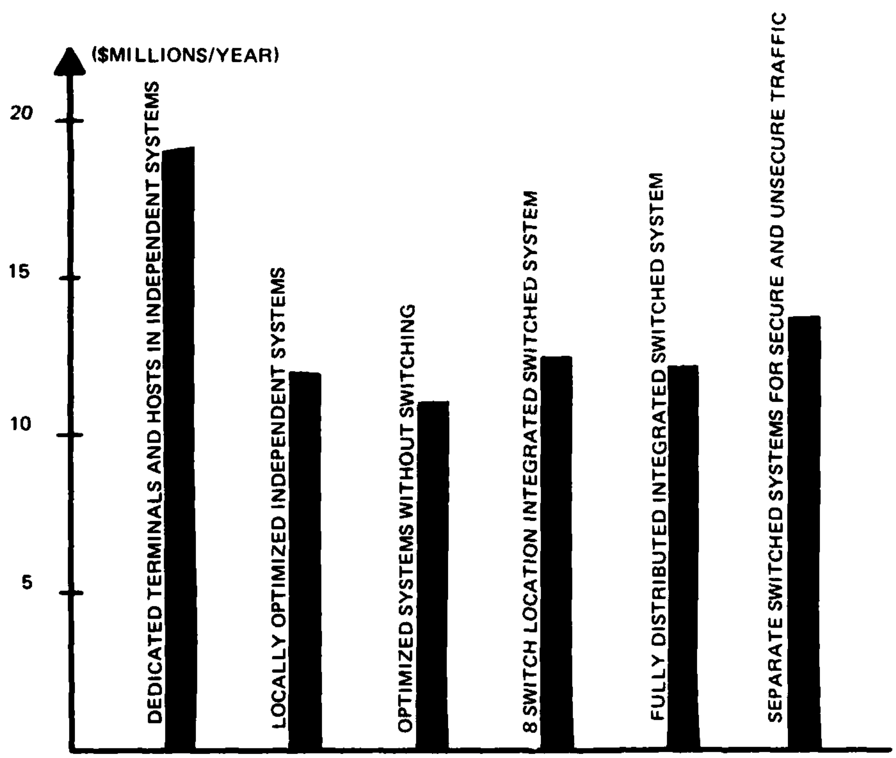


Figure 1.5: Annual Costs for Alternative Network Strategies

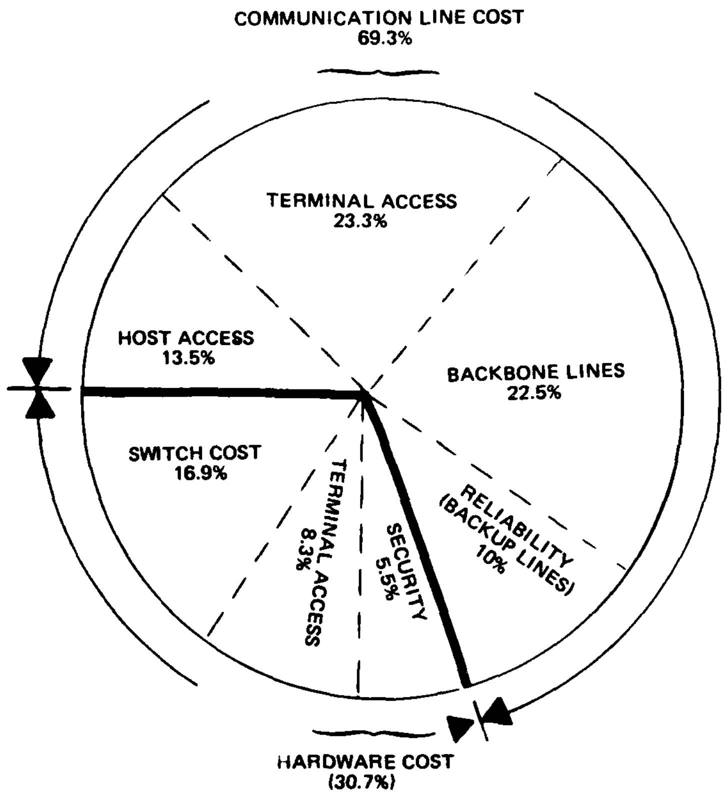


Figure 1.6: Eight Switching Site, Switched AUTODIN II System Annual Cost = $12,744,000

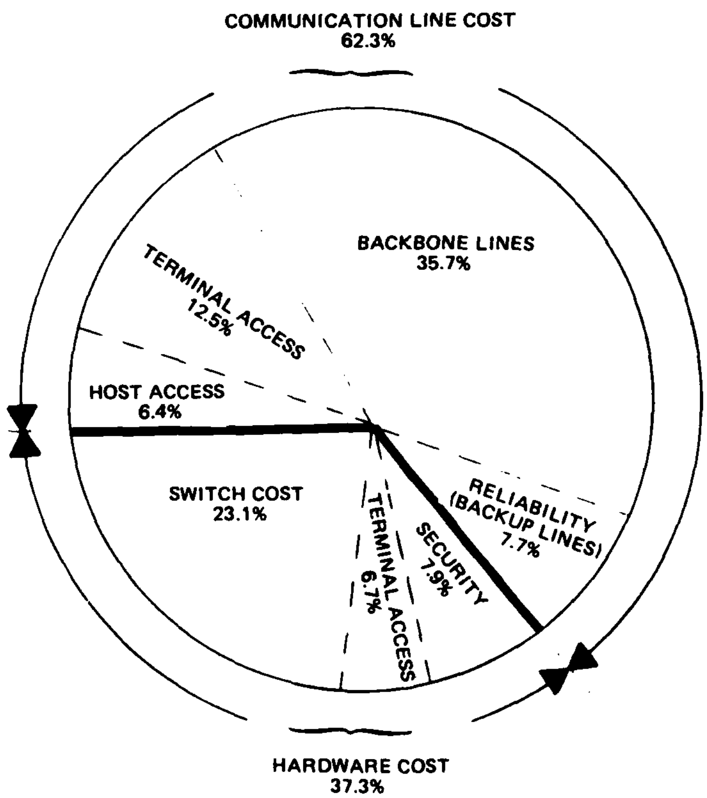


Figure 1.7: Twenty Seven Switching Site, Fully Distributed System Annual Cost = $12,552,000

Strategy Type	Description	Basic Communications Cost ($K/mo.)							Reliability Cost ($K/mo.)	Security Cost ($K/mo.)	Total Yearly Network Cost ($K)
		Comp. Access Line	Term. Access Line	Term. Access Hardw.	Back-bone Line	Back-bone Switch	Total Line	Total Hardw.	Backup Lines	Crypto Devices	
A	System Segregation. Direct, Dedicated Terminal–Host Connections.	–	–	–	–	–	1,375	–	145	84	19,248
B_1	System Segregation. Local Clustering.	–	–	–	–	–	807	66	50	84	12,084
B_2	System Segregation. Local Clustering Plus Intermediate Concentration.	–	–	–	–	–	723	85	47	84	11,268
C	Limited System Integration (Via TDMX). Local Clustering Intermediate Concentration	–	–	–	–	–	715	81	45	84	11,100
D	Full System Integration. 8-Node Backbone with Pluribus Switches.	144	248	88	239	179	631	267	106	58	12,744
D'	Full System Integration. IMP Cluster Switches.	144	248	88	239	196	631	284	106	58	12,948
E	Full System Integration–ARPA-like Backbone Design (27 Switching Sites)	67	131	70	373	242	571	312	80	83	12,552
F	Secure Systems Integrated on 8-Node Backbone; Unsecure Systems Integrated on an ARPA like Backbone (27 Switching Sites).	92	162	76	343	306	597	382	107	51	13,644

Table 1.1: Design Cost Summary

Chapter 2

BASIC ASSUMPTIONS AND REQUIREMENTS

2.1 LINE COST

Line cost between any two points is based on the most economical communications service offering (or interconnection of service offerings) available between such points, at the desired line speed. The following services are considered throughout this study:

- Voice grade service (Hi-Lo Density Tariff).
- Dataphone Digital Service (DDS).
- Series 8801 Service (for 50 Kbps line speed).

In addition to the above services, the Telpak C offering is considered in the Strategy D and E backbone evaluation. Table 2.1 shows recent tariffs that apply to the above service offerings. For each line speed, the mileage charge and the fixed charge are reported. The fixed charge is further itemized (when applicable) into: channel termination charge, station termination charge, modem charge, conditioning charge, and analog-digital interconnection charge. For these tariff services:

- DDS rates apply between 96 digital cities ('76 planning horizon).
- High density rates apply between 370 high density cities.
- Low density rates apply to the Hi-Lo or Lo-Lo segments of any connection involving at least one low density city.

The line cost between two points is defined as the cost of the minimum cost chain of Hi-Lo segments, Hi-Hi segments, and DDS segments (or if line speed is > 9.6 Kbps, Service 8801 and DDS segments) which connect the two points. As an example, consider the three node configuration shown in Figure 2.1. The direct Hi-Lo connection from Topeka to Chicago costs $1,240/mo., whereas the connection Topeka-Kansas City-Chicago (which involves one Hi-Lo and one Hi-Hi segment) costs $648/mo. The latter line configuration and cost is therefore selected.

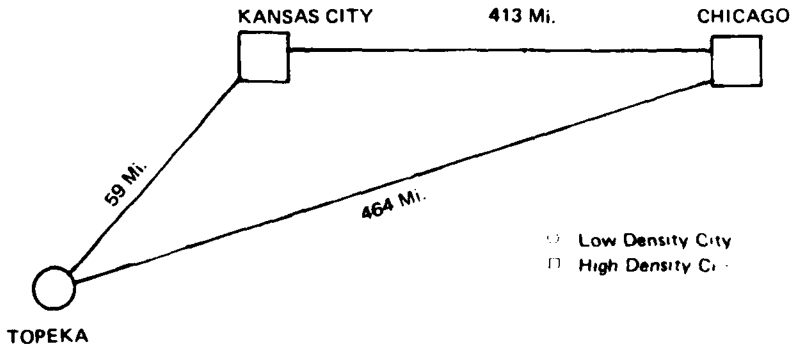


Figure 2.1: Example of Hi-Lo Density Interconnection

Table 2.1a: Dataphone Digital Service (DDS) Data Rates and Tariffs

Speed (Kbps)	Mileage charge	Fixed charge (both ends)
2.4	$ .40/mo.	$170/mo.
4.8	.60	250
9.6	.90	340
56	4.00	650

Table 2.1b: Hi-Lo Density Service—Monthly Costs. Station Termination: $25 for Hi and Lo; $15 for Short Haul

Data Speed (Kbps)	High Density Rate (Hi-Hi)		Low Density Rate (Hi-Lo) or (Lo-Lo)		Short Haul		Modems (both ends)	Conditioning	Analog-Digital Interconnection
	Mileage	Channel termination (each end)	Mileage	Channel termination (each end)	Mileage	Channel termination (each end)			
2.4	$.85	$35	$2.50	$15	$3	$3	$100		$ 70
4.8	.85	35	2.50	15	3	3	240		140
9.6	.85	35	2.50	15	3	3	530	$40	200

Table 2.1c: Type 8801 Service (50 Kbps)—Monthly Costs:

Line Length (Miles)	Mileage Charge	Service Term. (both ends)	Analog-digital Interconnection
1-250	$15.	$850	$50
251-500	10.5	850	50
500	7.5	850	50

Table 2.1d: Telpak C (Type 5751)—Monthly Costs

Data Rate (Kbps)	Mileage Charge	Service Term. (both ends)
230.4	$30	$1300
50 (derived channel)	5	850

The selection of the appropriate service(s) for a line depends on end point locations, speed, and costs. Table 2.2 provides the guidelines for such selection. The rows in Table 2.2 correspond to different service alternatives (e.g., DDS and Hi-Lo in series). The columns reflect the properties of the connection that must be established (e.g., line speed, end point locations, etc.). For each property, the candidate service alternatives are identified with an asterisk in the corresponding column. The intersection of the sets of feasible candidates for various properties of the connection yields the optimal service alternative. For example, if line speed is between 9.6 Kbps and 56 Kbps, and both end locations are in DDS cities, the best selection is DDS.

For links with one end in the continental U.S. and the other end outside the continental U.S. (e.g., Hawaii, Europe, etc.), only the cost of the national segment, up to the gateway (satellite station or underseas cable attachment) is considered in this study. Links with both ends outside the U.S. are not included in the cost-evaluation. Therefore, the cost of non-continental segments must be added to obtain overall worldwide cost.

2.2 HARDWARE COST

2.2.1 Concentrator

In our design model, the concentrator is a minicomputer with the following characteristics:

- 32K of core.
- 64 I/O ports for low and medium speed lines.
- Time division demultiplexing by software.
- High speed line interface to the Host computer (up to 56 Kbps).

According to a cost analysis performed by DCA, the purchase price of such a concentrator is $62,200. The annualization factor is 0.234 (based on a 10-year amortization plan and including installation charge at 20% base cost, initial support charge at 67% base cost and 10-year operation and maintenance costs at 47% base cost). The redundancy factor is 1.5. The capital factor is about 5% per year, based on 10% annual interest over 10 years. As a result, the monthly charge per concentrator is equal to:

$$\underbrace{.0438}_{\substack{\text{monthly}\\\text{coefficient}}} \times \underbrace{62{,}000}_{\substack{\text{purchase}\\\text{price}}} = \$2{,}724/\text{mo.}$$

This monthly cost is deemed representative of the most common commercial offerings, and therefore is used in this study.

2.2.2 Time Division Multiplexer

Cost of Common logic	$1,500/end (3,000 if wideband)
Average channel cost interface	$300/channel/end
Average TDMX cost (for N channels)	$1,500 + 300 x N (3,000 + 300 x N if wideband)

Table 2.2. Service Selection

Connection Properties / Service Alternatives	Both end locations in DDS Cities		Hi/Lo alone is less expensive than Hi-Lo & DDS		Line Speed			Multiple DDS Lines less expensive than one 230 Kbps line		ARPANET Growth
	Yes	No	Yes	No	No greater than 9.6 Kbps	Between 9.6 Kbps & 56 Kbps	Between 56 & 230 Kbps	Yes	No	
DDS	■				■	■				
Hi/Lo		■	■		■					
DDS and Hi/Lo		■		■	■					
DDS and Type 8801 (wideband)		■				■				
Multiple DDS	■						■	■		
Multiple DDS and Type 8801		■					■	■		
Telpak C (230.4Kbps)							■		■	
Telpack C (230.4 Kbps or 50 Kbps)										■

Estimated monthly cost (using the coefficient 2.25 for redundancy as suggested by DCA, and a monthly amortization and maintenance rate of 0.02; including installation charge of 20% base cost, 10-year operation and maintenance cost of 47% base cost, and a charge of 5% a year for the capital cost) is given below:

Output speed ≤ 9.5Kbps:
2.25 x .02 x (1,500 + 300 N) = $67 + 13 x N

Output speed up to 56 Kbps:
2.25 x .02 x (3,000 + 300 N) = $135 + 13 x N

2.2.3 Terminal Control Unit (TCU)

To bridge the cost and capacity gap between TDMX and concentrator devices, we assume in our study that a cluster of up to 20 CRT's or TTY's, all in the same location can be supported by a locally installed TCU. The TCU is a small minicomputer, or a microprocessor which has essentially the same function of a concentrator, except that it can accommodate no more than 20 terminals and can interface with the Host with a synchronous line of speed ≤ 9.6 Kbps. Furthermore, the TCU does not support software demultiplexing. Assuming a purchase price of $20,000 for a TCU, and assuming the same annualization factor and interest rate as for the concentrator (except for redundancy factor = 2.0), the monthly cost of a fully redundant TCU configuration is:

2 x .0295 x 20,000 = $1,170/mo.

2.2.4 Packet Switching Processors

Three types of packet switching processors are considered in this study:

- ARPANET IMP.
- ARPANET TIP.
- Pluribus IMP.

In addition, we assume the existence of a front end processor device (IMP-FEP) which can be installed at an IMP site for the purpose of interfacing several terminals and Host computers to the IMP.

Cost and characteristics of the above devices are discussed in Section 6. A cost summary for multiplexers, concentrators, and switching processors is presented in Table 2.3. The cost summary reflects: purchase price, redundancy factor, installation, initial support, operation and maintenance, and interest on the capital investment.

2.2.5 Modems

Modem costs are included in the cost of analog lines, as shown in Section 2.1. The following prices, representative of common commercial offerings, have been used:

Data Rate (Kbps)	Monthly Cost (both ends)
2.4	$100
4.8	240
9.6	530

Table 2.3: Multiplexer, Concentrator and Packet Switch Cost Summary

	Purchase Price	Redundancy Factor	Other Capital Costs (% of base price)		O & M % of base cost over 10 years	Capital Cost per year (10% interest over 10 years)	Mainte-nance and support ($/year)	Annual Cost	Monthly Cost
			Install-ation	Initial Support					
32K, 64 port Concentrator	62,200	1.5	20%	67%	47%	5%	–	$32,688	$2,724
9.6 Kbps MUX (N = # ports)	1500 +300N	2.25	20%	0	47%	5%	–	804 +156N	67 +13N
TCU	20,000	2.0	20%	67%	47%	5%	–	14,040	1,170
IMP - FEP	62,200	1.5	20%	67%	47%	5%	–	32,688	2,724
IMP	50,000	1.0	20%	67%	47%	5%	–	17,000	1,475
TIP	100,000	1.0	20%	67%	47%	5%	–	34,000	2,950
Pluribus IMP 8 units	4488K	1.0	2%	32%	–	5%	$1250K	2152.7K	179.41K
1 unit	561K	1.0	2%	32%	–	5%	156K	269K	22.41K

2.2.6 Encryption Devices

Encryption devices are installed on communications lines that carry secure data. We distinguish two types of encryption devices:

- Link encryption devices.
- End-to-end encryption devices.

Link encryption devices are installed at each end of a data link. End-to-end devices are installed at terminal and Host sites, and provide data security along the entire terminal-to-Host path (or Host-to-Host path in the case of Host-to-Host communications).

Encryption device costs are shown in Table 2.4. Purchase and installation cost data was provided by the DCA staff. Monthly cost is obtained multiplying the base cost by a monthly coefficient of .033, to account for full redundancy, 10-year amortization at 10% per year interest, and operation and maintenance cost at 47% of base cost.

Table 2.4. Encryption Device Costs

Item	Purchase and Installation Cost	Monthly Cost
Link crypto for speed up to 100 Kbps (each end)	$ 6,000	$ 198
Link crypto for speed up to 1.5 Mbps (each end)	$14,000	$ 462
End-to-end crypto (host site)	$40,000	$1,320
End-to-end crypto (terminal site)	$ 9,000	$ 297

2.3 LINE SPEED ASSIGNMENT

- The capacity of the link from terminal-to-concentrator (or TDMX, or Host) is sized according to line traffic T as follows:

$$C \geqslant T \times 1.5$$

where: C = line speed, to be chosen by minimum fit between 2.4, 4.8, 9.6 and 56 Kbps.

and:

$$T = \begin{cases} \max (T_{in}, T_{out}) \text{ if } 1.5 \times (T_{in} + T_{out}) \geqslant 1.2 \text{ Kbps} \\ T_{in} + T_{out}, \text{ if } 1.5 \times (T_{in} + T_{out}) < 1.2 \text{ Kbps} \end{cases}$$

under the assumption that, if $(T_{in} + T_{out}) \times 1.5 < 1.2$ Kbps, the terminal operates in half duplex mode.

The coefficient 1.5 accounts for 20% of line overhead, and for a total line utilization ≤ 80%.

- Time division multiplexed lines are sized as follows:

$$C \geq N \times 1.2$$

where: C = min fit capacity in Kbps

N = no. of terminals multiplexed on the line. Here the assumption is made that the average terminal speed is 1.2 Kbps. For a more accurate line sizing, the data speeds of all the terminals should be specified. With our assumption, a medium speed TDMX device, with output line < 9.6 Kbps, can accommodate only up to 8 terminals. If more than 8 terminals need to be multiplexed, the most economical of the following solutions is selected:

– Several medium speed TDMX devices in parallel;
– Wideband TDMX (with 50 Kbps output line);
– TCU;
– Concentrator.

- Link from concentrator (or TCU) to the Host:

$$C \geq T \times 1.5$$

where: C = main fit capacity in Kbps

T = total traffic in the busiest direction, sum of all terminal traffic contributions, as defined above.

Table 2.5 summarizes the line assignment rules for various types of connection as a function of traffic volume. From columns 1 and 2 of Table 2.5, one determines the row to be used for a specific connection. The corresponding entries in columns 3 and 4 will then provide all the elements for the selection of the line speed.

Table 2.5. Line Speed Selection Guide

From	To	Traffic Requirement	Min. Fit Capacity Selection*
Terminal	Host, Concentrator, MUX,	$1.5 \times (T_{in} + T_{out}) < 1.2$ Kbps	$1.5 (T_{in} + T_{out})$
		$1.5 \times (T_{in} + T_{out}) \geq 1.2$ Kbps	$1.5 \times \max (T_{in}, T_{out})$
MUX	Host Concentrator IMP	N Channels utilized ($N \leq 8$)	1,200 x N
Concentrator TCU IMP-FEP	Host Concentrator IMP	T = Total terminal traffic in the busiest direction	1.5 x T
IMP	IMP	T = Total traffic in the busiest direction	1.45 x T

*For non-backbone line, this means finding the smallest line speed among 2.4 Kbps, 4.8 Kbps, 9.6 Kbps, and 56 Kbps that is greater than the requirements. For backbone line, it means finding the smallest line speed among 56 Kbps, multiple of 56 Kbps, and 230.4 Kbps that will satisfy overall delay requirements.

2.4 SELECTION OF COMMUNICATIONS HARDWARE

The selection of the communications hardware (TDMX, TCU or concentrator) is made according to the requirements of the specific network strategy under consideration, and is aimed to optimizing the tradeoffs between hardware cost and line cost. The optimization is carried out automatically by NAC's network design programs.

2.5 TERMINAL AND HOST REQUIREMENTS

Terminal and Host computer locations, and traffic volumes from terminal-to-computer and computer-to-terminal have been obtained from the data base provided by the DCA staff.

The requirements correspond to the 1976 planning horizon, and consist of two components:

- AUTODIN I requirements.
- Requirements corresponding to 34 other defense communications systems.

2.6 RELIABILITY REQUIREMENTS

Network uptime for the general user must be ⩾ 99%. Network uptime for the critical user must be ⩾ 99.95%. The following is a list of critical users:

- WWMCCS
- MAJCOM
- MACIMS
- ENV. DATA NETWORK

In evaluating network availability, the following assumptions on network components are made:

- Line uptime ⩾ 99.6%
- TDMX uptime
  - Non-redundant ⩾ 99.9%
  - Redundant ⩾ 99.9999%
- TCU and concentrator uptime
  - Non-redundant ⩾ 99.5%
  - Redundant ⩾ 99.9975%

2.7 END-TO-END DELAY REQUIREMENTS

It is virtually impossible to specify a unique response time requirement to be met by all terminal-Host or Host-Host pairs in the AUTODIN II design. The Defense Communications environment, in fact, consists of a large variety of applications (e.g., interactive traffic, RJE, message switching, etc.), each requiring different delay performance. In principle, one should determine the delay (or bandwidth) requirement within each category and then verify that the requirements for different categories are met in the final design.

In this study, we follow a simpler approach. Specifically, we require that in a segregated configuration (i.e., A, B and C strategies) the average end-to-end delay for a 500-bit block transmission from terminal-to-Host (or from Host-to-Host) be less than one second. Similarly, for an integrated configuration (D, E and F strategies), we require that the delay for a 500-bit data block transmission be:

- Less than one second from terminal-to-backbone;
- Less than .250 sec from Host-to-backbone; and
- Less than .100 sec between any backbone node pair.

The above delay requirements were set under the assumption that end-to-end delays below one second are adequate for most Host-Host communications, and delays below two seconds are adequate for most terminal-to-Host communications.

In the design phase, the delay requirements for the local access segments (terminal-to-backbone and Host-to-backbone) are automatically met by virtue of the line speed assignment strategy mentioned in Table 2.3. Backbone delay requirements are met by properly designing backbone topology and line speeds.

If delays lower than the above mentioned values are required between some specific terminals and/or Hosts, line speeds higher than the values recommended in Table 2.3 must be assigned to such terminals and Hosts. However, the existance of very low delay requirements between a limited number of node pairs is not deemed critical to the validity of the main results and conclusions of this study.

End-to-end (internet) protocol issues also have an impact on response time and effective bandwidth of terminal-Host and Host-Host communications. In this preliminary analysis, we account for protocol overhead on line utilization both in local distribution and backbone network, but do not investigate the impact of specific protocol issues (sequencing, windowing, gateway reassembly, etc.) on end-to-end delay and bandwidth performance.

2.8 TRAFFIC REQUIREMENTS

Terminal and Host traffic requirements were supplied by the Defense Communications Agency. All designs for all system alternatives were developed to meet the same basic requirements. Requirements supplied were, in many cases, best guesses about situations which do not yet exist. Consequently, there is no way of verifying the validity of the data.

Chapter 3
TYPE A NETWORK STRATEGY—INDEPENDENT SYSTEMS WITH DEDICATED HOST AND TERMINAL LINES

3.1 TYPE A STRATEGY

- Terminal and traffic requirements correspond to the various Defense Communications Systems (excluding AUTODIN I switching cost).
- Each terminal is connected directly to its Host with a private line. Line speed is selected using the criteria indicated in Section 2.

Some of the systems consist of several disjoint subsystems with separate Hosts and terminals. Table 3.1 shows system names and corresponding ID's, as provided by the DCA staff. Multiple ID's indicate the presence of several subsystems within the same system. For the purposes of this analysis, we consider each subsystem as an independent system. In particular, for the strategies that require segregation of the systems, we also assume segregation between subsystems belonging to the same system.

3.2 RESULTS

Table 3.2 shows monthly system and subsystem costs, and total cost for the Type A strategy. Figure 3.1 represents the topology for Strategy A. Notice the rather intricate superposition of all the lines required with this strategy.

Table 3.1: System (and Subsystem) Code

System Name	Code
AMC Senet	AAB, AAC, AAE, AAF, AAG
COEMIS	ABC, ABF
AMC Speedex	ACA, ACC
AMC Teamup	ADA, ADC
AMC Data Banks	AEB
DSA RDT&E	D06
Num Control	F1B
MAJCOM	F1C
Shrimp	F1E
ATES	F1G
ASC (AUTODIN)	F1J
AFMTRS	F1H
APDS	F13
RADC	F37
ASD	F43
CREATE	F54
AIR STAFF	F63
MACIMS	F72
AMIS	F93
MASIIS	F94
CNET	NAA, NAB
MIS STK. PTS.	NBL, NBM, NMN, NBO, NBT
MIS. INV. CTR.	NCA, NCB, NCC
INTG. ACCT. & DISB.	N16
NMCSA	N21
NAV PERS	N23
NAV MMACLANT	N25
CAIMS	N28
NAV. FAC. SYS.	N29
ASAMRA	N30
BUR NAV PERS	NFC, NFA, NFG
ENV DATA NET	N07
ALS	F01
WWMCCS	W

Table 3.2: Line Costs for Type A Strategy

System	Monthly Line Cost	System	Monthly Line Cost
AAB	$ 9,614	NAA	$ 145,458
AAC	1,741	NAB	16,088
AAE	2,404	NBC	3,039
AAF	7,074	NBF	4,755
AAG	19,069	NBL	3,532
ABC	6,861	NBM	2,699
ABF	2,465	NBN	1,074
ACA	2,601	NBO	5,289
ACC	5,180	NBT	585
ADA	13,252	NCA	26,402
ADC	6,738	NCB	30,860
AEB	2,407	NCC	5,739
D06	47,304	N16	14,947
F1E HOST	5,556	N21	46,442
F1C	8,578	N23	41,974
F1E	4,888	N25	4,881
F1G	8,013	N28	6,425
F1H	1,810	N29	59,802
F13	62,749	N30	6,795
F37	8,606	NFC	5,662
F43	8,979	NFA	537
F54	70,068	NFG	988
F63	3,019	N07	9,939
F72	127,239	F01	15,173
F93	211,667	W	107,116
F94	121,930	F1J	39,300
		TOTAL	$1,375,300

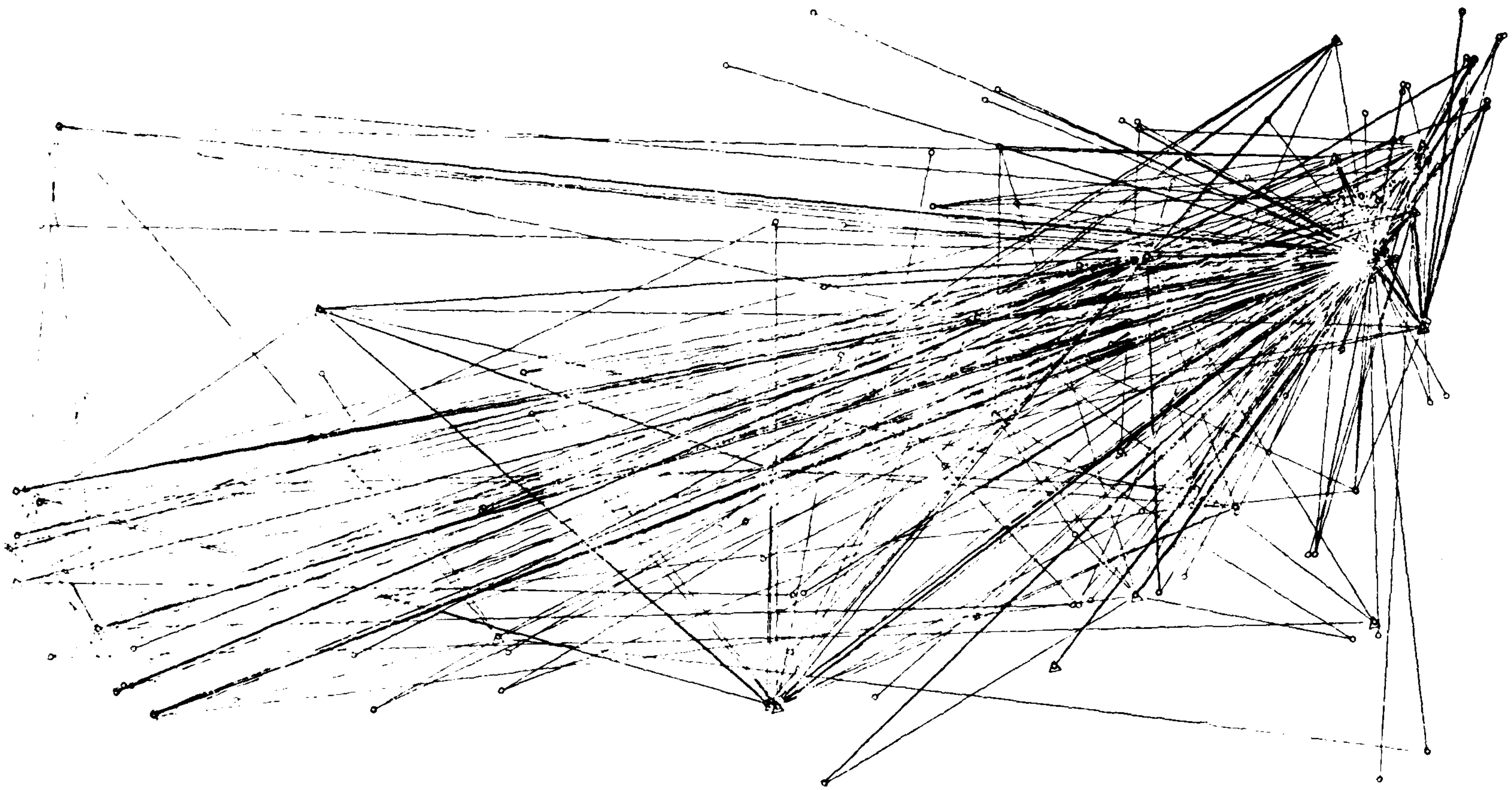


Figure 3.1: Global Line Layout for Type A Strategy

Chapter 4
TYPE B STRATEGY—INDEPENDENT SYSTEMS WITH LOCAL AND REGIONAL OPTIMIZATION

The Type B strategy is subdivided in two strategies, B1 and B2.

4.1 TYPE B1 STRATEGY

- Terminal and traffic requirements of the ADP Communications Systems listed in Table 3.1 (excluding AUTODIN I switching cost).
- Local clustering is allowed. Terminals at the same location and belonging to the same system can be merged, so that they share the same line to the Host, using time division multiplexers (TDMX), terminal control units (TCU), or concentrators. The merging is performed only when cost-effective.

4.2 RESULTS OF B1 STRATEGY

Line costs and communications hardware requirements for each individual system, and global cost for the B1 strategy are presented in Table 4.1. The global map with all the B1 topologies superimposed is shown in Figure 4.1.

4.3 TYPE B2 STRATEGY

- Terminal and traffic requirements of the ADP Communications Systems listed in Table 3.1 (excluding AUTODIN I switching cost).
- Local clustering (using TDMX, TCU's and concentrators) is allowed as in Strategy B1. In addition, intermediate multiplexing and concentration are allowed within each system (or subsystem). A local cluster, therefore, may be connected to a regional concentrator (instead of being linked directly to the Host) for line saving purposes. The concentrator may support several local clusters and is directly connected to the Host. Concentration points must correspond to system terminal installations. For reliability purposes, no more than two levels of concentration and/or multiplexing are allowed from terminal-to-Host.

4.4 RESULTS OF B2 STRATEGY

Line cost and communications hardware requirements for each individual system, and global cost for the B2 strategy are presented in Table 4.2. The global map with all the B2 topologies superimposed is shown in Figure 4.2. Maps of the individual systems and subsystems are shown in Appendix A.

Comparing B1 and B2 type strategies, we notice that the intermediate multiplexing and concentration allowed in B2 reduces line cost and increases hardware cost (as expected) with an overall network cost savings of about 8% with respect to Strategy B1.

Table 4.1: System Costs Under B1 Strategy

System	Monthly Line Cost	Hardware Requirements		
		TDMX	TCU	CON
F1J	$ 39,300			
AAB	5,168		1	1
AAC	1,741			
AAE	2,381	1		
AAF	5,476	4		
AAG	17,337	2		
ABC	3,379	4		
ABF	1,431	2		
ACA	1,300	1		
ACC	1,210	1	1	
ADA	13,252			
ADC	6,738			
AFB	2,407			
D06	40.856			
F1B	5,556			
F1C	8,578			
F1E	4,888			
F1G	8,013			
F1H	1,810			
F13	36,304	3	2	
F37	8,606			
F43	8,979			
F54	39,701	2	4	
F63	1,509	1		
F72	31,264	11	3	2
F93	48,673	16	2	3
F94	106,405	7		

Table 4.1: (Concluded)

System	Monthly Line Cost	Hardware Requirements		
		TDMX	TCU	CON
NAA	23,878		4	4
NAB	16,088			
NBC	2,396	1		
NBF	3,562	1		
NBL	3,532			
NBM	2,699			
NBN	1,074			
NBO	5,289			
NBT	585			
NCA	21,698	3		
NCB	4,302	1	1	1
NCC	1,434	1		
N16	14,947			
N21	30,806	10		
N23	40,270	2		
N25	4,451	3		
N28	4,055	1		
N29	27,152	9		
N30	6,795			
NFC	5,662			
NFA	537			
NFB	988			
N07	9,939			
F01	15,173			
W	107,116			
Total	$ 807,300	87	18	11

Total Monthly Hardware Cost—$66,000

Total Monthly Line Plus Hardware Cost—$873,300

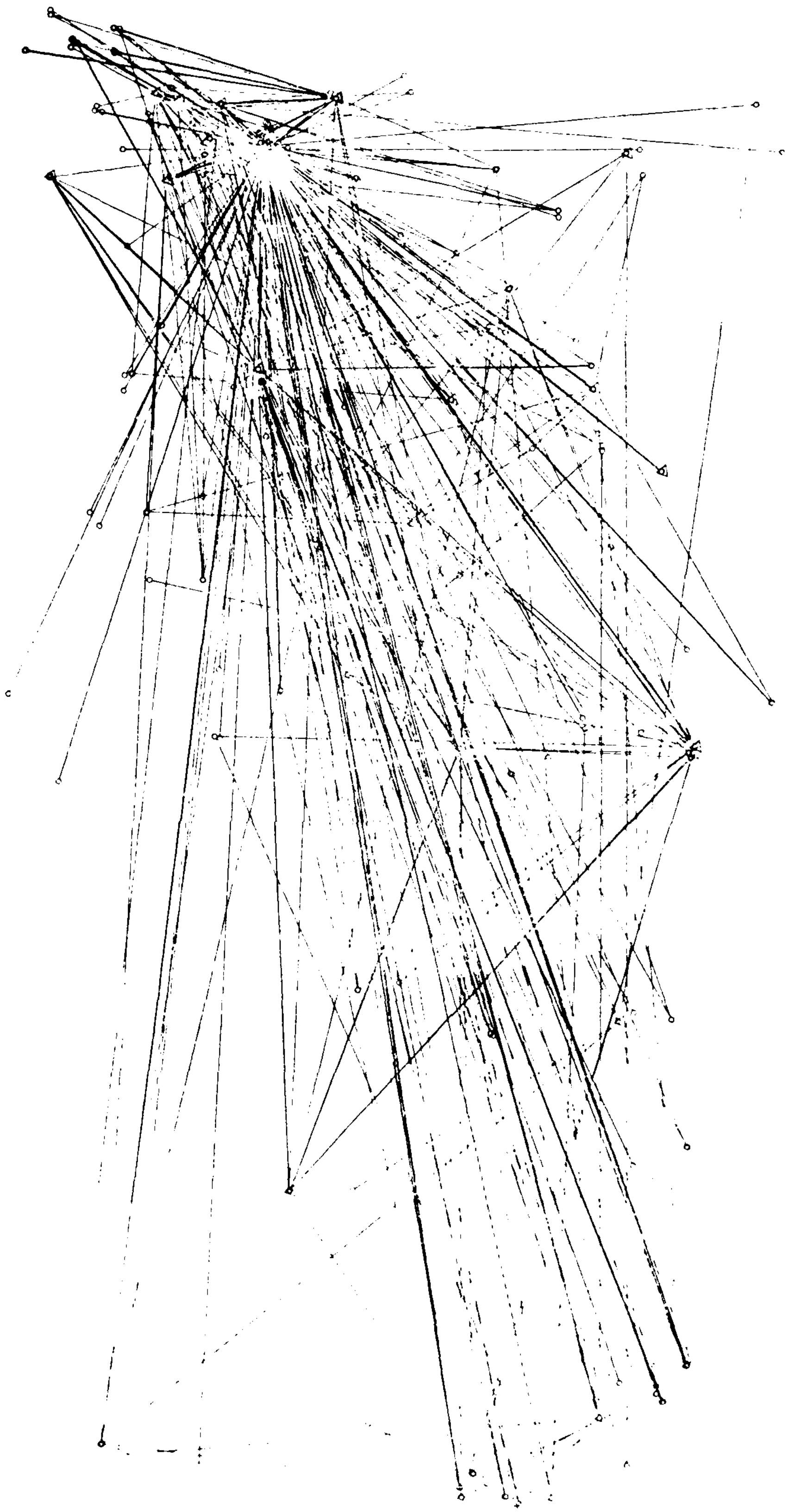


Figure 4.1: Global Topology Corresponding to B1 Strategy

Figure 4.2: Global Topology Corresponding to B2 Strategy

Table 4.2: System Costs Under Type B2 Strategy

System	Monthly Line Cost	Hardware Requirements		
		TDMX	TCU	CON
F1J	$ 39,300			
AAG	5,168		1	1
AAC	1,741			
AAE	2,381	1		
AAF	5,476	4		
AAG	14,788	5		
ABC	3,379	4		
ABF	1,431	2		
ACA	1,300	1		
ACC	1,210	1	1	
ADA	13,252			
ADC	6,738			
AEB	2,407			
D06	31,609	6	3	
F1B	5,556			
F1C	8,578			
F1E	4,888			
F1G	8,013			
F1H	1,810			
F13	28,785	3	3	
F37	6,688	1		
F43	7,950	1		
F54	39,173	3	4	
F63	1,509	1		
F72	28,519	13	3	2
F93	35,205	18	3	3
F94	106,905	7		

Table 4.2: (Concluded)

System	Monthly Line Cost	Hardware Requirements		
		TDMX	TCU	CON
NAA	$ 22,786	2	4	4
NAB	16,088			
NBC	2,396	1		
NBF	2,736	2		
NBL	3,299	1		
NBM	2,699			
NBN	1,074			
NBO	5,289			
NBT	585			
NCA	10,503	6		
NCB	3,577	2	1	1
NCC	1,434	1		
N16	11,065	2		
N21	18,335	13	1	
N23	30,776	4		1
N25	4,451	3		
N28	3,023	2		
N29	25,655	9		1
N30	5,137	3		
NFC	5,662			
NFA	537			
NFB	988			
N07	9,939			
F01	15,173			
W	107,116			
Total	$ 723,300	122	24	13

Total Monthly Hardware Cost–$85,000
Total Monthly Line Plus Hardware Cost–$808,300

Chapter 5
TYPE C NETWORK STRATEGY—LIMITED INTEGRATION WITHOUT SWITCHING

5.1 TYPE C STRATEGY

- Terminal and traffic requirements are those corresponding to the systems listed in Table 3.1 (excluding AUTODIN I switching cost).
- Multiplexing and concentration within each system (or subsystem) is allowed as in Strategy B2. In addition, different systems can share the same lines on a multiplexing basis (but without switching). For example, if a link of System A and a link of System B run parallel from the East to the West Coast, they can be merged and multiplexed between two convenient points, one on the East and another on the West Coast. The "merging points" must be colocated with defense terminal installations.

5.2 APPROACH

Preliminary Observations:

- It is desirable that the merging points be DDS locations in order to save on mileage rate and on modems, at least for the multiplexed segment.
- It is better to have a limited number of shared multiplexed links, each grouping several systems, rather than a large number of links with only a few systems each. By grouping several systems on the same link, we achieve:
  - Better economies of scale, both in line cost and TDMX cost.
  - Better redundancy, since shared links typically require multiple 9.6 Kbps lines in parallel.
  - Easier management, since the overall number of shared TDMX devices is smaller.

The design procedure is as follows:

- Candidate merging points are selected with the following criteria:
  - Only a small number of points ($\leqslant 10$).
  - Colocated with terminal installations (or Hosts).
  - Located in DDS cities.
  - Geographically distributed so as to match the distribution of the ADP terminal installations.
- In connecting a local cluster to the Host, the marginal cost of using a shared link is compared with the cost of a private connection to the Host. This private connection can be either direct or through private TDMX or concentration devices. Whichever solution results to be more economical, either shared or private connection, is implemented.

- The cost of a shared link is a function of the total number of multiplexed channels and is determined at the end of the optimization using the procedure described in Chapter 2.

5.3 RESULTS

Merging points were chosen in the following cities:

San Francisco	Memphis
San Diego	Atlanta
Colorado Springs	Cincinnati
Houston	Washington, D.C.

Line cost and hardware requirements for each individual system, and total cost for the private portion of the network (excluding shared links and TDMX devices) are shown in Table 5.1.

Cost and characteristics of each of the 12 shared multiplexed links are shown in Table 5.2. The line layout of the shared links is shown in Figure 5.1. The line and hardware cost of the shared network is $50,700/mo., and corresponds to traditional time division multiplexing. If statistical time division multiplexing is implemented, the line bandwidth is better utilized and the number of parallel lines can be reduced, leading to substantial cost savings. However, statistical multiplexers are complex machines (microprocessors or minicomputers), with cost ranging on the order of $1,000/mo. (including amortization, full redundancy, etc.), and therefore, much more expensive than traditional multiplexers. Our preliminary calculations show that the most economical strategy is probably a hybrid implementation with statistical multiplexing on a few long and heavily used links, and traditional multiplexing on the others, leading to a total cost of approximately $40,000/mo. The impact on the overall cost is limited, however. The hybrid strategy amounts to about only 1% in cost savings.

The total cost for Strategy C assuming traditional *TDMX* is $797,000/mo. The map in Figure 5.1 shows the superposition of private networks and shared TDMX links.

Table 5.1: System Costs Under Type C Strategy
(Excluding shared TDMX lines)

System	Monthly Line Cost	Hardware Requirements		
		TDMX	TCU	CON
F1J	$ 39,300			
AAB	5,168		1	1
AAC	1,741			
AAE	2,381	1		
AAF	5,476	4		
AAG	13,439	5		
ABC	3,379	4		
ABF	1,431	2		
ACA	1,285	1		
ACC	1,210	1	1	
ADA	13,252			
ADC	5,082			
AEB	2,407			
D06	26,981	5		
F1B	4,972			
F1C	8,578			
F1E	4,888			
F1G	7,262			
F1H	1,810			
F13	27,918	3	2	
F37	6,111			
F43	5,911			
F54	37,565	3	4	
F63	1,405	1		
F72	29,632	13	3	3
F93	27,046	18	3	3

Table 5.1: (Concluded)

System	Monthly Line Cost	Hardware Requirements TDMX	TCU	CON
F94	$106,905	7		
NAA	13,592		4	4
NAB	16,088			
NBC	2,396	1		
NBF	2,736	1		
NBL	3,299	2		
NBM	2,699			
NBN	1,074			
NBO	4,357			
NBT	585			
NCA	10,559	5		
NCB	2,656	1	1	1
NCC	1,362	1		
N16	8,396	1		
N21	17,431	13		
N23	28,467	8		
N25	4,451	3		
N28	2,244	1		
N29	14,968	9		
N30	3,803	1		
NFC	5,662			
NFA	537			
NFB	988			
N07	7,283			
F01	15,173			
W	107,116			
Total	$670,300	115	20	12

Total Monthly Hardware Cost—$76,000
Total—$746,300

Table 5.2: Cost and Characteristics of Shared Multiplexed Links

Link	No. of Systems Sharing the Link	No. of Channels Multiplexed on the Link	Number of Lines and Line Type	Monthly Costs (Line + TDMX)
Atl-Was	6	15	2 x 9.6 Kbps	1607 + 329 = 1936
Cin-Was	8	35	5 x 9.6 Kbps	3675 + 790 = 4465
Mem-Cin	2	12	2 x 9.6 Kbps	1407 + 290 = 1697
S.D.-Was	6	61	8 x 9.6 Kbps	19539 + 1329 = 20868
Hou-Atl	2	12	2 x 9.6 Kbps	1913 + 290 = 2203
Mem-Was	2	36	5 x 9.6 Kbps	4985 + 803 = 5788
Cin-Hou	2	3	1 x 4.8 Kbps	888 + 106 = 924
Atl-Cin	2	12	2 x 9.6 Kbps	1509 + 290 = 1799
Col.S-Cin	2	8	1 x 9.6 Kbps	1344 + 171 = 1515
Atl-Mem	2	24	3 x 9.6 Kbps	2016 + 513 = 2529
S.D.-Hou	2	5	1 x 9.6 Kbps	1447 + 132 = 1579
S.F.-Was	4	12	2 x 9.6 Kbps	5133 + 290 = 5423
			Total	$ 50,700

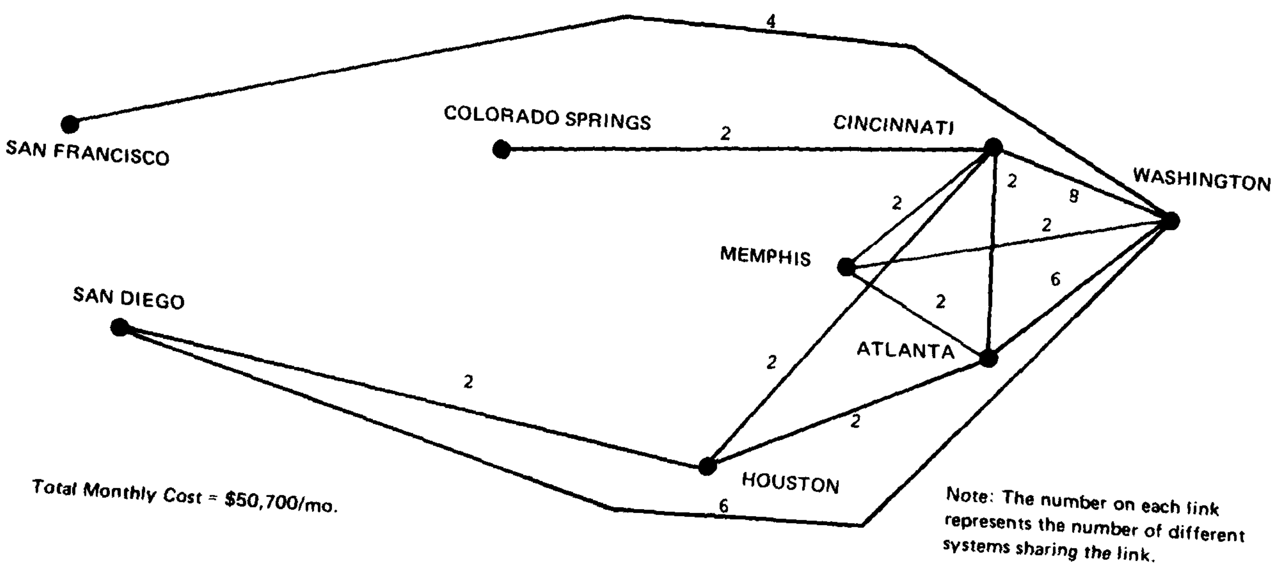


Figure 5.1: Shared TDMX Network Under Strategy C

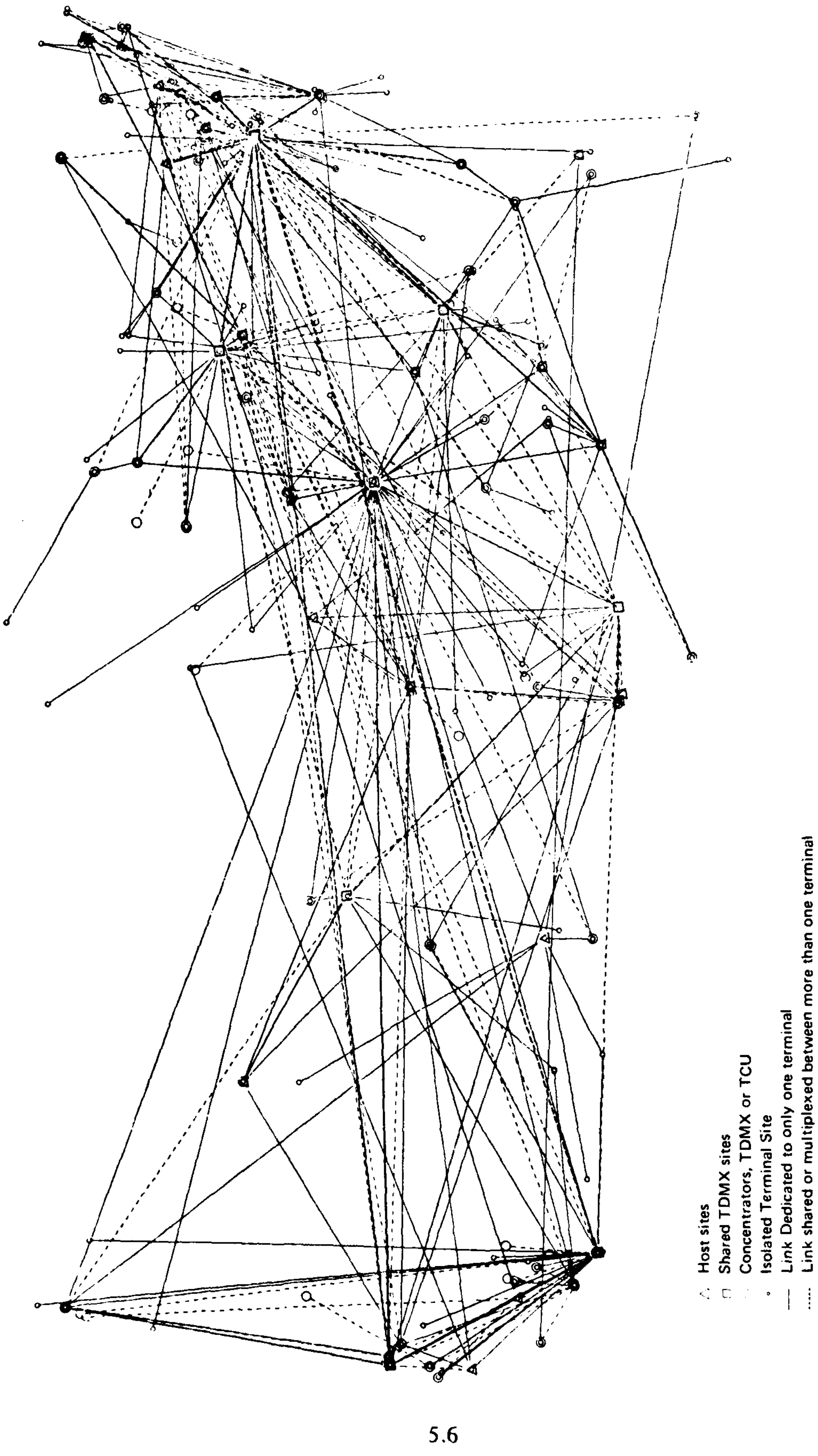


Figure 5.2: Global Topology Under Strategy C

Chapter 6
TYPE D NETWORK STRATEGY–A PACKET SWITCHED 8 SWITCHING NODE INTEGRATED NETWORK

The Type D strategy corresponds to a hierarchical implementation. The high level structure is a packet-switched network with nodal processors located at 8 AUTODIN store-and-forward sites. Terminals and Host computers are connected to the backbone network via local distribution networks. Traffic between terminals and computers is switched through the backbone nodes. Terminal and traffic requirements comprise all the ADP systems listed in Table 3.1, including AUTODIN I.

The evaluation of Type D strategy is carried out in two steps:

- Evaluation of the local distribution networks.
- Evaluation of the backbone network.

6.1 LOCAL DISTRIBUTION NETWORKS

The local distribution network design has the objective of providing the most cost-effective connections from terminals and Host computers to backbone nodes.

Host computers are connected directly to the backbone nodes with links of capacity 9.6 Kbps or higher in order to ensure adequate reliability and throughput capability to Host-backbone communications. The selection of the homing backbone node is based on nearness and load leveling criteria. Figure 6.1 illustrates the Host-Backbone connections.

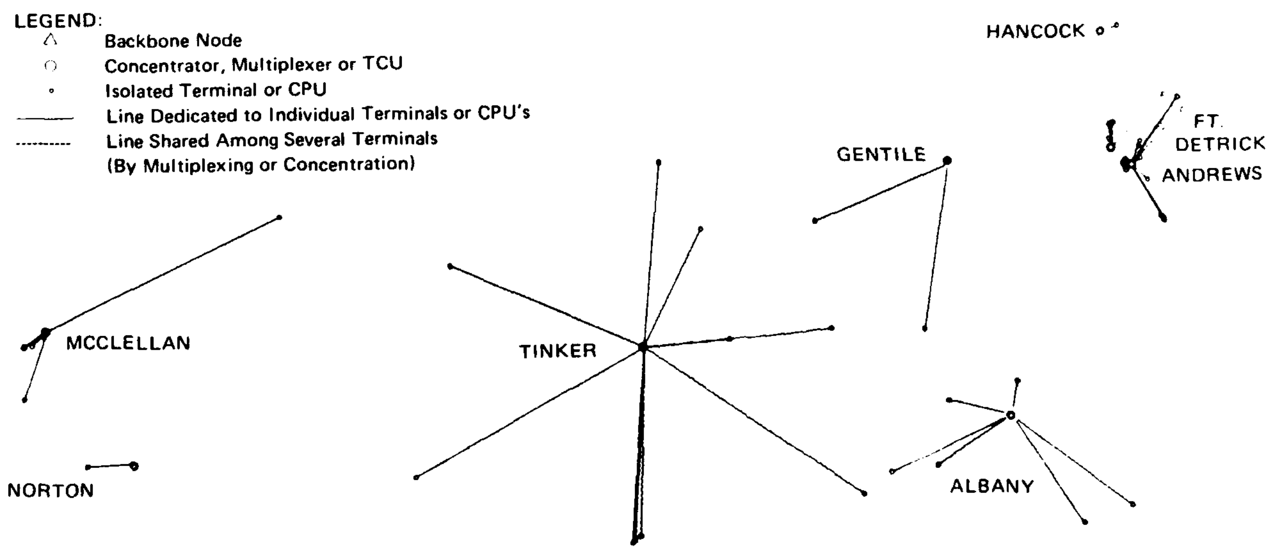


Figure 6.1: Host to Backbone Connections in Strategy D

Terminals are connected to backbone nodes with a fully integrated distribution network, in which TCU's, TDMX's and concentrators can all be shared between different systems. The design of the terminal access network is, therefore carried out using the same procedure as in Strategies B1 and B2, except that any distinction between systems is removed. The selection of the optimal backbone access node is based on nearness and load leveling criteria and is done automatically by computer.

Two different types of local distribution strategies have been evaluated:

- Strategy D1, which allows only local clustering of terminals and is analogous to B1.
- Strategy D2, which allows intermediate multiplexing and concentration and is thus analogous to B2.

In both D1 and D2 strategies, the Hosts are directly connected to backbone nodes on private links.

The terminal access network under Strategy D1 is shown in Figure 6.2. Total computer access cost is $144,000/mo. Total line cost of the terminal network is $248,000/mo. Hardware requirements and cost are as follows:

Type	Number	Cost
TDMX	87	$15,353
TCU	18	21,060
Concentrators	19	51,756
	Total	$88,200/mo.

Total cost for local distribution D1 is therefore $480,000/mo.

The terminal access network under Strategy D2 is shown in Figure 6.3. Total computer access cost is $144,000/mo. Total line cost for the terminal network is $224,000/mo. Hardware requirements and cost are as follows:

Type	Number	Cost
TDMX	106	$18,602
TCU	18	21,060
Concentrators	20	54,480
	Total	$94,142/mo.

Total cost for local distribution D2 is therefore $462,000/mo.

6.2 BACKBONE NETWORK DESIGN USING PLURIBUS IMP's

The design of the backbone network was carried out under the following assumptions:

- Nodal processors are implemented with Pluribus IMP's with throughput capacity $\geqslant$ 1.15 Mbps.
- Average packet length in the network is 500 bits.
- 45% of overhead is added to net input traffic to account for two overhead contributions:
  1. Terminal-Host protocols, and
  2. Backbone network protocols.
- Average packet delay, on the backbone path, is required to be $\leqslant$ 100 msec.
- Line speeds of 56 Kbps and 230 Kbps are used. Multiple 56 Kbps channels in parallel are allowed.

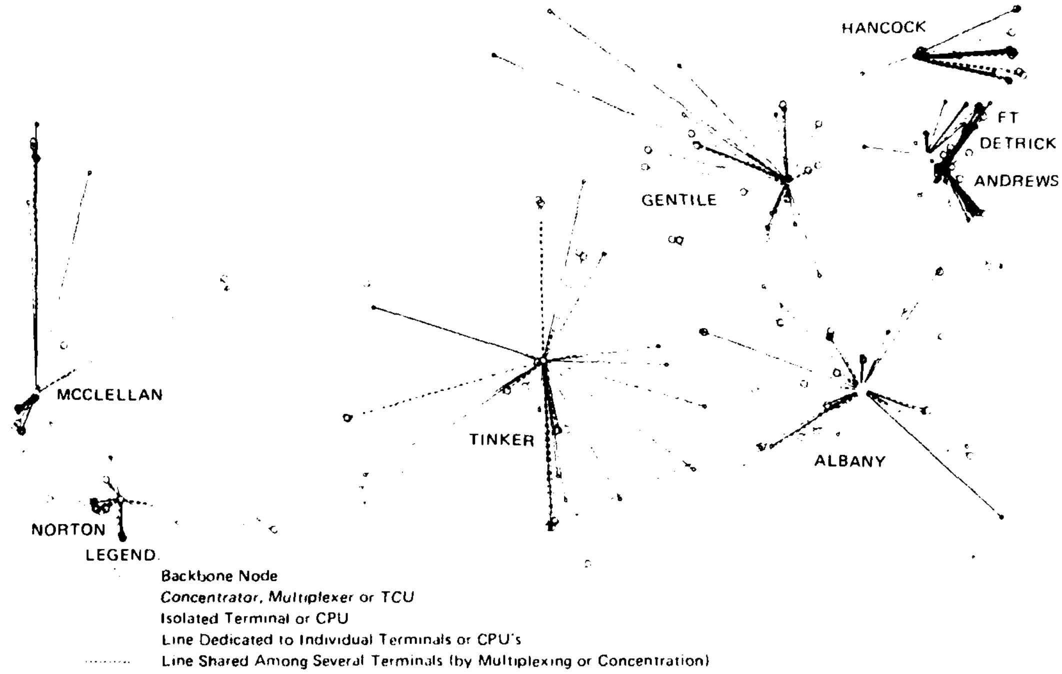


Figure 6.2: Terminal Access under Strategy D1

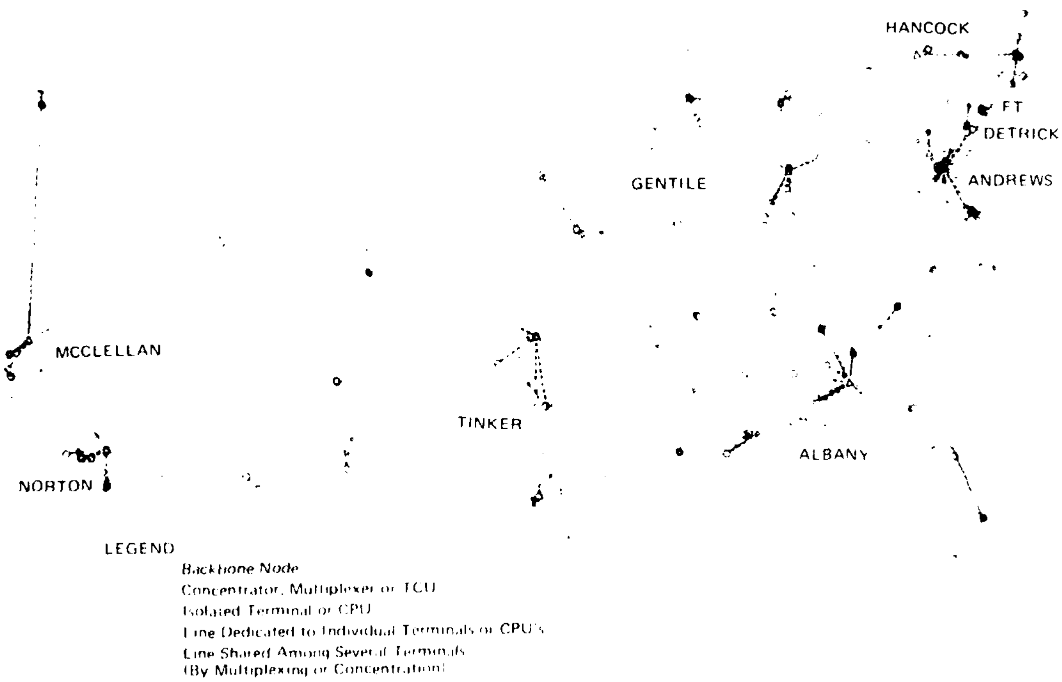


Figure 6.3: Terminal Access under Strategy D2

The net information traffic that arrives to backbone nodes is 1,260 Kbps. Of this traffic, an amount corresponding to 305 Kbps is "local," i.e., it does not access backbone trunks. Therefore, the net information traffic on backbone trunks is 955 Kbps.

A low cost backbone topology is shown in Figure 6.4. Total line cost is $239,000/mo. Total estimated cost for 8 Pluribus IMP's (including amortization, interest, maintenance, and support) is $179,000/mo. (This does not include redundancy.) Total backbone cost is, therefore, $418,000/mo.

The total communications cost for D1 is therefore $898,000/mo. or $10,700,000/yr., and for D2 is $880,000/mo. or $10,500,000/yr. The global map for the D2 configuration (including backbone and local access networks) is shown in Figure 6.5.

In order to appraise the effect of AUTODIN I traffic on backbone cost, the backbone network design was repeated assuming no AUTODIN I traffic on backbone trunks. The resulting overall network cost (local access and backbone) is $873,000/mo. ($10,400,000/yr.) for Strategy D1 and $855,000/mo. ($10,200,000/yr.) for Strategy D2.

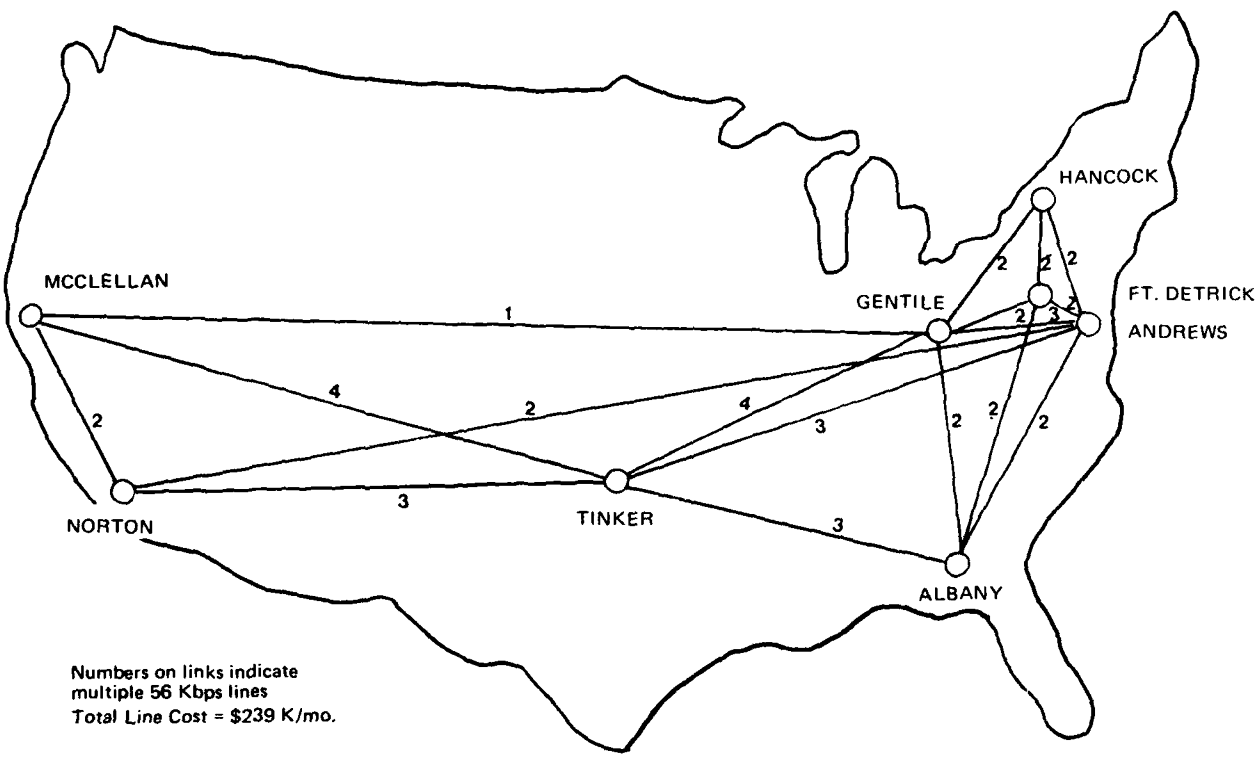


Figure 6.4: Backbone Network with Pluribus IMP's

6.3 BACKBONE NETWORK DESIGN USING REGULAR IMP's

6.3.1 Switching Processor Requirements

From design results obtained in the last subsection, it is apparent that, under the projected AUTODIN II traffic environment with a large number of user terminals and Host computers, the backbone packet-switching processors must be capable of handling high volume traffic, accommodating a large number of high speed I/O ports, and interfacing with a variety of different terminals and computers.

6.3.1.1 High Speed I/O Ports. The following are the high speed I/O port requirements (56 Kbps or higher) at each of the eight backbone nodes to interface with backbone trunks, Host computers, concentrators and high speed peripheral devices:

Tinker	23 I/O ports
McClellan	15 I/O ports
Norton	10 I/O ports
Albany	19 I/O ports
Andrews	35 I/O ports
Ft. Detrick	16 I/O ports
Gentile	19 I/O ports
Hancock	7 I/O ports

6.3.1.2 Traffic Volume. The total information traffic (including both traffic originating and terminating locally plus transit traffic) that must be handled by a backbone switch ranges from about 150 Kbps at Hancock to over 800 Kbps at Tinker.

6.3.1.3 Terminal Interfacing. There are a wide variety of different terminal types among the 1,200 plus terminals that a switch must interface, including various TTY's, CRT's, RJE's, intelligent terminals, etc. In addition, the backbone switch must be able to interface with remote concentrators and to handle software time division multiplexing/demultiplexing.

6.3.2 IMP and TIP's Capabilities

To evaluate whether IMP's and TIP's can be used for AUTODIN II backbone node implementation, one must first examine IMP and TIP capability to satisfy AUTODIN II traffic requirements.

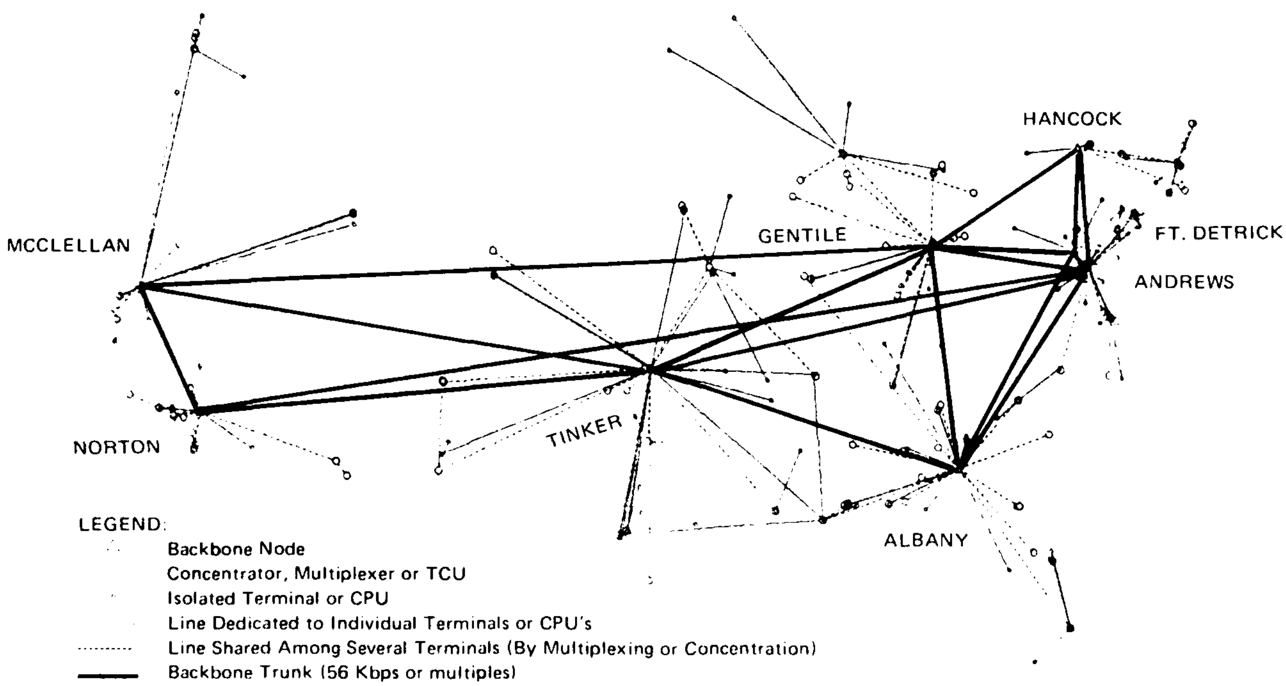


Figure 6.5: Local Distribution and Backbone Network

6.3.2.1 Number of High Speed I/O Ports. An IMP can accommodate up to seven high speed (up to 230.4 Kbps) I/O ports. A TIP can accommodate up to five high speed I/O ports.

6.3.2.2 Throughput. The traffic volume, in kilobits per second, that can be handled by an IMP or a TIP is a function of an average number of packets per message and average packet length. ARPANET measurements indicate that the average number of packets per message is 1.12 [KLEI, 74]. Assuming, therefore, one packet per message, IMP maximum throughput as a function of packet length is shown in Figure 6.6 [McQU, 72]. It can be seen that at 1000 bits per packet, the maximum throughput is about 430 Kbps and at 500 bits per packet, it is about 235 Kbps.

6.3.2.3 Terminal Interfacing. An IMP basically cannot interface directly with any terminal. A TIP can handle up to 63 low-speed terminals. But at the present time, it cannot handle high speed terminals (except special cases). Furthermore, it is not designed for interfacing with remote concentrators or performing software multiplexing/demultiplexing.

6.3.3 Expansion of IMP's Capabilities

It is apparent from the above discussion that an IMP or TIP alone does not have the capability required by any of the eight switches. The question is then whether there are ways to expand IMPs' and/or TIPs' capabilities. We suggest two methods to be used for this purpose: the use of "IMP-Cluster" and "IMP Front End Processor" configurations.

6.3.3.1 IMP-Cluster Configuration. An IMP-cluster consists of the interconnection of several IMP's to form a "Super IMP". By properly distributing the traffic load among the IMP's, the "IMP-Cluster" or "Super IMP" becomes essentially a switching processor with a high throughput and with a large number of high speed I/O ports.

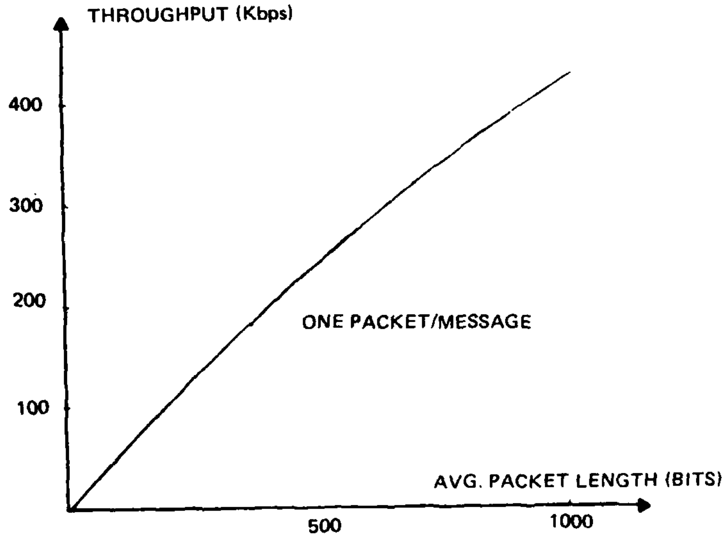


Figure 6.6: IMP Throughput vs. Avg. Packet Length

Let us assess throughput and I/O port capability of the super IMP. Assuming that the cluster consists of N fully interconnected IMP's, and that the traffic load in the cluster is balanced (i.e., it is uniformly distributed among the N IMP's), the maximum throughput that the super IMP can handle is given by:

$$\frac{N^2}{2N-1} \times \text{single IMP throughput}$$

Recalling that an IMP can support up to seven high speed I/O ports, the I/O port capability of the cluster is given by:

$$N(8-N), \text{ for } N \leq 8.$$

For example, if the IMP maximum throughput is 235 Kbps (corresponding to the maximum throughput achievable with 500 bits per packet, one packet per message), and the cluster consists of 5 IMP's, i.e., N=5, then the cluster's maximum throughput is 653 Kbps, and the number of high speed I/O ports is 15.

It is easily seen that, in order to have an adequate high speed I/O port availability, only clusters with 3, 4, or 5 IMP's should be considered. This imposes an upper limit on the throughput that can be obtained with the cluster approach. If higher levels of throughput are required, individual clusters may be interconnected to form a "Super Cluster" with increased performance with respect to the individual components. Alternatively, we may relax the requirement of full interconnection of the IMP's in a cluster, and thus free up ports for external connections. Since I/O ports are no longer the critical constraint, we may then construct clusters with unlimited number of IMP's and throughput capacity. In this case, the cluster can be viewed as a "mini network" of colocated IMP's.

Installation and operation procedures for the super IMP are identical to those applied to regular IMP's. In fact, the cluster is only a topological concept. IMP's in a cluster are functionally identical to IMP's installed in a single IMP configuration.

In evaluating throughput performance for a cluster we have made the assumption that the traffic is balanced. The balance is achieved with careful design of the connections between the cluster and the network, and with proper assignment of Host computers and IMP Front End Processors to the IMP's in the cluster. If the throughput requirement of a Host computer exceeds the throughput capacity of a single IMP in the cluster, dual or multiple homing is necessary. In the case of load fluctuations within the cluster, the adaptive routing procedure provides the rerouting of traffic around heavily loaded nodes and to some extent re-establishes the balance.

In summary, the IMP cluster can be viewed as a simple, non-sophisticated approach to the implementation of a packet switch with high throughput and port requirements. With respect to the Pluribus IMP, the IMP cluster has the following drawbacks:

- It requires a "balanced" design of cluster-network connections, and Host-cluster homing links.
- It introduces higher nodal processing delays, since a packet in transit must visit at least two IMP's in the cluster.
- It takes larger floor space.
- It has higher operation and maintenance costs. (These higher costs are reflected in the cost basis used to price the clusters.)

On the other hand, the IMP cluster has the initial advantage of being based on software fully developed and tested, while Pluribus IMP software is still experimental. Furthermore, the IMP cluster is better protected against failures due to its high redundancy, and IMP's can be removed or added to the cluster without interrupting network operations.

6.3.3.2 **IMP Front End Processor (IMP-FEP).** The IMP-FEP can be implemented with a modified version of a TIP, an ANTS, and ELF, a commercially available concentrator, or a commercially available front end processor. The IMP-FEP will act like a Host computer or a VDH (Very Distant Host) to an IMP on one side and interface with a variety of terminals on the other side. Cost and hardware configurations of an IMP-FEP are the same as those of the concentrator, and maximum throughput is 100 Kbps.

6.3.4 Design (Using Regular IMP's)

The 8 Pluribus IMP's for the design shown in Figure 6.4 can be replaced with IMP's and IMP-FEP's without degradation in network throughput. This can be achieved by the following steps:

- Replacing the Tinker switch with three 5-IMP clusters (i.e., a total of 15 IMP's), and three IMP-FEP's.
- Replacing the McClellan switch with two 4-IMP clusters (i.e., a total of 8 IMP's) and two IMP-FEP's.
- Replacing the Norton switch with two 4-IMP clusters (i.e., a total of 8 IMP's) and two IMP-FEP's.
- Replacing the Albany switch with two 4-IMP clusters and four IMP-FEP's.
- Replacing the Andrews switch with four 4-IMP clusters and eight IMP-FEP's.
- Replacing the Ft. Detrick switch with two 4-IMP clusters and four IMP-FEP's.
- Replacing the Gentile switch with two 5-IMP clusters and four IMP-FEP's.
- Replacing the Hancock switch with one 5-IMP cluster and one IMP-FEP.

The IMP-cluster and IMP-FEP requirements for the eight backbone nodes are shown in Figure 6.7. Backbone trunk connections are as shown in Figure 6.4.

There are a total of 78 IMP's and 30 IMP-FEP's. At $1,475/mo. for each IMP (no redundancy cost is included since there are many IMP's in a cluster, and each cluster may be regarded as perfectly reliable), and $2,724/mo. for each IMP-FEP (assuming same cost as an IMP, plus full redundancy), the total hardware cost is $196,000/mo. This is about 10% higher than the hardware cost for the Pluribus IMP implementation. However, the cost is quite conservative since it includes 67% of the base cost as initial software support (a factor used by DCA in estimating processor costs). Even though additional memory and some software modifications will be necessary to allow the IMP's to be connected in a network with more than 64 IMP's, this additional cost should be quite less than 2.6 million dollars (78 x .67 x $50,000).*

The total backbone network with IMP's costs $435,000/mo. This is about 4% higher in cost than the design with Pluribus IMP's. It does not provide more throughput. However, the reliability is better due to the high IMP redundancy at each site.

*It should be noted that new minicomputers are now available at approximately one half of the current IMP cost. However, software compatibility issues prevent, at the current time, a direct one-for-one replacement.

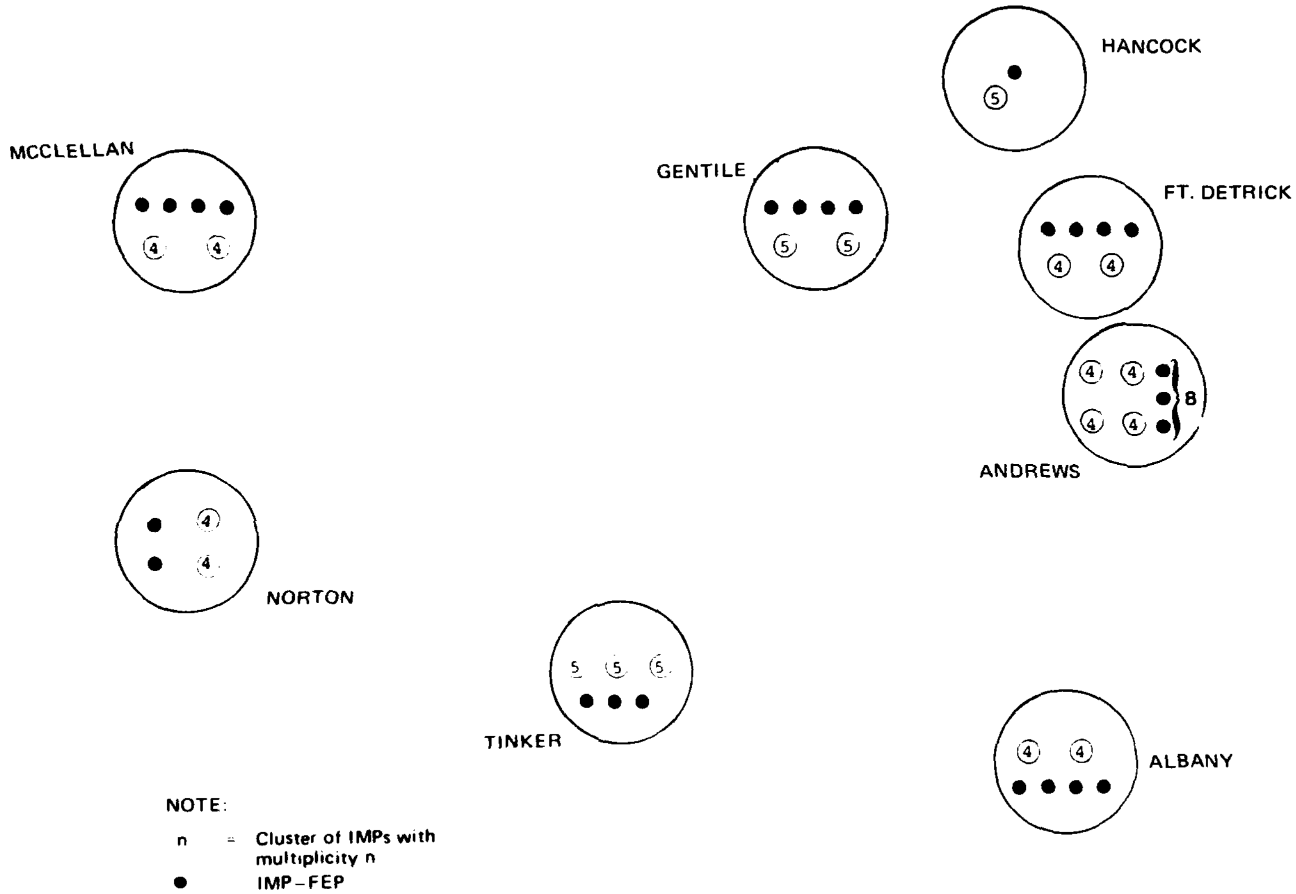


Figure 6.7: Backbone Node Implementation at Various Sites Using Regular IMP's. Connections *Between Supernodes are as Indicated in Figure 6.4*

Chapter 7

TYPE E NETWORK STRATEGY—A FULLY DISTRIBUTED PACKET SWITCHED INTEGRATED NETWORK

The Type E strategy is similar to the Type D strategy, except:

- Backbone sites are not limited to the eight AUTODIN sites
- Backbone nodes are implemented with IMP's, and
- Topological structure is based on ARPANET philosophy.

The ARPANET philosophy is characterized by the installation of IMP's and TIP's at (or in the proximity of) Host computer and terminal sites, so as to reduce local access cost. During the early stages of ARPANET development, it was actually possible to place IMP's at all the computer sites. In recent years, however, the growth of the network (and of the number of Hosts in the network) has made it more cost-effective to link some of the new Hosts to the network via Very Distant Host (VDH) connections, rather than installing IMP's at all sites.

The Type E strategy reflects the ARPANET philosophy in that the backbone network consists of a large number of geographically well-distributed IMP's. Number and location of the IMP's are selected so as to obtain the best tradeoff between backbone cost and local access costs. The network design is also subject to constraints such as IMP throughput capability, number of IMP ports, and redundancy requirements for each IMP installation.

A cost-effective backbone configuration for Strategy E consisting of 27 IMP sites is shown in Figure 7.1. IMP locations were selected using the following preference criteria:

- Locations with more than one Host
- Locations with critical Hosts (i.e., critical reliability requirements)
- Locations with high throughput Hosts, and
- Locations at the center of high terminal density areas.

Typically, more than one IMP is required at each site because of the large number of network connections and Host interfaces, the high traffic volume (both local and transit traffic), and the reliability requirements. The basic IMP site configuration considered in this analysis consists of one IMP dedicated primarily to trunk connections, one IMP dedicated primarily to Host connections, one spare IMP (for redundancy), and one IMP-FEP (Front End Processor) for terminal and RJE access. For sites with high Host concentration and considerable traffic requirements, the basic configuration is expanded according to the requirements and can include several IMP's.

For the 27-node backbone network configuration shown in Figure 7.1, a total of 109 IMP's and 30 IMP-FEP's are required, corresponding to a total monthly cost of $242,000/mo.

Backbone trunk capacities are 50 Kbps or 100 Kbps, as indicated on the map in Figure 7.1. The 100 Kbps option is implemented with two 50 Kbps lines in parallel. Average packet delay

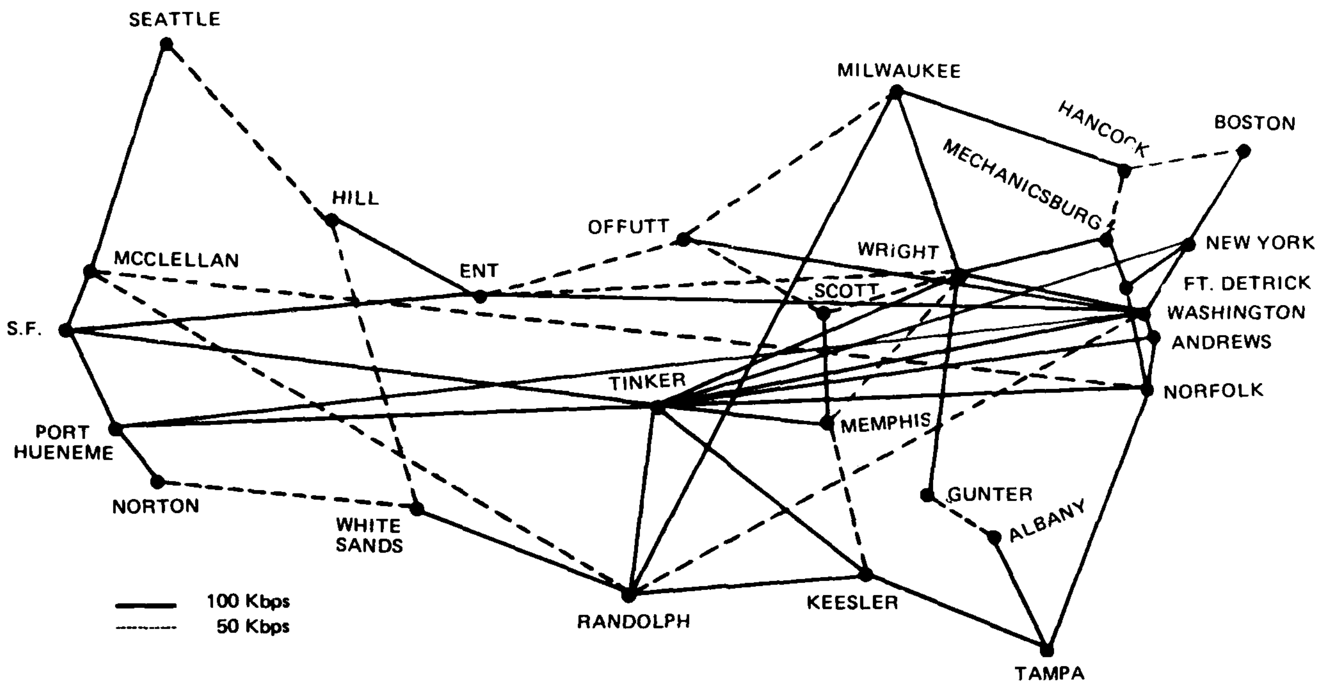


Figure 7.1: Strategy E Backbone Topology

between any source and destination IMP at nominal traffic level is less than 100 msec. The total trunk cost is $373,000/mo. using Telpak lines; it is $474,000/mo. using DDS lines.

Host and terminal connections into the backbone network are shown in Figures 7.2 and 7.3, respectively. Notice that no intermediate TDMX or concentration points are required. Host access cost is $67,000/mo. and terminal line access cost is $131,000/mo. The hardware cost for TDMX, TCU, and concentrators at terminal clustering sites is $70,000/mo., which is 20% lower than the corresponding cost for Strategy D ($88,000/mo.), due to hardware savings obtained at clusters colocated with backbone nodes. Total access cost (line plus hardware) is therefore $268,000/mo.

The total cost for Strategy E, the sum of backbone hardware cost, backbone trunk cost, and local access cost is $883,000/mo.

Next, the cost of Strategy E is calculated under the assumption that AUTODIN I traffic requirements are routed on a separate network. In this case, some of the backbone trunk cost, can be eliminated, and the overall cost is reduced to $835,000/mo.

If the Strategy E network is implemented as an outgrowth of the present ARPANET, i.e., it is obtained by relocating the present IMP's and adding new IMP's as required, the present ARPA Hosts need to be connected to the new backbone via VDH links.

Presently, about 60 Hosts in the continental U.S. are connected to ARPA. Among them, six already have VDH connections. The total cost for connecting the ARPA Hosts to the Strategy E backbone network via 50 Kbps Telpak lines is $55,000/mo. The monthly cost for a pair of VDH interfaces—one on the Host and one on the IMP—is about $500/mo. (assumptions: $25,000 for the purchase of two interfaces; installation and maintenance = 67% of base cost;

10-year amortization at 10% per year interest). Therefore, the monthly cost for 54 VDH interfaces is $27,000/mo. The total cost for the VDH connections (lines plus interfaces) is $82,000/mo.

For line saving purposes, multiple Host ARPA sites may be equipped with a common front end processor, so that only one VDH link per site is required. By introducing front end processors where economical, the total cost is reduced to $74,000/mo.

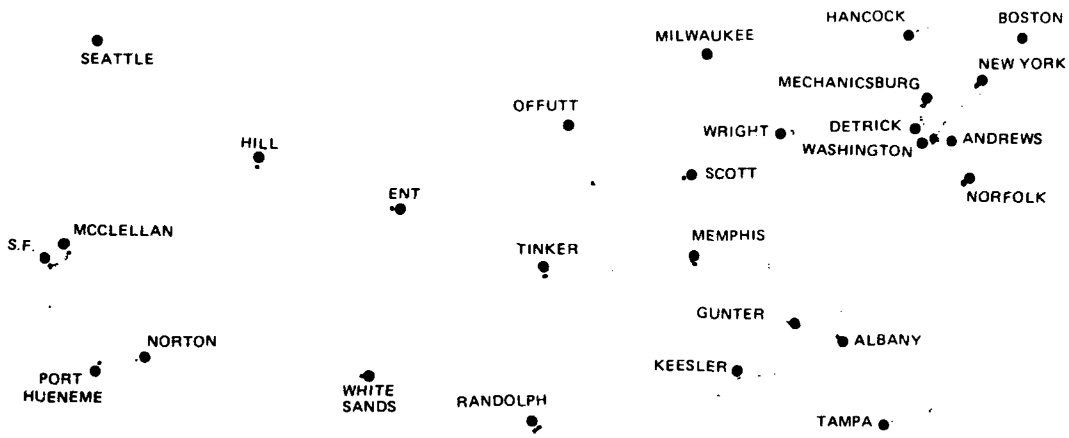


Figure 7.2: Host-Backbone Connections in Strategy E

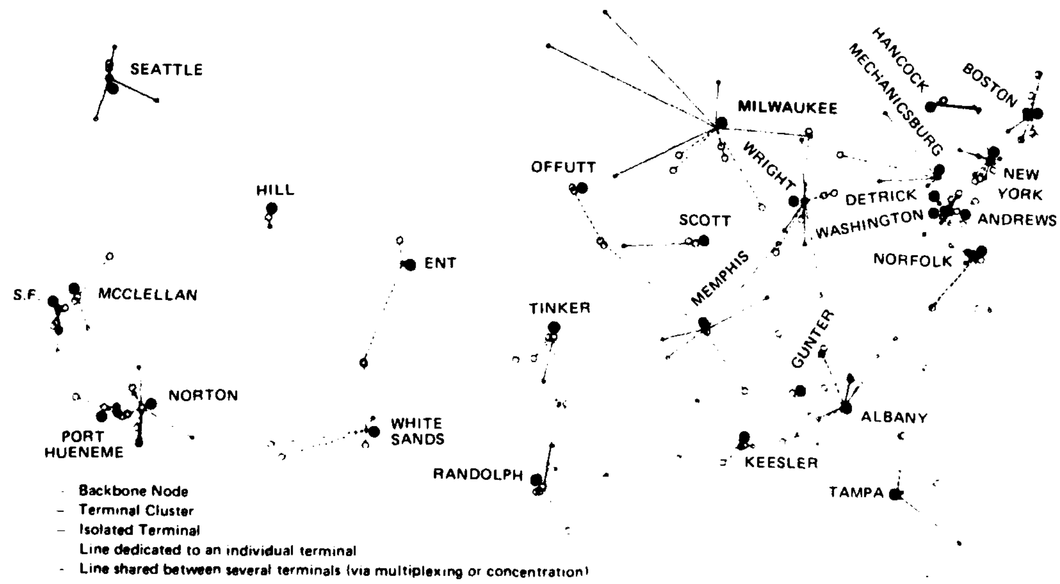


Figure 7.3: Terminal-Backbone Connections in Strategy E

Chapter 8
TYPE F NETWORK STRATEGY—SEPARATE NETWORKS FOR SECURE AND UNSECURE TRAFFIC

8.1 TYPE F STRATEGY

Type F strategy is essentially a combination of Strategy D2 and E. Secure and unsecure systems are segregated, and their requirements are accommodated on separate networks. In particular, secure traffic is accommodated on an 8-node backbone network as in Strategy D2, and unsecure traffic is accommodated on an ARPA-like network as in Strategy E.

On the 35 ADP Defense Communications Systems considered in this study, the following systems require security:

N07	:	NAVY ENV. SYSTEM
NFA-NFC	:	NAVPERS
N28	:	CAIMS
D06	:	DEFENSE RDT
W	:	WWMCCS
ACA-ACC	:	SPEEDEX
ADA-ADC	:	TEAM-UP
AEA-AEC	:	ARMY MATERIAL COMM.
F01	:	ADVANCED LOGISTIC SYS.
F13	:	ADVANCE PERS. DATA SYS.
F63	:	AIR STAFF & OSD SUPPORT
F1J	:	AUTODIN I

The total secure traffic is 416 Kbps, of which 101 Kbps is switched locally in the 8 backbone nodes and therefore does not access the backbone trunks. The total unsecure traffic is 843 Kbps.

8.2 SECURE NETWORK

The design of a cost-effective 8-node backbone network (with nodes colocated with AUTODIN I sites) for the secure traffic was performed following the basic assumptions and guidelines discussed in Chapter 6 of this report. An 8-node low cost topology which satisfies the secure traffic requirements is shown in Figure 8.1. Total line costs for such topology is $93,000/mo.

High nodal throughput and I/O port requirements make it necessary to implement the backbone nodes with Pluribus IMP's or IMP clusters (as discussed in Section 6.3). The cost of the Pluribus IMP implementation is $179,000/mo. The cost of the IMP-cluster and IMP-FEP implementation (requiring 30 IMP's and 15 IMP-FEP's) is $85,000/mo. The latter solution is more cost-effective (at least for the 1976 secure traffic requirements) and therefore is selected for the purpose of our cost comparison. The total backbone cost is therefore $178,000/mo.

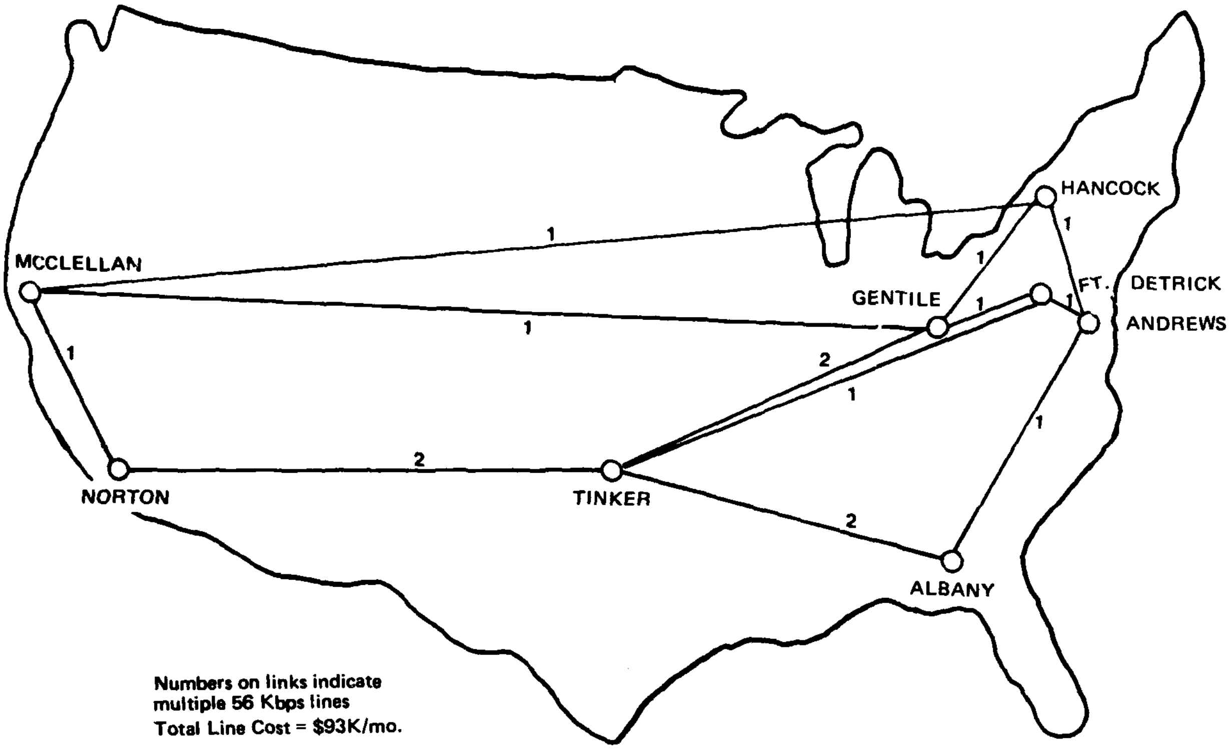


Figure 8-1: 8-Node Backbone Network for Secure Traffic

Local access cost for the secure systems is calcualted by prorating the local access cost for Strategy D2, according to the percentage of the traffic which is secure. Under this assumption, local access cost (Host plus terminal) is $153,000/mo.

The total cost for the secure network is $331,000/mo.

8.3 UNSECURE NETWORK

The network for unsecure requirements was designed following the ARPA philosophy described in Chapter 7. The design requires 100 IMP's and 27 IMP-FEP's, installed in 27 different sites (note: each site has at least three IMP's and 1 IMP-FEP). The topology is shown in Figure 8.2. Trunk lines are implemented with 50 Kbps and 100 Kbps line capacities, as indicated on the map.

Nodal processor cost (including IMP's and IMP-FEP's) for the backbone is $221,000/mo. Trunk cost is $250,000/mo. using the Telpak service, and $341,000/mo. using the DDS offering. Total backbone cost (using Telpak lines) is therefore $471,000/mo.

Host and terminal access cost is obtained by prorating the local access cost for Strategy E, based on the ratio between unsecure traffic and total traffic volume. Using this procedure, local access cost for unsecure traffic is $177,000/mo.

The total cost for an ARPA-like strategy which accommodates all unsecure requirements is therefore $648,000/mo.

8.4 TOTAL COST FOR STRATEGY F

The overall cost for Strategy F is given by the sum of secure and unsecure network costs, and is equal to $979,000/mo., or $11,700,000/yr.

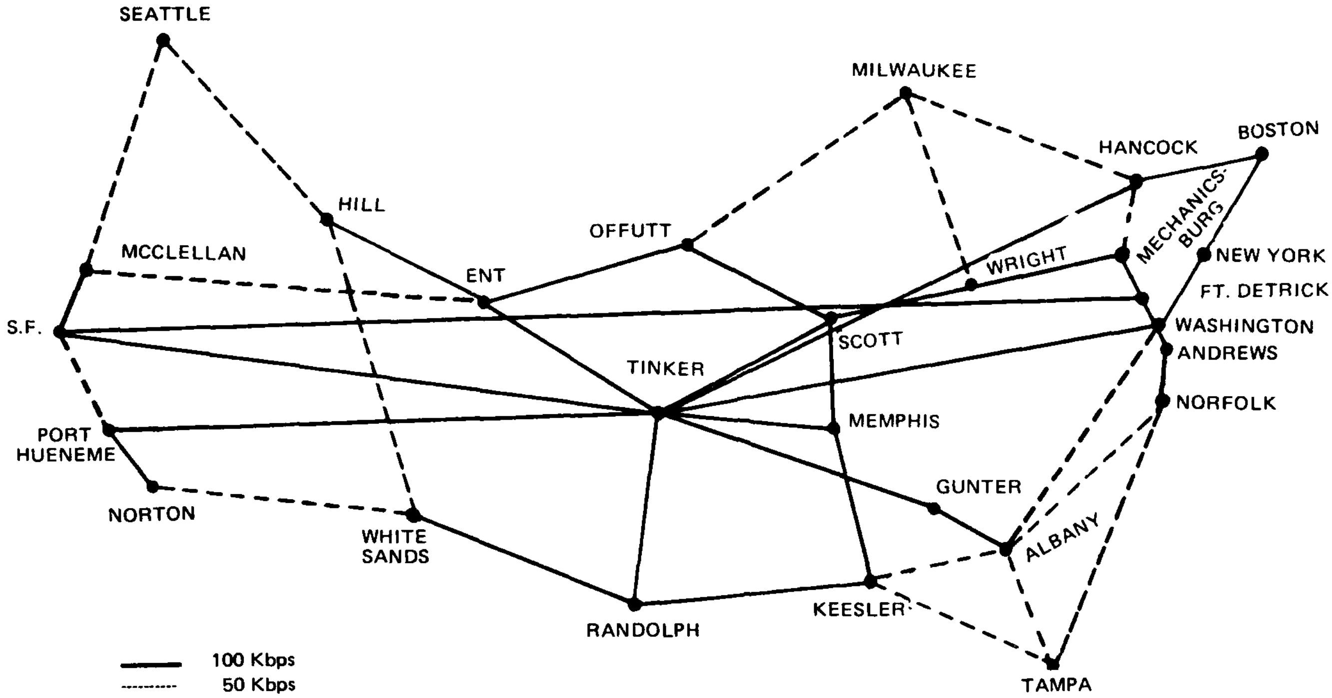


Figure 8.2: Strategy F Backbone Topology (Unsecure Requirements)

Chapter 9
NETWORK SECURITY AND ENCRYPTION

9.1 GENERAL

Two types of encryption are considered in this study:

- Link encryption, obtained with two cryptos, one at each end of a link, and
- End-to-end encryption obtained with two cryptos, one at each end of the path.

Link encryption has an effect on everything that flows on the link, and therefore makes both data and end-to-end protocols secure from outside observation along the link. However, the destination address information must be reconstructed at intermediate concentrators and switching nodes for routing purposes. If link encryption alone is implemented, the data is also reconstructed at such nodes. Therefore, concentrators and switching nodes must be installed in secure areas.

End-to-end encryption is applied at the originating device (terminal or Host) to the data field of each message. Therefore, the data is secure all along the path, even if intermediate concentration and switching nodes are not in secure areas.

In summary, link encryption provides data and traffic flow security, but requires that all network installations be in secure areas. End-to-end encryption provides data security, but no traffic flow security. The combination of link and end-to-end encryption provides both data and traffic flow security. Figure 9.1 shows a few examples of different encryption schemes.

In the following, the encryption requirements for the AUTODIN II environment are identified, and global encryption cost is evaluated for several network strategies, using as a cost basis the encryption device costs reported in Chapter 2.

9.2 SECURITY REQUIREMENTS

In the AUTODIN II environment, the following 12 systems require security:

NAVY ENV. SYSTEM	TEAM-UP
NAVPERS	ARMY MATERIAL COMM.
CAIMS	ADVANCED LOGISTIC SYS.
DEFENSE RDT	ADVANCE PERS. DATA SYS.
WWMCCS	AIR STAFF & OSD SUPPORT
SPEEDEX	AUTODIN I

It can be assumed that all the Host computers associated with the above systems must be secure. Therefore 49, out of a total of 87 Host computers, are secure. Within the 12 secure systems, some of the terminals require security, some others do not. Based on information provided by the DCA staff, there are 66 secure terminals, equivalent to 6% of the total AUTODIN II terminal population.

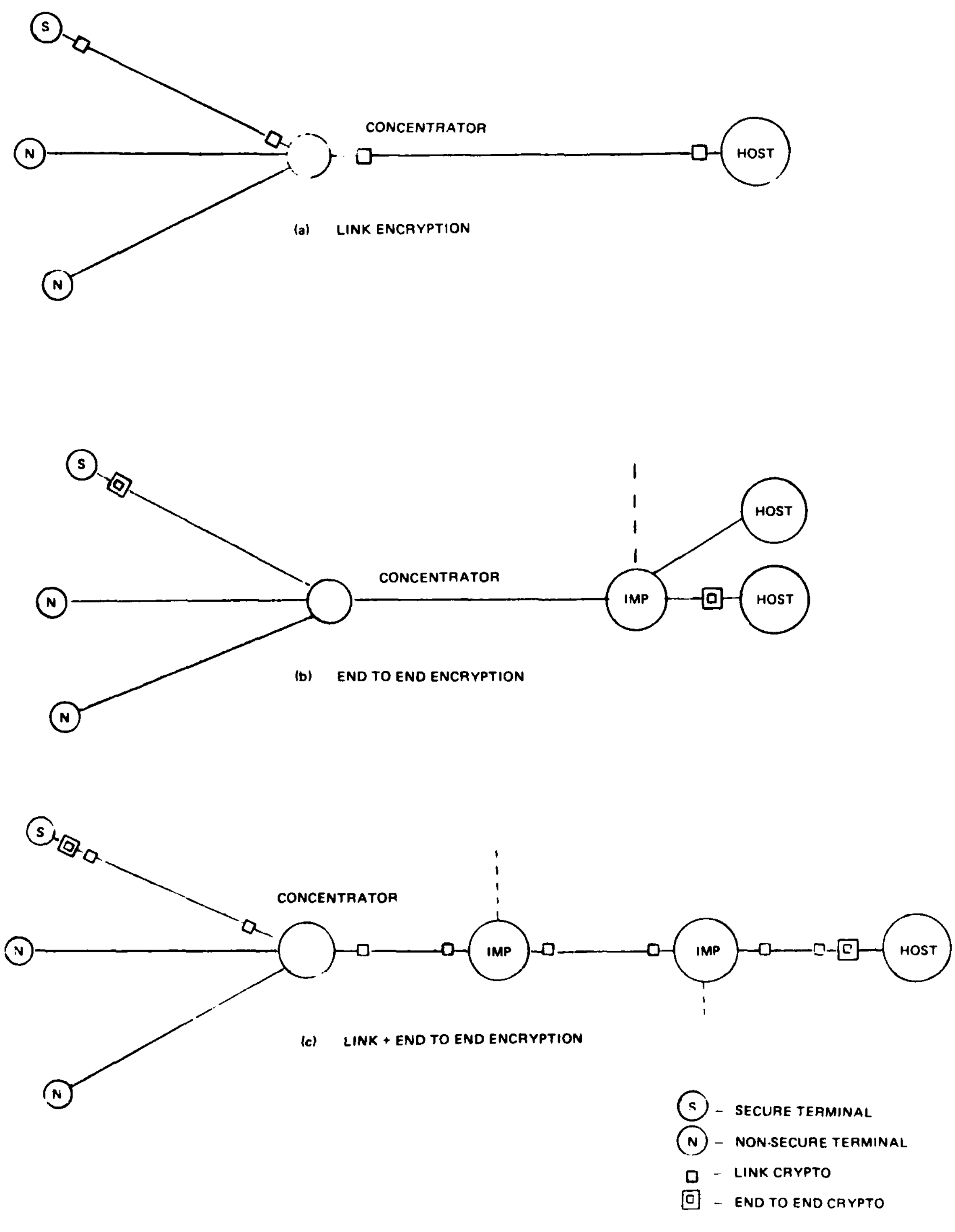


Figure 9-1: Examples of Network Encryption

All secure communications must be encrypted, either by means of link encryption on all the links of the network path, or by means of end-to-end encryption at origin and destination. For additional security, both link and end-to-end encryption may be implemented.

For the link encryption approach to be feasible, it is required that all multiplexers, concentrators and packet-switching processors which handle secure traffic be installed in secure areas. We assume that such a requirement is satisfied for all the network strategies considered in this study.

Furthermore, we make the assumption that none of 66 secure terminals and 49 secure Hosts are colocated. This will lead to a conservative encryption cost estimate, since potential savings are available in the actual implementation by sharing link cryptos among clustered terminals, or by relaxing the encryption requirement between colocated Hosts and terminals.

In the sequel, we consider the various network strategies orginally analyzed in Chapters 3 to 8. For each strategy, we evaluate the following encryption costs:

- Cost of link encryption on all paths carrying secure data,
- Cost of end-to-end encryption for all secure Hosts and terminals.
- Cost of link plus end-to-end encryption on all secure paths and for all secure Hosts and terminals, and
- Cost of link encryption on all network links.

The least cost encryption scheme for each network strategy is then selected. The choice is clearly between link and end-to-end encryption. The cost of link plus end-to-end encryption and of overall network link encryption strategies is always higher than the cost of the two former strategies and is reported here only as a term of reference.

It is important to note that security costs for the link encrypted options do not reflect the high costs for establishing and operating secure switches with suitably cleared personnel. Costs for link and end-to-end encryptors represent current costs based on existing technology. End-to-end encryption costs are based on PLI devices whose costs may decrease significantly in the near term. Consequently, this dynamic cost factor should be considered when comparing encryption alternatives.

9.3 ENCRYPTION COSTS FOR DIFFERENT NETWORK STRATEGIES

9.3.1 Strategy A (See Chapter 3)

■ Number of secure Host-to-Host links (excluding AUTODIN I)	157
■ Number of secure terminal-to-Host links	66
■ Total number of links in Strategy A	1260
■ Link encryption cost	$ 89K/mo.
■ End-to-end encryption cost	$ 84K/mo.
■ Link plus end-to-end encryption cost	$173K/mo.
■ Cost of the encryption of all network links	$499K/mo.

9.3.2 Strategy B1 (See Chapter 4)

■ Number of secure Host-to-Host links	157
■ Number of secure terminal-to-Host links	66
■ Total number of links in Strategy B1	396
■ Link encryption cost	$ 89K/mo.
■ End-to-end encryption cost	$ 84K/mo.
■ Link plus end-to-end encryption cost	$173K/mo.
■ Cost for the encryption of all network links	$157K/mo.

9.3.3 Strategy B2 (See Chapter 4)

In B2, we have a total number of seven intermediate time division multiplexing points which handle secure traffic.

■ Number of secure Host-to-Host links	157
■ Number of secure terminal-to-Host (or terminal-TDMX) links	66
■ Number of secure TDMX-Host links	7
■ Total number of links in Strategy B2	439
■ Link encryption cost	$ 91K/mo.
■ End-to-end encryption cost	$ 84K/mo.
■ Link plus end-to-end encryption cost	$175K/mo.
■ Cost for the encryption of all network links	$174K/mo.

9.3.4 Strategy C (See Chapter 5)

■ Number of secure Host-to-Host links	157
■ Number of secure terminal-to-Host (or terminal-TDMX) links	66
■ Number of secure TDMX-TDMX (or TDMX-Host) links	25
■ Total number of links in Strategy C	479
■ Link encryption cost	$ 99K/mo.
■ End-to-end encryption cost	$ 84K/mo.
■ Link plus end-to-end encryption cost	$183K/mo.
■ Cost for the encryption of all network links	$199K/mo.

9.3.5 Strategy D1 (See Chapter 6)

■ Number of Host-backbone links requiring link encryption	41

- Number of backbone trunks — 40
- Number of terminal-backbone links carrying secure traffic — 66
- Total number of links for Strategy D1 — 358
- Link encryption cost — $ 58K/mo.
- End-to-end encryption cost — $ 84K/mo.
- Link plus end-to-end encryption cost — $142K/mo.
- Cost for the encryption of all network links — $142K/mo.

9.3.6 Strategy D2 (See Chapter 6)

In Strategy D2, there are 22 intermediate points in the path from terminals (or terminal clusters) to backbone nodes; more precisely, there are 21 TDMX devices and one concentrator. We assume that all the 22 links from intermediate points to backbone nodes handle secure traffic.

- Number of Host-backbone links carrying secure traffic — 41
- Number of backbone trunks — 40
- Number of secure terminal backbone (or secure terminal-intermediate point) links — 66
- Number of secure links from intermediate points to backbone — 22
- Total number of links in Strategy D2 — 380
- Link encryption cost — $ 67K/mo.
- End-to-end encryption cost — $ 84K/mo.
- Link plus end-to-end encryption cost — $151K/mo.
- Cost for the encryption of all network links — $150K/mo.

9.3.7 Strategy E (See Chapter 7)

In Strategy E, about 30% of the secure Hosts are colocated with IMP's. For those Hosts, no Host-IMP link security is required. We recall that no intermediate multiplexing or concentration stations are required in Strategy E.

- Number of backbone links — 110
- Number of Host-IMP links carrying secure traffic — 35
- Number of terminal-IMP links carrying secure traffic — 66
- Total number of links in Strategy E — 384
- Link encryption cost — $ 83K/mo.
- End-to-end encryption cost — $ 84K/mo.

- Link plus end-to-end encryption cost $167K/mo.
- Cost of encryption of all network links $152K/mo.

9.3.8 Strategy F (See Chapter 7)

Strategy F consists of two networks: one for the secure, and another for the unsecure systems.

Only the secure network requires encryption. The encryption evaluation procedure for the secure network is the same as for Strategy D2.

■ Number of Host-backbone links carrying secure traffic	41
■ Number of backbone links	15
■ Number of terminal-backbone (or terminal-intermediate point) links carrying secure traffic	66
■ Number of TDMX-backbone links carrying secure traffic	7
■ Total number of links in the network	183
■ Link encryption cost	$ 51K/mo.
■ End-to-end encryption cost	$ 84K/mo.
■ Link plus end-to-end encryption cost	$135K/mo.
■ Cost for the encryption of all network links	$ 72K/mo.

9.4 COMPARISON OF ENCRYPTION ALTERNATIVES

Table 9.1 summarizes the costs of different encryption alternatives for various network strategies.

End-to-end encryption is more cost-effective than link encryption for all the segregated strategies (A, B1, B2, and C even when the high site security costs associated with link encryption are ignored). For such strategies, link encryption is very costly because of the very large number of Host-to-Host links (135) interconnecting the secure, distributed computer networks (ALS, WWMMCS, and AUTODIN I).

For the integrated configurations, link by link encryption is the most conservative option. For the distributed strategy (Type E), the end-to-end and link by link strategies have equivalent current costs, when the costs for providing secure switch installations for link by link encryption are ignored. Hence, in this case, end-to-end encryption is clearly the superior alternative. For the other integrated network design approaches, link encryption appears to be 20 - 40% less costly than end-to-end encryption when the switch security costs for link encryption are ignored. Hence; end-to-end encryptors would have to decrease by this percentage over the next few years to be clearly superior, or the switch security costs would have to be identified in order to select the least costly alternative.

Table 9.1: Cost of Data Security for Various Network Configurations Under Different Encryption Alternatives

Network Configuration (By Strategy Type)	Link Encryption K$/Mo.	End-to-End Encryption K$/Mo.	Link Plus End-to-End Encryption K$/Mo.	Encryption on all Links K$/Mo.	Least Cost Encryption Alternative K$/Mo.
A	89	84	173	499	84
B1	89	84	173	157	84
B2	91	84	175	174	84
C	99	84	183	199	84
D1	58	84	142	142	58
D2	67	84	151	150	67
E	83	84	167	152	83
F	51	84	135	72	51

Chapter 10
RELIABILITY CONSIDERATIONS

10.1 GENERAL

The emphasis of the preceding sections was on cost and delay performance rather than on availability performance. In this section, we evaluate network availability for each of the strategies considered in Chapters 3 through 8. If network availability does not meet AUTODIN II requirements, alternative techniques to achieve such requirements are presented and cost-evaluated.

Network availability is defined as the expected fraction of time during which a communication path is available from terminal-to-Host, or Host-to-Host. AUTODIN II availability requirements are the following:

- Availability $\geq$ .99 for non-critical systems.
- Availability $\geq$ .9995 for critical systems (i.e., MAJCOM, MACIMS, ENV DATA NET, AND WWMCCS).

In the sequel, network availability for various strategies is evaluated based on network component failure rates reported in Section 2.

10.2 STRATEGY A

The terminal-Host line is down $\leq$ 0.4% of the time. Therefore, the non-critical requirements are met.

As for the critical systems, WWMCCS is implemented with a distributed, highly connected network which is deemed adequately reliable. The remaining critical systems require full line backup, for a total cost of $145,000/mo., or dialup backup, for a much lesser cost. Dial backup is feasible in general when line speed is $\leq$ 4.8 Kbps, and when the system does not require security (recall that WWMCCS and ENV DATA NET are secure). Even for secure systems, however, it may be possible to implement adequate protections that make dialup feasible.

10.3 STRATEGY B

Since no more than two hops from terminal-to-Host are allowed in Strategy B, the network down time is $\leq$ .8% and, consequently, the non-critical requirements are met.

For critical systems (with the exception of the WWMCCS network, which meets the requirements), full line backup or terminal-to-Host dialup backup is required. The cost of full line backup is $50,000/mo. for B1, and $47,000/mo. for B2.

10.4 STRATEGY C

In Strategy C, the shared TDMX links have high redundancy, and their down time can be assumed $\leq 10^{-4}$. Therefore, non-critical requirements are met by the basic configuration.

For all critical systems, except WWMCCS, full line backup (or dialup) is required. The cost of full line backup is $45,000/mo.

10.5 STRATEGY D

The backbone net is very reliable, in both Pluribus IMP and IMP-cluster cases, and yields a down time $\leq 10^{-4}$ between any two backbone nodes. For non-critical terminals that are at one hop distance from backbone nodes, the network reliability requirement is satisfied, since the terminal-to-Host path involves two hops (plus the very reliable backbone segment) and therefore is down $\leq$ .8% of the time.

For non-critical terminals that are two hops away from backbone nodes, the requirement is not satisfied. Therefore, dual homing or full line backup from intermediate TDMX devices or concentrators to the backbone net is required. The cost of full line backup is $22,000/mo. The cost of dual homing can be expected to be somewhat higher, say about $30,000/mo.

For critical systems, WWMCCS included, dual homing or line backup from critical Host to backbone node, and full backup from critical terminal to backbone is required. The cost of Host connection backup is $76,000/mo., and the cost of terminal connection backup is about $3,000/mo.

10.6 STRATEGY E

The backbone network in Strategy E has a source-to-destination node pair availability on the order of 0.9999. The backbone availability performance is therefore similar to that of Strategy D backbone and derives from high nodal redundancy and network connectivity.

Availability requirements for non-critical systems are met, since terminals and Hosts are at most one hop away from backbone nodes.

For the critical systems, dual homing from Hosts and from terminals to backbone network is required, for a total estimated cost of $80,000/mo. This cost could be somewhat reduced by providing dialup backup, instead of dual homing, from terminals to backbone network.

10.7 STRATEGY F

For non-critical systems, the unsecure ARPA-like network is adequately reliable, whereas the secure 8-node backbone network requires full line backup from intermediate TDMX devices to the backbone nodes, for a total estimated cost of $7,000/mo.

As for the critical systems, the systems in the secure net (i.e., WWMCCS and ENV DATA NET), require Host and terminal full line backup into the 8-node backbone, for an estimated cost of $70,000/mo. The critical systems in the unsecure net (i.e., MAJCOM, and MACIMS) require dual homing from Hosts and from terminals into the backbone network, for an estimated cost of $30,000/mo. Alternatively, dialup backup from terminals to Hosts can be implemented.

10.8 COST SUMMARY

The cost summary of the network improvements required to meet the AUTODIN II reliability requirements for each strategy is presented in Table 10.1. The costs correspond to the full line backup (or dual homing) alternative, and could be somewhat reduced if the dialup backup alternative was considered.

Table 10.1: Additional Cost to Meet AUTODIN II Reliability Requirements

Strategy	Basic Cost Including Security K$/mo.	Additional Cost to Meet Reliability Requirements K$/mo.
A	1459	145
B1	957	50
B2	892	47
C	880	45
D1	956	106
D2	947	128
E	966	80
F	1030	107

REFERENCES

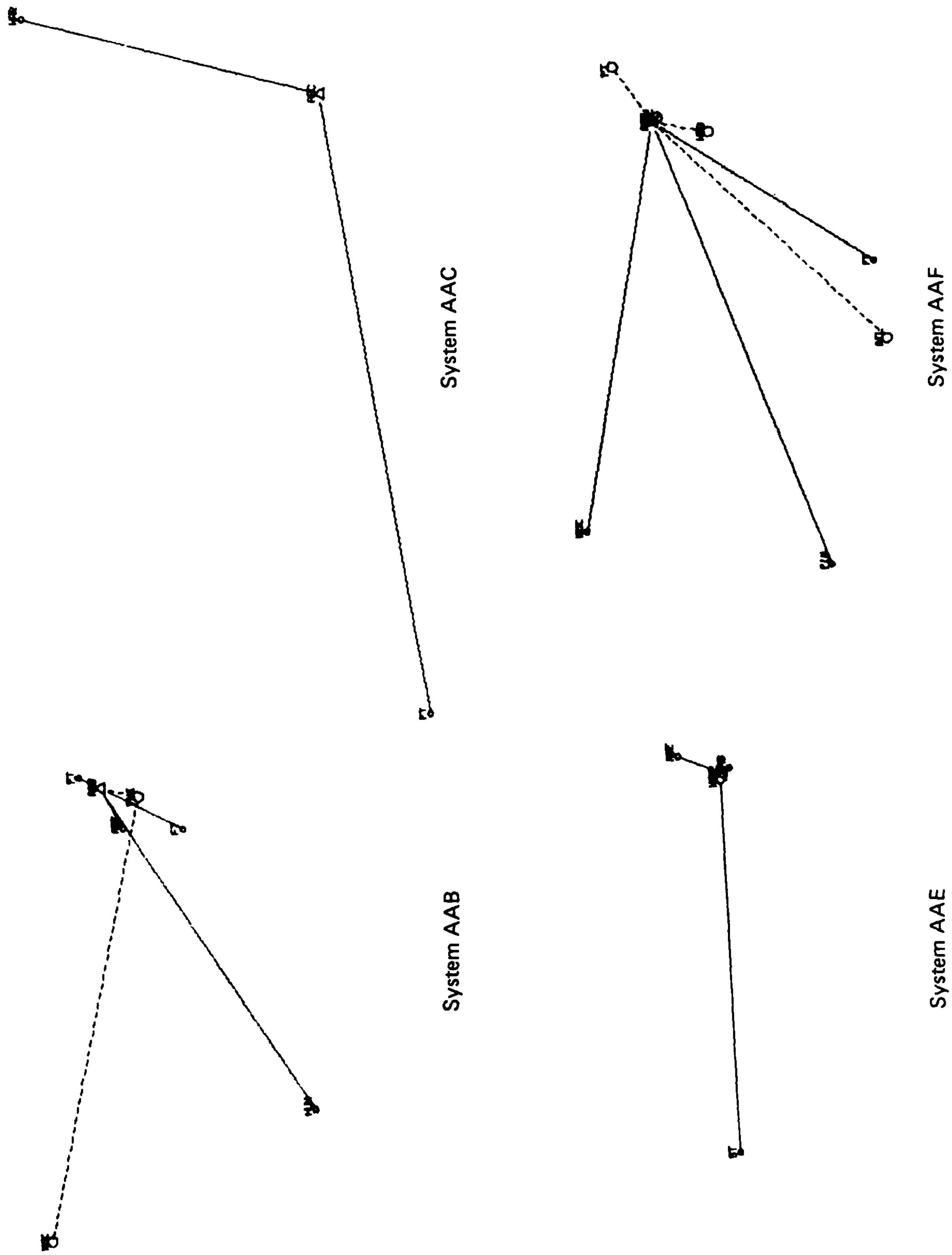
[KLEI, 74] Kleinrock, L. and W. Naylor, "On Measured Behavior of the ARPA Network," *NCC Proceedings*, 1974, pp. 767-780.

[MCQU, 72] McQuillan, J., et. al., "Improvements in the Design and Performance of the ARPA Network," *FJCC Proceedings*, 1972, pp. 741-754.

Appendix A
OPTIMIZED TOPOLOGIES FOR INDEPENDENT SYSTEMS UNDER B2 DESIGN STRATEGY

Notation:

△	Host
○	Concentrator, TDMX, or TCU (with associated terminals, when applicable)
•	Isolated Terminal
———	Direct connection from isolated terminal to Host
------------	Connection from concentrator, TDMX or TCU to Host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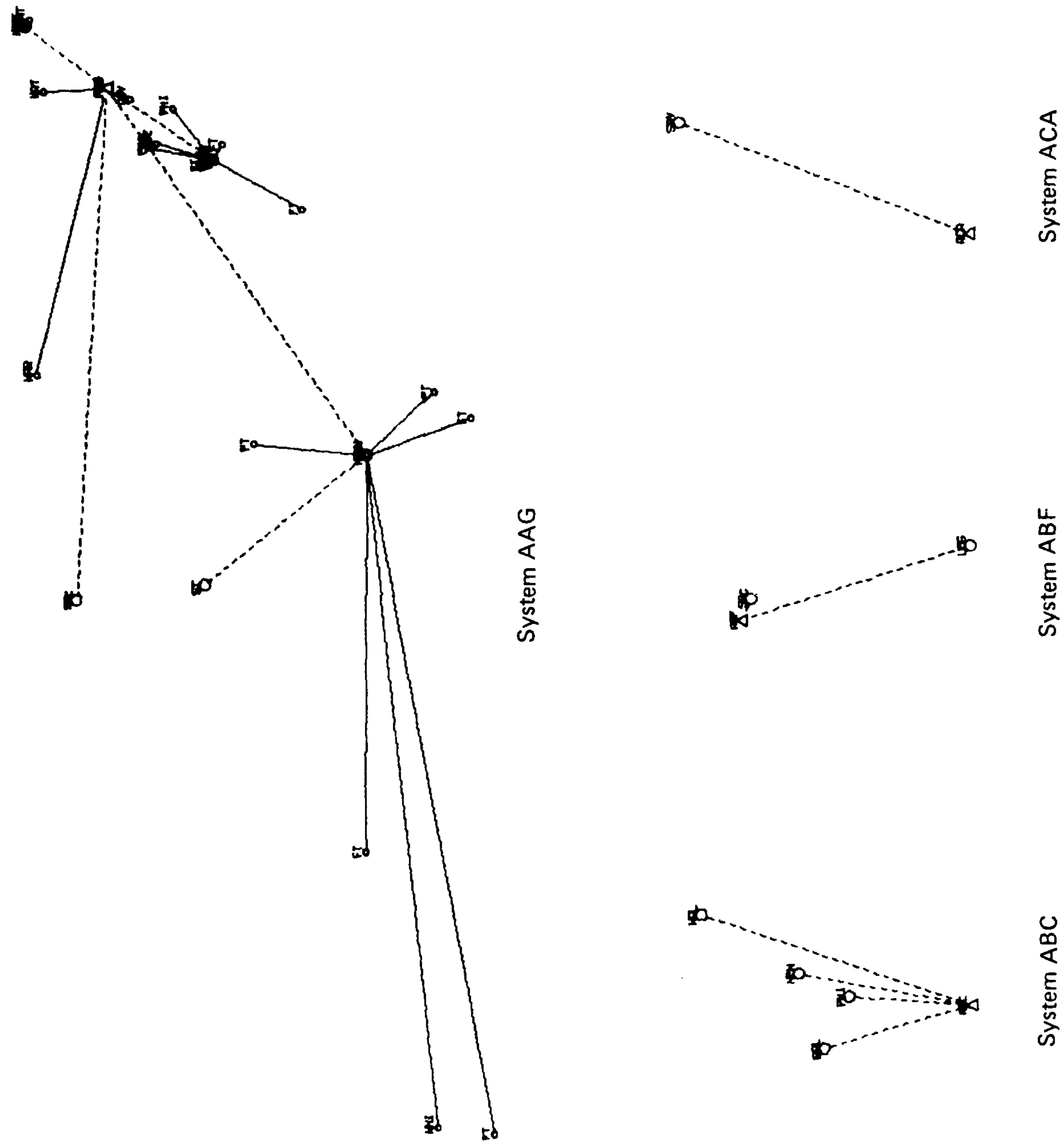
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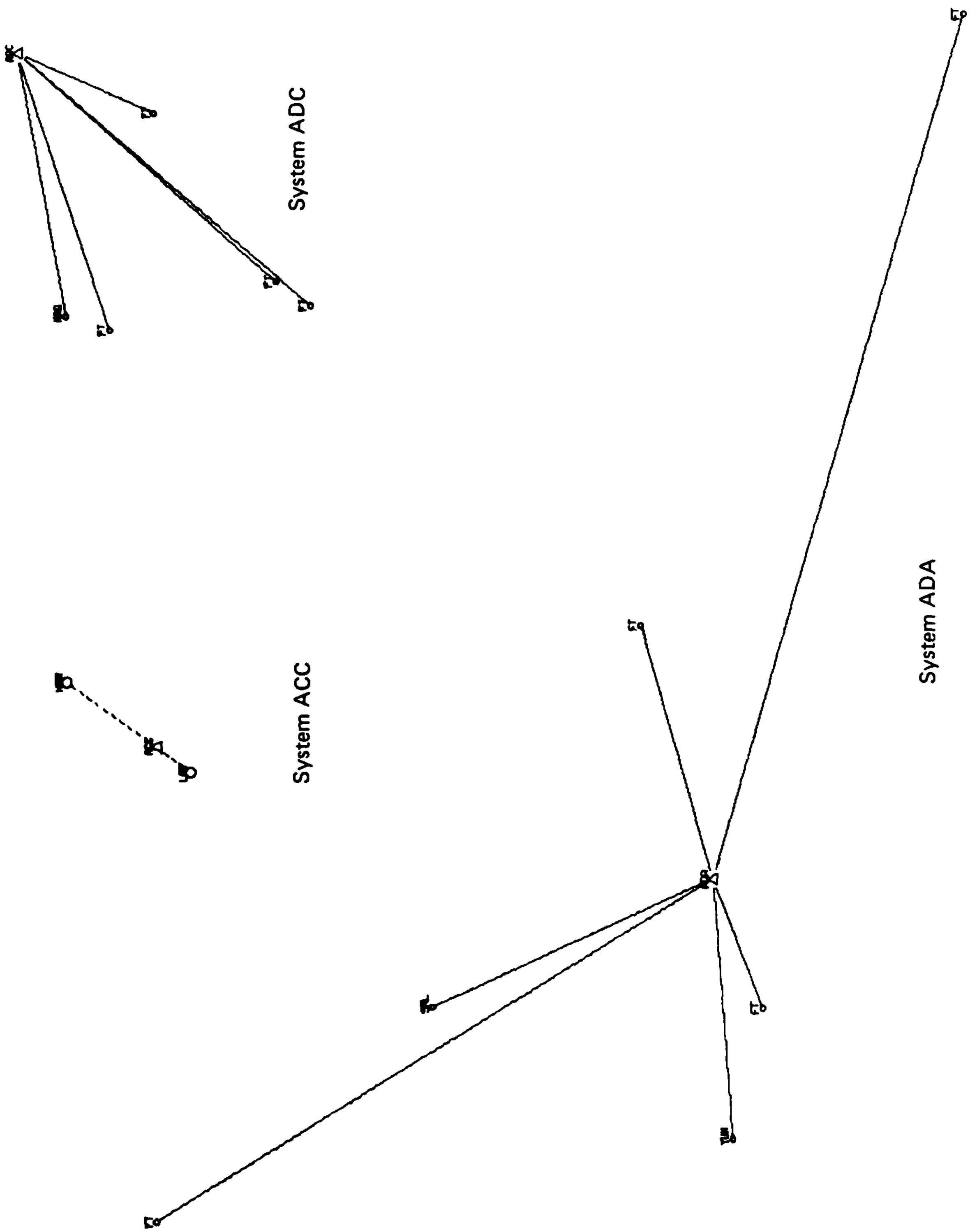
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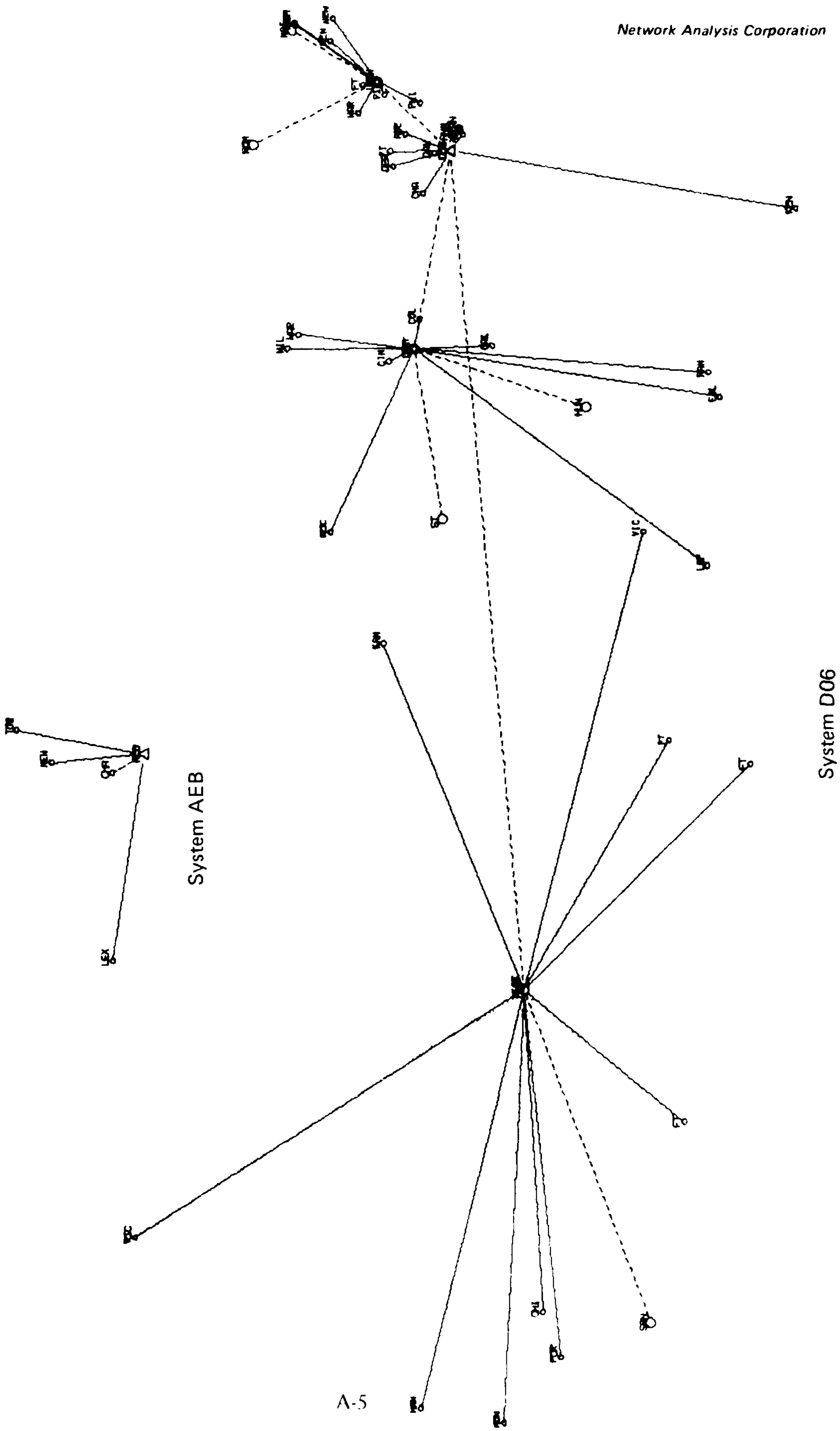
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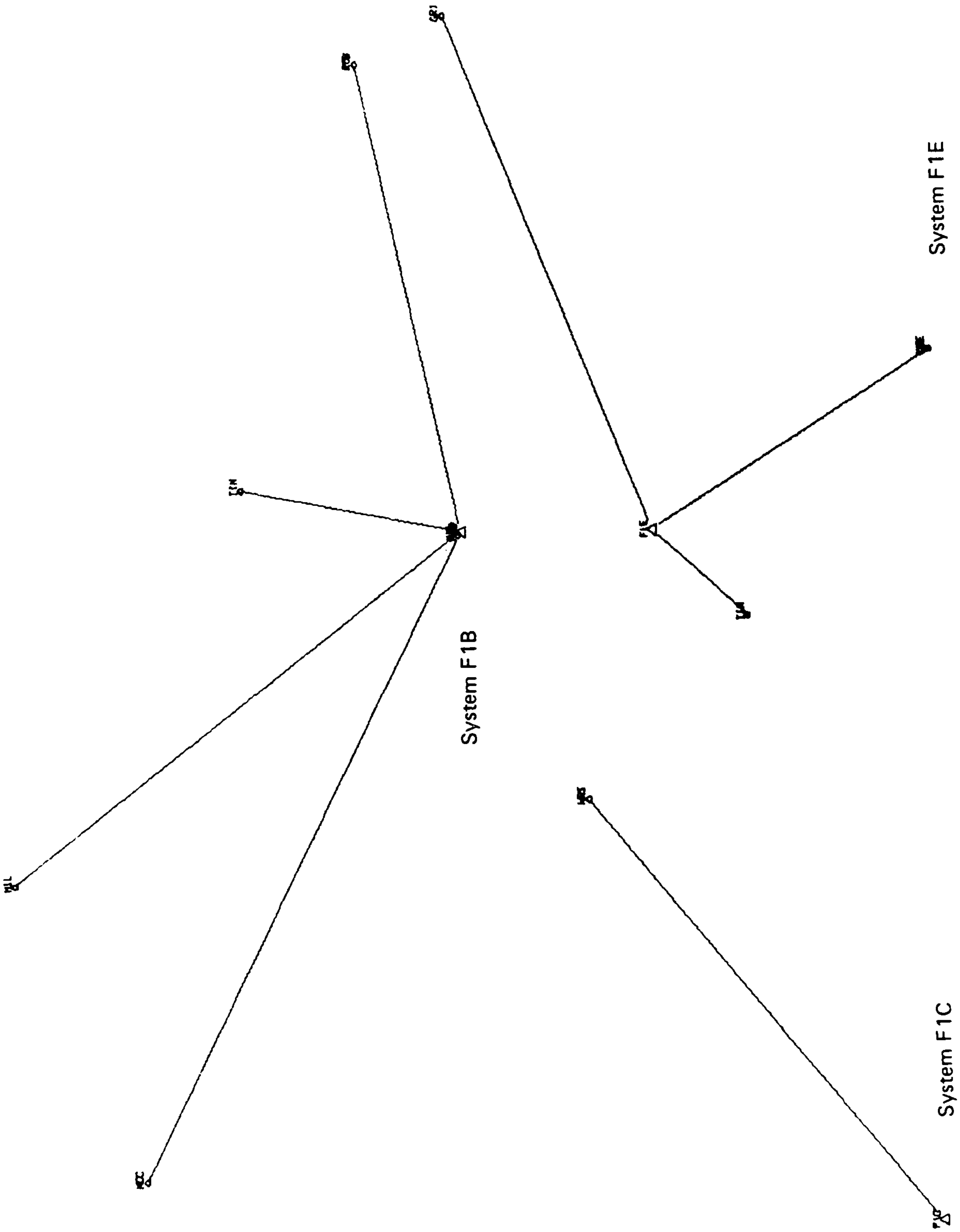
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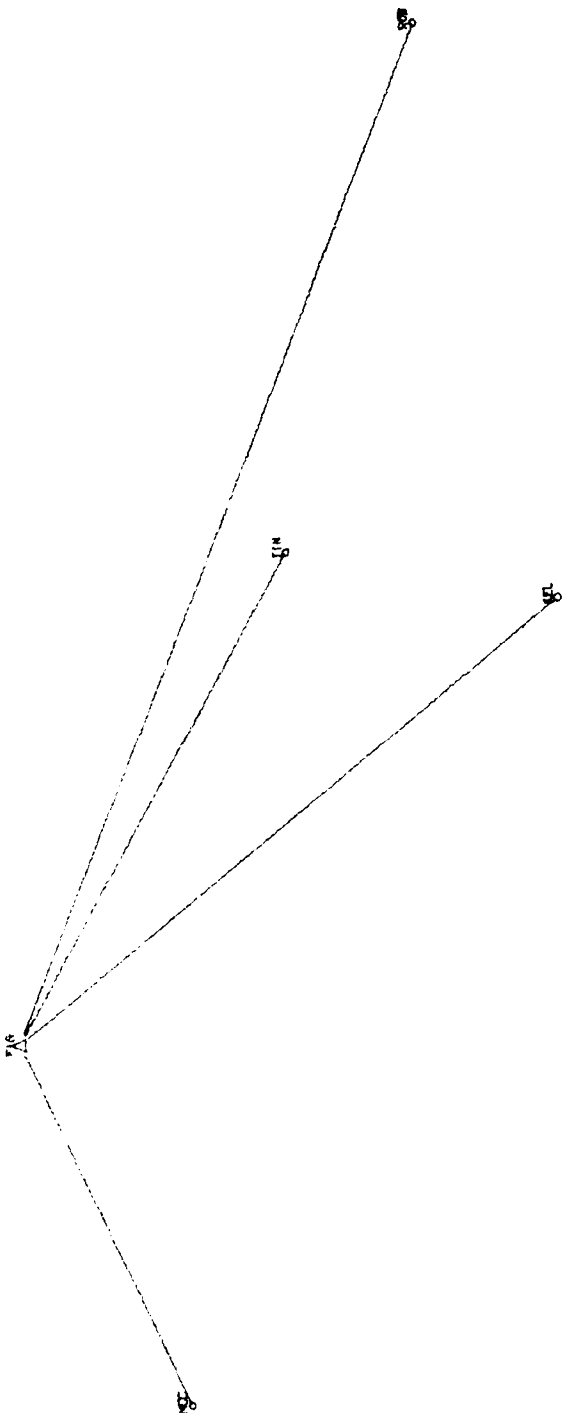

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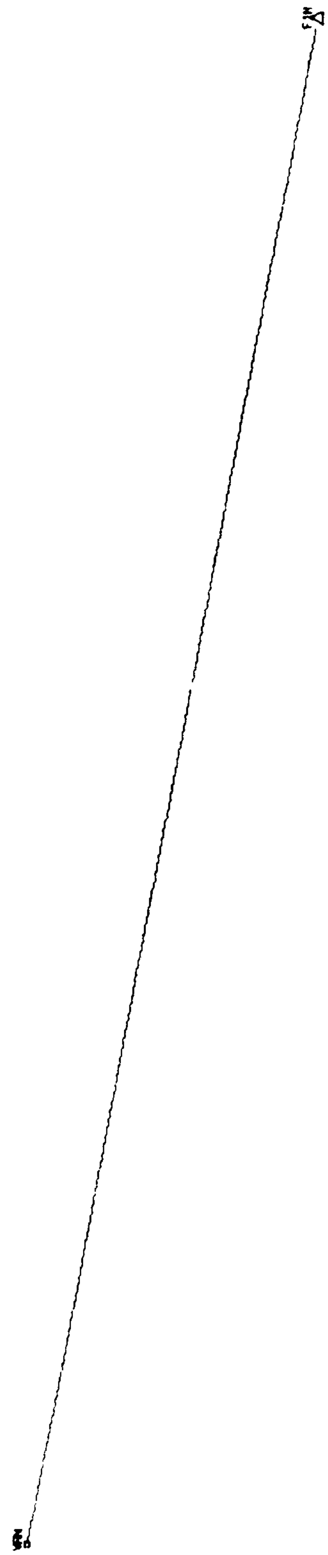

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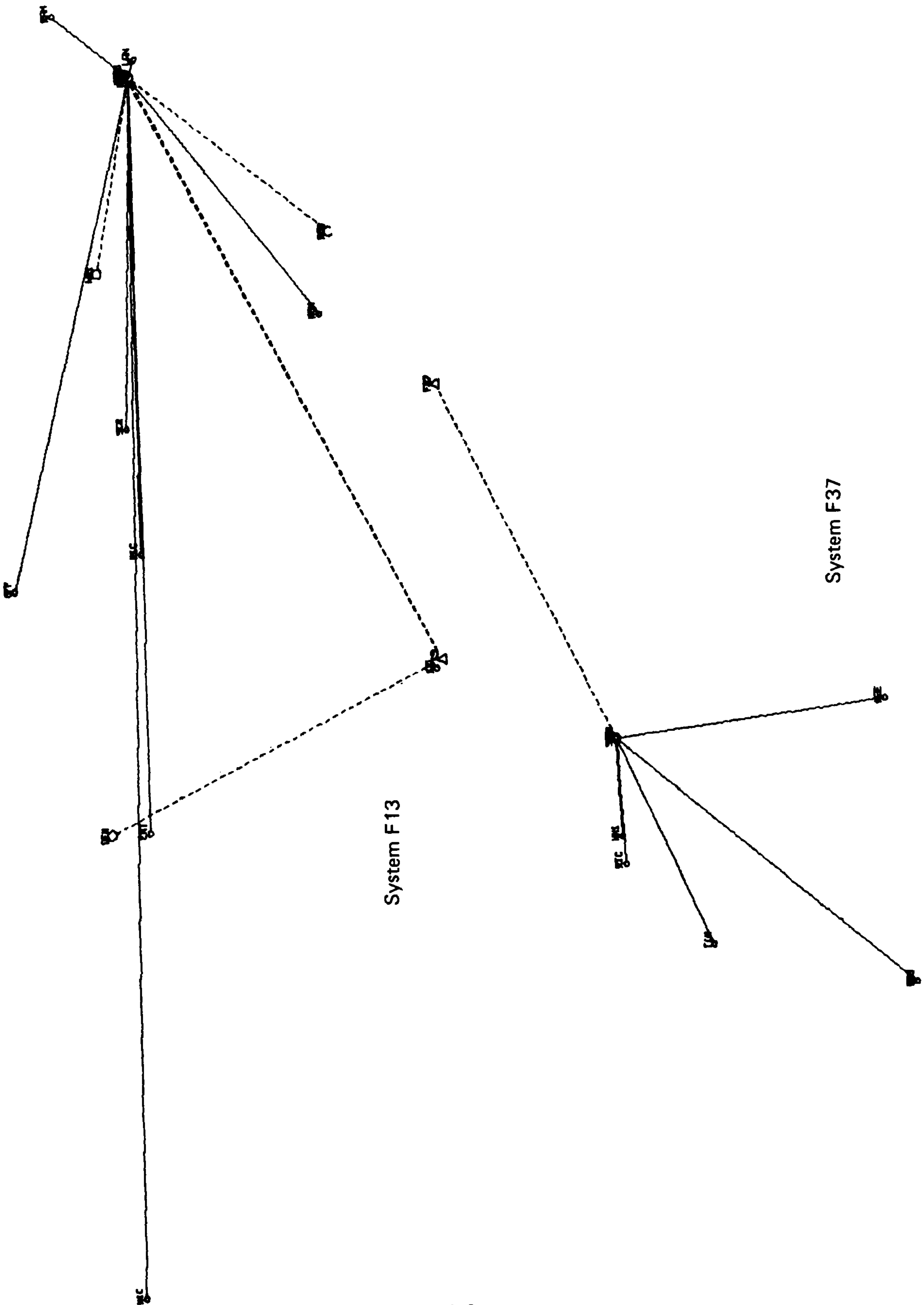
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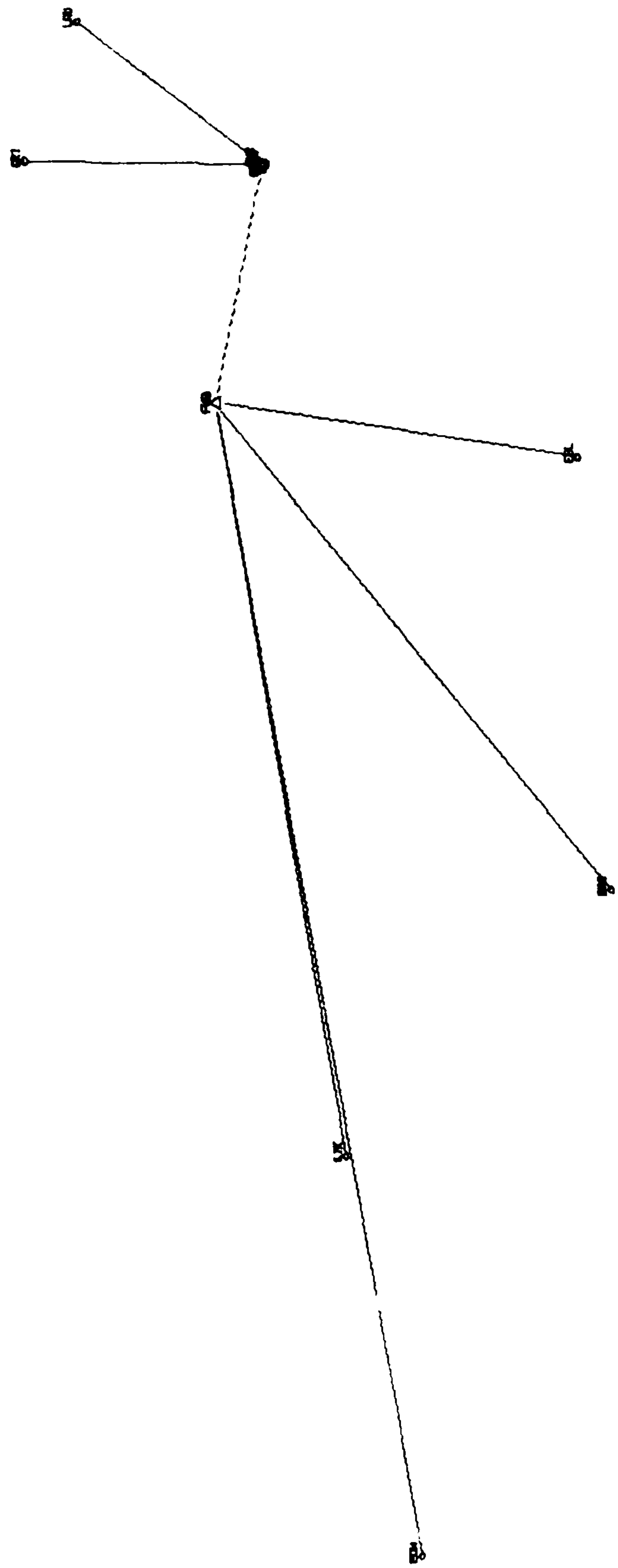

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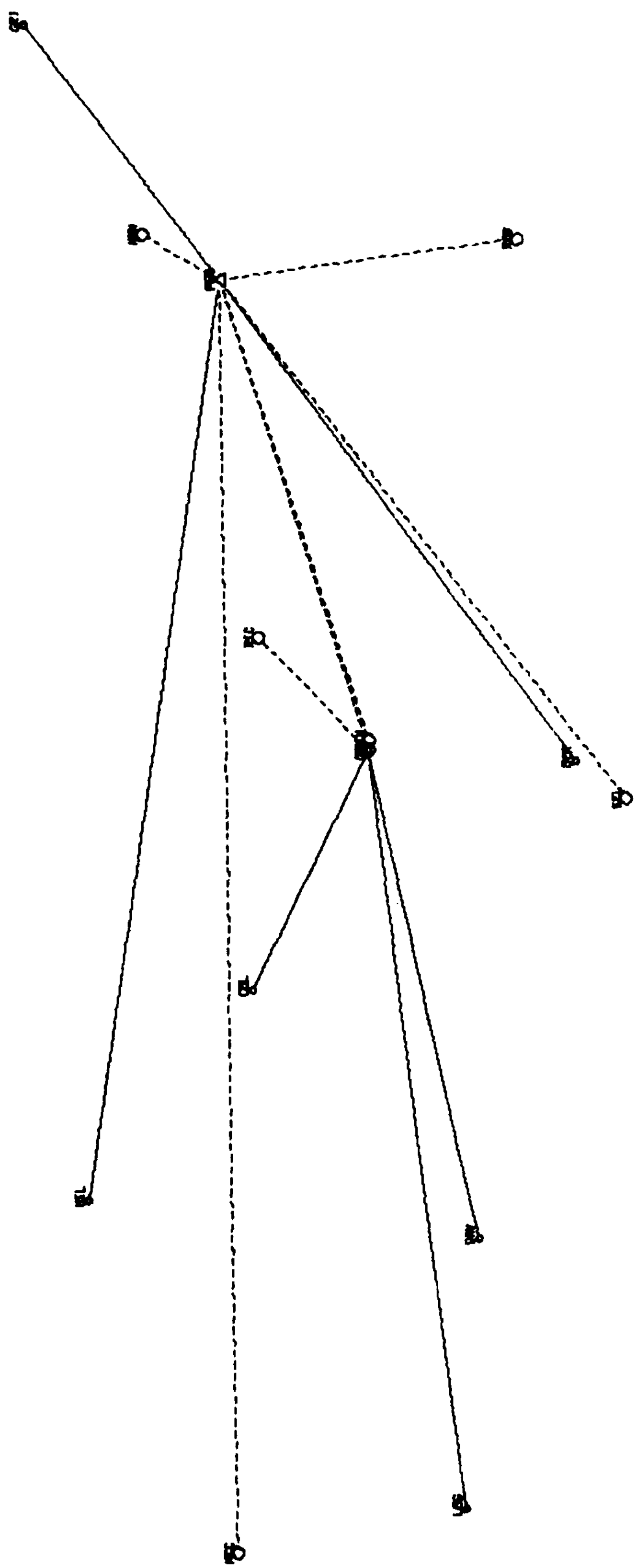

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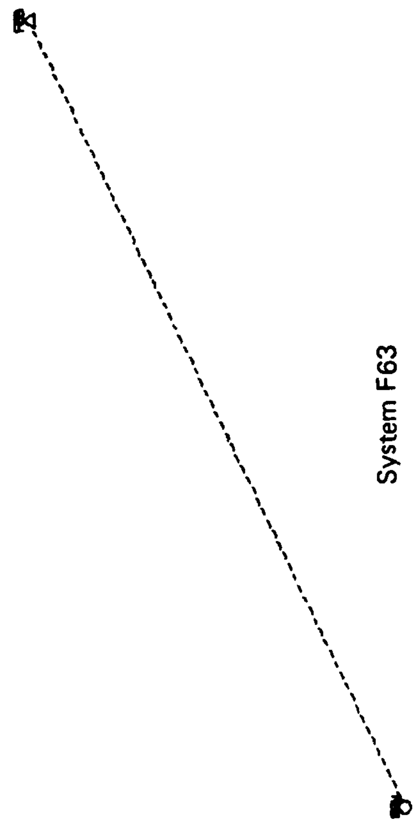

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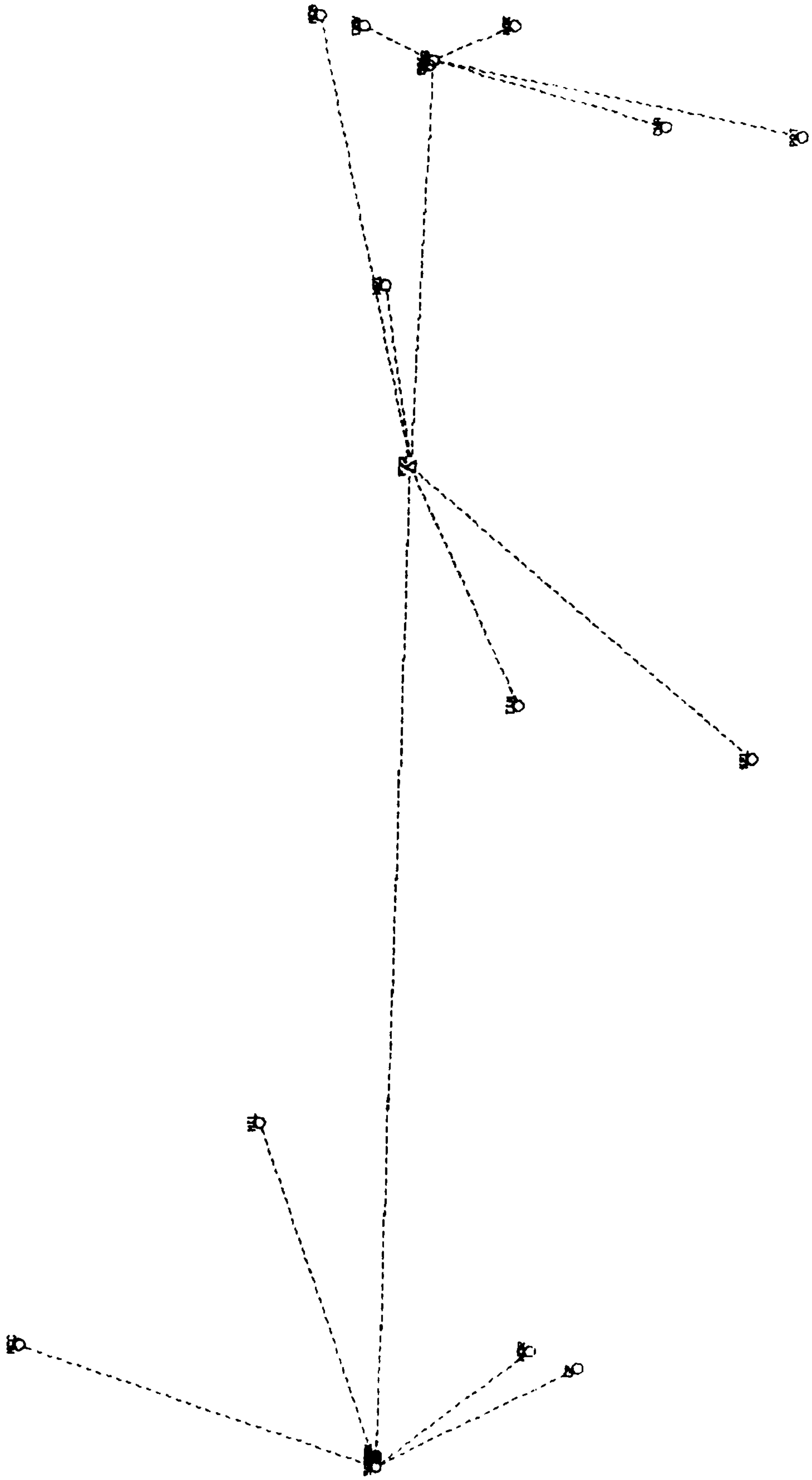

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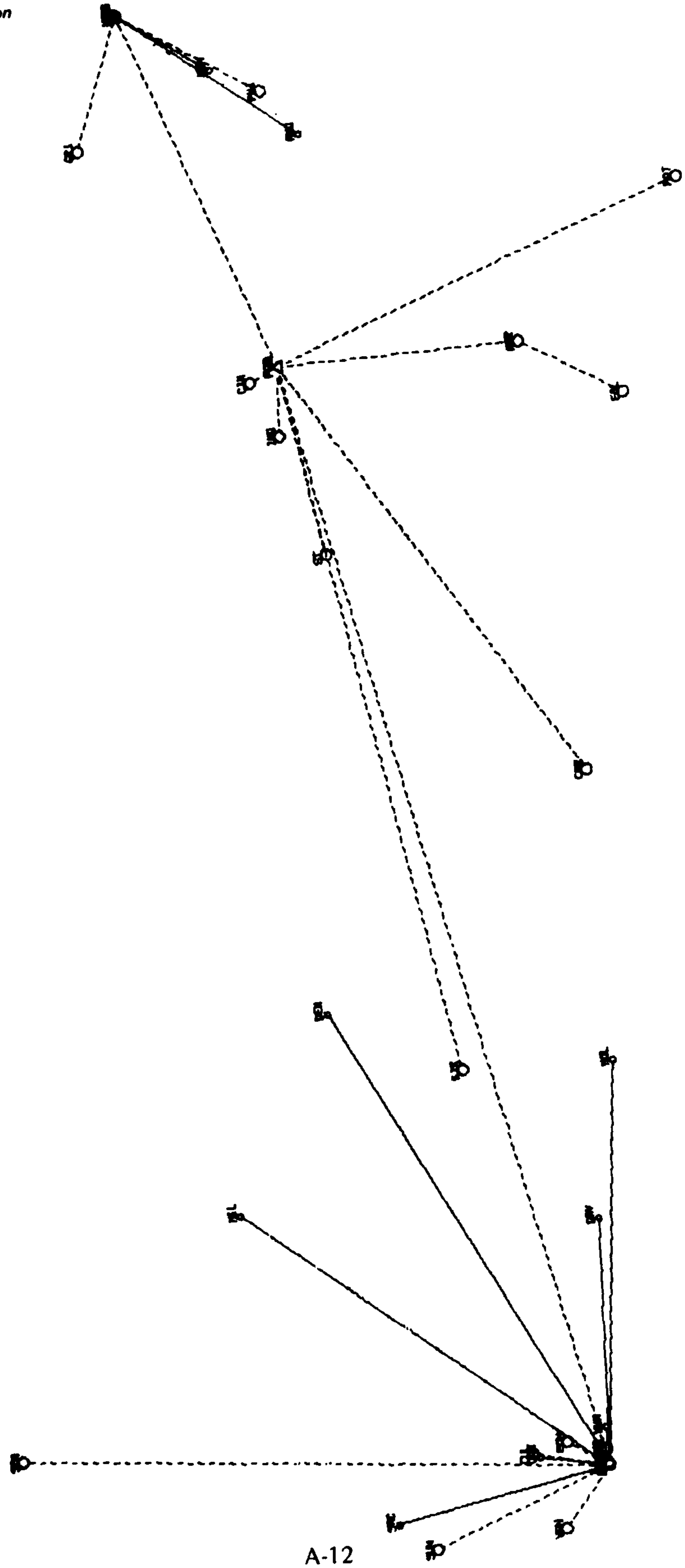

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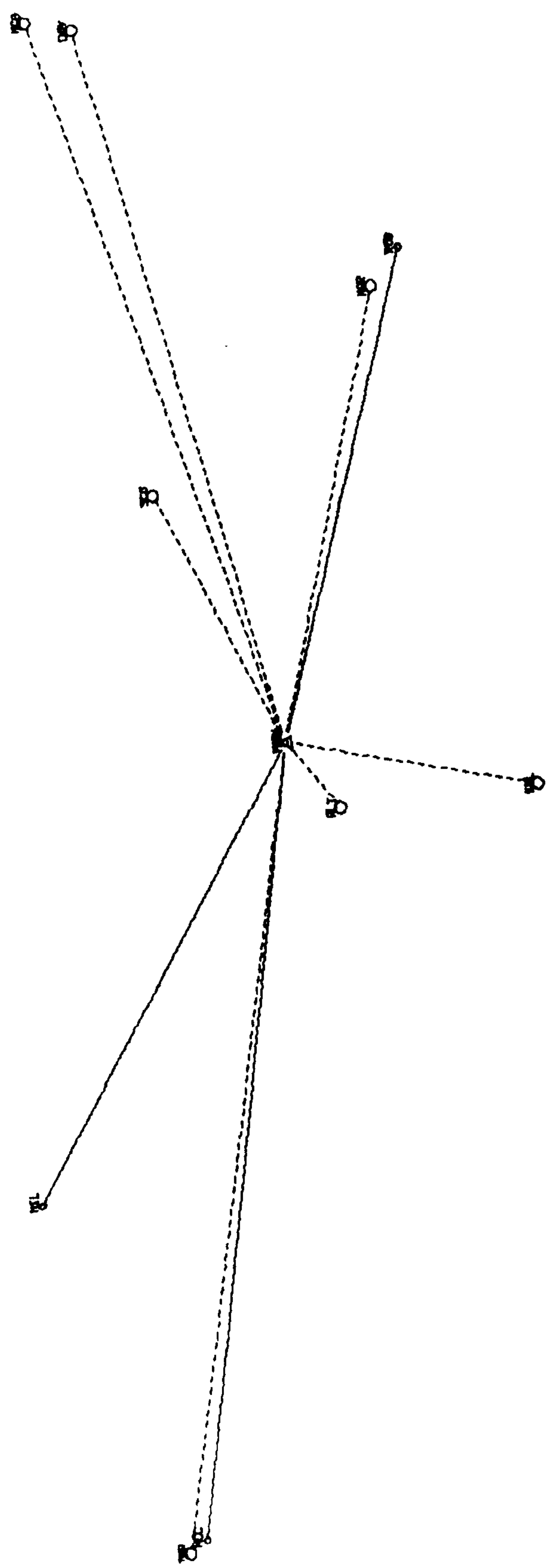

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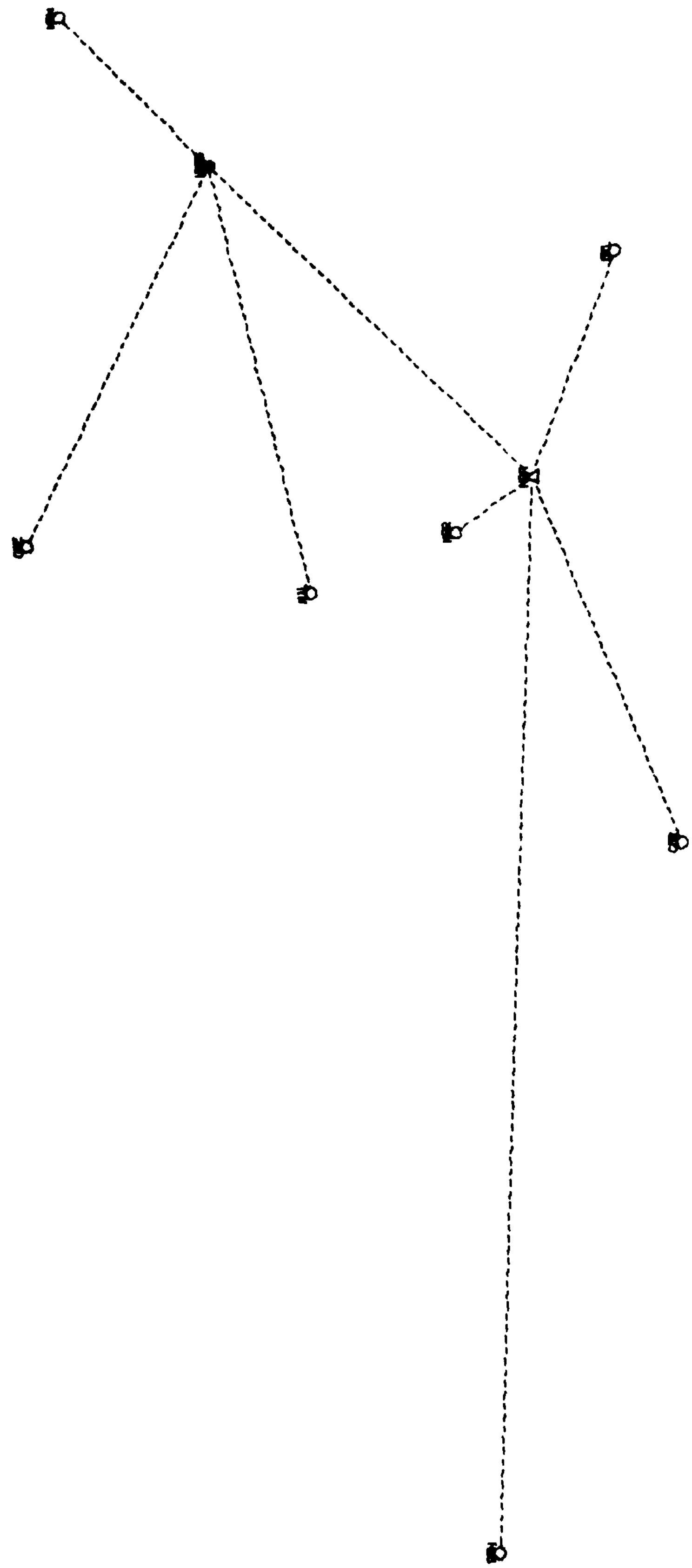

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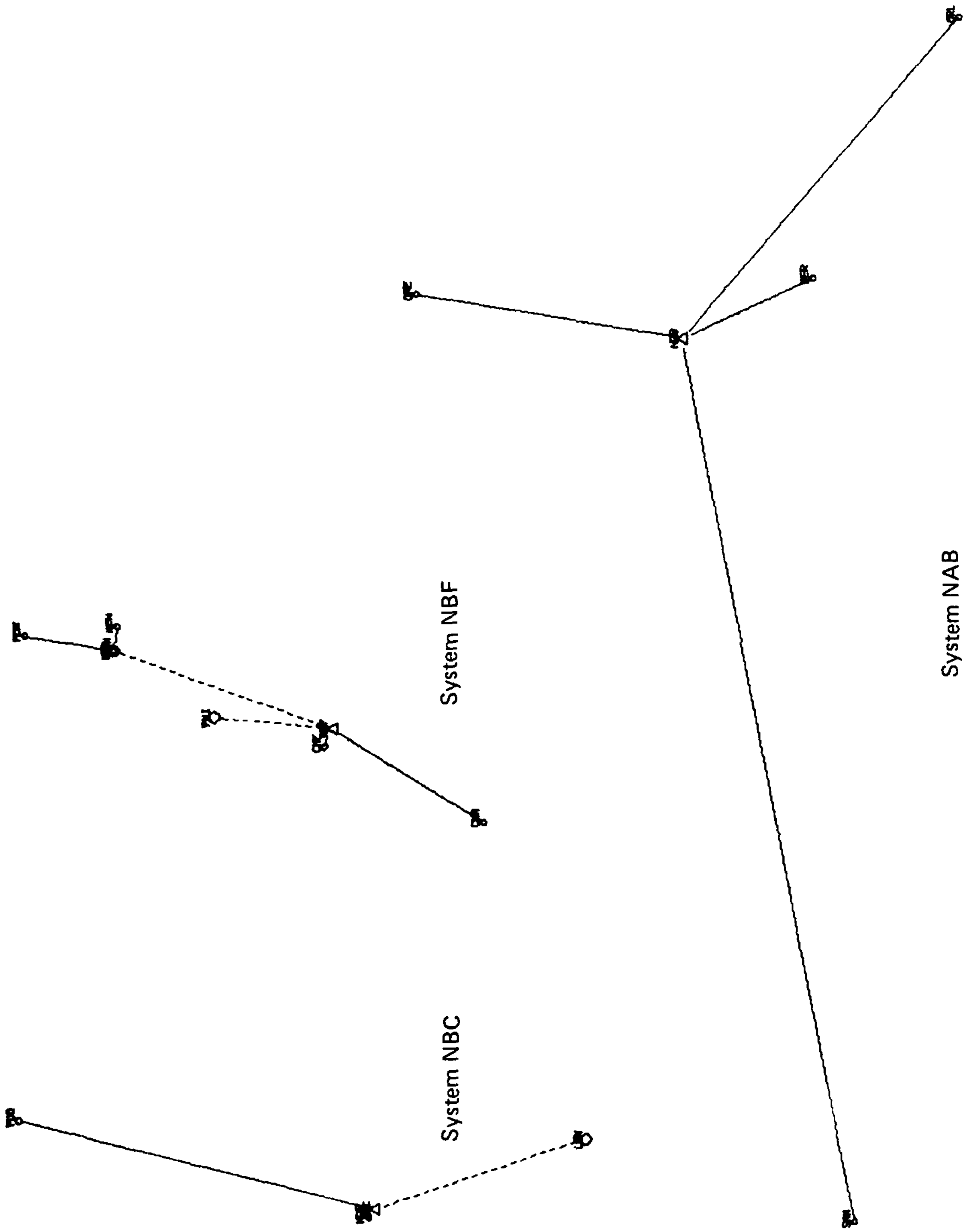
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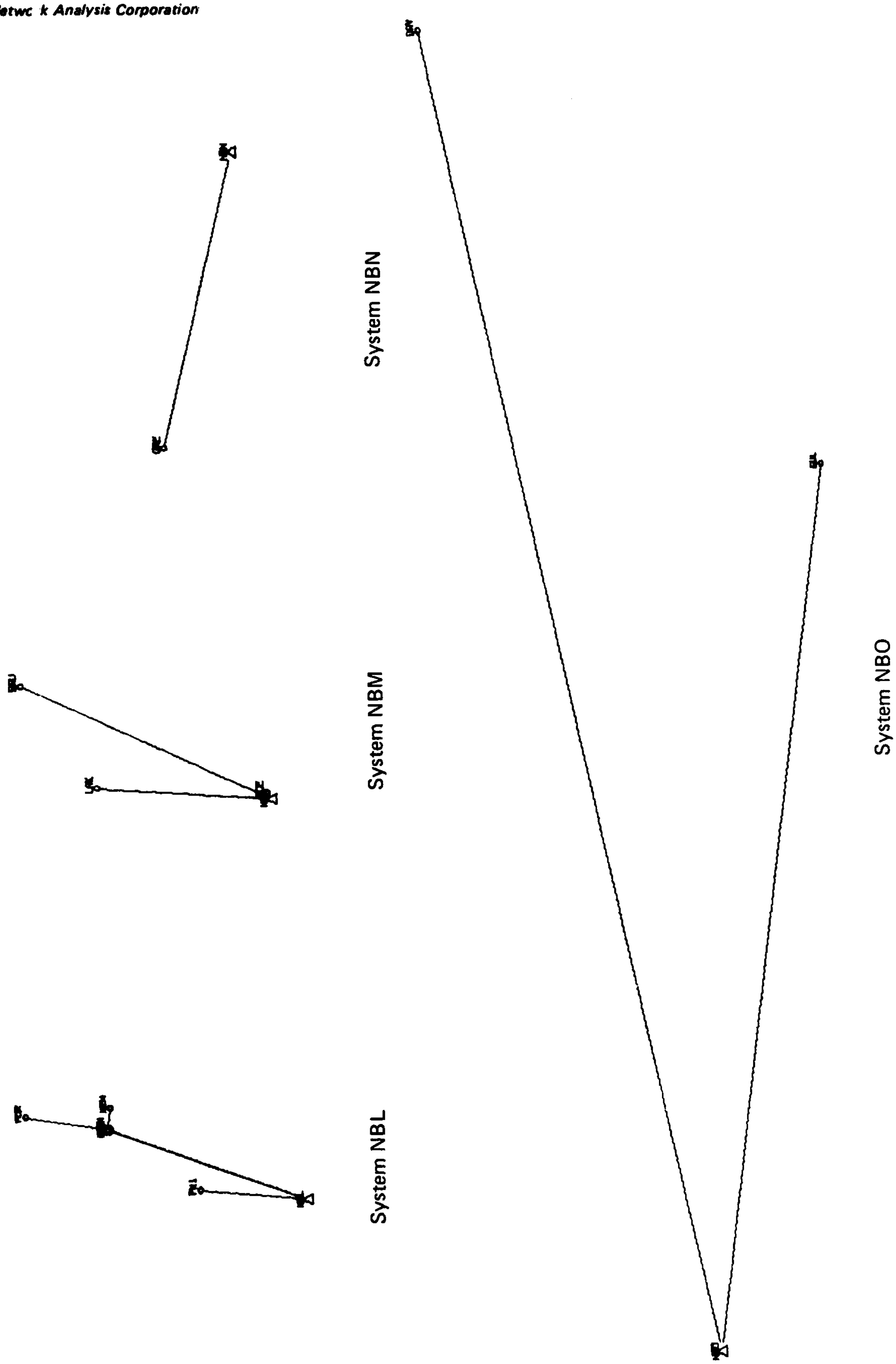
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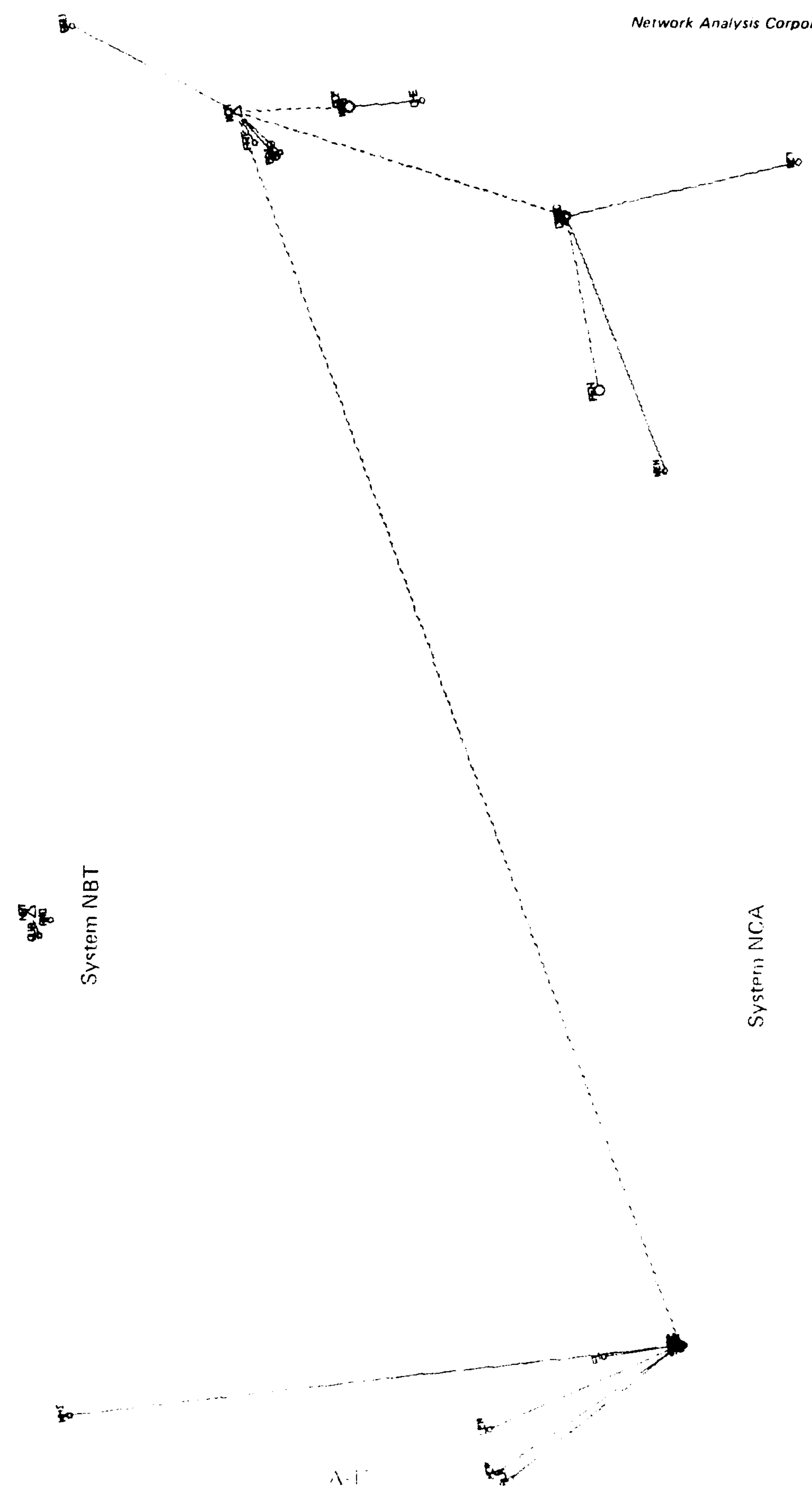
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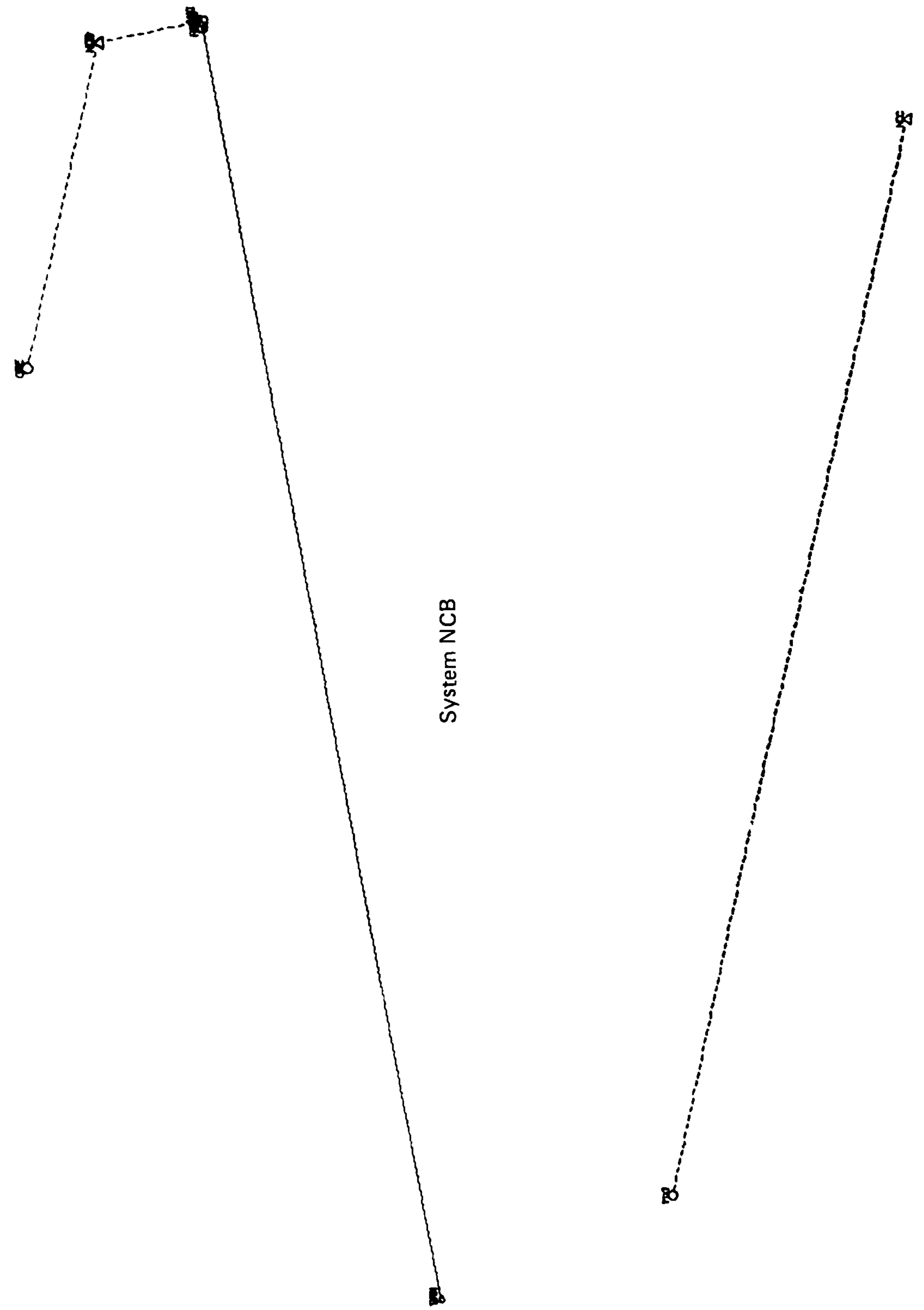
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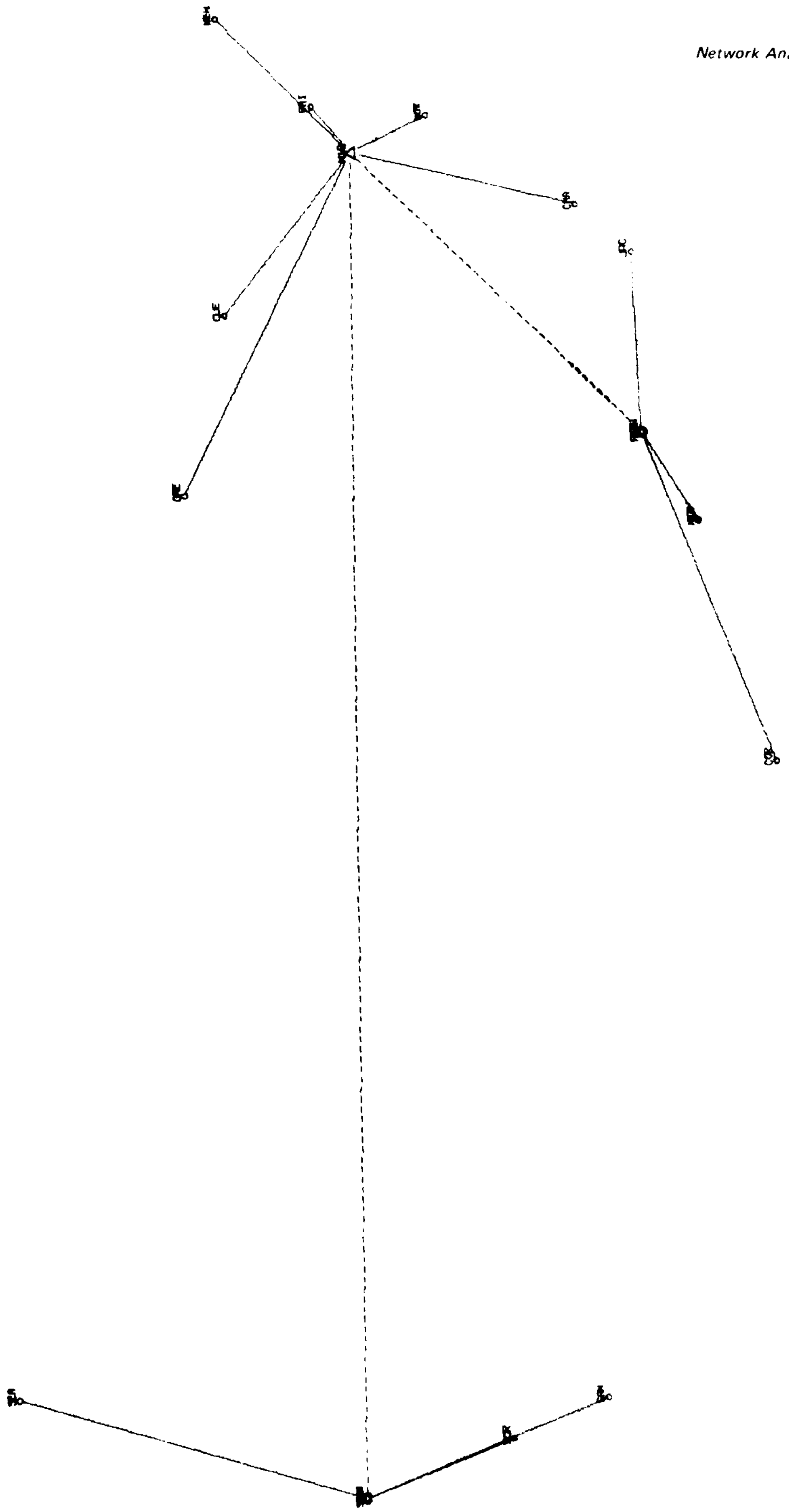

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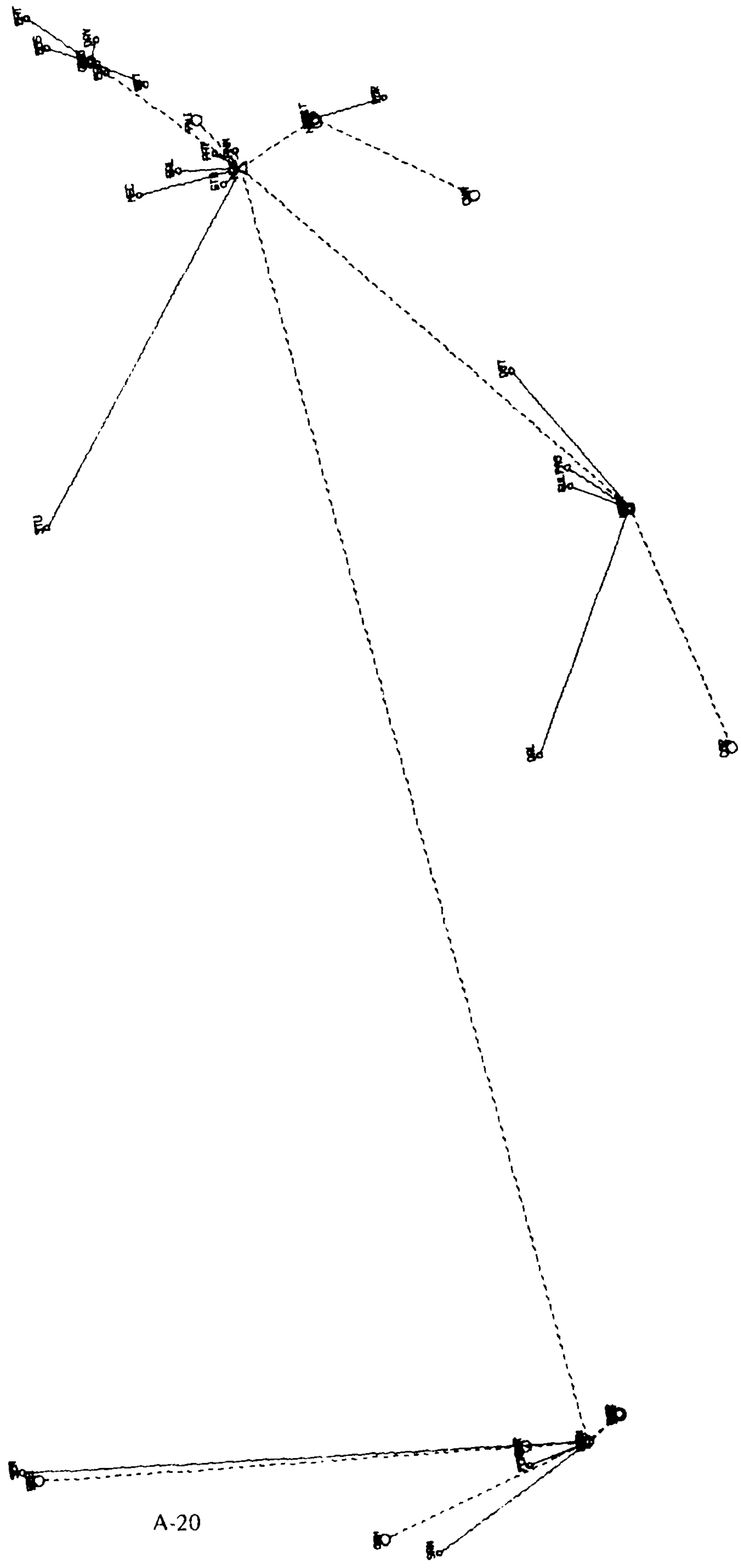

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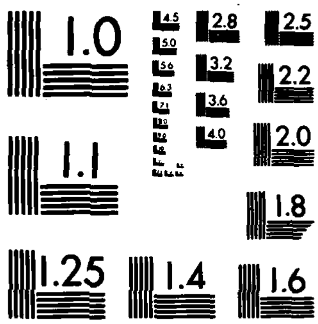

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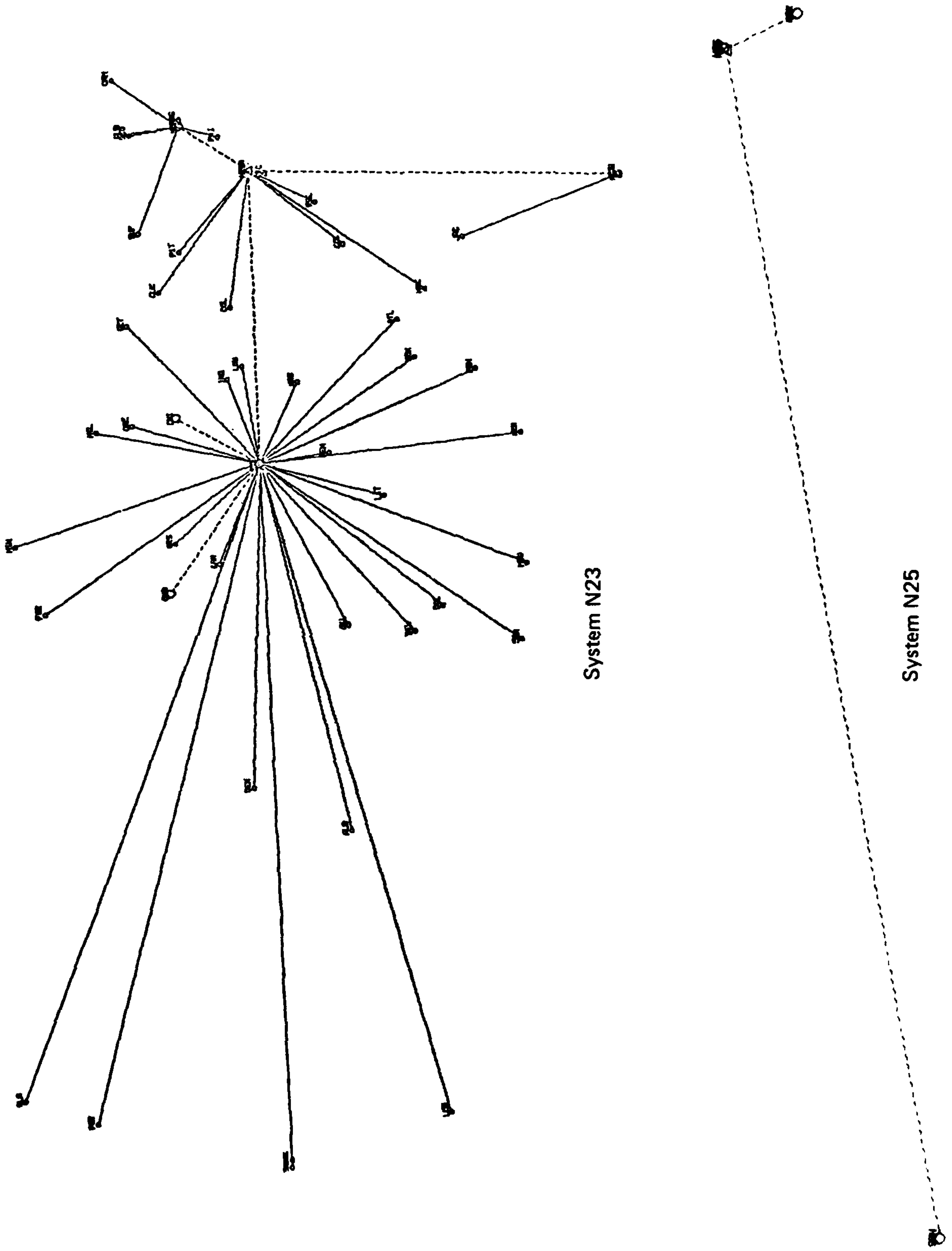
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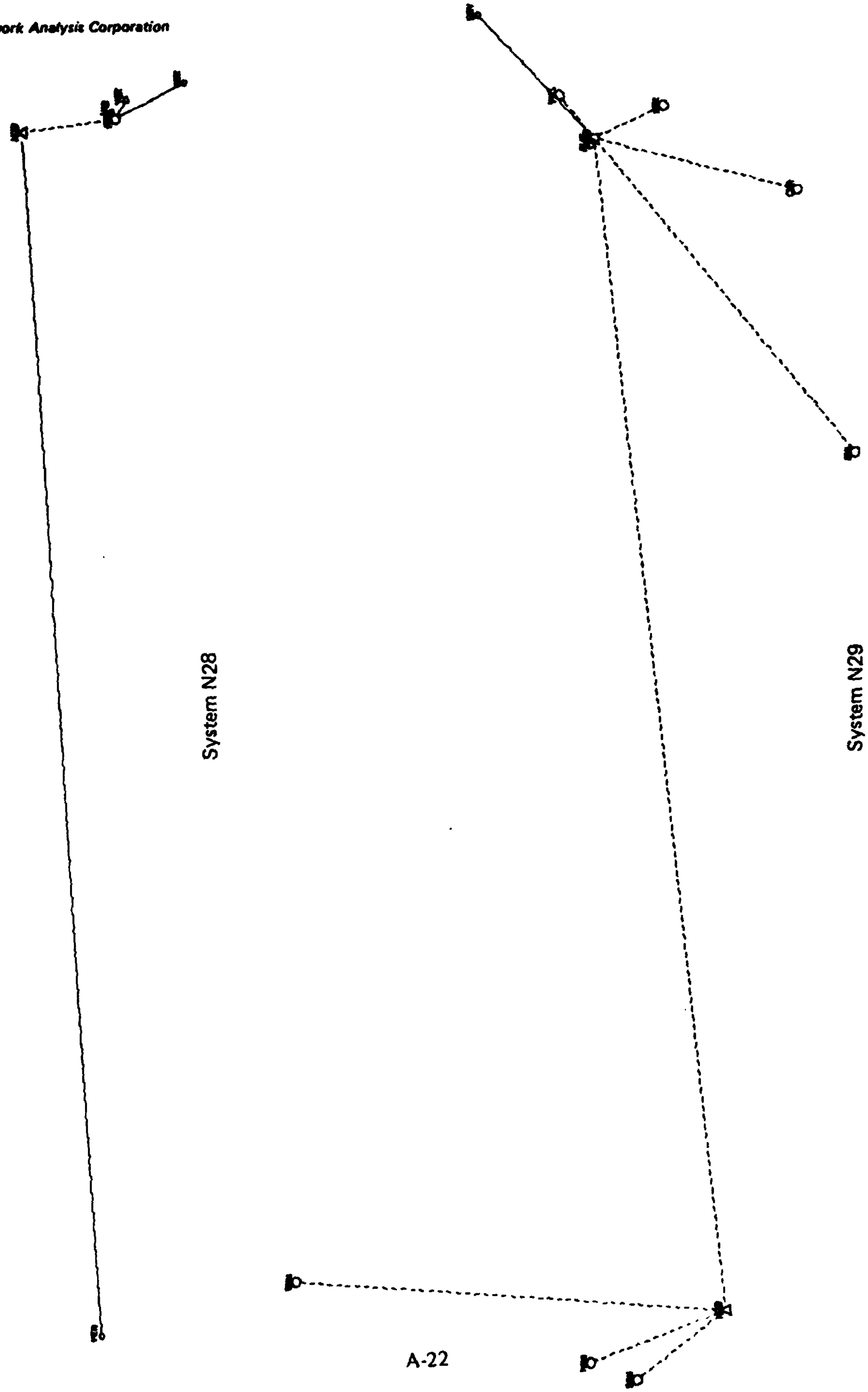
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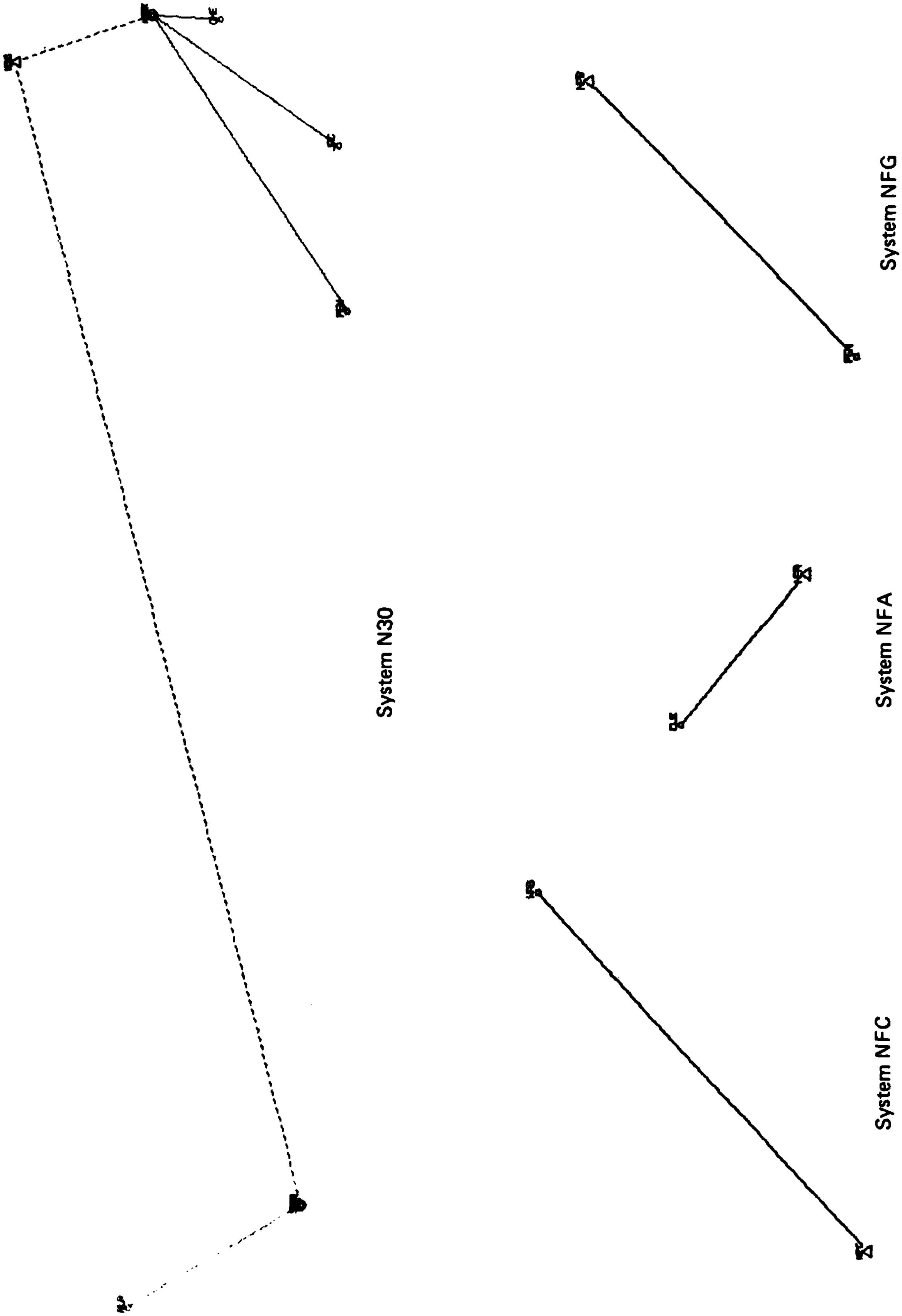
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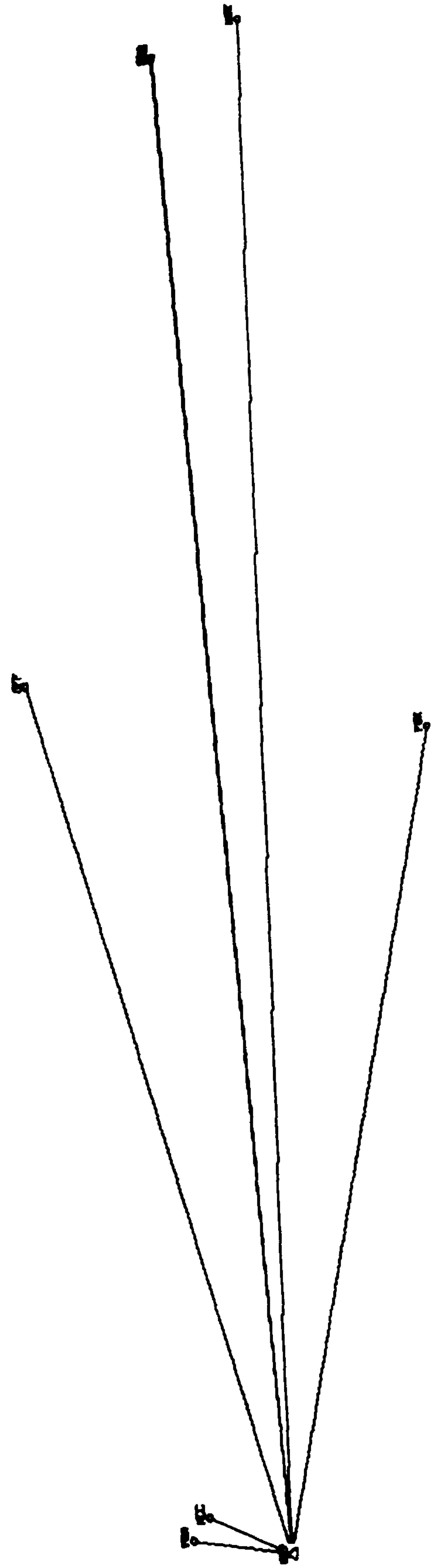

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