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A TECHNICAL AND ECONOMIC STUDY ON THE IMPACT OF THE INTRODUCTION OF NEW SERVICES ON EXISTING TELECOMMUNICATIONS NETWORKS

by

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ERRATA

Page 65:

3rd and 4th lines: to be suppresssed;
last word in 6th line: to be suppressed;
1rst word in 7th line: to be suppressed.

Page 66:

Equation [6.5]: U_{-1} to be replaced by U_{j-1}.

Page 103:

Last phrase in the first paragraph: sentence "serve a basis" replaced by "served as basis".

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LIST OF DIAGRAMS AND TABLES (2)

SUMMARY

The present document is the final report of the project entitled "A Technical and Economic Study of the Impact of the Introduction of New Services on Existing Telecommunications Networks". As such, it represents a synthesis of progress made since the inception of the project and of work done in the last period of the contract (February 15, 1980 - March 31, 1980).

In this study, after having made a general characterization of currently proposed new services and the telecommunications plant in Canada, the authors limited themselves to videotex services and to the telephone network. The basic reasons for this restriction are quite simple: (a) the videotex services, on the one hand, have a certain generality and, in some sense, include other services as special cases or variants, and, on the other, are receiving enormous amount of attention at the national and international levels: it appeared urgent to us to examine this service's potential impact in the interest of maintaining a certain national leadership in this area; (b) since the telephone network will probably be the principal means of access to the videotex databases, even though user requests and system responses may be shunted through higher-level packet-switching networks;it seemed essential to us to determine the impact the videotex services might have on this network, in particular upon the local telephone network.

To this end, the authors developped several software tools that will aid in understanding this problem. The first tool is an adaptation of a method developped by P.M. Lin for determining the node-to-node-grade-of-service (NNGOS) for the European Autovon telephone network. This method, which we have programmed and tested, is based upon an analytical approach, although it does not yield closed forms for the NNGOS's desired. Instead they must be calculated through an iterative procedure. Since Lin considered only one class of service, we suggest a simple method for approximating the effects of several such classes. In the continuation of this project, Lin's procedure will be revised to permit explicit inclusion of several classes of services.

The second tool is a simulation program, taking explicit account of service classes. At this writing, this program is still under development.

There remain two serious problems: (1) - acquiring accurate data about the structure and behavior of the local telephone network, and (2) - determining realistic estimates for the arrival times, holding times and other critical parameters of videotex services. As for the first, the author's have gained sufficient information - and are expecting more - to permit an approximation to the telephone network for a city of the size of Ottawa or Québec. Indeed, by taking advantage of recent developments such as the programmable digital switch, a radically new architecture might result. These ideas will be pursued in later work.

Concerning the second problem, namely estimating the videotex loading parameters, this falls into the category of marketing research. This subject will be examined further in the continuation of this project.

Thus, the major results of this study are;

1 - the development of effective software tools for telephone network performance evaluation;

2 - insight into the structure of modern local telephone networks.

1. INTRODUCTION:

1.1 General Objectives:

The general long-term objective of this project is twofold:

- to determine the impact upon the performance of existing telecommunications networks caused by the introduction of planned new services, and
- to develop economic justifications of strategies either for expanding and modifying current existing networks or for developing networks of novel architecture and technology.

This implies the following three goals:

(1) the development of a general methodology for a uniform description of the characteristics of the traffic generated by the various classes of new services;

(2) the investigation of the ability of the existing networks to accommodate the new and varied traffic loads;

(3) the formulation of proposals, together with economic justifications, for either an orderly expansion of existing networks or the development of networks of novel architecture and design.

Given the complexity of the telecommunications plant in Canada and the large number of new services currently being considered, the authors have, in this report, after a general discussion of planned new services and the Canadian telecommunications networks, restricted their attention to the local circuit-switched telephone network and to the class of services known as videotex.

The plan of this report is as follows: in the remainder of this chapter a general overview of Canadian telecommunications networks is given followed by some comments on the potential impact of new services. Next, in Chapter 2, a survey of several planned new services is given. This survey does not pretend to be exhaustive, but does include the major services currently being contemplated. In Chapter 3, services are characterized in terms of parameters relating to resource requirements, traffic flow, and service levels. Major Canadian telecommunications networks are further discussed in Chapter 4. In Chapter 5, the general approach to the impact study is outlined and in Chapter 6, performance evaluation models developped for the study of networks in general are presented. In Chapter 7, a methodology for performance evaluation of local telephone networks is given. Finally, in Chapter 8, an example is given using Autovon. A modest bibliography follows.

1.2 Overview of Telecommunications in Canada:

The over-all telecommunications plant in Canada can be described as in Figure 1.1 [1.3]*. Its major components are:

S1 - the circuit-switched telephone network systems, mostly regrouped into the TransCanada Telephone System (TCTS);

S2 - the Datapac packet switching system [6]* whose major carrier is the TCTS;

S3 - the INFOSWITCH circuit and packet switching system, the major carrier being Canadian National Telecommunications and Canadian Pacific Telecommunications (CNCP);

S4 - the conventional unidirectional cable television systems;

S5 - the various pilot projects in urban and rural areas offering (or soon to offer) integrated telephone and video services (IDA and the Elie, Manitoba tests).

In Table 1.1., a summary of the voice and data networks available in Canada is given.

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* The bibliography is divided into sections, section 1 being a general category, section 2 covers electronic fund transfer, section 3, electronic mail, etc. Thus, [1.3] refers to the third reference in section, whereas [6] refers to all of section 6.

TABLE 1.1 - PRINCIPAL CANADIAN TELECOMMUNICATIONS NETWORKS (FROM [1.3])

SERVICE	SWITCHED OR NON-SWITCHED	SPEED RANGE: SUB-VOICE (<300) BAUD	VOICE (300-9600) BITS PER SECOND	ABOVE VOICE (>9600) BITS PER SECOND	MAJOR CARRIER
Direct Distance Dialing Network (DDD)	Cct Switched	1	up to 1200 async up to 2400 sync		TCTS
Telex	Cct Switched	50 Baud			CNCP
TWX	Cct Switched	up to 110 Baud			TCTS
Data Telex	Cct Switched	up to 180 Baud			CNCP
International Telex	Cct Switched	50 Baud			Teleglobe Canada
Multicom 1	Cct Switched		up to 1200 async up to 2400 sync		TCTS
Broadband Exchange Service	Cct Switched		up to 9600 BPS	up to 48KBPS	CNCP
Multicom 2	Cct Switched		up to 4.8KBPS		TCTS
International Datel 600	Cct Switched		600 BPS		Teleglobe Canada
Multicom 3	Cct Switched			up to 50KBPS	TCTS
ICAS	Packet Switched	300 Baud	1200 Baud		Teleglobe Canada
Telenet	Message Switched	1	1	1	CNCP
Autocom	Message Switched	50 Baud			Teleglobe Canada
Infodat	Non-Switched Digital	1	1	up to 56KBPS	CNCP

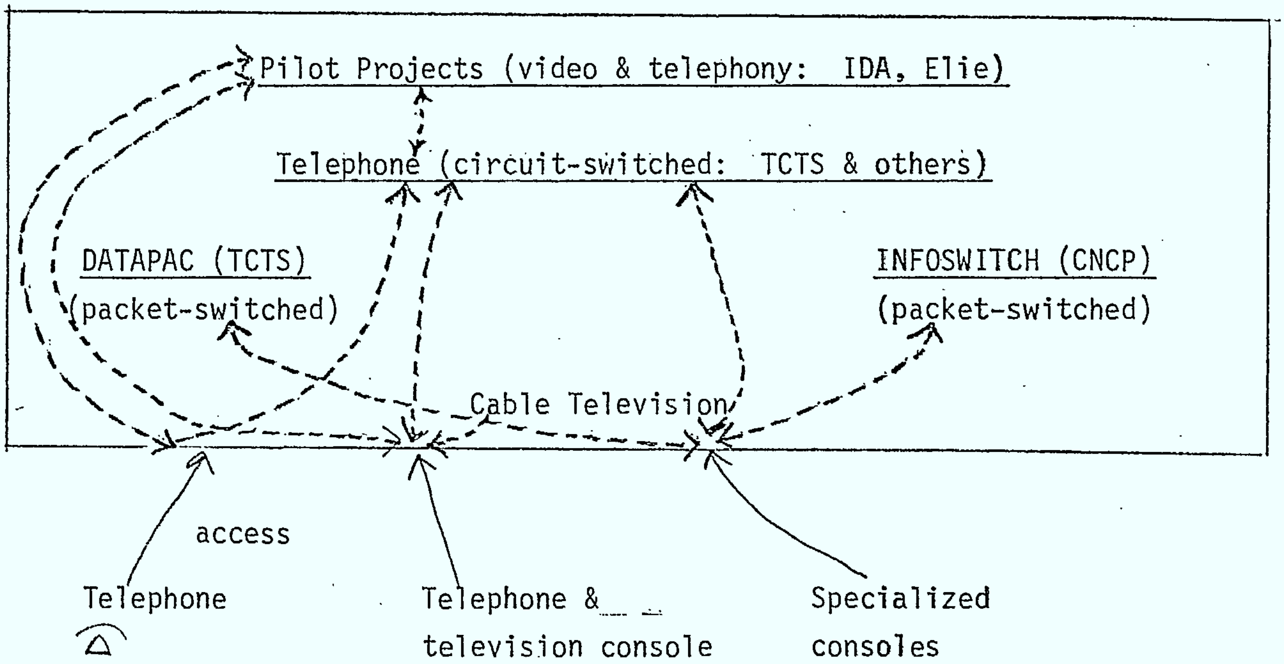
TABLE 1.1 - PRINCIPAL CANADIAN TELECOMMUNICATIONS NETWORKS (FROM [1.3])

SERVICE	SWITCHED OR NON-SWITCHED	SPEED RANGE			MAJOR CARRIER
		SUB-VOICE (<300) BAUD	VOICE (300-9600) BITS PER SECOND	ABOVE VOICE (>9600) BITS PER SECOND	
Dataroute	Non-Switched Digital	1	1	up to 56KBPS	TCTS
Datapac	Packet Switched	1	1		TCTS
Infoswitch	CCT Switched, Virtual Connection, Packet Switched	1	1	1	CNCP
Alta-Net	Not-switched		up to 2400 sync.		A.G.T.
Computer Message Switching Service (CMSS)	Message Switched	1	1	1	CNCP

[1] a full range of speeds available

FIGURE 1.1

OVERVIEW OF THE TELECOMMUNICATIONS PLANT IN CANADA



The user accesses, or will eventually be able to access, the resources of this composite system in several ways:

- via the local telephone network, using his private telephone;
- via the local telephone network, using a domestic terminal configuration coupled to the network through the telephone. The terminal may include a television console, a keyboard or a keypad, local intelligence and memory, and facsimile among others;
- via a cable television network, using a terminal configuration similar to the one described above;
- via a hybrid telephone-cable television arrangement, again using a terminal configuration similar to the above;
- via a direct line, using non-domestic terminals varying from simple specialized devices to elaborate computer configurations;
- via an interface between a local, in-house network (e.g., Ethernet, Fibernet) and one of the above-mentioned networks, using a non-domestic terminal as described above.

The user's access to the network may be effected by dial-up procedures or by hard wire connections.

At this time, a number of new services [1.7] are being considered that will make as yet unknown demands upon the systems mentioned above. Many of these new services, in particular the domestic ones, will use the telephone system as primary means of network access, and will require terminals of the first and second categories mentioned above. Some of the planned new services are summarized in Table 2.1. Most of these new services will require databases geographically distributed throughout the country: the exact locations of these databases are, if known at all, known only to the services' designers. Moreover, as these services are currently in the testing stage, there is almost no hard data concerning user habits. For the moment, therefore, hypotheses mut be made about:

- user habits, and
- distribution and capacity of network databases.

For example:

a) Bell Canada plans a 1000-user trial of its VISTA (videotex) service for late 1980. The databases will be located in Toronto, Montréal and Québec City. Access will be via telephone using a special terminal to be developped by Northern Telecom, based upon the Télidon terminal. Studies of network loading and traffic patterns have apparently been done, but are not in the public domain [4.3 - 4.5];

b) COSTPRO (TRADEX) will soon have out twenty terminals accessing Datapac and Infoswitch [5];

c) Télécâble-Vidéotron plans to introduce Télidon in its system, at first in a broadcast mode, later using more sophisticated versions, one perhaps involving packet switching;

d) the Manitoba Telephone System is completing a pilot project of an integrated system offering telephony, cable television, alarm (medical, fire), and meter reading services in a suburb of Winnipeg. This project, called IDA (after Ida Cates, who became Manitoba's first female telephone operator in 1882), uses conventional coaxial cable technology and will provide 50 homes with the services mentioned, another 100 being connected for automatic fire alarm reporting alone. A similar project is being planned in the rural town of Elie; this time the network will use optical fiber technology.

For all the above trials, expected user patterns are unknown, although hints may be obtained from such experiences as the British with Prestel and the French with Antiope.

The general problem then implies detailed knowledge of the architecture and operations of the major Canadian telecommunications carriers networks together with reasonable hypotheses about user loading and network capacity as functions of the service being considered.

1.3 Impact of New Services:

When new telecommunication services are introduced into the existing telecommunications networks, the additional traffic generated may have a considerable impact both on the networks as well as upon other already existing services:

a serious degradation of performance may result. It is thus important to evaluate this impact, both from the technical as well as from the economic point of view, for planned new services, in order to justify strategies for expanding present networks or developing networks of novel architecture and technology.

The above general objective requires several different research activities. First of all, the new services must be identified and their characteristics fully understood. Resource requirements, traffic patterns and service levels must be expressible in quantitative terms. Secondly, the characteristics of the existing networks in terms of capacity and capability must be obtained. Unfortunately, these characteristics may depend on the type of new services and may be altered by their presence in the networks. Each new service potentially requires some expansion or modification of the existing networks, which are not unique, so that various alternatives must be compared. Thirdly, a quantitative method must be developed to assess the impact of new services on the performance of existing networks or on networks of novel architecture, given the service and network characteristics. This will lead to the development of models, of the mathematical or simulation type, to represent the interaction between new services and networks together with their existing services.

The research activities outlined above are generally not exclusive in the sense that the working method used to carry out one activity tends to dictate what is needed for the others. Also, the activities should be carried out in a top-down fashion to permit obtaining results that could be refined or extended by augmenting the level of detail in each activity.

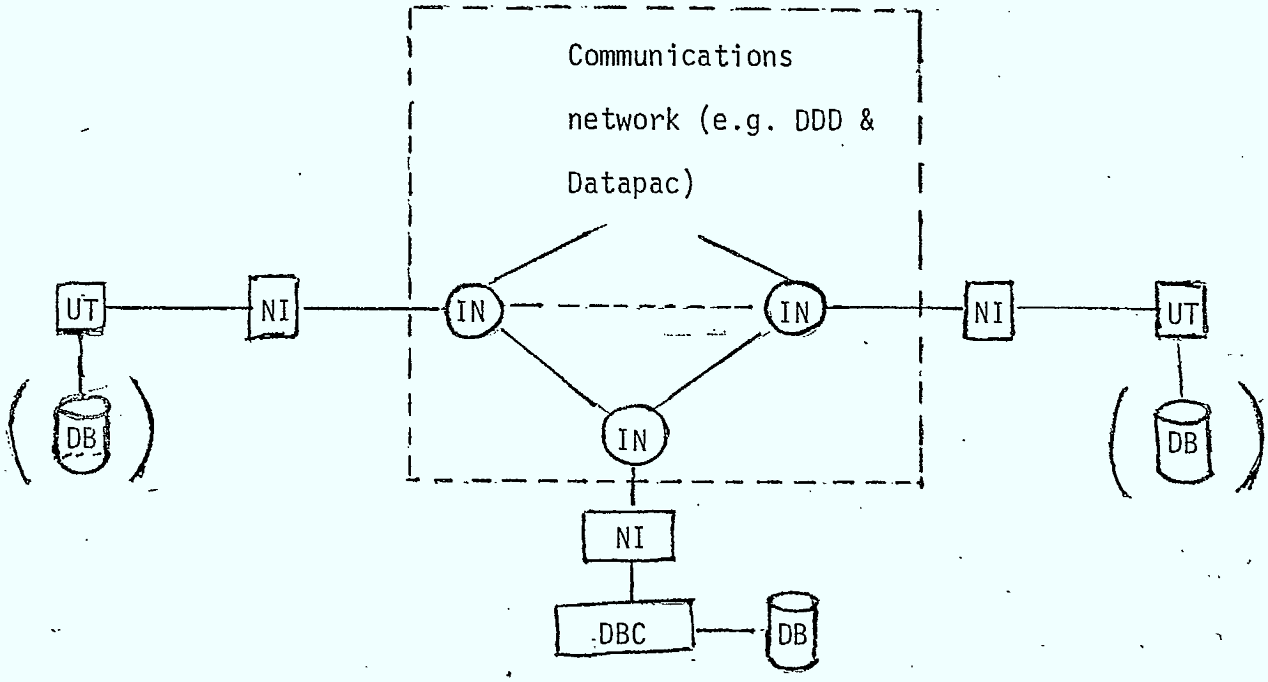
One purpose of this report is to outline the methodology, the level of detail and the sequencing of the research activities needed to achieve our objective. In the next few chapters, we shall be concerned with the choice of new services to be studied, the method for characterizing the services, the choice of existing telecommunications network, the modeling technique and data collection. In Chapter 7, a detailed model for the local telephone network is outlined.

A general schema relating the new services and the telecommunications networks is given in Figure 1.2.

FIGURE 1.2

GENERAL SCHEMA FOR NEW SERVICES

The new services being introduced in Canada and their relationship to the existing telecommunications plants may be represented schematically as below:



UT: user terminal configuration

NI: network interface

IN: internal network node

DBC: database control computer (there may be several such)

DB: databases

Databases may or may not be located at user sites, depending on the service (or variation of service) required. There may be specialized nodes within the network connecting to a database handling computer (DBC). The user terminal may vary from a simple keyboard plus console to a complete computer system. The interface unit will handle line conversion and line protocol problems. Communication protocols are handled by the referred nodes, uniformity being guaranteed at this level.

2. SURVEY OF PLANNED NEW SERVICES:

Modern telecommunications systems permit, in principle, a variety of new innovative services whose limits are bound only by the human imagination [1.1]. In fact, there is a kind of Parkinson's law ã la James Martin [1.2] that might apply: "If operator terminals provide a useful service, their utilization will expand to fill system capacity". The new version of this law might read: "As powerful new services are introduced into our telecommunications systems, unexpected imaginative and completely unforeseen applications are likely to arise so as to saturate system capacity". Thus, for example, an interactive videotex service may be found to be an extremely useful tool in, say, primary school hockey instruction, with the result that, very rapidly, there is an insatiable demand for the service on a nationwide basis. While this might appear to be an exagerated case, experience does show that unexpected usage patterns tend to arise when new services are introduced. A purpose of the current study is to explore the effects upon current system capacity as a function of various loading conditions caused by new services.

While the number of new services is potentially very large, in this study the following classes of services only will be considered (see Table 2.1):

- videotex (VISTA, Télidon) (as a special case of visual information systems),
- COSTPRO (TRADEX),

TABLE 2.1

PLANNED NEW SERVICES IN CANADA

<u>COSTPRO</u> or <u>TRADEX</u> (trade data element exchange)

<u>Electronic Finds Transfer</u>

<u>Electronic Mail</u>

<u>Télidon</u> (CRC, Télécâble-Vidéotron)

<u>VICOM</u> (Alberta Government Telephone)

<u>Videotex</u> (British Columbia Telephone Co.)

<u>VISTA</u> (Bell Canada's version of Télidon)

- EFT (electronic funds transfer),
- electronic mail.

Each of these services is examined briefly in the following paragraphs.

A special word is due concerning videotex services: these are special cases of a broader class of services called visual information services or systems (see Section 2.1). Since these systems have a number of unique implications, they are given a special treatment in the following section.

2.1 Visual Information Systems [4.1 - 4.8]:

2.1.1 Background:

The past few years have witnessed the introduction in Canada, Europe, Japan and the United States of a new class of information storage and retrieval systems in which responses to users' requests are visual images that are retrieved from system databases and transmitted to the users over a communications network such a public telephone network or a cable television system. The medium displaying the images to the user (machine-to-human interface) is a television receiver, while the medium accepting input from the user (human-to-machine interface) may vary from none at all (unidirectional systems) to a complex of cameras microphones, and other sensor devices (full interactive systems). Given that in such systems deliberate appeal has been made to the human user's remarkable visual information processing capabilities, they have been called visual information systems. Since they may in fact be subsystems embedded in a broader class of systems, they are sometimes referred to as visual information services. Visual information systems represent a significant step in the evolution of computer-based information systems towards those that will be needed for the wired information society of the future.

Hidden in the above characterization is a bandwidth matching problem, namely, matching the traditionally narrowband computer system with the broadband human visual information subsystem: computer input and output tend to be sequences of symbols with relatively low information content (as measured in bits per second, say, especially in the interactive mode) whereas for the human's visual subsystem, input stimuli derive from complex two- and three-dimensional scenes containing images or gestalts having very high information content that are rapidly recognized, stored and processed by the brain. In terms of our conventional sequential processors, the bandwidth (expressed in bits per second, say) equivalent of the human being is enormous, whereas that of the computer is relatively low. To illustrate, a color television frame requiring perhaps several hundred megabits for its representation, hence, large bandwidth for transmission, is rapidly processed by the brain while a single page of output text may entail only several thousands of bits and much lower transmission bandwidth. Therefore, in a computer-based system, to be able to present the human user with visual images, one must either reduce or compress the image bandwidth requirements so that they are tractable in narrowband systems or one must find transmission, storage, and display media of an essentially broadband nature. In the last few years, both approaches have been attempted, separately and in an integrated way.

2.1.2 Classification of Visual Information Systems:

Visual information systems may be tentatively grouped into three categories: (a) those using narrowband media, (b) those using broadband media, and (c) those having mixed broad- and narrowband properties. By media is meant storage, processing and transmission media. The determining factor is almost exclusively, but not quite, the transmission medium's bandwidth. Considered as bit units treated per unit time, one can apply also the term bandwidth to processing and storage devices.

The first category includes the various still-image services (in the subsystem sense as mentioned earlier) being offered over the public telephone networks such as PRESTEL (England), ANTIOPE (France), and the planned Canadian services VISTA (Bell Canada, 4.3) and Télidon (CRC, 4.1). In all these cases, encoded digitalized images are stored in system databases, transmitted over the carrier network to the subscribers with various levels of interactivity possible. In some cases, specialized graphic languages and bandwidth compression techniques are employed, necessitating microprocessor intelligence in the subscriber's receiver, and permitting effective use of the narrowband voice circuit-switched telephone networks. In other cases, broadband cable television channels are used, although the images are stored as above. Clearly, other network possibilities exist: for example, computer packet-switched, etc.

Non-interactive services of this category in which the images are transmitted downstream (via broadcast) in a cyclic fashion, the images desired by the user bieng selected by a multiplexing arrangement are often called teletext, whereas the interactive still-image services are referred to as videotex. The qualifier "still-image" is used to distinguish this category of service, which usually involves narrowband transmission media, from the moving cinematographic services described below and which involves broadband media.

The second category involves moving cinematographic images and includes as a special case broadcast television, ordinary one-way cable television and interactive cable television systems. In this class, system database devices are broadband media such as videotape or videodisk units.

In both the above categories, the downstream transmission media, i.e., those leading from the image database to the user's terminal (telephone network, cable television, the atmosphere, etc.) may be different from the upstream media, i.e., those leading from the user back to the databases. For example, a user may transmit his requests upstream via the telephone network and receive his images downstream via cable television.

For the third category, many hybrid possibilities are therefore possible and the current tendancy is to speak of integrated systems offering a combination of voice, data, and television services. Examples of such systems include the planned Elie, Manitoba system which will use optical fibers as the down- and up-stream transmission medium, IDA, also in Manitoba, using coaxial cable, and the ambitious Hi-OVIS (Highly-Interactive Optical Visual Information System) in Higashi-Ikoma [4.8], Japan, this latter being the world's first wired-city project to use optical fibers.

In Figure 2.1 are shown various network configurations possible for visual information systems. The properties of the macrocomponents of such systems are summarized in Table 2.2. Finally, in Figure 2.2, a user (home) terminal configuration is indicated.

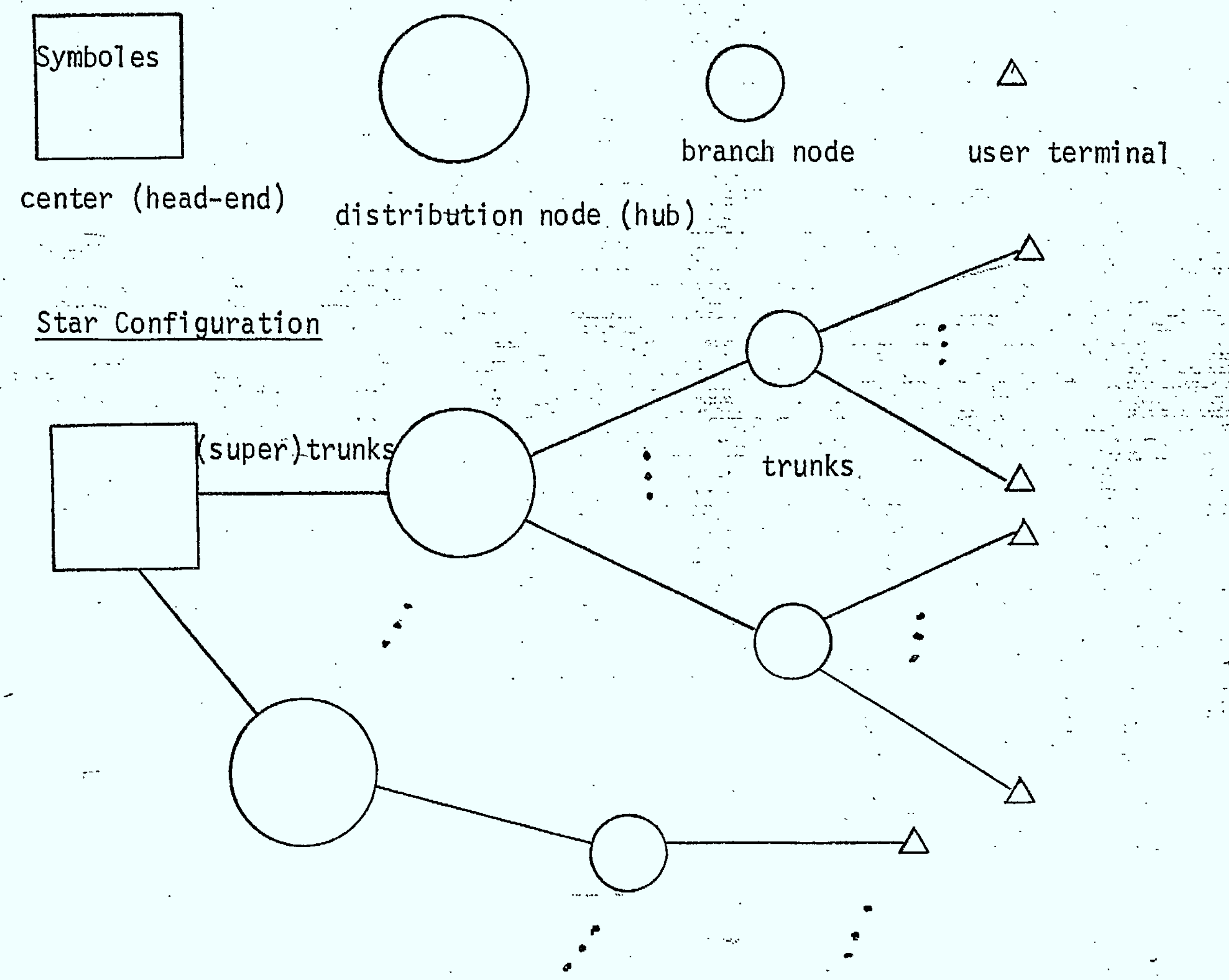
2.1.3 New Media:

The term "new media" [11.1] has been used to designate the plethora of new transmission, storage, and display media currently appearing or soon to appear on the market-place. These include optical fibers and their associated optical and electro-optical components, lasers, satellites, laser videodisks [11.2], wide-screen television receivers, mini-videotape recorders, LSI, VLSI, and superconductor memories [11.3]. The introduction of such new media into existing or planned new networks will eventually permit far greater broadband capability than is possible at this time, thus matching more effectively system bandwidth with the human's and allowing a wide range of integrated services.

2.1.4 Design Considerations:

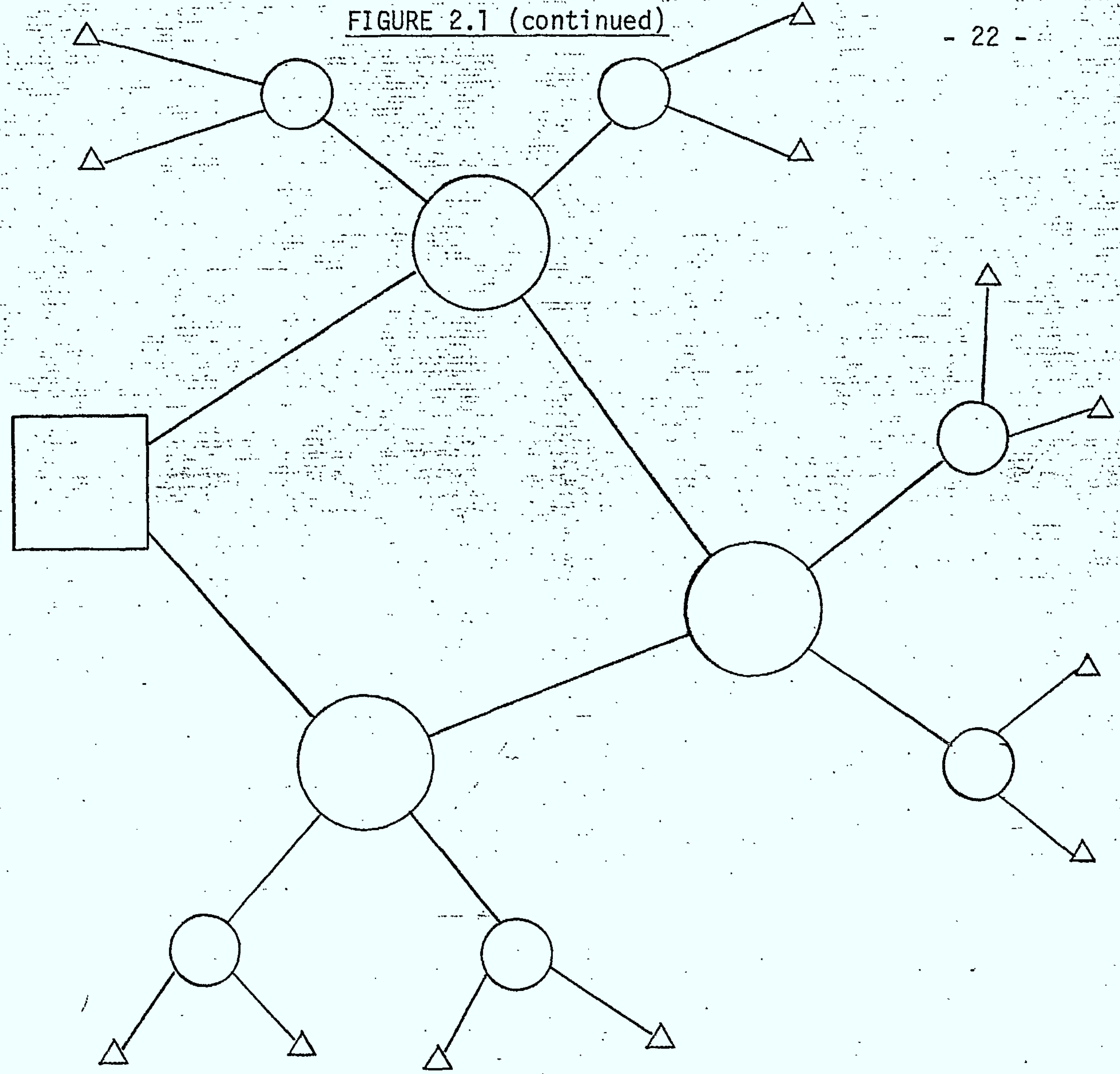
System and architectural considerations raised by new media and visual information services include: location of the image databases, impact on the

FIGURE 2.1 - NETWORK CONFIGURATIONS FOR VISUAL INFORMATION SYSTEMS (see also TABLE 2.2)

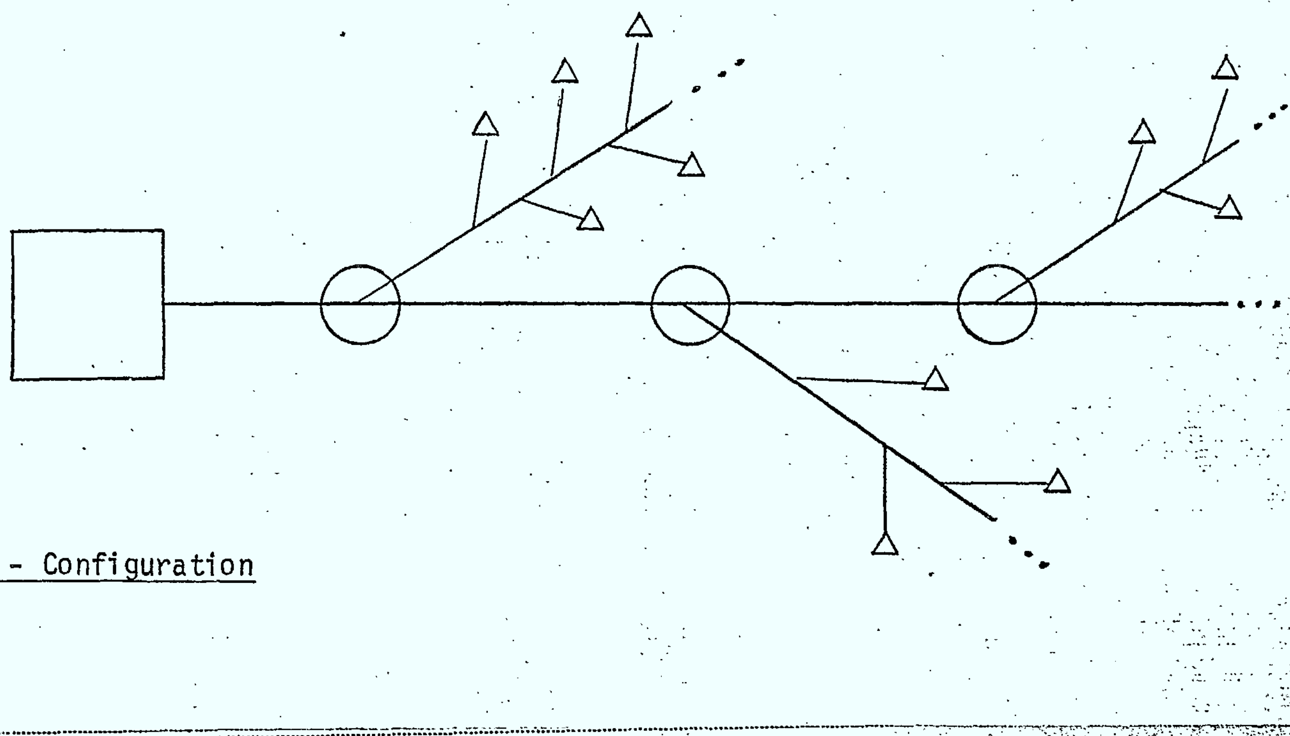


Legend

In Table 2.2 a summary is given of the principal functions realized by the macrocomponents of a visual information system. In this figure three types of network architecture are indicated: the star, the star-ring, and the classical cable television "tee" configurations. The star configuration corresponds roughly to the basic underlying hierarchical structure found in telephone networks. Notice that many combinations of these configurations are possible, for example, from the distribution nodes in the star-ring example, the local network may be in a "tee" configuration rather than the star as indicated. Or, from these some nodes, the users may be connected by a ring structure (this might specially be true for local in-house networks), etc. (see [12.1, 12.2])



Star-Ring Configuration



"Tee" - Configuration

FIGURE 2.2 - DOMESTIC TERMINAL CONFIGURATION

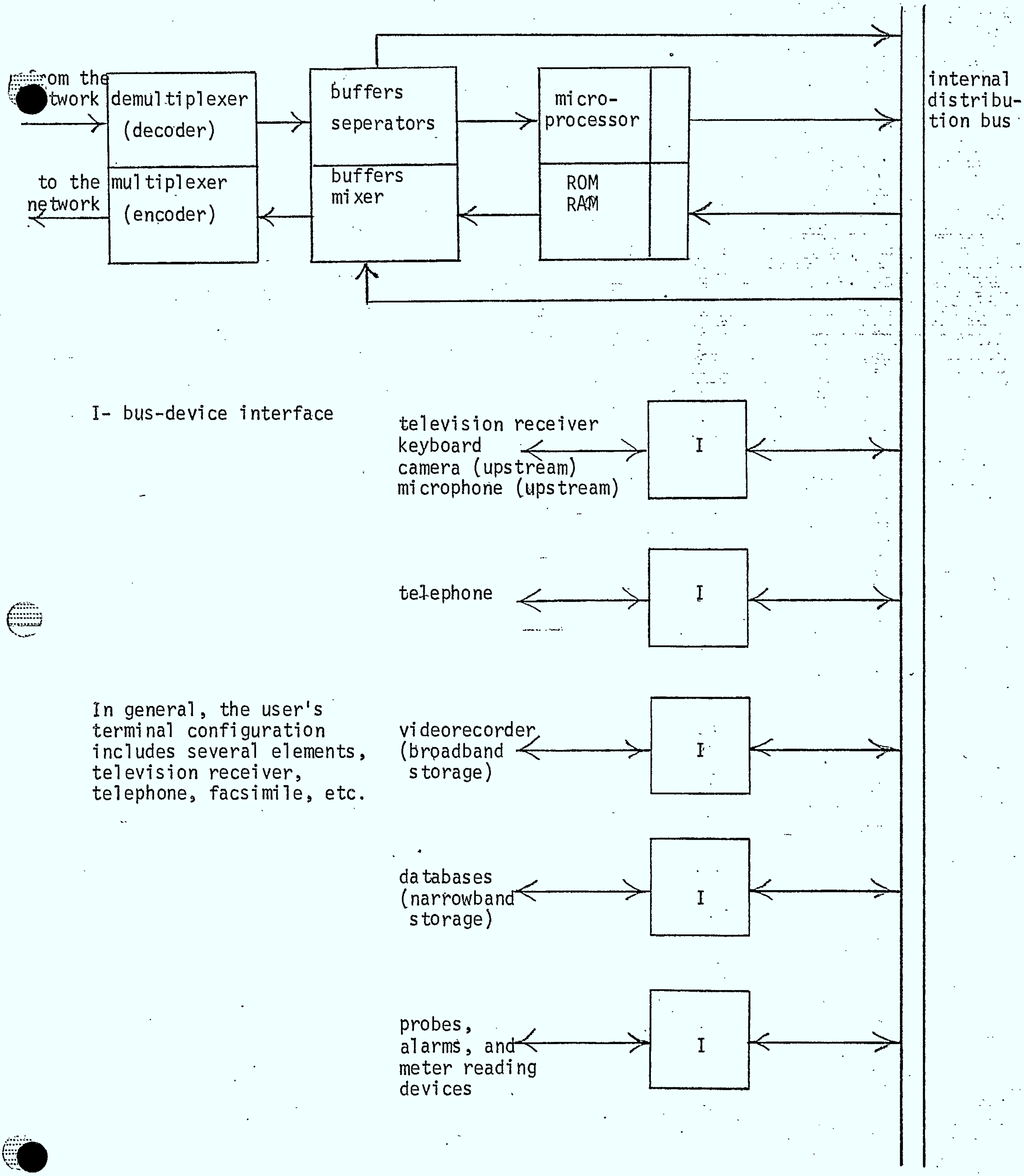


TABLE 2.2 MACROCOMPONENTS FOR A VISUAL INFORMATION SYSTEM

(see FIGURE 2.1)

The four major macrocomponents of a visual information system are: the center (head-end), the distribution nodes (hubs), the branch points, and the user terminals.

Center

Functions:
- reception and retransmission of UHF, VHF and FM
- maintenance of databanks
- programming
- control of network operations
- user request processing

Functional elements:
- antennas or hook-ups for UHF, VHF, and FM
- broadband videobanks ("vidéothèque")
- narrowband databases (for videotex, computer data, etc.)
- studio, control room
- command and control computer
- transmitters (micro-waves, coaxial cables, fibres optiques, ...)

Distribution Nodes

Functions:
- reception and regeneration of signals arriving from the center
- downstream switching of signals arriving from the center to the users

TABLE 2.2 (continued)

Distribution Nodes (continued)

- upstream switching
- partial processing of user requests
- in some cases, some of the center's functions can be off-loaded to the distribution nodes: databanks, studios, and others.

Functional elements:
- receivers, repeaters, retransmitters
- (video) switch
- local databanks
- local computer

Branch Points:

Functions:
- distribution of wires arriving from a distribution node destined for the users
- in some cases some distribution node function can be off-loaded to the branch points.

Functional elements:
- connectors, splicings, etc.

User Terminal (see also Figure 2.2)

Functions:
- display (of user-requested services)
- point-of-origination of user requests
- controle of meter reading, alarms, or probes

TABLE 2.2 (continued)

Functional elements:	- network interface
	- television console
	- microcomputer
	- keyboard (or keypad)
	- camera, microphone (upstream)
	- alarms, probes
	- FAX
	- local databases
	- local videobanks

performance of existing networks of the introduction of new services, distribution of intelligence and others. Several novel architectures using new media are reviewed by one of the authors of this report in reference [12.1] of the Bibliography.

Human factors and sociological considerations form a key element of system design: these include such things as eye fatigue, image design and presentation, responsivity of the system to user needs and others. The term "social software" or "serviceware" refers to the techniques needed to create useful and cost-effective visual information services. It is clear that hardware and software designers must work with specialists in the human behavioral sciences.

In visual information systems, the computer subsystem is distributed over the network from the user terminals to switching and distribution nodes to the database machines. Use of high-level database software, will eventually permit natural language requests (with time, spoken requests) as a critical element. The relation between serviceware and software must be elaborated. Indeed, a fundamental problem posed by new media and new services which give rise to systems of radically new architectures and designs is precisely that of developing a coherent formalism for describing systems functions and performance. This problem is being addressed by one of the authors elsewhere [4.7].

In this report, design factors relating to the "social software" will be reduced to the strict minimum necessary for estimating the system loading parameters (to be discussed in more detail in a later section).

One simple generalization of videotex should be mentioned, namely the addition of an accompanying audio message: videotex could then be created and transmitted with voice commentaries. This is essentially a question of encoding techniques and mechanisms and affects primarily the message length parameters and, if packetizing is used, the packet reassembly procedures. Further generalizations extend to a full video moving image service, as in Hi-OVIS, where users may consult a mass video information bank of videotapes. This, however, implies broadband media, and falls outside the scope of the present study.

2.1.5 Generality of Videotex:

As a forerunner of the powerful visual information systems of the future, the videotex services represent, for modest bandwidth media, outside of the telephone itself, a most general class of services. The basic logic is simple: an interactive visual information service can be offered in the immediate future using the telephone network infrastructure while awaiting the perfectioning of new media and the resultant new infrastructures for the implementation of the systems of the future.

2.2 COSTPRO (TRADEX) [5.1 - 5.2]:

The Canadian Organization for the Simplification of Trade Procedures (COSTPRO) has attempted to offer to Canadian trade organizations a systematic computerized way of simplifying exchange of shipping and business forms. To this end, a specialized terminal has been developed as well as network interfaces: the X.25 protocol has been adopted. At this writing, five terminals are operating and twenty more are due soon. Public and private networks can be used. The authors' current understanding of the COSTPRO or TRADEX (trade element data exchange) network is that it may be regarded as a special case of a videotex service: subscribers create "images" (pages of text) according to certain conventions depending upon the trade form used, and transmit these either to other subscribers or to a database. Subscribers may receive the forms addressed to them by interrogation of a database of directly on their receiving terminals.

Concerning estimates of possible subscriber loading characteristics, a bound may be obtained by considering that in Canada there are about thirty million shipments per year, each shipment requiring about ten documents: paper costs alone are about a billion dollars. There are around 250,000 terminals. Should these terminals be plugged into the TRADEX network, estimates for some of the critical system loading parameters could thus be obtained.

Finally, it is interesting to note that the TRADEX system includes a form of electronic mail as well as EFT (electronic fund transfer).

2.3 Electronic Fund Transfer Systems (EFTS) [2.1 - 2.19]:

Electronic fund transfer refers to "a collection of innovative methods of gathering and processing transaction related data. Collectively these methods constitute an alternative payment system in which the processing and communications necessary to effect economic exchange are dependent wholly or in large part on the use of electronics". Four main types of EFT may be distinguished:

- EFT involving transfers of money between banks for clearing operations;
- EFT involving transfers between the computers of other organizations and the bank's computers;
- EFT via public use terminals (CBCT's or customer bank communications terminals);
- customer payment of almost all bills (restaurants, stores, etc.) by vastly extended CBCT's.

The last item represents probably the real "cashless society".

EFT systems promise both financial benefits for the institutions that use them and potential convenience for their customers. They are, also, however, a potential source of problems in such areas as reliability and privacy. These, and other related sociological and economic issues, are beyond the scope of this work.

From the point of view of this study, EFT may be considered as a special case of videotex services: information is entered according to some standardized format and routed to a database, shared or private. Once again, a major problem will be that of estimating the network loading parameters.

2.4 Electronic Mail [3.1 - 3.6]:

The growth of computer networks has given rise to a first form of electronic mail, the so-called computer mail. In this form, the message originator, using a time-shared computer terminal, enters his message to be stored in a database element corresponding to the "mail-box" of the intended receiver. The receiver may access his mail-box by request or may be automatically informed by the system of the presence of mail in his mail-box. Once again, the generalization of this service to a wider population would seem to reduce to a kind of videotex service with the attendant problem of estimating the system loading parameters.

The legal, social, and administrative problems involved in the integration of electronic mail systems with the current Post Office are beyond the scope of this study.

2.5 Summary:

While a wide variety of (narrowband) services exist, in limiting ourselves to modest bandwidth media, the most inclusive appears to videotex. A number of user terminal configurations exist as well as network tie-in possibilities. Using data to be obtained from existing videotex systems, current business transactions and EFT systems, estimates can be made of the system loading parameters. These, coupled with information about the network architecture, constitute the basic data needed for this study.

3. NEW SERVICES:

3.1 Classification of Services:

Services which are applications of computer networks are numerous and limited only by our imagination. The networks involve the use of computers, but computation in the narrow sense does not necessarily dominate the services. The scope of the services include, no less than computation, computer-based applications in which the main emphasis is on communication among people, on access to information, or on control of systems organization. J.C.R. Licklider and A. Vezza [1.1] have briefly examined thirty services which could make use of telecommunication networks. These services would be classified as Electronic Mail, Teleconferencing, "The Office of the Future", Management Information Systems, Modeling and "Computerized Commerce". This classification schema for telecommunication services is too "loose" to be taken as basis for study of new services since a service in one class could do the job of a service in another class. At the present time, there is no ideal classification of telecommunication services in which each class has its proper characteristics. One has to understand a service as it is known. This implies that one cannot study the telecommunication services by class or by category to obtain general results. Instead we have to study service by service. Hence, we limit ourselves to a number of well-known services as already suggested in the preceding section, <u>via</u>: Electronic Mail [3], Electronic Fund Transfer (EFT) [2], "Videotex" [4] and COSTPRO - type services [5]. It is anticipated that by studying these services, we will be able to obtain results that by deduction could be applicable to other services once their characteristics become known.

3.2 Characterization of services:

A new service, as the existing ones, will compete for the resources available in the network. These resources may not all belong to the same telecommunication network. Indeed, a service requires the resources of different computer networks to perform different functions. Thus, we can partially characterize a service by its resource requirements from the networks. There are three principal types of resource requirements: transmission requirements, processing requirements and storage requirements. These requirements are not equally important for all services but each service tends to emphasize only one or two types of resource. Needless to say, the resource requirements of a service vary from user to user and are not even unique for a user. In other words, resource requirements of a service vary from request to request. The best we could characterize the resource requirements of a service is in terms of statistical distributions or only in terms of a few first moments of the distributions. The most commonly used characterization is the average amount of resource per request. Some example of resource requirements are given in Table 3.1.

The resource requirements are not the only characteristics of the telecommunication services. Some measure must be used to indicate the quality of service the users expect from or impose on the networks. This measure can be called the level of service [6]. The level of service measures the degree of satisfaction of the users. There are various metrics already invented for service level of computer applications but the most relevant ones are <u>responsivity</u>, <u>availability</u> and <u>cost</u>. Responsivity is a measure of the transit time delay including the signal transit time and the signal-waiting-in-buffer time. Availability does not limit access to the service offered both in time and in space. Finally, cost represents the financial investment that must be made to maintain the service at some level of responsivity and availability. It can be seen that the three basic metrics of the service level are of conflictual nature. For example, in order to maintain a high responsivity, one must limit the availability or increase the cost. Of course, all the metrics of the service level can only be given in statistical distributions or in percentiles of statistical distributions. Some examples are given in Table 3.1.

Besides the resource requirements and the service level, a service must also be characterized by the traffic it generates in various links and nodes of the networks. This traffic depends on subscribers population and on the regional subscribers distribution. Moreover, the traffic is also time-dependent as shown by an example in Figure 3.1.

To characterize the traffic flow of a service, the request arrival pattern from each source and the routing of subscribers' requests must be given. The method of describing the traffic flow depends on the modeling technique employed for description of the interactions between subscribers'

TABLE 3.1

EXAMPLES OF SERVICE CHARACTERISTICS

RESOURCE REQUIREMENTS	TRAFFIC FLOW	SERVICE LEVEL
- Holding time per call	- Number of arrivals or calls per time unit	- Mean transit delay
- Number of characters per message	- Routing probabilities in the networks	- Percentile (90%) of transit delay
- Number of pages retrieved per request	- Traffic intensity	- Priority
- Number of packet switchings per call	- Subscribers population	- Cost per request
	- Regional distribution of subscribers	- Cost per subscriber

requests and networks.

3.3 Problem of traffic characterization:

Unlike the resource requirements and the service level, which can be partially estimated from the nature of the service, the traffic flow generated by the subscribers to a service is difficult to forecast. Unless the subscribers population is somehow known, the traffic forecast problem requires at least some population sampling study or socio-economic study. This is a forecast problem for which network analysis techniques are of little help.

Fortunately, a precise forecast of traffic flow is not absolutely needed for the purpose of network capacity planning because the planning usually aims at a wide range of anticipated traffic levels rather than a specific level. For long term planning, we can thus consider the traffic level as a variable rather than a parameter. This means that we will study network performance as a function of traffic flow. Figure 3.2 gives an example of response time as a function of service requests arrival rate.

Our remark about the traffic forecast problems is not intended to undermine its importance for the objective of our project. On the contrary, some quantitative knowledge about the traffic level must be obtained in order to assess the impact of a new service on a network. However, the problem of forecasting the traffic flow with good accuracy would exceed the resources allocated for this project. It should be carried out at a lower level of detail in the top down process mentioned previously (see Section 1.3).

FIGURE 3.1

EXAMPLE OF TRAFFIC VARIATION IN A DAY

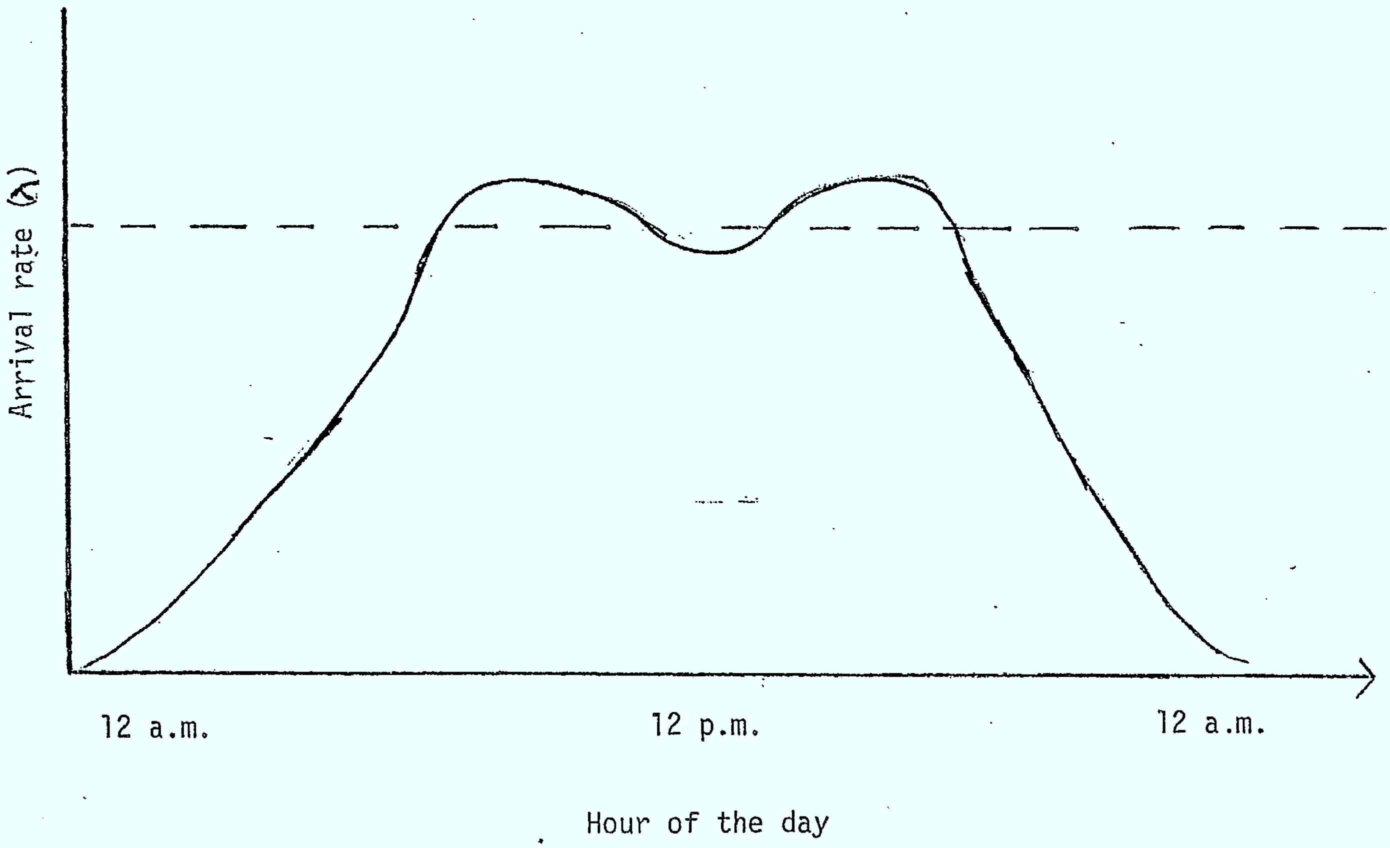
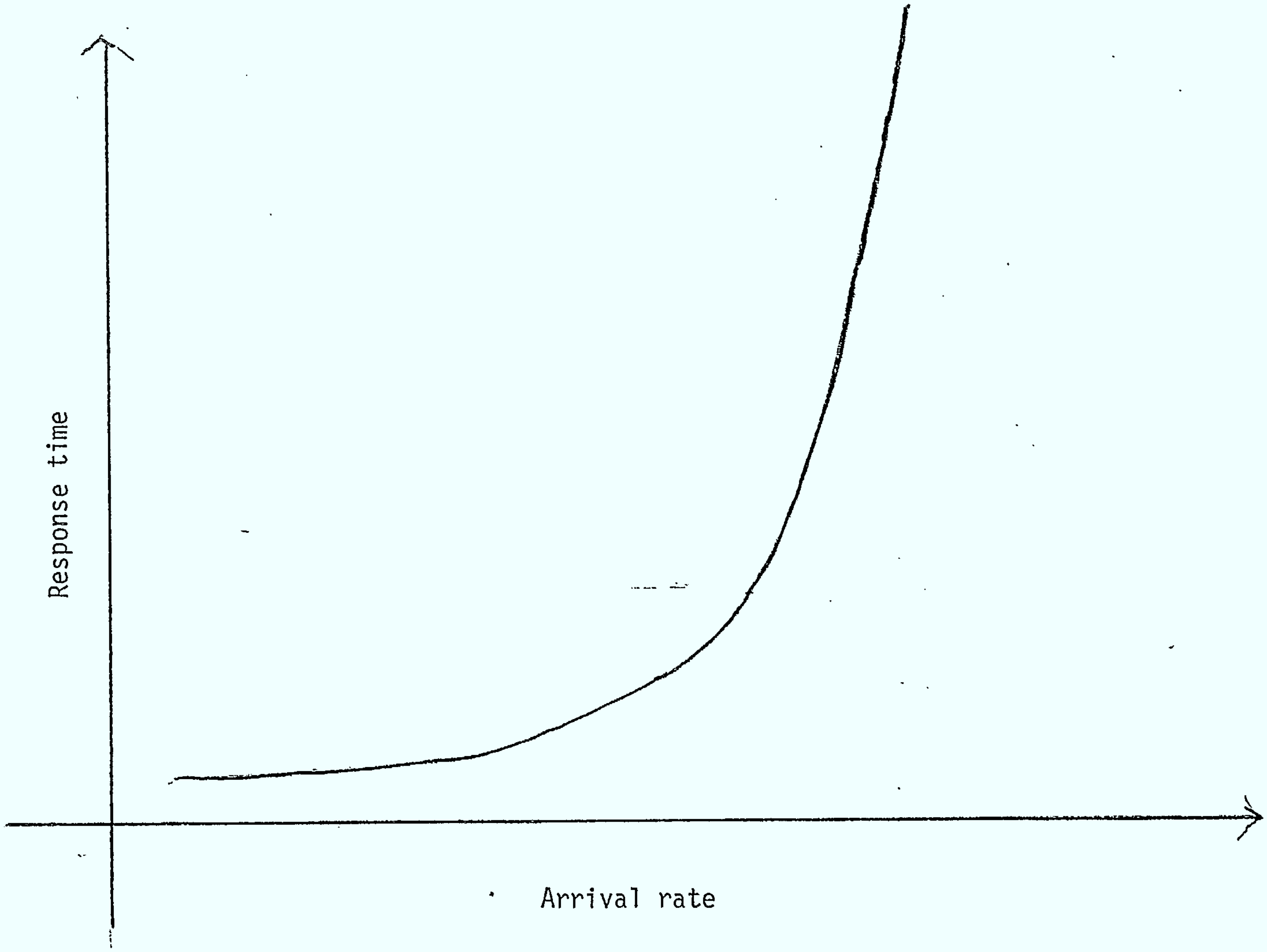


FIGURE 3.2

EXAMPLE OF RESPONSE TIME AS
A FUNCTION OF REQUEST ARRIVAL RATE



4. TELECOMMUNICATION NETWORKS:

4.1 Public Telecommunication Networks [1.3]:

There are a considerable number of private and local networks operated by private or governmental institutions such as banks, public schools and universities. However, we will concentrate our attention only on the public nation-wide networks in Canada.

Many services are concurrently offered by public nation-wide networks for information processing, storage and retrieval. These are the DATAPAC network of the Computer Communication Group of the TransCanada Telephone System (TCTS) [6], the INFOSWITCH Network of CNCP [7] and the Direct Distance Dialing telephone switching network (DDD) of the TransCanada Telephone System.

Most of the new-planned services can be introduced into these nation-wide networks. The important question is: how this can be done?

To answer the above question, we must document the architecture of, and the services presently offered by, these networks. We shall briefly summarize the salient features of these networks gleaned from easily accessible sources (and perhaps somewhat dated) but work remains to be done to obtain precise information.

- DATAPAC [6, 8]:

The Datapac network is a call-based store-and-forward packet switching network operated by TCTS with nodes situated in 8 major Canadian cities, to be extended to 14 cities by 1980. Interconnection is by 56 kb/s Dataroute trunk facilities such that all nodes are doubly connected for high reliability. The network is monitored from a Network Control Center (NCC) located in Ottawa which is connected to other nodes by 9.6 kb/s transmission links.

The Datapac network is based on the "virtual circuit" concept: circuit connection requires network bandwidth only when data is actually being transmitted.

There are two classes of subscriber interfaces to Datapac, each one tailored to several kinds of applications. The first class provides access for packet-mode terminals using the Standard Network Access Protocol (SNAP). SNAP, in turn, conforms to the CCITT Recommendation X.25 and defines conventions allowing packet-mode terminals to establish, maintain, and clear calls and manage data flow to and from the network. The second class provides access to Datapac for terminals not using SNAP such as teletypewriter and point-of-sale terminals. These non-packet-mode terminals are connected to Datapac by the Network Interface Machines (NIMs). The NIM handles the specific terminal protocol and performs a number of functions to allow the terminal to communicate with a host computer connected to the network by a SNAP/X.25 interface. The

Datapac 3000 service provides the basic access to the Datapac network for the (host) computers and other intelligent devices such as front-end processors or programmable terminals. ITI, the Interactive Terminal Interface, is a non-packet-mode interface which provides the end-to-end protocol for the Datapac 3101 access service. This access mode is used by asynchronous teletypewriters. The NIMs are also used for Datapac 3201 and 3203. These two access services support buffered, pollable, asynchronous terminals. The NIMs poll terminals associated with these services on an on-line basis over multipoint, multidrop facilities shared by several users; for Datapac 3201 the terminals must operate under the ISO poll/select transmission line protocol. Datapac 1000 is a service design to provide various transaction terminals to communicate with several host mainframes. Finally, Datapac services are offered internationally to select countries through the International Computer Access Services (ICAS) provided by Teleglobe Canada.

The switching system used in Datapac is the SL-10 packet switch designed by Bell Northern Research and manufactured by Northern Telecom Ltd.

- INFOSWITCH [7]:

Infoswitch is a nation-wide, digital, data-switching network offering both circuit and packet switching technology to the users. The network is divided into three services offering: Info-Exchange Service, Info-Call Service and Info-Gram Service.

Info-Exchange Service is a simple circuit-switching operation that connects to users on demand. Users are expected to be those with heavy volume but low frequency requirements, sending data in batches. Info-Exchange users are offered a variety of transmission speeds up to 9.6 kb/s. With the aid of a user's directory, they will be assigned a link between their own terminal and a desired receiver. Connection time is somewhat less than one second and once established data can flow directly between the connected terminals. Costs for Info-Exchange are based on the length of circuit connect time.

Info-Call Service meets the need of customers who communicate with computers for inquiry-response type applications. The user has a "virtual calling" capability which in effect gives a direct circuit connection but without actually tying up and paying for one. Once access is gained to the network, Info-Call Service gives access to a 50 kilobaud circuit that is constantly carrying packets from many sources to many destinations.

Info-Gram Service provides constant users of the network, such as those with a large number of point-of-sale terminals, or credit card verification systems, with permanent and active connection to the network. Using Info-Gram Service, packets of data are processed by the customer who gains entry to the network by means of a standard Canadian access protocol. Charges are based on volume of packets transmitted.

- DIRECT DISTANCE DIALING NETWORK (DDD):

The long distance network connects the many local central offices by means of facilities, called connecting trunks, enabling any telephone subscriber to be connected to any other telephone on the network. The Direct Distance Dialing (DDD) Service, although primarily a voice offering, is capable of transmitting data at speed of 1.2 kb/s asynchronous and 2.4 kb/s synchronous with a telephone company data set and up to 9.6 kb/s with commonly available equipment. To connect a business machine to the network, a data set must be used to convert the digital output of the machine into tones compatible with the transmission facilities of the telephone network.

Besides basic features such as voice transmission, data transmission (two-wire half duplex), DDD network offers optional features:

- Numerous service combinations: service related to DDD, such as WATS, Zenith, Foreign Exchange, Datacom can be combined or used alternately.
- Full-Duplex: Full-duplex service is available at speeds up to 1.2 kb/s.
- Customer Provided Terminals and Modems: the connection of customer provided terminals and modems is permitted provided the modem is used along with either a telephone company provided data connector (coupler) or with newly certified equipment made by other manufacturers. If a telephone company

data set is used with a customer provided terminal, a data connector is not required.

Table 1.1 of the Introduction summarizes the characteristics of the three discussed networks.

4.2 Characterization of the Networks for Traffic Analysis:

4.2.1 Packet-Switched Network:

A packet-switched network is a collection of nodes connected by links which transmit data under the control of the communication protocols adopted by the network. Hence, the characterization of a network implies the characterization of three of its basic entities: the nodes, the links and the protocols.

The nodes can be characterized by their processing capacity and their storage capacity. As in the characterization of a service, we can use statistical distributions to characterize the processing time at a node. The most incomplete, but perhaps sufficient, way to characterize the processing time is in terms of mean switching time per message or packet, which is normally independent of the length and type of the message and is negligible at tandem nodes (for DATAPAC, it is of the order of 1 to 3 msec). The storage capacity at a node or the buffer size is usually fixed and easily specified. Both the processing and storage capacities are important factors which influence the service level.

The most important characteristic of the link is its transmission capacity (bandwith) which is usually expressed interms of bps (bits per second). Another important characteristic of a link is its capacity of transmitting data in half-duplex or in full-duplex modes. The distance of a link is of little importance for data transmission delay because data progation delay is negligible. It can be important, however, if cost is to be considered.

The telecommunication protocol is very complex but relatively easy to characterize for traffic analysis purposes. It is usually characterized by the transmission control overhead which can be given in terms of number of characters per packet or message.

Finally, the maximum packet size that a network can handle is also an important characteristic.

4.2.2 Circuit-switched Network:

All circuit-switched networks employ some form of alternating routing [13.1]. By this, we mean that for any S-D call* more than one path is considered for completing the call. The alternative paths between an S-D exchange pair are attempted in a predefined order according to the routing hierarchy for the node pair. A successful call is one which, on arriving at the source, finds a free path to the destination; that is a path on which at least one free trunk exists on each link at the instant of the call arrival. Calls which fail to find a free path are said to overflow and are lost to the network.

* S-D: source-destination

The routing schema in a network is determined by a routing table and a call control rule. Figure 4.2 shows a typical routing table for the network of Figure 4.1.

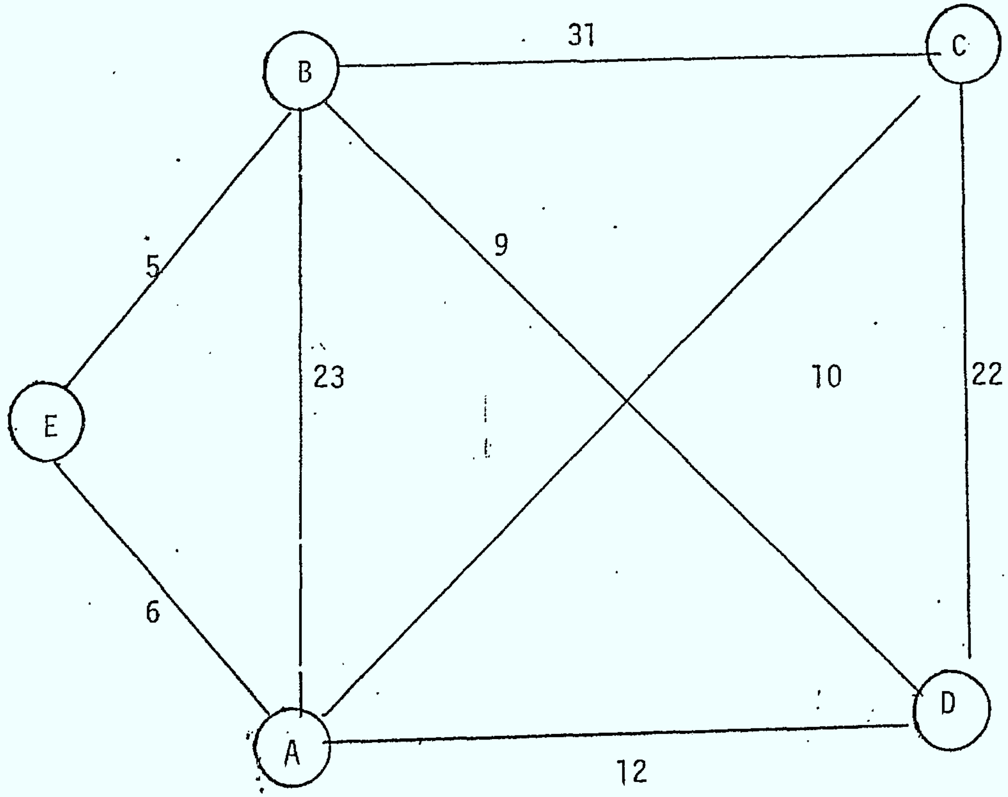
The routing table can be expressed in the form of a matrix of nxn blocks with the diagonal blocks unused. Each block contains an ordered set of nodes. The significance of the entries in each will be explained shortly.

A number of call control rules are presently used in various communication networks. The Canadian DDD network employs the successive-office-control rule, also known as segmental routing, progressive routing, stage-by-stage routing, etc. A precise description of the rule follows [13.1]:

"Let the nodes in the J-to-K block of the routing table be $(N_1, N_2, \ldots , N_m)$. A call reaching node J (or originated at node J) and destined for node K is routed to some adjacent node by the use of the first available link from the sets of links $(J\text{-}N_1, J\text{-}N_2, \ldots , J\text{-}N_m)$, searched in the prescribed order. If all links in the set are unavailable, then the call is lost".

As an example, consider the routing of E-to-D calls in Figure 4.1 The E-to-D block of Figure 4.2 has two ordered entries (A, B). At node E, an attempt is first made to route the call to node A. If the link E-A is blocked, then the next choice link E-B is attempted. If link E-B is also blocked, then the call is lost. Similar actions are taken at every node. The complete

FIGURE 4.1: A SMALL TELEPHONE NETWORK



Integers indicate numbers of channels (trunks)

FIGURE 4.2: A ROUTING TABLE FOR FIGURE 4.1

From \ To	A	B	C	D	E
A		B	C, B	D, C, B	E, B
B	A		C, D	D, C	E
C	A, B	B, A		D	A, B
D	A, B, C	B, C	C		B, A
E	A, B	B, A	A, B	A, B	

process of routing the E-D calls can be depicted very clearly by a route tree shown in Figure 4.3. Observe that except for the destination node D, every node J in the route tree has outgoing branches terminated in nodes in the order (top to bottom) prescribed by the entries (left to right) of the J-to-D block.

For every source-to-destination node pair, there is a corresponding route tree. Once the route tree for any source-to-destination node pair has been constructed, we can list the sequence of routes from the calls by tracing from the root (source node) to all tips (destination node), using the "depth first search" [3.2.

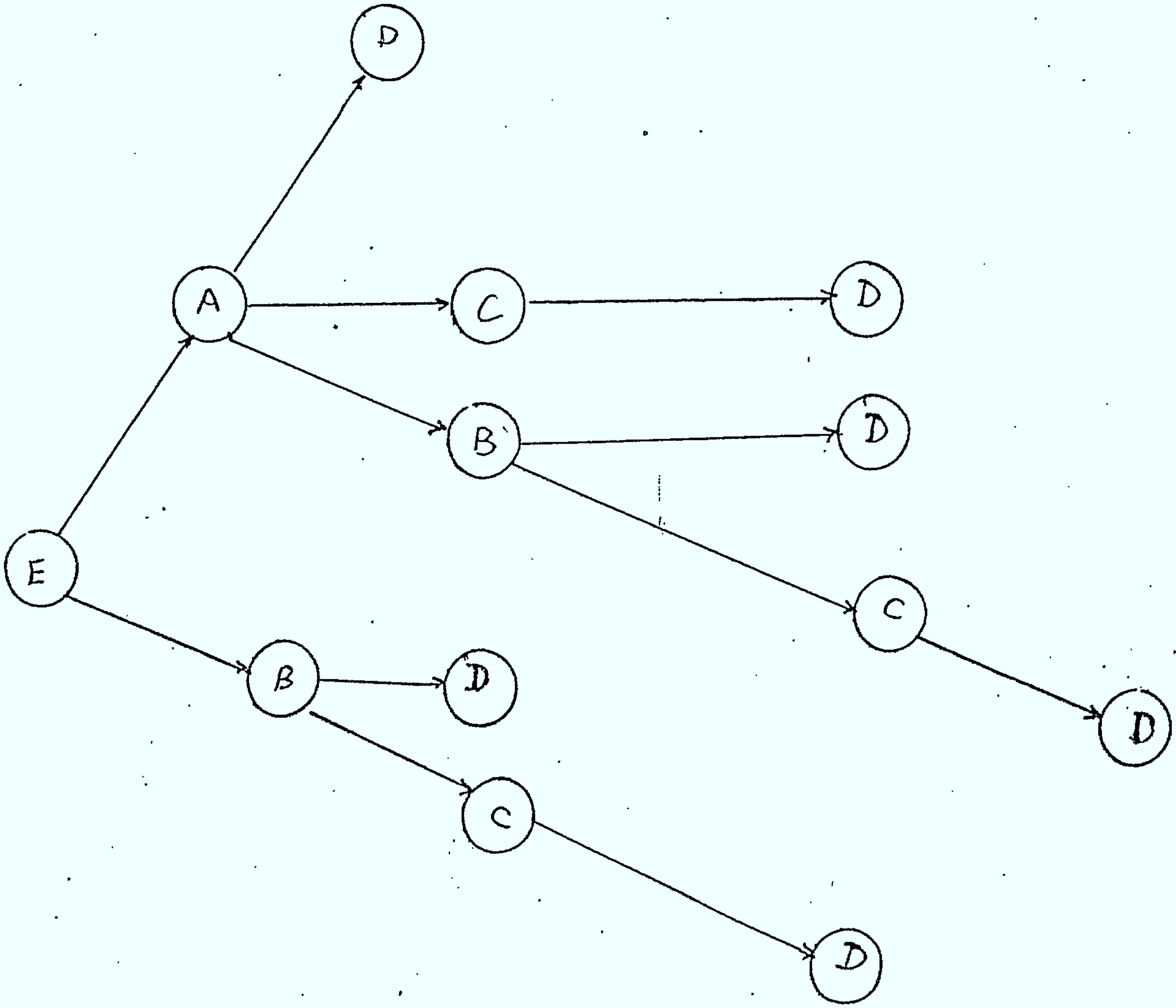
For example, Figure 4.3 shows that there are six paths for E-D calls. In the order of preference, they are: P_1 (EAD), P_2 (EACD), P_3 (EABD), P_4 (EABCD), P_5 (EBD), P_6 (EBCD). An E-D call, if not blocked, will be routed through one of the above six paths, in the indicated order of preference.

In summary, a circuit-switched network can be characterized by:

- the network configurations (connection between links and nodes);
- the routing table;
- the links capacities (number of trunks in all trunk groups).

The performance of a circuit-switched network is a function at the above characteristics and the traffics intensity generated at all nodes. We

FIGURE 4.3: ROUTE TREES FOR E-D CALLS



will consider the traffic intensity as a characteristic of the services rather than a characteristic of the network. Methodes for studying the performance of a circuit-switched network will be discussed shortly.

5. IMPACT OF NEW SERVICES ON THE TELECOMMUNICATION NETWORKS:

5.1 Network Performance:

Having discussed the characteristics of the new services and those of telecommunication networks, it is possible now to turn our attention to the problem of evaluating the impact of the introduction of new services on existing telecommunication networks. The method we are going to outline shortly will be applicable to networks of novel architectures or technologies.

To evaluate the impact of new services is to evaluate the performance of the networks with respect to the workload generated by the old as well as new services. From the users' point of view, the performance is measured by the service level that the networks are able to maintain. However, from the point of view of the networks' managers, the performance of a network is represented by the throughput and the utilization of resources in the network. It can be seen that the users' point of view is in conflict with the managers' point of view: high throughput brings high profit, high utilization reduces cost but high throughput and utilization lower the service level.

5.2 Methods for network performance evaluation:

Methods for evaluation of computer systems performance have been extensively discussed in the literature [9.3]. These methodes involve at least some of three principal techniques: direct measurement, mathematical modeling and digital simulation.

Direct measurement will be needed to obtain the characteristics of the networks and the services, both old and new, and to measure the performance of existing networks driven by already existing services. The networks have usually some hardware or software monitors which are able to collect some performance related data. For example, DATAPAC network performance is monitored by the network control center. However, the performance data are usually kept confidential by the networks' managers so that it may be difficult or impossible to have access to them. Thus, the most difficult task of our project will be the collection of data on the characteristics of the services and those of the networks.

Mathematical modeling, especially that using queueing theory, is very useful for network performance evaluation. Despite simplistic assumptions about workload and network characteristics, such as statistical independence between service times and inter-arrival times at network nodes, markovian properties for service times and inter-arrival times, queueing theory has been successfully applied for network analysis [9.4]. We will have occasion to use queueing theory models to evaluate the impact on network performance of new services.

Simulation is the most powerful technique for network performance evaluation thanks to its ability to model the interactions between the networks and their workload at any desired level of detail. However, simulation is a time consuming and costly procedure that should be used only when tractable mathematical modeling fails to represent the network at the desired level of detail and when cost can be compensated by the benefit. It should be noted that one should not attempt simulation if the networks and their characteristics are not known to some respectable degree of accuracy.

5.3 The Videotex Service:

Among the telecommunication services that we have discussed, the videotex service is most likely to be implemented in the near future. It is thus logical to choose this service as a candidate for our first study.

As already mentioned, the basic idea of the videotex service is quite simple: send to the subscriber's television console screen images stored in a database that are pertinent to the subscriber's needs. The videotex service to be considered will use as transmission medium resources from the public telephone networks and perhaps from other networks such as the DATAPAC, the INFOSWITCH packet switching networks.

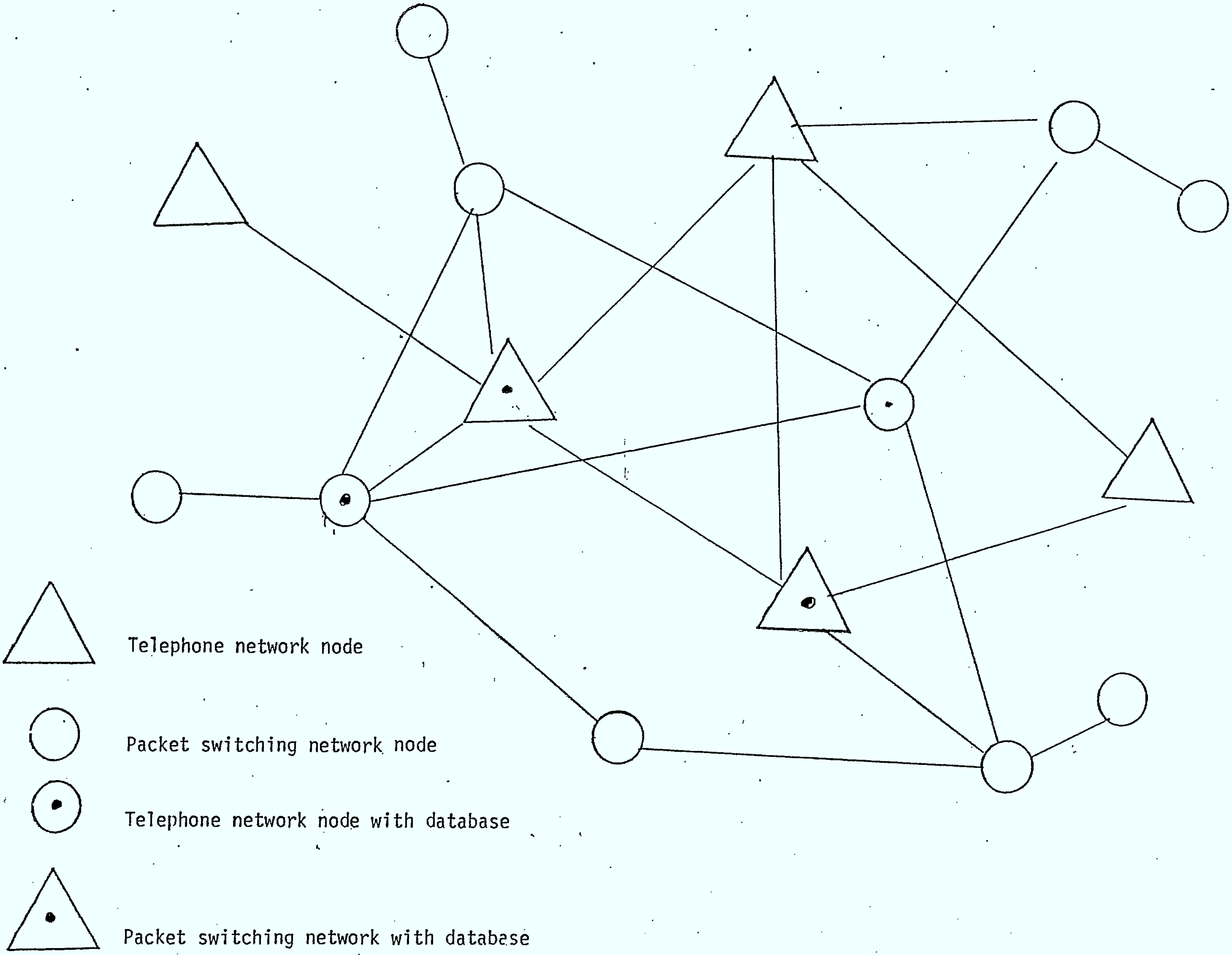
Thus, the introduction of a videotex service will induce some impact on the performance of public telephone networks and data packet switching networks. This impact will depend on the network capacity, the geographical distribution of the videotex databases, the information content of the databases and finally on subscribers' usage patterns. Given some knowledge about the above characteristics, we can evaluate the impact of the videotex service on each of the networks involved. It will be seen that each network can be treated separately and the evaluation techniques used for telephone networks is quite different from those used for packet switching networks. We shall argue that the telephone network is the critical transmission medium for the videotex services envisaged and that it must receive our first attention.

The general schema for a videotex service is presented in Figure 5.1. The databases are distributed over both the telephone network and the packet switching networks. The locations of the databases are chosen as functions of performance and cost considerations. We shall assume, without loss of generality, that each database is located at an existing network node or that it constitutes a new node for the network.

A link in the telephone network carries traffic generated by telephone subscribers and also by videotex service subscribers. We assume that videotex subscribers will have access to databases in the packet switching networks via the telephone network through specified entry ports. To the telephone network, the packet switching networks behave as if they were extra nodes (or offices) of the telephone networks located at entry ports. To the packet switching networks, the telephone network appears as a number of nodes whose main function is to accept external traffic coming from the telephone network.

It can be easily seen that performance analyzes can be done separately for each network. For example, by replacing each entry port of the packet-

FIGURE 5.1: GENERAL SCHEMA FOR VIDEOTEX SERVICES



switching network by an abstract node of the telephone network, the packet switching networks can be completely ignored. These abstract nodes behave as any other node of the telephone network in the sense that their main function is to exchange calls with other nodes.

Although packet-switched network performance evaluation methods will also be discussed in this report, we propose to restrict our attention primarily to telephone networks for the following reasons:

(i) The local telephone network will be the critical resource for videotex service. This is because, initially, the videotex databases will probably be located at low level nodes of the local telephone network, initial access to these databases being essentially from local subscribers.

(ii) The current Canadian packet switching networks appear to be somewhat under-loaded and we can expect good performance even with the introduction of videotex service. Also, as already stressed, videotex subscribers will have access to databases in packet switching networks *via* the telephone network.

For the performance evaluation problem of packet-switched networks, the main objective is to evaluate the impact of a new service on the *service level* of a packet switching network. To this end, queueing theory or simulation can be used. However, the performance evaluation techniques needed for telephone networks are quite different from those used for a packet switching networks because of the circuit switching used in the former.

In the next section, we will present models to be used for performance evaluation of telephone and packet-switched networks.

6. MODELS FOR NETWORK PERFORMANCE EVALUATION:

6.1 Performance Evaluation Problem for Telephone Network:

The performance of a telephone network is mainly determined by the capacity of links (number of trunks in trunk groups) and node-to-node traffic loads (or traffic intensities). The traffic will be of two types: that generated by telephone subscribers and that generated by videotex subscribers. The latter are not presently known but can be qualitatively characterized as follows:

- Videotex traffic has a mean holding time probably larger than that of telephone traffic.
- Telephone traffic will be split into two parts, one of which will be due to videotex users, the other to conventional telephone users.
- There will be a new videotex traffic resulting from the introduction of the videotex service. Given all node-to-node traffic and the capacity for all links in a telephone network, the performance evaluation problem consists in finding the following variables:

  - Node-to-node grade of service (NNGOS, blocking probabilities).
  - Link or trunk groups grade of service (TGOS, blocking probabilities).
  - Average number of links used per call.

- Trunk group carried load (TGCL).
- Trunk group offered load (TGOL).

The determination of these quantities for a large telephone network is somewhat complicated and can be carried out by an event-driven simulation program or by analytical techniques. However, when only the steady state behavior of the network is concerned, simulation is a poor method to use because of the extremely long computer running time required to reach the steady state. Because of this difficulty, analytical methods have always been favored for steady state analysis. Classical analytical methods have been extensively used by telephone traffic engineers for network capacity planning and are based on simple models of traffic patterns and holding time distributions. Most classical traffic engineering methods deal with a small number of trunk groups treated as isolated and independent links in the network but do not attack the traffic engineering problem of the whole network. Some recent efforts have extended classical methods to treat a complex telephone network such as the Canadian or American Telephone Networks [see references 13.1, 13.7, 13.8]. We shall propose a modern analytical model to evaluate the impact of videotex service on a telephone network by developing first a model applicable to telephone networks of arbitrary complexity and discussing how this model can be applied to a local telephone network.

6.2 Model for Performance Evaluation of Telephone Networks*:

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* This section follows closely Ref. 13.1.

6.2.1 Traffic Intensity Matrix:

In a telephone network, one important measure of the quality of service, as far as the user is concerned, is the node-to-node grade of service (NNGOS), which is the blocking probability for calls originated at a node S (source) and destined for another node D (destination). For a well-designed telephone network, the NNGOS for all node pairs should be kept below some specified value, say 0.01.

The grade of service of a telephone network is a function of traffic intensity. These are the matrices of all node-to-node traffic intensities generated by the telecommunication services. Each telecommunication service which uses the telephone network will generate a traffic intensity matrix. For example, business telephone traffic is quite different from residential telephone traffic. Videotex service traffic will be different from ordinary telephone traffic since its mean holding time may be very different from that of ordinary telephone traffic. Conventional telephone network analysis methods do not distinguish business telephone traffic from residential telephone traffic and consider only the sum of all traffic intensity matrixes. This is satisfactory for ordinary telephone traffic since the mean holding time of business traffic may be quite close to the mean holding time of residential telephone traffic. But merely adding the traffic intensity matrix generated by the videotex service to the existing ordinary telephone traffic matrix may yield unsatisfactory analysis results due to the fact that videotex service holding time may be very different from ordinary telephone holding time. Intuitively, we can still obtain satisfactory results if videotex service arrival rate is small with respect to ordinary telephone arrival rate. An example of traffic matrix is given in Table 6.1.

6.2.2 Traffic carried on a path:

Let $\underset{\sim}{y}$ be the vector of link blocking probabilities and $\underset{\sim}{x}$ the corresponding vector of linking probabilities ($x_i = 1-y_i$). The link blocking probabilities are a very complicated function of the traffic offered to the link. We shall show how under some simplifying assumptions such link blocking probability can be determined. For the present discussion, we shall assume that the link probabilities are given and we wish to determine the traffic carried on a link.

Consider a link i in a path U_j between some S-D pair. According to the routing hierarchy, a call is only carried on path U_j if it finds all the previous paths $U_1, \ldots , U_{j-1}$ congested and that path U_j is available. We write:

$$\begin{aligned} \text{Traffic carried on path } U_j &= A \Pr (U_j \text{ used}) \\ &= A \Pr (U_1, \ldots , U_{j-1} \text{ congested}, U_j \text{ available}), \end{aligned} \qquad [6.1]$$

where A is the originating traffic between the S-D pair. The traffic which is carried on link i on path U_j is the traffic which finds all the links on U_j free. Conditioning on this event is [6.1], we may write the carried traffic on link i, c_i, as

TABLE 6.1: BUSY HOUR TRAFFIC MATRIX (IN CCS)

To From	A	B	C	D	E
A		200	150	250	50
B	375	350		200	40
C	125	300		325	20
D	200	60	60		20
E	40	30	10	20	

$$c_i = A \Pr (U_1, \ldots , U_{j-1} \text{ congested} \mid U_j \text{ free}) \quad \Pr (U_j \text{ free}) \qquad [6.2].$$

If the links in U_j up to i are elements of link set L_1, then

$$\Pr (U_j \text{ free}) = \sum_{k \in U_j} x_k$$

Next, consider the first factor in Eqn. [6.2]. The given condition "U_j free" can be achieved by letting the blocking probabilities of all links to i in U_j be zero, or equivalently, by removing the links in the link set U_j. We assume that this has been done prior to the evaluation of the first factor in [6.2]. Then the problem is to determine

$$\Pr (U_1, U_2, \ldots U_{j-1} \text{ all congested}).$$

If the sets U_1, U_2, ...U_{j-1} are disjoint, i.e., without overlapping links, then we have

$$\Pr (U_1, U_2, \ldots U_{j-1} \text{ all congested}), \qquad [6.3]$$
$$= \Pr (U_1 \text{ congested}) \ldots \Pr (U_{j-1} \text{ congested})$$

where each factor may be evaluated by

$$\Pr\,(U_k \text{ congested}) = 1 - \sum_{i \in U_k} x_i \qquad [6.4]$$

For the general case where $U_1, \ldots U_{j-1}$ have some overlapping links, the calculation of [6.3] is a much more complicated problem, particularly if j is large. Fortunately, the problem can be reduced to that of system reliability analysis, therefore can be solved by one of several existing techniques [13.3]. To see this, let us write [6.3] as

$$\begin{aligned} &\Pr\,(U_1,\, U_2, \ldots U_{j-1} \text{ all congested}) \\ &\quad = 1 - \Pr\,(\text{at least one of } U_1,\, U_2, \ldots U_{j-1} \text{ is available}). \end{aligned}$$

Then, the crux of the problem is to evaluate

$$\Pr\,(\text{at least one of } U_1,\, U_2, \ldots U_{-1} \text{ is available}), \qquad [6.5]$$

The evaluation of [6.5] is immediately recognized as the same problem encountered in system reliability analysis [13.3]. This identification is important because it enables us to apply many of the recent results in that field [13.3].

6.2.3 A One-Moment Method for Calculating Node-to-Node Grade of Service:

Consider a telephone network for which the following information is given:

(a) Network configuration:

- link-node incidence relationships;
- link sizes (number of channels in each link).

(b) Routing table.

(c) Traffic matrix (node-to-node).

A one-moment method of analysis is one in which all the streams of traffic in a network are characterized by their first moments, i.e., their mean. The standard assumptions can be briefly stated as follows:

(1) An origin exchange is offered Poisson traffic for each destination.

(2) Call holding times are independent with exponential distribution function.

(3) The network is in statistical equilibrium.

(4) Each exchange has full access to outgoing trunks.

(5) Negligible call set-up times.

(6) Blocked calls are cleared (BCC) and do not return.

(7) The occupancy distributions of all trunk groups are mutually independent.

(8) The total offered traffic to a link is a Poisson process being the superposition of a number of (independent) Poisson processes.

With respect to a single link, this assumption implies that the offered, overflow and carried traffics are all Poisson. This results in the link appearing as a two-state system, each call being in effect allocated to the overflow or carried streams with fixed probabilities. We shall now develop a method for calculating the node-to-node grades of service.

First, define the following notation:

$\underset{\sim}{y}$ - vector of link blocking probabilities;

$\underset{\sim}{x}$ - vector of link availabities $x_i = 1-y_i$;

$\underset{\sim}{c}$ - vector of link carried traffics;

$\underset{\sim}{a}$ - vector of link offered traffics.

Before calculating the node-to-node grade of service, it is necessary to determine $\underset{\sim}{y}$ with the information given by (a) - (c) above. The unknown $\underset{\sim}{y}$, $\underset{\sim}{c}$ and $\underset{\sim}{a}$, are related by a system of non-linear functional equations. If the link blocking probabilities are known, then we can determine the link carried traffic as in Section 6.2. Thus, we write symbolically:

$$\underset{\sim}{c} = F_1 (\underset{\sim}{y}) \quad [6.6].$$

For each link, the offered traffic, the carried traffic are related by

$$c_i = a_i (1-y_i), \; i = 1, 2, \ldots , L$$

where L is the number of links in the network.

We can write

$$a_i = \frac{c_i}{1-y_i}, \quad i = 1, 2, \ldots L$$

or more compactly

$$\underset{\sim}{a} = F_2 (\underset{\sim}{c}) \quad [6.7].$$

Under the assumptions 1-8, the call arriving on each link is a Poisson process. Therefore, we can use Erlang's loss formula to determine the link blocking probability [13.5]:

$$y_i = \frac{a_i^{N_i} / N_i\,!}{\sum_{k=0}^{N_i} (a_i^k / k!)}, \quad i = 1, \ldots L$$

where N_i is the number of trunks in the i^{th} link. We can write

$$\underset{\sim}{y} = F_3 (\underset{\sim}{a}) \qquad [6.8]$$

Equations [6.6], [6.7] and [6.8] constitute the set of non-linear equations characterizing the network in steady state. It is impossible to obtain closed form solution of $\underset{\sim}{y}$, $\underset{\sim}{c}$ and $\underset{\sim}{a}$: an iterative procedure must be used to solve the non-linear equation. We have chosen the fixed-point algorithm. From [3.6], [3.7] and [3.8] we have,

$$\underset{\sim}{y} = F_3 (\underset{\sim}{a}) = F_3 (F_2(F_1(\underset{\sim}{y}))) = F (\underset{\sim}{y}) \qquad [6.9]$$

The iterative procedure is compactly described by the recursive formula:

$$\underset{\sim}{y}_{n+1} = F (\underset{\sim}{y}_n), \; n = 0, 1, 2, \ldots$$

The iteration is carried out until the differences between all the corresponding entries in $\underset{\sim}{y}_{n+1}$ and $\underset{\sim}{y}_n$ are smaller than some prescribed error. The final result $\underset{\sim}{y} = \underset{\sim}{y}_n$ is considered to be the solution of Eqn. [6.9]. Once $\underset{\sim}{y}$ is found, the node-to-node grade of service can be determined using the relation:

$$\text{Node-to-node-grade-of-service} = 1 - \sum_j \Pr (P_j \text{ used}) \qquad [6.10]$$

where the P_j are the alternate paths for the node-to-node calls of the corresponding node pair. To evaluate $\Pr (P_j \text{ used})$ in Eqn. [6.10], we can use the method described in Section 6.2.2.

6.3 A Queueing Model for Packet-Switched Networks Evaluation:

Queueing models for networks analysis have been thoroughly discussed in an excellent review paper by F.A. Tobagi, M. Gerla, R.W. Peebles and

E.G. Manning [9.5]. These models are able to yield reasonable approximation to performance indices such as transit delay, packet loss probability, line and buffer utilizations, network throughput and so forth.

The simplest model of a network consists in treating each switch link as an independent M/M/1 or M/G/1. This depends upon whether or not it is reasonable to believe that the process of passing through a switch does not alter the basic Poisson nature of the traffic. Pioneering work was done in this area by Burke [10.2] and by Jackson [10.3].

Burke showed that the output of an M/M/1 queue is Poisson. Jackson extended this work to include feedback networks of N servers as well. If $\tilde{n} = (n_1, n_2, \ldots n_N)$ is the global state variable denoting n_i customers at server i, then the equilibrium probability distribution has a simple product form:

$$P(n_1, n_2, \ldots, n_N) = P(n_1)\, P(n_2) \ldots P(n_N)$$

where $P(n_i)$ is the marginal probability of finding n_i customers at server i, and is given by the simple M/M/1 formula. To apply Jackson's result, we must know the actual traffic arriving at server i. This is easily computed if we know the external arrival rate a_i and the customer branching probabilities, $b_{i,j}$. This yields a set of equations:

$$\lambda_j = a_j + \sum_{i=1}^{N} \lambda_i b_{ij}$$

The most general results have been derived by Basket <u>et al</u> [10.4]. They assume that there are N nodes, L classes of customers (such that each class may have different routing through the network and possibly different service time at a node), and four allowed node types which satisfy the Poisson output property and thus guarantee a product form solution. These are: type 1 - FCFS, M/M/1; type 2 - RR, M/G/1; type 3 - processor sharing M/G/∞; type 4 - LCFS, M/G/1. The network can be open for some class of customers and closed for others. The case of a completely open system is of special interest; it can be showed that

$$P(\tilde{n}) = \prod_{j=1}^{N} P_j(n_j)$$

where

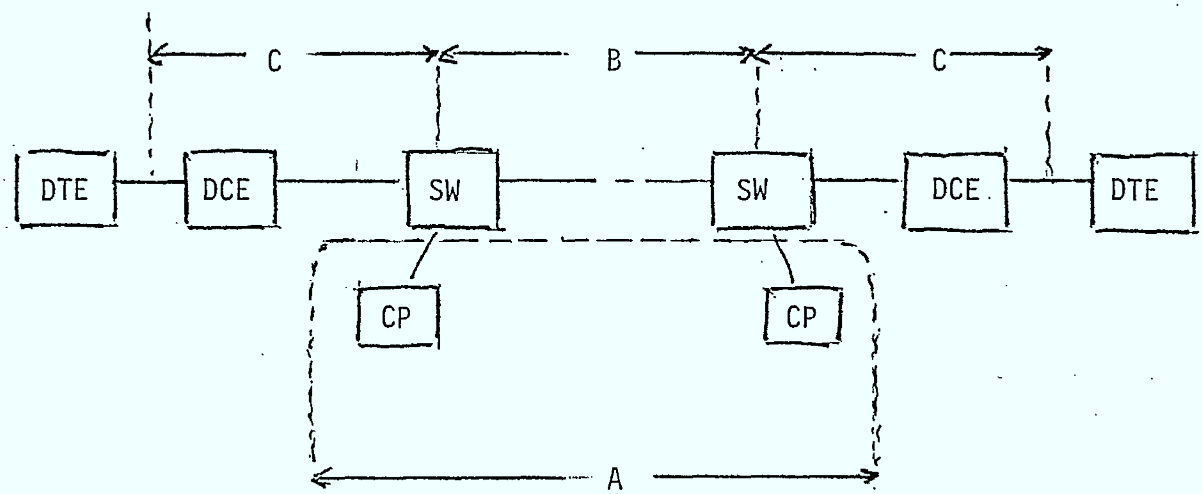
$$P(n_j) = \begin{cases} (1-P_j)\, P_j^{\,n_j}, & \text{for node types 1, 2, 4} \\ P_j^{\,n_j}\, e^{-P_j} / n_j!, & \text{for node type 3.} \end{cases}$$

That is, these rather complex systems (node types 1, 2 and 4) behave just like a set of connected but independent M/M/1 queues. Type 3 nodes behave like isolated M/G/∞ servers. This gives us very powerful tools for analytic modeling of computer networks and telecommunication services.

Some of the important problems cannot be handled by queueing modeling but must be handled by simulation. These are: dynamic storage allocation at a

FIGURE 6.1

A MODEL FOR COST ANALYSIS



DTE: Data terminal equipment

DCE: Data circuit terminating equipment

SW: Data switching equipment switching unit

CP: Data switching equipment call processing unit

A: Call connect cost

B: Call transmission cost

C: Subscriber facilities cost

switch which allows for variable size blocks; the flow of multiple customer classes through a node in which the classes have different service time distributions; state dependent customer routing and priorities.

6.4 Model for cost analysis

To assess the economical merit for the introduction of a new service or a new network architecture, a cost-benefit analysis must be carried out. For this, a communication cost model [9.6] must be introduced. The model is divided to three cost components and shown in Figure 6.1. Component A is called connect cost. It represents call processing cost and depends on call handling capacity of a processing unit. Component B is called transmission cost for a request, occupied while a call is established. Subscriber facilities cost represents cost for data circuit terminating equipment, subscriber circuit and the part of switching facilities constantly occupied by a subscriber. Considering this model, communication cost for a subscriber is determined as follows:

$$y = A\, c/h + B\, c + C \quad (1)$$

where

y = network cost per subscriber

h = call duration

c = traffic intensity per subscriber (i.e., sum of call durations within a time unit.

c/h = number of calls per subscriber

A = connect cost index

B = transmission cost index

C = subscriber facilities cost index

With these equations, network cost characteristics can be analyzed using these indices.

As an example, using suffixes 1 and 2 for two different network architectures, equation (1) for each network architecture can be described as follows:

$$y_1 = A_1 c/h + B_1 c + C_1$$

$$y_2 = A_2 c/h + B_2 c + C_2$$

Putting $y_1 = y_2$, cost boundary between two different networks can be derived as follows:

$$c = (C_2 - C_1) / [(A_1 - A_2)/h + (B_1 - B_2)]$$

When the traffic intensity is higher than c, the network architecture of configuration 2 is more favorable. It is pertinent to emphasize here that the cost indices A, B, C will depend on the service level that the network wants to maintain.

6.5 Computer Software for Telephone Network Performance Evaluation:

The performance of a telephone network is mainly determined by the link capacities (numbers of trunks in trunk groups) and node-to-node traffic loads (or traffic intensities). The performance evaluation problem consists in finding the following variables:

- Node-to-node grade of service (NNGOS, blocking probabilities).
- Link or trunk group grade of service.
- Average number of links used per call.
- Trunk group carried load.
- Trunk group offered load.

The method of performance evaluation adopted is the one-moment method proposed by P.M. Lin et al [13.1]. This method requires intensive computing which can be programmed on a digital computer. We have modified and implemented a computer program developped by Lin et al [13.6] in such a way that it may be applicable to any telephone network. Tests have been done to verify our computer program using data from the European Autovon Network. Much of the work required for implementation of the computer program has been: (i) modification to algorithms in the STARTUP program to accomodate the successive office control discipline adopted in conventional telephone networks and (ii) changes in computer codes for IBM machine.

The computer program can also perform automatic routing table updating: given a network configuration and a traffic matrix, update the existing routing table if any node-to-node grade of service exceeds the maximum allowable value. Although routing table updating is not an objective of the present project, it is of potential future use for network design, especially it can be used to design a model of telephone networks (see section 7.3).

Although the one-moment method proposed by Lin et al [13.1] is based on a number of reasonable assumptions, the results obtained from this method should be validated. Our efforts in designing an event driven simulator has met with considerable success. We have found that it is relatively simple to develop a simulation program which can simulate any telephone network. The simulator can be used to validate the one-moment model and other mathematical models or to predict telephone network performance. The design objectives of the simulator are the following:

From its principal inputs namely the traffic intensity matrix, the links capacity matrix and the routing control table, the simulator generates a series of route-trees for all origin-destination node pairs. Arriving calls are routed to destination nodes following the route-trees. Network initial state can be inputted by the user or automatically generated by the simulator To accelerate computer running time to reach the steady state, the simulator chooses the initial state by applying the one-moment method proposed by Lin et al (1). Standard network performance indices such as link blocking propabilities and various grades of service are outputted by the simulator. Distribution of offered and carried traffic on each links are provided on demand. Network states can be displayed by sampling at demanded intervals of time.

The implémentation of the simulator is in progress.

7. MODEL FOR PERFORMANCE EVALUATION OF LOCAL TELEPHONE NETWORKS:

7.1 Reasons for Studying Local Telephone Networks:

The basic problem of evaluating the impact of a videotex service on a telephone network is to calculate the node-to-node grade of service when the traffic matrix is modified as a result of the introduction of the videotex service. The traffic matrix may be considered as a sum of two traffic matrixes of which one is generated by normal telephone exchange and one by videotex calls. We may write the traffic matrix conceptually as

$$\underset{\sim}{A} = \underset{\sim}{A}_1 + \underset{\sim}{A}_2$$

where A_1 is telephone traffic matrix and A_2 is the videotex traffic matrix.

If $\underset{\sim}{A}_1$ and $\underset{\sim}{A}_2$ are known and if all link capacities of the telephone networks are given, we can apply the method developed in Section 3 to evaluate the telephone network performance. However, the evaluation problem for a national telephone network with a national videotex service taken as a whole is a formidable one due to its complexity and the enormous amount of data required. We must, at least at first, concentrate our attention on a local geographical region of the network and to the local videotex service. In doing this, we must make following assumptions:

(i) Major videotex service demands will be essentially local so that it affects significantly only the local telephone network.

(ii) Traffic exchange between nodes far apart is negligible with respect to local exchange traffic.

These two assumptions imply that we can divide a telephone network such as a national one into a number of regional networks which are approximately closed in the sense that the traffic entering and leaving a regional network is small with respect to its internal traffic. This division of a network into approximately independent subnetworks should be done in consideration of all node-to-node traffic. Unfortunately, complete data on traffic between node pairs are not available, therefore, for the time being, we must rely on our intuition and judgement.

Telephone networks are hierarchically structured such that nodes are assigned to classes [13.4]. The central office trunking entities at which telephone loops are terminated for purposes of interconnection to each other and to the network are called "End Offices" and are designated as class 5 offices.

The switching centers which provide the first hierarchical stage of concentration for network traffic originating at end offices and the final stage of distribution for traffic terminating at end offices are called "Toll Centers" or "Toll Points" and are designated as class 4. The class 4 switching nodes connect a grouping of end offices to each other and to the network. Certain switching centers, in addition to connecting a grouping of end offices (class 5) to each other and to the network, are selected to serve higher level switching functions on the basis of overall network economics. Those levels are: Primary Centers designated as class 3, Sectional Centers designated as class 2 and Regional Centers designated as class 1. Collectively, the class 1, 2 and 3 nodes (switching systems) constitute the control switching points (CSP) of the call routing for distance dialing. It is important to note that higher level switching systems (nodes) can also perform lower level switching functions.

This systematic grouping of switching centers results in a similar grouping of the areas they serve. Each regional center (class 1) serves a large area known as a Region (there are two regional areas in Canada). Each region is subdivided into smaller areas known as sections: the principal switching system in the section is the sectional center (class 2). The section is still rather large and it, too, is further divided into smaller parts known as primary areas, each of which is served by a primary center (class 3). The remaining centers that do not fall into these categories are the toll centers (class 4) and end offices (class 5). Traffic between any node pair is first routed to a high-usage trunk group (link). Overflow traffic from the last high-usage trunk is offered next to a final trunk group.

Figure 7.1 presents a global view of the telephone network in which

FIGURE 7.1: AN EXAMPLE OF HIERARCHICAL TELEPHONE NETWORK

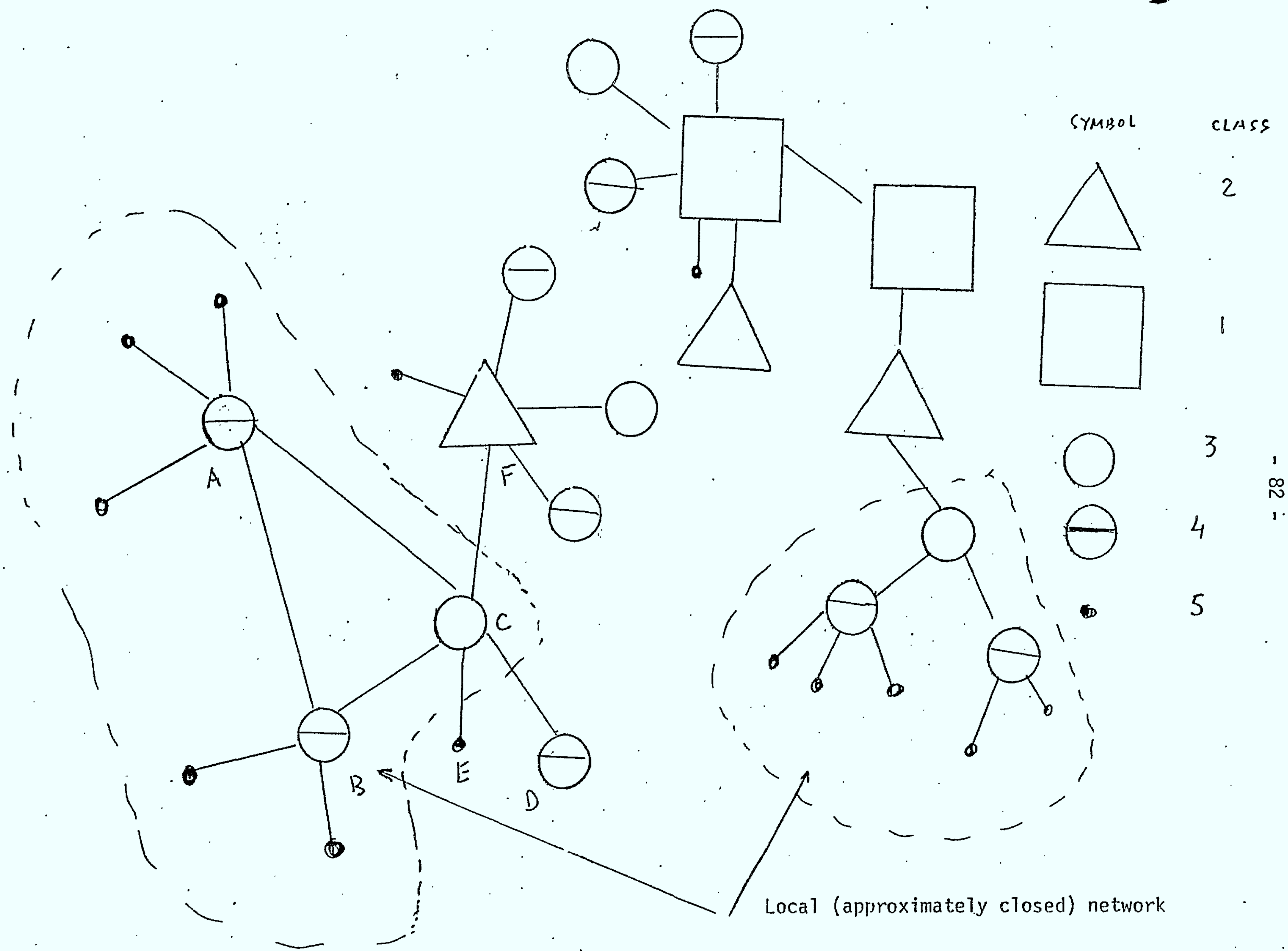
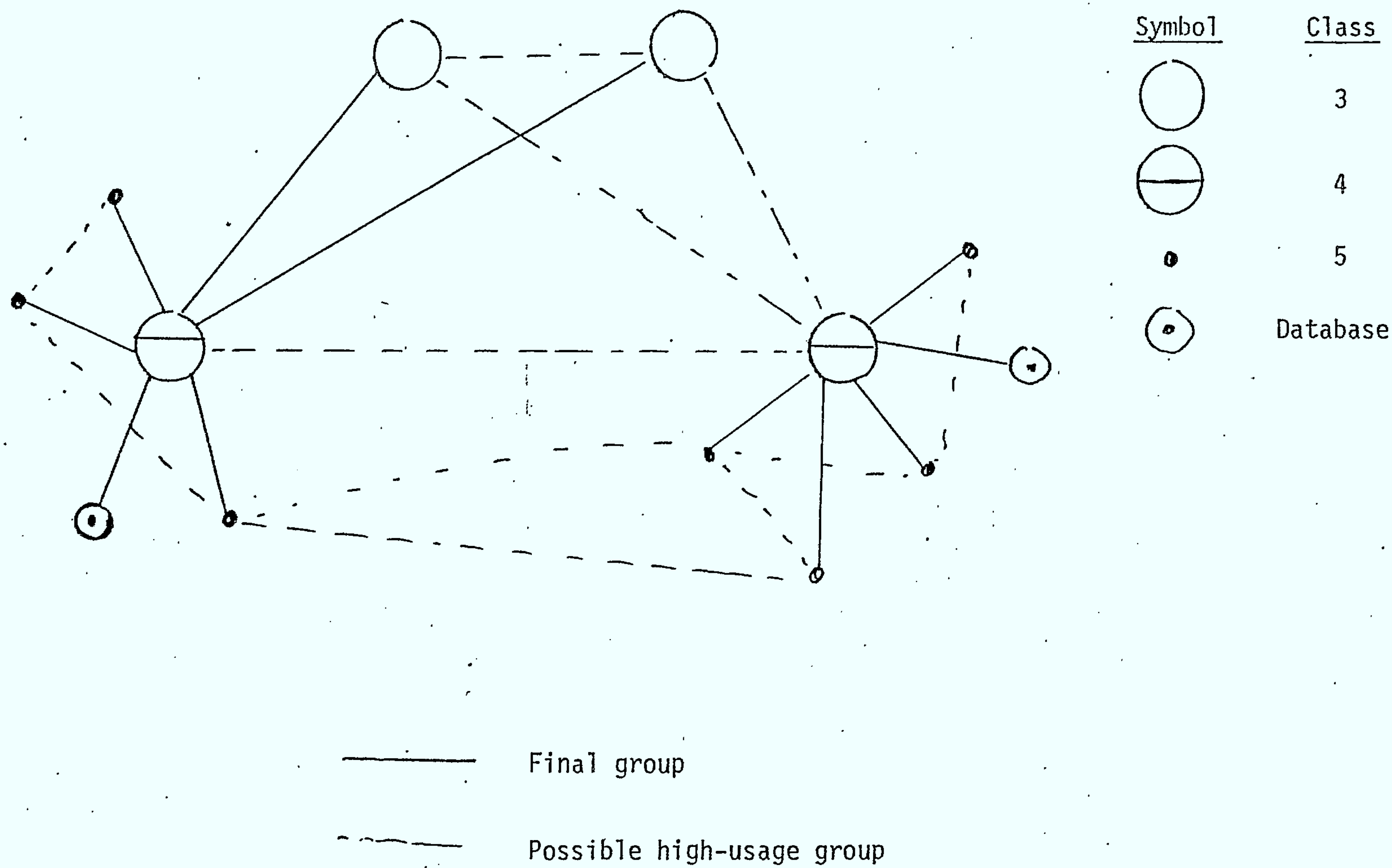


FIGURE 7.2: AN EXAMPLE OF LOCAL NETWORK



only final trunk groups are shown. A subnetwork such as those encircled by a dashed line can be approximately closed in the sense that incoming and outgoing traffic is negligible with respect to internal traffic. We will consider such a subnetwork as one which represents a metropolitain region such as Ottawa or Quebec City. Such subnetworks will serve for our initial modeling of local telephone network. An example of such a network is the one consisting of nodes A, B, C and all nodes linked to A and B. By our assumption, nodes such as D or E do not significantly affect the subnetwork considered and can be ignored (see Figure 7.1).

7.2 A Prototype of Local Network:

Consider a metropolitain region that is sufficiently large so that traffic entering and leaving it is negligible with respect to traffic within the region. Some reflection shows that such a region would have about two class 4 offices and about twenty to thirty class 5 offices. The videotex databases serving the region could be conveniently designed as isolated class 5 offices. The capacities of high-usage and final trunk groups are assigned so that the node-to-node grades of service are kept at reasonable levels. An example of local networks of our concern is shown in Figure 7.2. Such local networks can be analysed using the method described in Section 6.2 if the network configuration (number of trunks in each groups together with identification of all trunk groups and their routing functions) and the traffic matrix are known. Unfortunately, such information is the private property of telephone companies and may not be easily accessible. A remedy to this difficulty is to build a model of a network based on statistical assumptions. Some variables which must be taken into account when modeling a local network are:

(i) distribution of the population;

(ii) distribution of commercial and residential area telephone networks;

(iii) design objectives of telephone company (e.g., end-to-end grade-of-service is 0.01).

Variables (i) and (ii) may help to estimate call arrival patterns from node-to-node, which together with assumed mean holding times (approximately 3 minutes), can yield estimates of node-to-node traffic intensities. Variable (III) - the telephone company's target grade of service - together with estimates of traffic intensities, may help to estimate trunk groups (links) capacities. For example, consider a simple network consisting of only one trunk group. Knowing the traffic intensity in this trunk group and assuming a 0.01 blocking probability, we can use the well-known Erlang loss formula to estimate the number of trunks in this trunk group. For more complex networks, the estimation would be more complicated but the method remains the same.

It is important to note that database locations may dictate the inclusion of certain parts of the network, but not all, into the modeling process. For example, if the videotex databases are located at isolated class 5 offices, then videotex traffic will have impact only on class 5 final trunk groups but not on class 5 high-usage trunk groups. This means that, in studying the impact of videotex service on telephone networks, we may ignore all high-usage trunk groups connecting class 5 offices.

7.3 Modeling of Local Telephone Network Configuration and Traffic:

The important inputs for analysis of network performance are:

(i) The configuration of a typical local telephone network: number of class-4 and class-5 offices, high-usage trunk groups, final trunk groups, and number of trunks in each trunk group.

(ii) Telephone traffic matrix: all node-to-node traffic intensities of present or anticipated telephone subscribers, arrival rates and average telephone holding time.

(iii) Characteristics of videotex services: user request rate in number of pages per request, transmission and access times (at data base) per request, user holding time, etc.

(iv) Locations of data bases.

The above input information cannot be derived purely from theoretical considerations but must be estimated from data. Data concering (i) and (ii) may be available from telephone companies and their cooperation in providing them is necessary. Bell Canada has indicated willingness to provide such data in the near future. Data concerning (iii) can be inferred from the Vista pilot project where user request rate and holding time can be observed. Transmission and access times are obtainable from the characteristics of the services offered by videotex facilities. At the present time, little information is available so that crude extrapolation from available data will have to be made. The locations of the data bases can be determined from network and traffic characteristics. Optimal choices for data base locations can be made with the aid of analysis tools that we have developed once telephone network characteristics and videotex service characteristics become available or when they can be estimated.

An alternative approach to the problem of obtaining hard data on the telephone networks is to model them. Using exogenous variables such as subscribers population, industrial and commercial offices distributions, together with a knowledge about typical busy hour traffic and about usual telephone companies' network design practice, we can build a realistic model for a typical local network. Some of this knowledge is summarized in Table 7.1. These include typical data concerning average busy hour traffic, average number of subscribers per class 5 office, typical number of interoffice trunks per trunk group, average urban loop length and trunk length.

TABLE 7.1 SOME DATA ON TELEPHONE NETWORK AND TRAFFIC*

1.	Average busy hour traffic: -	
	Resident	3.6 ccs
	Business	5.5 ccs
	Data terminal	≈10.0 ccs
2.	Ratio of inter versus intra office calls	50:50
3.	Average number of subscribers per C5 office	15,000
4.	Typical number of interoffice trunks	1,500
5.	Business lines versus residential lines: -	
	Urban	60% business lines
		40% residential lines
	Suburban	20% business lines
		80% residential lines
6.	Average urban loop lengths	~ 2 miles
	Maximum urban loop lengths	~ 5 miles
7.	Average trunk lengths (between C5's)	~ 5 miles

Source: Data obtained from consultation with specialists in North American telephony.

The principle which can be used in modeling a telephone network is the following: using our knowledge about number of subscribers per class 5 office and the maximum loop length and average trunk length, we can devide an urban local region into a number of zones - each of which is served by a class 5 office. Characteristics of these zones are established using data about geometrical distribution of commercial and residential subscribers. Node-to-node traffic intensities can be generated taking into account the zones' characteristics and geographical locations. Following common practice of telephone network design, we can generate the trunk groups (links) and assign capacities to trunk groups - this modeling process will be carried out in an iterative fashion until a typical telephone network with a typical performance is obtained. Consulation with experts and telephone companies will be sought in order to arrive at a representative model for local telephone networks.

8. EUROPEAN AUTOVON NETWORK EXAMPLE:

In this section we will apply some of the methods and tools that we have developped in this report to the European Autovon network. The reason for choosing this network to illustrate our methodogy is that it is the only network from which real data are available to us.

8.1 NETWORK CONFIGURATION:

The European Autovon is a circuit-switched network employing a routing strategy called "originating office control with spill forward". For the purpose of network performance evaluation, the European Autovon network can be modeled by the graph of Figure 8.1. The network topology is comprised of 10 nodes plus the CONUS Gataway node and 26 links (including the three links to CONUS Gataway) interconnecting the various offices. Each of the 11 nodes in the model is assumed to be perfectly reliable (blocking probability =0) and that it takes negligible time for the control equipment in the offices (nodes) to establish originating, terminating, or tandem calls. On the other hand, the 26 links are modeled on the basis of their capacity, and then availability for use is therefore considered probabilistic. The capacity of each link is given in Table 8.1. The network routing table (1) is depicted in Table 8.2.

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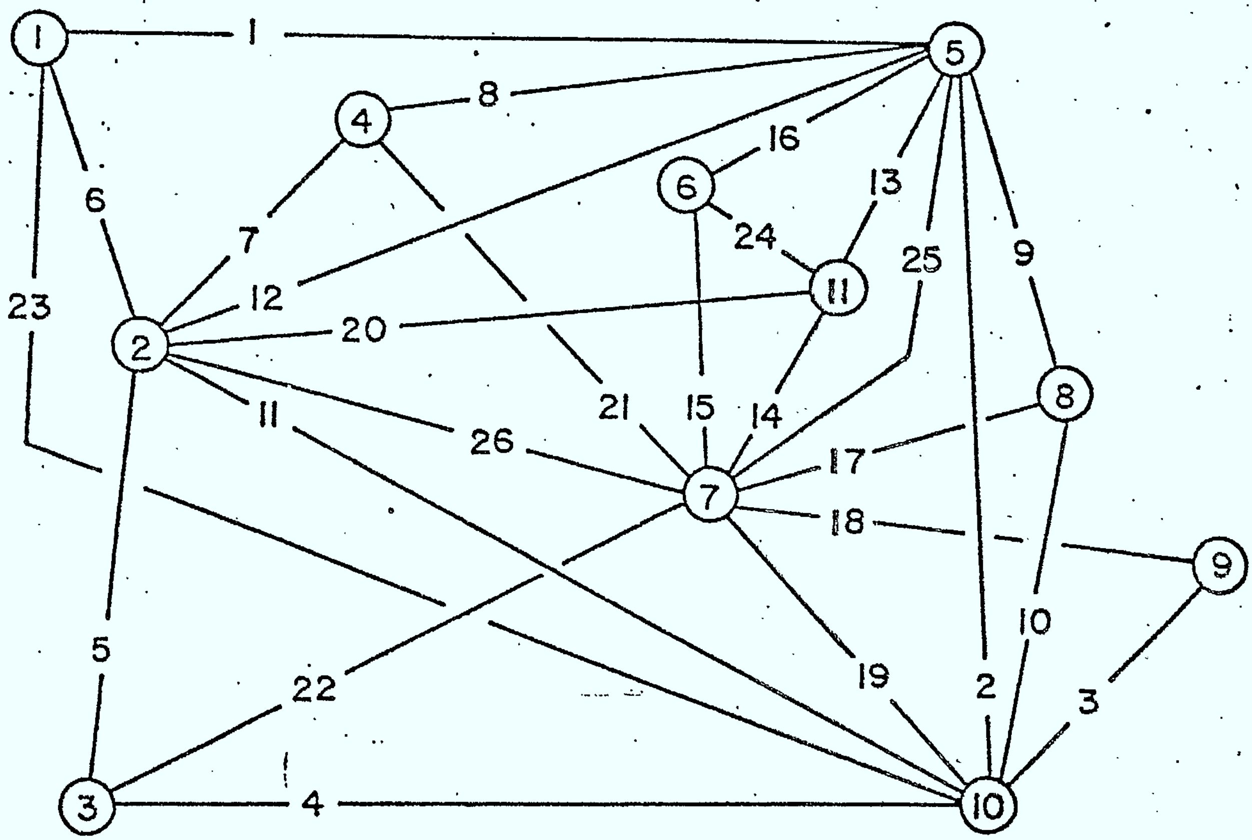
(1) Based on July 1974 Autovon data.

FIGURE 8.1.

European AUTOVON Network



Node 1 -- CONUS Gateway (CON)

Node 2 -- HILLINGDON (HIN)

Node 3 -- HUMOSA (HUM)

Node 4 -- MARTLESHAM HEATH (MAM)

Node 5 -- FELDBERG (FEL)

Node 6 -- SCHOENFELD (SCH)

Node 7 -- DONNERSBERG (DON)

Node 8 -- COLTANO (CTO)

Node 9 -- ATHENS (ATH)

Node 10 - NAPLES (NPS)

Node 11 - LANGERKOFF (LKF)

TABLE 8.1

Trunk group information for the European AUTOVON network

LINK NUMBER	TERMINAL NODE NUMBERS	NUMBER OF TRUNKS
1	1 - 5	36
2	5 - 10	20
3	9 - 10	17
4	3 - 10	18
5	2 - 3	10
6	1 - 2	22
7	2 - 4	34
8	4 - 5	10
9	5 - 8	11
10	8 - 10	9
11	2 - 10	7
12	2 - 5	15
13	5 - 11	30
14	7 - 11	34
15	6 - 7	12
16	5 - 6	13
17	7 - 8	12
18	7 - 9	7
19	7 - 10	15
20	2 - 11	14
21	4 - 7	10
22	3 - 7	12
23	1 - 10	11
24	6 - 11	8
25	5 - 7	30
26	2 - 7	5

TABLE 8.2

Routing Table for European AUTOVON Network

From \ To	1	2	3	4	5	6	7	8	9	10	11
1		2,5	10,2	2,5	5,2	5,2	5,10	10,5	10,5	10,5	5,2
2	1,5,10		3,11,5	4	5,4	11,5	7,4,5	10,5	10,4	10,5	11,5
3	2,10*	2,10*		2,10*	7,10*,2	7,10*,2	7,10*,2	10*,7,2	10*,7	10*,2	7,10*,2
4	2,5	2	2,7,5		5,7	7,5	7,5	7,5	7,2,5	7,2,5	7,2,5
5	1,2,10	2,4	10,7,2	4,7		6,7	7,11	8,7	10,7	10,7	11,7
6	5,7*	11,5	7*,5	7*,5	5,7*		7*,11,5	7*,5	7*,5	7*,5	11,7*,5
7	5,2,10	2,4,5	3,10,5	4,2,5	5,11	6,11,5		8,5	9,8,10	10,8,5	11,5
8	10,5	10,5	10,7	7,5	5,7	7,5	7,5		10,7	10,5	7,5
9	10*	10*	10*	10*	7,10*	7,10*	7,10*	10*		10*	7,10*
10	1,5,2	2,5	3,2,7	7,2,5	5,7	7,5	7,8,5	8,5	9		7,5
11	5,2	2,5	7,5,2	7,2,5	5,7	6,7,5	7,6,5	7,5	7,5	7,5	

8.2 PERFORMANCE EVALUATION OF AUTOVON:

On the basis of the trunk group information (Table 8.1), the routing table (Table 8.2) and the traffic matrix for "routine level", (see Table 8.3), performance evaluation of Autovon can be done.

Performance data are shown in the Appendix. Performance Developments of a trunk group is given principally by "Trunk Group Actual GOS" which is the trunk group blocking probability. Offered traffic to a trunk group is given by "Offered Load". These informations are important for identifying bottlenecks in the network. For example, links 1, 7 and 23 are important bottlenecks because these blocking probabilities are high and offered traffic to them is also high.

The most important performance indices are the source-to-destination blocking probabilities given on pages A11 to A13.. Also given are the source-to-destination weights blocking probabilities which are equal to the source-to-destination probabilities multiplied by weight factors. The weight factors are chosen in relation to users' considerations with respect to the source-destination pairs. To emphasize certain origin-destination pairs, one assigns weight factors greater than one to them, and to de-emphasize an origin-destination pair, one assigns a weight factor less than one to it.

The weight factors allow us to compare all node-to-node grades of service in a uniform way. For Autovon, the distribution of all source-to-destination grades of service (blocking probabilities) is shown in Figure 8.2. It can be seen that most source-to-destination grade of service are good (less than 0.0[illegible]). However, it is not true that most users experience good grade

TABLE 8.3

"Routine" Traffic in CCS for the European AUTOVON Network

From \ To	1	2	3	4	5	6	7	8	9	10	11
1		131	138.	111.	864.	59.4	993.	23.4	126.	256.	697.
2	131.		32.4	216.	144.	7.2	25.2	3.6	14.4	25.2	95.4
3	139.	25.2		43.1	112.	39.6	12.6	10.8	46.8	39.6	72.
4	112.	205.	25.2		245.	9.	9.	10.8	12.6	10.8	81.
5	864.	43.2	57.5	57.5		59.5	126.	39.6	72.	16.2	190.
6	59.4	9.	36.	21.6	205.		72.	23.4	7.2	1.	90.
7	993.	33.4	37.8	16.2	230.	28.8		23.4	30.6	19.8	155.
8	23.4	3.6	10.8	14.4	57.6	3.6	43.2		18.	39.6	43.2
9	126.	7.2	39.6	14.4	140.	3.6	21.6	25.2		43.2	55.7
10	256.	14.4	36.	7.2	46.8	1.	7.2	86.4	46.8		18.
11	697.	46.8	72.	72.	313.	36.	190.	50.4	48.6	25.2	

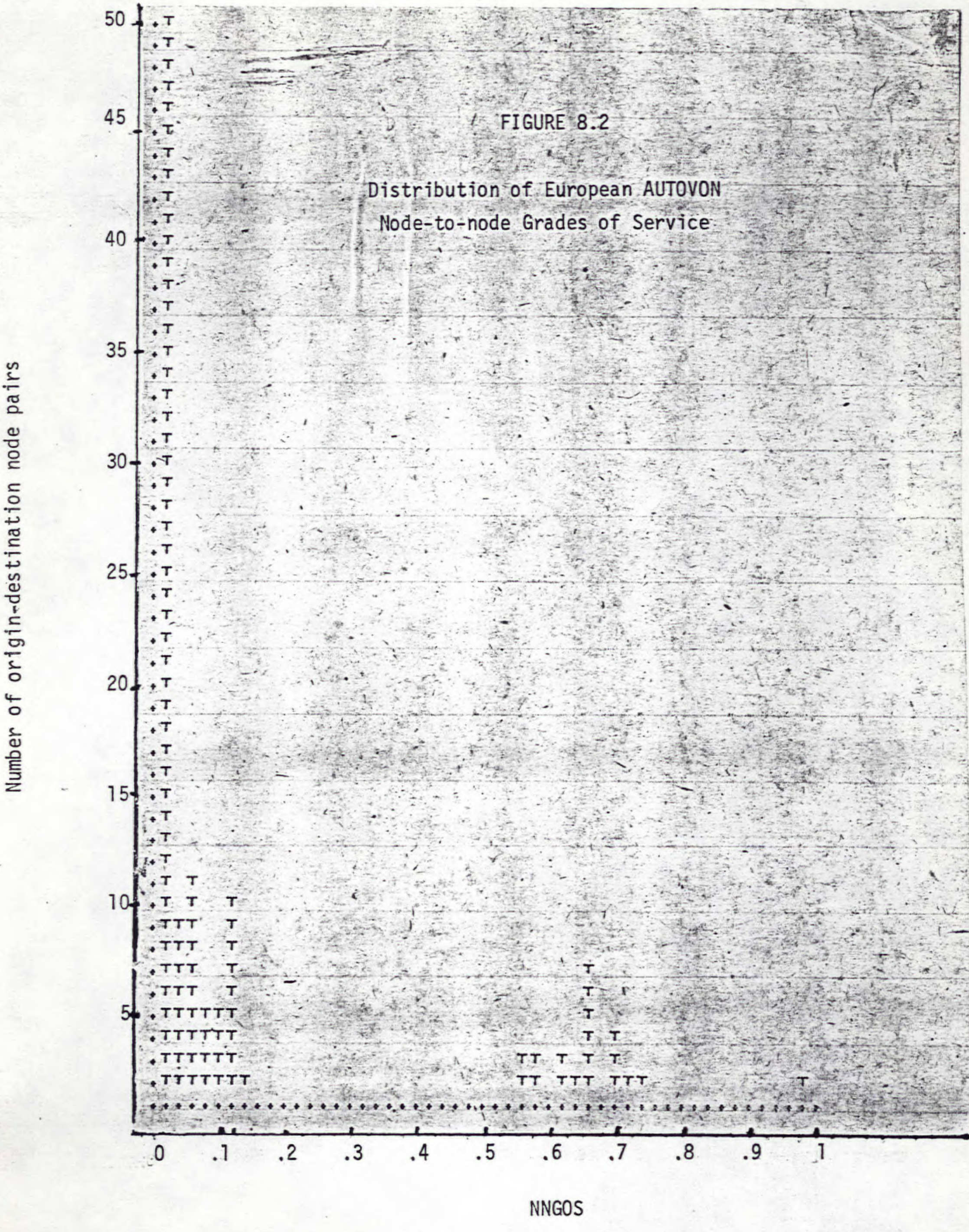


FIGURE 8.2

Distribution of European AUTOVON Node-to-node Grades of Service of service. In fact, in European Autovon, most users experience a bad grade of service. This can be seen from the indice "network grade of service" which is defined as the probability that a call coming from any origin is blocked from the network. For European Autovon, the network grade of service is .37 (or 37%). This is because of the fact that, although a majority of source-to-destination grades of service are good, those bad grade of service ($\geq .1$) belong to origin-destination node pairs which have large traffic intensity.

8. Impact of Increased Traffics on European AUTOVON

Let us assume that a new telecommunication service is introduced into European AUTOVON Networks and that this introduction induces an increase in traffic by a non-negligible factor. We will assume for simplicity that all origin-destination traffics are increased by the same factor.

Figure 8.3 shows the distribution of node-to-node grades of service (NNGOS) when the traffic in AUTOVON is increased by 20%. Comparing with Figure 8.2, we can see that most NNGOS now shift two the right and vary from 0.08 to 0.92, which means that network performance degrades significantly. The overall network grade of service (blocking probability) increases from 0.37 to 0.64 when the traffic increases by 20%; a performance degradation by 70%.

Figure 8.4 shows the distribution of NNGOS when network traffic increases by 40% with respect to "routine" level. The distribution shifts further to the right with respect to the situation in Figure 8.2 and most NNGOS are greater than 0.40. The overall network blocking probability is 0.75 in comparison with 0.37 corresponding to "routine" traffic level.

Figure 8.5 shows the increase in network grade of service as a function of traffic increase factor. It can be seen that network grade of service increases very rapidly and approaches the asymptotic value (1.00) when the increase factor approaches 100%.

FIGURE 8.3

AUTOVON's Grade of Service when traffic
increases by 20%

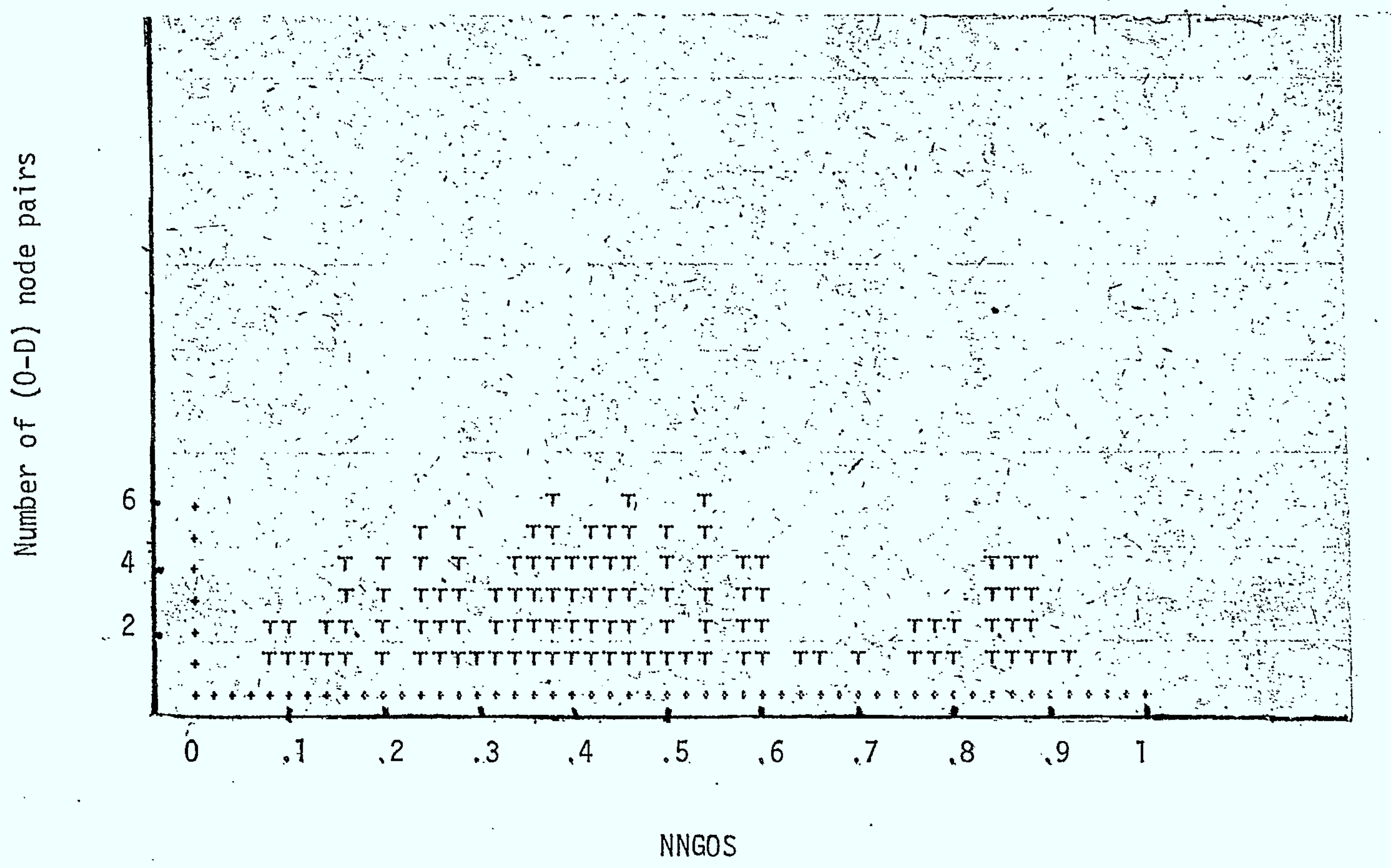


FIGURE 8.4

AUTOVON's Grade of Service when traffic increases by 40%

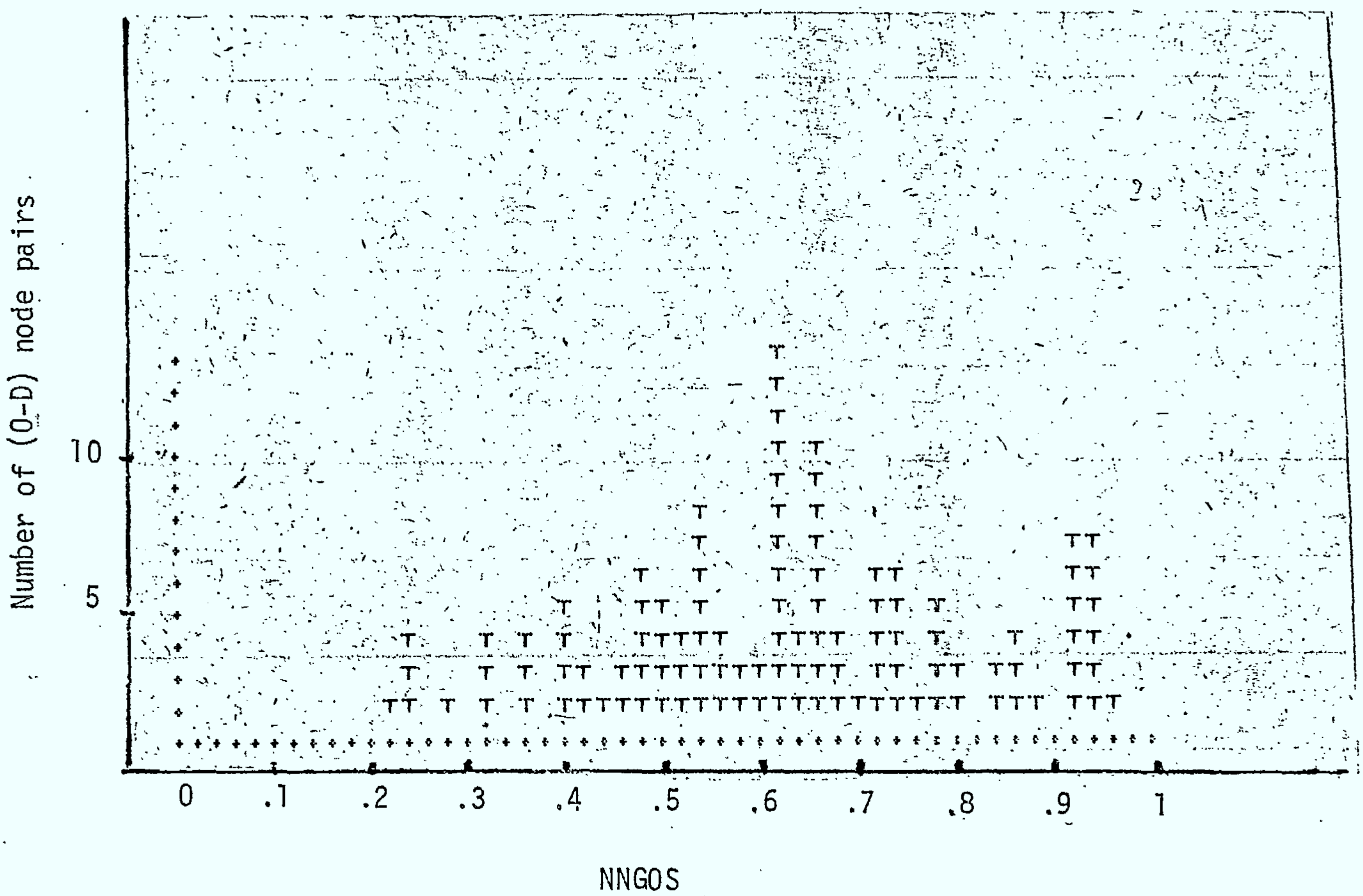
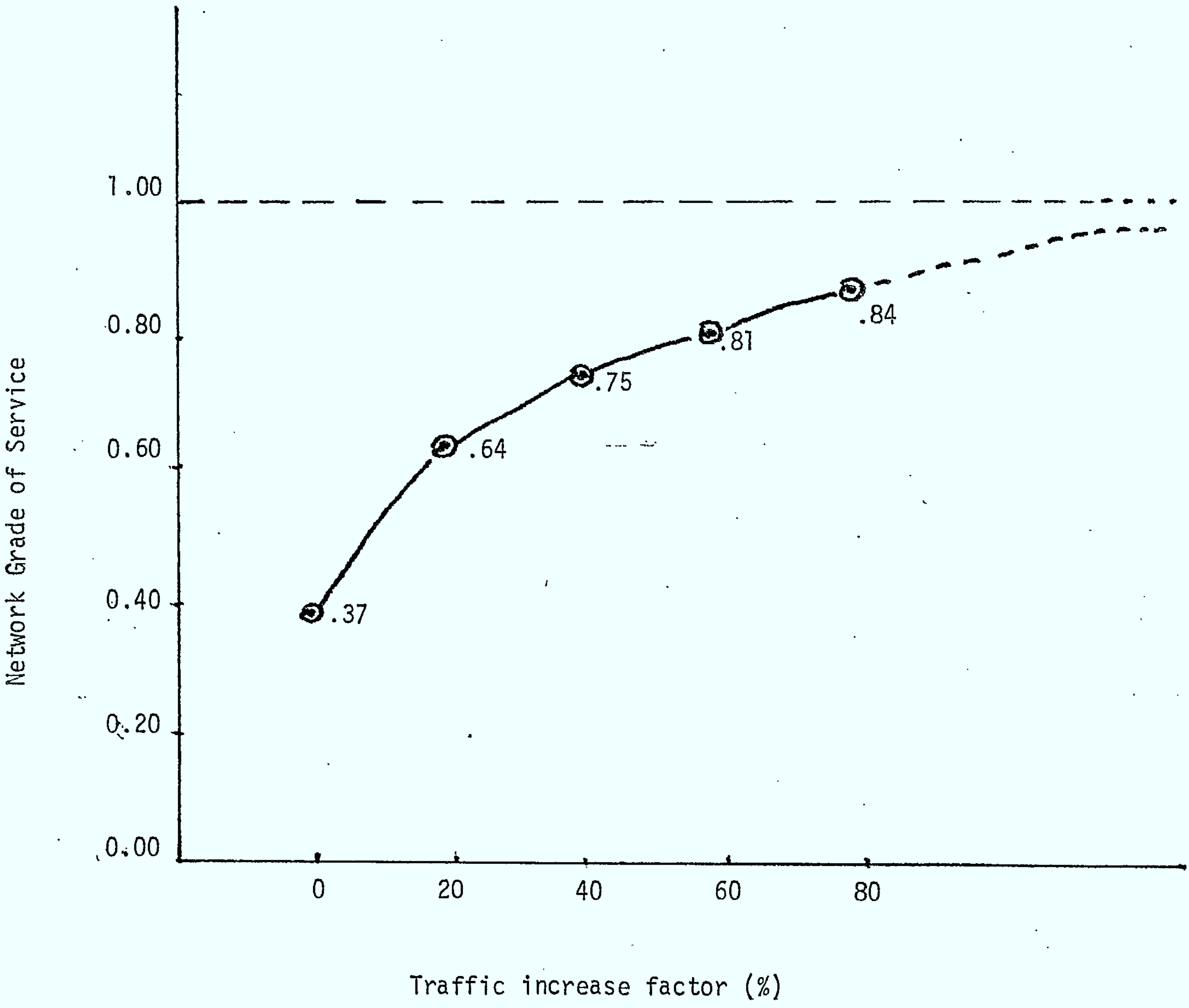


FIGURE 8.5

Network Grade of Service versus increase in traffic



We have seen that European AUTOVON Network performance degrades quite drastically when traffic level increases. This is because at "routine" level, its performance is already critical, with an overall network blocking probability of 0.37. Commercial telephone networks possess a much better grade of service which is usually less than 0.01. Nevertheless, one can expect significant degradation in grade of service when additional traffic is introduced into the networks. As a rule of thumb, one can expect that performance degradation rate is much faster than traffic increase rate and that the degradation rate is exponential rather than linear or polynomial.

9. CONCLUSION:

In this report we have laid a sound basis for evaluating technical and economic impacts of the introduction of new services on existing telecommunication networks. After a brief survey of planned new services such as Videotex, COSPRO, Electronic Fund Transfer System and Electronic Mail, we proposed methods for networks and service characterization. This allowed us to state the problem of evaluating the impact of new services as a network performance evaluation problem with respect to the additional workload generated by new services. For packet-switched networks, the performance measure to be studied is the so called "service level" and for circuit-switched networks, it is the "grade of service". We then developped models and tools for network performance evaluation. We argued that the videotex service and local telephone networks should be studied first. We then showed how a realistic model of local telephone network can be constructed which can serve a basis for evaluating existing local telephone networks.

In essence, work done on this project lays the basis for its continuation: the basic analytical and simulation tools needed for telephone network performance evaluation have been developped and sufficient understanding of the local telephone network has been gained permitting the design of an "idealized" local network. This "idealized" network could then be taken as prototype for judging the impact of new services such as videotex. The authors feel that these two achievements are extremely important.

Concerning the problem of estimating the network loading parameters of new services, the authors foresee several methods to be explored in the continuation of this project. One would involve a simulation of videotex in the university environment which could give parameter value estimates useful for this subclass of videotex users. Various marketing research techniques are also being considered.

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APPENDIX

OUTPUT OF THE STARTUP PROGRAM

FOR EUROPEAN AUTOVON NETWORK

************************** EUROPEAN AUTODVON NETWORK ****************************

VERBATIM ACCOUNT OF INPUT DATA

```
1 1 1 1 0 CCS

11 26  .080 1.000  .010
 1 5  1        36
 510  2        20
 910  3        17
 310  4        18
 2 3  5        10
 1 2  6        22
 2 4  7        34
 4 5  8        10
 5 8  9        11
 810 10         9
 210 11         7
 2 5 12        15
 511 13        30
 711 14        34
 6 7 15        12
 5 6 16        13
 7 8 17        12
 7 9 18         7
 710 19        15
 211 20        14
 4 7 21        10
 3 7 22        12
 110 23        11
 611 24         8
 5 7 25        30
 2 7 26         5
 1 2  2  5  0131.00   .01
 1 3 10  2  0138.00   .01
 1 4  2  5  0111.00   .01
 1 5  5  2  0864.00   .01
 1 6  5  2  0 59.40   .01
 1 7  5 10  0993.00   .01
 1 8 10  5  0 23.40   .01
 1 9 10  5  0126.00   .01
 110 10  5  0256.00   .01
 111  5  2  0697.00   .01
 2 1 -1  5 10131.00   .01
 2 3  3 11  5 32.40 -0.00
 2 4  4  0  0216.00  0.00
 2 5  5  4  0144.00 -0.00
 2 6 11  5  0  7.20 -0.00
 2 7  7  4  5 25.20 -0.00
 2 8 10  5  0  3.60 -0.00
 2 9 10  4  0 14.40 -0.00
 210 10  5  0 25.20 -0.00
 211 11  5  0 95.40 -0.00
 3 1  2-10  0139.00   .01
 3 2  2-10  0 25.20 -0.00
 3 4  2-10  0 43.10 -0.00
 3 5  7-10  2112.00 -0.00
 3 6  7-10  2 39.60 -0.00
 3 7  7-10  2 12.60 -0.00
 3 8-10  7  2 10.80 -0.00
 3 9-10  7  0 46.80 -0.00
 310-10  2  0 39.60 -0.00
 311  7-10  2 72.00 -0.00
 4 1  2  5  0112.00   .01
 4 2  2  0  0205.00  0.00
 4 3  2  7  5 25.20 -0.00
 4 5  5  7  0245.00 -0.00
 4 6  7  5  0  9.00 -0.00
 4 7  7  5  0  9.00 -0.00
 4 8  7  5  0 10.80 -0.00
 4 9  7  2  5 12.60 -0.00
 410  7  2  5 10.80 -0.00
 411  7  2  5 81.00 -0.00
 5 1 -1  2 10864.00   .01
 5 2  2  4  0 43.20 -0.00
 5 3 10  7  2 57.50 -0.00
 5 4  4  7  0 57.50 -0.00
 5 6  6  7  0 59.50 -0.00
 5 7  7 11  0126.00 -0.00
 5 8  8  7  0 39.60 -0.00
 5 9 10  7  0 72.00 -0.00
 510 10  7  0 16.20 -0.00
 511 11  7  0190.00 -0.00
 6 1  5 -7  0 59.40   .01
 6 2 11  5  0  9.00 -0.00
 6 3 -7  5  0 36.00 -0.00
 6 4 -7  5  0 21.60 -0.00
 6 5  5 -7  0205.00 -0.00
 6 7 -7 11  5 72.00 -0.00
 6 8 -7  5  0 23.40 -0.00
 6 9 -7  5  0  7.20 -0.00
 610 -7  5  0  1.00 -0.00
 611 11 -7  5 90.00 -0.00
 7 1  5  2 10993.00   .01
 7 2  2  4  5 33.40 -0.00
 7 3  3 10  5 37.80 -0.00
 7 4  4  2  5 16.20 -0.00
 7 5  5 11  0230.00 -0.00
 7 6  6 11  5 28.80 -0.00
 7 8  8  5  0 23.40 -0.00
 7 9  9  8 10 30.60 -0.00
 710 10  8  5 19.80 -0.00
 711 11  5  0155.00 -0.00
 8 1 10  5  0 23.40   .01
 8 2 10  5  0  3.60 -0.00
 8 3 10  7  0 10.80 -0.00
 8 4  7  5  0 14.40 -0.00
 8 5  5  7  0 57.60 -0.00
 8 6  7  5  0  3.60 -0.00
 8 7  7  5  0 43.20 -0.00
 8 9 10  7  0 18.00 -0.00
 810 10  5  0 39.60 -0.00
 811  7  5  0 43.20 -0.00
 9 1-10  0  0126.00   .01
 9 2-10  0  0  7.20 -0.00
 9 3-10  0  0 39.60 -0.00
 9 4-10  0  0 14.40 -0.00
 9 5  7-10  0140.00 -0.00
 9 6  7-10  0  3.60 -0.00
 9 7  7-10  0 21.60 -0.00
 9 8-10  0  0 25.20 -0.00
 910-10  0  0 43.20 -0.00
 911  7-10  0 55.70 -0.00
10 1 -1  5  2256.00   .01
10 2  2  5  0 14.40  0.00
10 3  3  2  7 36.00 -0.00
10 4  7  2  5  7.20 -0.00
10 5  5  7  0 46.80 -0.00
10 6  7  5  0  1.00 -0.00
10 7  7  8  5  7.20 -0.00
10 8  8  5  0 86.40 -0.00
10 9  9  0  0 46.80 -0.00
1011  7  5  0 18.00 -0.00
11 1  5  2  0697.00   .01
11 2  2  5  0 46.80 -0.00
11 3  7  5  2 72.00 -0.00
11 4  7  2  5 72.00 -0.00
11 5  5  7  0313.00 -0.00
11 6  6  7  5 36.00 -0.00
11 7  7  6  5190.00 -0.00
11 8  7  5  0 50.40 -0.00
11 9  7  5  0 48.60 -0.00
1110  7  5  0 25.20 -0.00

CON KIN HUM MAM FEL SCH DON CTO ATH NPS LKF
```

USER SPECIFIED OPTIONS:

LIST OF PATHS REQUIRED: YES
DETAILS OF PATH RELIABILITY AND PATH CARRIED LOAD REQUIRED: YES

OPTION NUMBER FOR INITIALIZING ROUTING TABLE FOR REVISION= 1
(NOTES ON THE OPTION USED:
ALL SPILL SWITCHES OF THE ORIGNAL ROUTING TABLE ARE CONVERTED
INTO NON-SPILL SWITCHES BEFORE REVISION)

MAXIMUM ALLOWABLE BLOCKING PROBABILITY(BPMAX) .080

STEP SIZE OF PBPMAX REDUCTIONS= .010

GIVEN NETWORK IS AUTOVON

AN ATTEMPT TO IMPROVE CONUS TRAFFIC IS NOT REQUIRED

NETWORK DESCRIPTION

NUMBER OF SWITCHES IN NETWORK 11
NUMBER OF TRUNK GROUPS IN NETWORK 26

LINK NUMBER	SWITCH PAIR		EXISTING NUMBER OF TRUNKS
1	1 (CON)	5 (FEL)	36
2	5 (FEL)	10 (NPS)	20
3	9 (ATH)	10 (NPS)	17
4	3 (HUM)	10 (NPS)	18
5	2 (HIN)	3 (HUM)	10
6	1 (CON)	2 (HIN)	22
7	2 (HIN)	4 (MAM)	34
8	4 (MAM)	5 (FEL)	10
9	5 (FEL)	8 (CTO)	11
10	8 (CTO)	10 (NPS)	9
11	2 (HIN)	10 (NPS)	7
12	2 (HIN)	5 (FEL)	15
13	5 (FEL)	11 (LKF)	30
14	7 (DON)	11 (LKF)	34
15	6 (SCH)	7 (DON)	12
16	5 (FEL)	6 (SCH)	13
17	7 (DON)	8 (CTO)	12
18	7 (DON)	9 (ATH)	7
19	7 (DON)	10 (NPS)	15
20	2 (HIN)	11 (LKF)	14
21	4 (MAM)	7 (DON)	10
22	3 (HUM)	7 (DON)	12
23	1 (CON)	10 (NPS)	11
24	6 (SCH)	11 (LKF)	8
25	5 (FEL)	7 (DON)	30
26	2 (HIN)	7 (DON)	5

SWITCH-TO-SWITCH TRAFFIC

ORIGINAL ROUTING TABLE

FROM	TO	TRAFFIC IN CCS	CHOICE 1 (PRIMARY ROUTES)	CHOICE 2	CHOICE 3	WEIGHT
1 (CON)	2 (HIN)	131.0	2 (HIN)	5 (FEL)	0 (---)	.01
1 (CON)	3 (HUM)	138.0	10 (NPS)	2 (HIN)	0 (---)	.01
1 (CON)	4 (MAM)	111.0	2 (HIN)	5 (FEL)	0 (---)	.01
1 (CON)	5 (FEL)	864.0	5 (FEL)	2 (HIN)	0 (---)	.01

1 (CON)	6 (SCH)	59.4	5 (FEL)	2 (HIN)	0 (---)	.01
1 (CON)	7 (DON)	993.0	5 (FEL)	10 (NPS)	0 (---)	.01
1 (CON)	8 (CTO)	23.4	10 (NPS)	5 (FEL)	0 (---)	.01
1 (CON)	9 (ATH)	126.0	10 (NPS)	5 (FEL)	0 (---)	.01
1 (CON)	10 (NPS)	256.0	10 (NPS)	5 (FEL)	0 (---)	.01
1 (CON)	11 (LKF)	697.0	5 (FEL)	2 (HIN)	0 (---)	.01
2 (HIN)	1 (CON)	131.0	-1 (CON)	5 (FEL)	10 (NPS)	.01
2 (HIN)	3 (HUM)	32.4	3 (HUM)	11 (LKF)	5 (FEL)	1.00
2 (HIN)	4 (MAM)	216.0	4 (MAM)	0 (---)	0 (---)	1.00
2 (HIN)	5 (FEL)	144.0	5 (FEL)	4 (MAM)	0 (---)	1.00
2 (HIN)	6 (SCH)	7.2	11 (LKF)	5 (FEL)	0 (---)	1.00
2 (HIN)	7 (DON)	25.2	7 (DON)	4 (MAM)	5 (FEL)	1.00
2 (HIN)	8 (CTO)	3.6	10 (NPS)	5 (FEL)	0 (---)	1.00
2 (HIN)	9 (ATH)	14.4	10 (NPS)	4 (MAM)	0 (---)	1.00
2 (HIN)	10 (NPS)	25.2	10 (NPS)	5 (FEL)	0 (---)	1.00
2 (HIN)	11 (LKF)	95.4	11 (LKF)	5 (FEL)	0 (---)	1.00
3 (HUM)	1 (CON)	139.0	2 (HIN)	-10 (NPS)	0 (---)	.01
3 (HUM)	2 (HIN)	25.2	2 (HIN)	-10 (NPS)	0 (---)	1.00
3 (HUM)	4 (MAM)	43.1	2 (HIN)	-10 (NPS)	0 (---)	1.00
3 (HUM)	5 (FEL)	112.0	7 (DON)	-10 (NPS)	2 (HIN)	1.00
3 (HUM)	6 (SCH)	39.6	7 (DON)	-10 (NPS)	2 (HIN)	1.00
3 (HUM)	7 (DON)	12.6	7 (DON)	-10 (NPS)	2 (HIN)	1.00
3 (HUM)	8 (CTO)	10.8	-10 (NPS)	7 (DON)	2 (HIN)	1.00
3 (HUM)	9 (ATH)	46.8	-10 (NPS)	7 (DON)	0 (---)	1.00
3 (HUM)	10 (NPS)	39.6	-10 (NPS)	2 (HIN)	0 (---)	1.00
3 (HUM)	11 (LKF)	72.0	7 (DON)	-10 (NPS)	2 (HIN)	1.00
4 (MAM)	1 (CON)	112.0	2 (HIN)	5 (FEL)	0 (---)	.01
4 (MAM)	2 (HIN)	205.0	2 (HIN)	0 (---)	0 (---)	1.00
4 (MAM)	3 (HUM)	25.2	2 (HIN)	7 (DON)	5 (FEL)	1.00
4 (MAM)	5 (FEL)	245.0	5 (FEL)	7 (DON)	0 (---)	1.00
4 (MAM)	6 (SCH)	9.0	7 (DON)	5 (FEL)	0 (---)	1.00
4 (MAM)	7 (DON)	9.0	7 (DON)	5 (FEL)	0 (---)	1.00
4 (MAM)	8 (CTO)	10.8	7 (DON)	5 (FEL)	0 (---)	1.00
4 (MAM)	9 (ATH)	12.6	7 (DON)	2 (HIN)	5 (FEL)	1.00
4 (MAM)	10 (NPS)	10.8	7 (DON)	2 (HIN)	5 (FEL)	1.00
4 (MAM)	11 (LKF)	81.0	7 (DON)	2 (HIN)	5 (FEL)	1.00
5 (FEL)	1 (CON)	864.0	-1 (CON)	2 (HIN)	10 (NPS)	.01
5 (FEL)	2 (HIN)	43.2	2 (HIN)	4 (MAM)	0 (---)	1.00
5 (FEL)	3 (HUM)	57.5	10 (NPS)	7 (DON)	2 (HIN)	1.00
5 (FEL)	4 (MAM)	57.5	4 (MAM)	7 (DON)	0 (---)	1.00
5 (FEL)	6 (SCH)	59.5	6 (SCH)	7 (DON)	0 (---)	1.00
5 (FEL)	7 (DON)	126.0	7 (DON)	11 (LKF)	0 (---)	1.00
5 (FEL)	8 (CTO)	39.6	8 (CTO)	7 (DON)	0 (---)	1.00
5 (FEL)	9 (ATH)	72.0	10 (NPS)	7 (DON)	0 (---)	1.00
5 (FEL)	10 (NPS)	16.2	10 (NPS)	7 (DON)	0 (---)	1.00
5 (FEL)	11 (LKF)	190.0	11 (LKF)	7 (DON)	0 (---)	1.00
6 (SCH)	1 (CON)	59.4	5 (FEL)	-7 (DON)	0 (---)	.01
6 (SCH)	2 (HIN)	9.0	11 (LKF)	5 (FEL)	0 (---)	1.00
6 (SCH)	3 (HUM)	36.0	-7 (DON)	5 (FEL)	0 (---)	1.00
6 (SCH)	4 (MAM)	21.6	-7 (DON)	5 (FEL)	0 (---)	1.00
6 (SCH)	5 (FEL)	205.0	5 (FEL)	-7 (DON)	0 (---)	1.00
6 (SCH)	7 (DON)	72.0	-7 (DON)	11 (LKF)	5 (FEL)	1.00
6 (SCH)	8 (CTO)	23.4	-7 (DON)	5 (FEL)	0 (---)	1.00
6 (SCH)	9 (ATH)	7.2	-7 (DON)	5 (FEL)	0 (---)	1.00
6 (SCH)	10 (NPS)	1.0	-7 (DON)	5 (FEL)	0 (---)	1.00
6 (SCH)	11 (LKF)	90.0	11 (LKF)	-7 (DON)	5 (FEL)	1.00
7 (DON)	1 (CON)	993.0	5 (FEL)	2 (HIN)	10 (NPS)	.01
7 (DON)	2 (HIN)	33.4	2 (HIN)	4 (MAM)	5 (FEL)	1.00
7 (DON)	3 (HUM)	37.8	3 (HUM)	10 (NPS)	5 (FEL)	1.00
7 (DON)	4 (MAM)	16.2	4 (MAM)	2 (HIN)	5 (FEL)	1.00

7 (DON)	5 (FEL)	230.0	5 (FEL)	11 (LKF)	0 (---)	1.00
7 (DON)	6 (SCH)	28.8	6 (SCH)	11 (LKF)	5 (FEL)	1.00
7 (DON)	8 (CTO)	23.4	8 (CTO)	5 (FEL)	0 (---)	1.00
7 (DON)	9 (ATH)	30.6	9 (ATH)	8 (CTO)	10 (NPS)	1.00
7 (DON)	10 (NPS)	19.8	10 (NPS)	8 (CTO)	5 (FEL)	1.00
7 (DON)	11 (LKF)	155.0	11 (LKF)	5 (FEL)	0 (---)	1.00
8 (CTO)	1 (CON)	23.4	10 (NPS)	5 (FEL)	0 (---)	.01
8 (CTO)	2 (HIN)	3.6	10 (NPS)	5 (FEL)	0 (---)	1.00
8 (CTO)	3 (HUM)	10.8	10 (NPS)	7 (DON)	0 (---)	1.00
8 (CTO)	4 (MAM)	14.4	7 (DON)	5 (FEL)	0 (---)	1.00
8 (CTO)	5 (FEL)	57.6	5 (FEL)	7 (DON)	0 (---)	1.00
8 (CTO)	6 (SCH)	3.6	7 (DON)	5 (FEL)	0 (---)	1.00
8 (CTO)	7 (DON)	43.2	7 (DON)	5 (FEL)	0 (---)	1.00
8 (CTO)	9 (ATH)	18.0	10 (NPS)	7 (DON)	0 (---)	1.00
8 (CTO)	10 (NPS)	39.6	10 (NPS)	5 (FEL)	0 (---)	1.00
8 (CTO)	11 (LKF)	43.2	7 (DON)	5 (FEL)	0 (---)	1.00
9 (ATH)	1 (CON)	126.0	-10 (NPS)	0 (---)	0 (---)	.01
9 (ATH)	2 (HIN)	7.2	-10 (NPS)	0 (---)	0 (---)	1.00
9 (ATH)	3 (HUM)	39.6	-10 (NPS)	0 (---)	0 (---)	1.00
9 (ATH)	4 (MAM)	14.4	-10 (NPS)	0 (---)	0 (---)	1.00
9 (ATH)	5 (FEL)	140.0	7 (DON)	-10 (NPS)	0 (---)	1.00
9 (ATH)	6 (SCH)	3.6	7 (DON)	-10 (NPS)	0 (---)	1.00
9 (ATH)	7 (DON)	21.6	7 (DON)	-10 (NPS)	0 (---)	1.00
9 (ATH)	8 (CTO)	25.2	-10 (NPS)	0 (---)	0 (---)	1.00
9 (ATH)	10 (NPS)	43.2	-10 (NPS)	0 (---)	0 (---)	1.00
9 (ATH)	11 (LKF)	55.7	7 (DON)	-10 (NPS)	0 (---)	1.00
10 (NPS)	1 (CON)	256.0	-1 (CON)	5 (FEL)	2 (HIN)	.01
10 (NPS)	2 (HIN)	14.4	2 (HIN)	5 (FEL)	0 (---)	1.00
10 (NPS)	3 (HUM)	36.0	3 (HUM)	2 (HIN)	7 (DON)	1.00
10 (NPS)	4 (MAM)	7.2	7 (DON)	2 (HIN)	5 (FEL)	1.00
10 (NPS)	5 (FEL)	46.8	5 (FEL)	7 (DON)	0 (---)	1.00
10 (NPS)	6 (SCH)	1.0	7 (DON)	5 (FEL)	0 (---)	1.00
10 (NPS)	7 (DON)	7.2	7 (DON)	8 (CTO)	5 (FEL)	1.00
10 (NPS)	8 (CTO)	86.4	8 (CTO)	5 (FEL)	0 (---)	1.00
10 (NPS)	9 (ATH)	46.8	9 (ATH)	0 (---)	0 (---)	1.00
10 (NPS)	11 (LKF)	18.0	7 (DON)	5 (FEL)	0 (---)	1.00
11 (LKF)	1 (CON)	697.0	5 (FEL)	2 (HIN)	0 (---)	.01
11 (LKF)	2 (HIN)	46.8	2 (HIN)	5 (FEL)	0 (---)	1.00
11 (LKF)	3 (HUM)	72.0	7 (DON)	5 (FEL)	2 (HIN)	1.00
11 (LKF)	4 (MAM)	72.0	7 (DON)	2 (HIN)	5 (FEL)	1.00
11 (LKF)	5 (FEL)	313.0	5 (FEL)	7 (DON)	0 (---)	1.00
11 (LKF)	6 (SCH)	36.0	6 (SCH)	7 (DON)	5 (FEL)	1.00
11 (LKF)	7 (DON)	190.0	7 (DON)	6 (SCH)	5 (FEL)	1.00
11 (LKF)	8 (CTO)	50.4	7 (DON)	5 (FEL)	0 (---)	1.00
11 (LKF)	9 (ATH)	48.6	7 (DON)	5 (FEL)	0 (---)	1.00
11 (LKF)	10 (NPS)	25.2	7 (DON)	5 (FEL)	0 (---)	1.00

(CHOICE LEVEL WITH MINUS SIGN DENOTES A SPILL SWITCH)

PATHS DEFINED BY THE ORIGINAL ROUTING TABLE

```
FROM  1 TO  2
( -1)(  2)(
( -1)(  5)(  2)(

FROM  1 TO  3
( -1)( 10)(  3)(
( -1)(  2)(  3)(

FROM  1 TO  4
```

```
( -1)(  2)(  4)(
( -1)(  5)(  4)(

FROM  1 TO  5
( -1)(  5)(
( -1)(  2)(  5)(

FROM  1 TO  6
( -1)(  5)(  6)(
( -1)(  2)( 11)(  6)(

FROM  1 TO  7
( -1)(  5)(  7)(
( -1)( 10)(  7)(

FROM  1 TO  8
( -1)( 10)(  8)(
( -1)(  5)(  8)(

FROM  1 TO  9
( -1)( 10)(  9)(
( -1)(  5)( 10)(  9)(

FROM  1 TO 10
( -1)( 10)(
( -1)(  5)( 10)(

FROM  1 TO 11
( -1)(  5)( 11)(
( -1)(  2)( 11)(

FROM  2 TO  1
( -2)( -1)(
( -2)(  5)( -1)(
( -2)( 10)( -1)(

FROM  2 TO  3
( -2)(  3)(
( -2)( 11)(  7)(  3)(
( -2)(  5)( 10)(  3)(

FROM  2 TO  4
( -2)(  4)(

FROM  2 TO  5
( -2)(  5)(
( -2)(  4)(  5)(

FROM  2 TO  6
( -2)( 11)(  6)(
( -2)(  5)(  6)(

FROM  2 TO  7
( -2)(  7)(
( -2)(  4)(  7)(
( -2)(  5)(  7)(

FROM  2 TO  8
( -2)( 10)(  8)(
( -2)(  5)(  8)(

FROM  2 TO  9
( -2)( 10)(  9)(
( -2)(  4)(  7)(  9)(

FROM  2 TO 10
( -2)( 10)(
( -2)(  5)( 10)(

FROM  2 TO 11
( -2)( 11)(
( -2)(  5)( 11)(

FROM  3 TO  1
( -3)(  2)( -1)(
( -3)(-10)( -1)(
( -3)(-10)(  5)( -1)(
( -3)(-10)(  2)( -1)(

FROM  3 TO  2
( -3)(  2)(
( -3)(-10)(  2)(
( -3)(-10)(  5)(  2)(

FROM  3 TO  4
( -3)(  2)(  4)(
( -3)(-10)(  7)(  4)(
( -3)(-10)(  2)(  4)(
( -3)(-10)(  5)(  4)(

FROM  3 TO  5
( -3)(  7)(  5)(
( -3)(-10)(  5)(
( -3)(-10)(  7)(  5)(
( -3)(  2)(  5)(

FROM  3 TO  6
( -3)(  7)(  6)(
( -3)(-10)(  7)(  6)(
( -3)(-10)(  5)(  6)(
( -3)(  2)( 11)(  6)(

FROM  3 TO  7
( -3)(  7)(
( -3)(-10)(  7)(
( -3)(-10)(  8)(  7)(
( -3)(-10)(  5)(  7)(
( -3)(  2)(  7)(

FROM  3 TO  8
( -3)(-10)(  8)(
( -3)(-10)(  5)(  8)(
( -3)(  7)(  8)(
( -3)(  2)( 10)(  8)(

FROM  3 TO  9
( -3)(-10)(  9)(
( -3)(  7)(  9)(

FROM  3 TO 10
( -3)(-10)(
( -3)(  2)( 10)(

FROM  3 TO 11
( -3)(  7)( 11)(
( -3)(-10)(  7)( 11)(
( -3)(-10)(  5)( 11)(
( -3)(  2)( 11)(

FROM  4 TO  1
( -4)(  2)( -1)(
( -4)(  5)( -1)(

FROM  4 TO  2
( -4)(  2)(

FROM  4 TO  3
( -4)(  2)(  3)(
( -4)(  7)(  3)(
( -4)(  5)( 10)(  3)(

FROM  4 TO  5
( -4)(  5)(
( -4)(  7)(  5)(

FROM  4 TO  6
( -4)(  7)(  6)(
( -4)(  5)(  6)(

FROM  4 TO  7
( -4)(  7)(
( -4)(  5)(  7)(

FROM  4 TO  8
( -4)(  7)(  8)(
( -4)(  5)(  8)(

FROM  4 TO  9
( -4)(  7)(  9)(
( -4)(  2)( 10)(  9)(
( -4)(  5)( 10)(  9)(

FROM  4 TO 10
( -4)(  7)( 10)(
( -4)(  2)( 10)(
( -4)(  5)( 10)(

FROM  4 TO 11
( -4)(  7)( 11)(
( -4)(  2)( 11)(
( -4)(  5)( 11)(

FROM  5 TO  1
( -5)( -1)(
( -5)(  2)( -1)(
( -5)( 10)( -1)(

FROM  5 TO  2
( -5)(  2)(
( -5)(  4)(  2)(

FROM  5 TO  3
( -5)( 10)(  3)(
( -5)(  7)(  3)(
( -5)(  2)(  3)(

FROM  5 TO  4
( -5)(  4)(
( -5)(  7)(  4)(

FROM  5 TO  6
( -5)(  6)(
( -5)(  7)(  6)(

FROM  5 TO  7
( -5)(  7)(
( -5)( 11)(  7)(

FROM  5 TO  8
( -5)(  8)(
( -5)(  7)(  8)(

FROM  5 TO  9
( -5)( 10)(  9)(
( -5)(  7)(  9)(

FROM  5 TO 10
( -5)( 10)(
( -5)(  7)( 10)(

FROM  5 TO 11
( -5)( 11)(
( -5)(  7)( 11)(

FROM  6 TO  1
( -6)(  5)( -1)(
( -6)( -7)(  5)( -1)(
( -6)( -7)(  2)( -1)(
( -6)( -7)( 10)( -1)(

FROM  6 TO  2
( -6)( 11)(  2)(
( -6)(  5)(  2)(

FROM  6 TO  3
( -6)( -7)(  3)(
( -6)( -7)( 10)(  3)(
( -6)( -7)(  5)( 10)(  3)(
( -6)(  5)( 10)(  3)(

FROM  6 TO  4
( -6)( -7)(  4)(
( -6)( -7)(  2)(  4)(
( -6)( -7)(  5)(  4)(
( -6)(  5)(  4)(

FROM  6 TO  5
( -6)(  5)(
( -6)( -7)(  5)(
( -6)( -7)( 11)(  5)(
```

A5

```
FROM  6 TO  7
( -6)( -7)(
( -6)( 11)(  7)(
( -6)(  5)(  7)(

FROM  6 TO  8
( -6)( -7)(  8)(
( -6)( -7)(  5)(  8)(
( -6)(  5)(  8)(

FROM  6 TO  9
( -6)( -7)(  9)(
( -6)( -7)(  8)( 10)(  9)(
( -6)( -7)( 10)(  9)(
( -6)(  5)( 10)(  9)(

FROM  6 TO 10
( -6)( -7)( 10)(
( -6)( -7)(  8)( 10)(
( -6)( -7)(  5)( 10)(
( -6)(  5)( 10)(

FROM  6 TO 11
( -6)( 11)(
( -6)( -7)( 11)(
( -6)( -7)(  5)( 11)(
( -6)(  5)( 11)(

FROM  7 TO  1
( -7)(  5)( -1)(
( -7)(  2)( -1)(
( -7)( 10)( -1)(

FROM  7 TO  2
( -7)(  2)(
( -7)(  4)(  2)(
( -7)(  5)(  2)(

FROM  7 TO  3
( -7)(  3)(
( -7)( 10)(  3)(
( -7)(  5)( 10)(  3)(

FROM  7 TO  4
( -7)(  4)(
( -7)(  2)(  4)(
( -7)(  5)(  4)(

FROM  7 TO  5
( -7)(  5)(
( -7)( 11)(  5)(

FROM  7 TO  6
( -7)(  6)(
( -7)( 11)(  6)(
( -7)(  5)(  6)(

FROM  7 TO  8
( -7)(  8)(
( -7)(  5)(  8)(

FROM  7 TO  9
( -7)(  9)(
( -7)(  8)( 10)(  9)(
( -7)( 10)(  9)(

FROM  7 TO 10
( -7)( 10)(
( -7)(  8)( 10)(
( -7)(  5)( 10)(

FROM  7 TO 11
( -7)( 11)(
( -7)(  5)( 11)(

FROM  8 TO  1
( -8)( 10)( -1)(
( -8)(  5)( -1)(

FROM  8 TO  2
( -8)( 10)(  2)(
( -8)(  5)(  2)(

FROM  8 TO  3
( -8)( 10)(  3)(
( -8)(  7)(  3)(

FROM  8 TO  4
( -8)(  7)(  4)(
( -8)(  5)(  4)(

FROM  8 TO  5
( -8)(  5)(
( -8)(  7)(  5)(

FROM  8 TO  6
( -8)(  7)(  6)(
( -8)(  5)(  6)(

FROM  8 TO  7
( -8)(  7)(
( -8)(  5)(  7)(

FROM  8 TO  9
( -8)( 10)(  9)(
( -8)(  7)(  9)(

FROM  8 TO 10
( -8)( 10)(
( -8)(  5)( 10)(

FROM  8 TO 11
( -8)(  7)( 11)(
( -8)(  5)( 11)(

FROM  9 TO  1
( -9)(-10)( -1)(
( -9)(-10)(  5)( -1)(
( -9)(-10)(  2)( -1)(

FROM  9 TO  2
( -9)(-10)(  2)(
( -9)(-10)(  5)(  2)(

FROM  9 TO  3
( -9)(-10)(  3)(
( -9)(-10)(  2)(  3)(
( -9)(-10)(  7)(  3)(

FROM  9 TO  4
( -9)(-10)(  7)(  4)(
( -9)(-10)(  2)(  4)(
( -9)(-10)(  5)(  4)(

FROM  9 TO  5
( -9)(  7)(  5)(
( -9)(-10)(  5)(
( -9)(-10)(  7)(  5)(

FROM  9 TO  6
( -9)(  7)(  6)(
( -9)(-10)(  7)(  6)(
( -9)(-10)(  5)(  6)(

FROM  9 TO  7
( -9)(  7)(
( -9)(-10)(  7)(
( -9)(-10)(  8)(  7)(
( -9)(-10)(  5)(  7)(

FROM  9 TO  8
( -9)(-10)(  8)(
( -9)(-10)(  5)(  8)(

FROM  9 TO 10
( -9)(-10)(

FROM  9 TO 11
( -9)(  7)( 11)(
( -9)(-10)(  7)( 11)(
( -9)(-10)(  5)( 11)(

FROM 10 TO  1
(-10)( -1)(
(-10)(  5)( -1)(
(-10)(  2)( -1)(

FROM 10 TO  2
(-10)(  2)(
(-10)(  5)(  2)(

FROM 10 TO  3
(-10)(  3)(
(-10)(  2)(  3)(
(-10)(  7)(  3)(

FROM 10 TO  4
(-10)(  7)(  4)(
(-10)(  2)(  4)(
(-10)(  5)(  4)(

FROM 10 TO  5
(-10)(  5)(
(-10)(  7)(  5)(

FROM 10 TO  6
(-10)(  7)(  6)(
(-10)(  5)(  6)(

FROM 10 TO  7
(-10)(  7)(
(-10)(  8)(  7)(
(-10)(  5)(  7)(

FROM 10 TO  8
(-10)(  8)(
(-10)(  5)(  8)(

FROM 10 TO  9
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FROM 10 TO 11
(-10)(  7)( 11)(
(-10)(  5)( 11)(

FROM 11 TO  1
(-11)(  5)( -1)(
(-11)(  2)( -1)(

FROM 11 TO  2
(-11)(  2)(
(-11)(  5)(  2)(

FROM 11 TO  3
(-11)(  7)(  3)(
(-11)(  5)( 10)(  3)(
(-11)(  2)(  3)(

FROM 11 TO  4
(-11)(  7)(  4)(
(-11)(  2)(  4)(
(-11)(  5)(  4)(

FROM 11 TO  5
(-11)(  5)(
(-11)(  7)(  5)(

FROM 11 TO  6
(-11)(  6)(
(-11)(  7)(  6)(
(-11)(  5)(  6)(

FROM 11 TO  7
(-11)(  7)(
(-11)(  6)( -7)(
(-11)(  5)(  7)(

FROM 11 TO  8
(-11)(  7)(  8)(
(-11)(  5)(  8)(
```

```
FROM 11 TO 9
(-11)(  7)(  9)(
(-11)(  5)( 10)(  9)(

FROM 11 TO 10
(-11)(  7)( 10)(
(-11)(  5)( 10)(

 PROBABILITY (PATH USED) AND PATH CARRIED LOAD(CCS)

FROM    1     TO    2
PR (PATH1)= .002205     LOAD CARRIED BY PATH1=  28.879
PR (PATH2)= .001364     LOAD CARRIED BY PATH2=  17.874

FROM    1     TO    3
PR (PATH1)= .001238     LOAD CARRIED BY PATH1=  17.080
PR (PATH2)= .001890     LOAD CARRIED BY PATH2=  26.087

FROM    1     TO    4
PR (PATH1)= .002204     LOAD CARRIED BY PATH1=  24.466
PR (PATH2)= .001259     LOAD CARRIED BY PATH2=  13.977

FROM    1     TO    5
PR (PATH1)= .002183     LOAD CARRIED BY PATH1= 188.611
PR (PATH2)= .001382     LOAD CARRIED BY PATH2= 119.375

FROM    1     TO    6
PR (PATH1)= .002101     LOAD CARRIED BY PATH1=  12.477
PR (PATH2)= .001446     LOAD CARRIED BY PATH2=   8.590

FROM    1     TO    7
PR (PATH1)= .001864     LOAD CARRIED BY PATH1= 185.054
PR (PATH2)= .000984     LOAD CARRIED BY PATH2=  97.692

FROM    1     TO    8
PR (PATH1)= .001158     LOAD CARRIED BY PATH1=   2.711
PR (PATH2)= .001929     LOAD CARRIED BY PATH2=   4.513

FROM    1     TO    9
PR (PATH1)= .001104     LOAD CARRIED BY PATH1=  13.910
PR (PATH2)= .001616     LOAD CARRIED BY PATH2=  20.364

FROM    1     TO   10
PR (PATH1)= .001244     LOAD CARRIED BY PATH1=  31.846
PR (PATH2)= .001821     LOAD CARRIED BY PATH2=  46.623

FROM    1     TO   11
PR (PATH1)= .002058     LOAD CARRIED BY PATH1= 143.447
PR (PATH2)= .001518     LOAD CARRIED BY PATH2= 105.773

FROM    2     TO    1
PR (PATH1)= .002205     LOAD CARRIED BY PATH1=  28.879
PR (PATH2)= .001364     LOAD CARRIED BY PATH2=  17.874
PR (PATH3)= .000747     LOAD CARRIED BY PATH3=   9.780

FROM    2     TO    3
PR (PATH1)= .978626     LOAD CARRIED BY PATH1=  31.707
PR (PATH2)= .015939     LOAD CARRIED BY PATH2=    .516
PR (PATH3)= .004131     LOAD CARRIED BY PATH3=    .134

FROM    2     TO    4
PR (PATH1)= .999831     LOAD CARRIED BY PATH1= 215.964

FROM    2     TO    5
PR (PATH1)= .801759     LOAD CARRIED BY PATH1= 115.453
PR (PATH2)= .146650     LOAD CARRIED BY PATH2=  21.118

FROM    2     TO    6
PR (PATH1)= .830401     LOAD CARRIED BY PATH1=   5.979
PR (PATH2)= .130843     LOAD CARRIED BY PATH2=    .942

FROM    2     TO    7
PR (PATH1)= .570757     LOAD CARRIED BY PATH1=  14.383
PR (PATH2)= .335178     LOAD CARRIED BY PATH2=   8.446
PR (PATH3)= .064382     LOAD CARRIED BY PATH3=   1.622

FROM    2     TO    8
PR (PATH1)= .869082     LOAD CARRIED BY PATH1=   3.129
PR (PATH2)= .104887     LOAD CARRIED BY PATH2=    .378

FROM    2     TO    9
PR (PATH1)= .828160     LOAD CARRIED BY PATH1=  11.926
PR (PATH2)= .088521     LOAD CARRIED BY PATH2=   1.275

FROM    2     TO   10
PR (PATH1)= .933214     LOAD CARRIED BY PATH1=  23.517
PR (PATH2)= .051018     LOAD CARRIED BY PATH2=   1.286

FROM    2     TO   11
PR (PATH1)= .866766     LOAD CARRIED BY PATH1=  82.689
PR (PATH2)= .100709     LOAD CARRIED BY PATH2=   9.608

FROM    3     TO    1
PR (PATH1)= .002157     LOAD CARRIED BY PATH1=  29.988
PR (PATH2)= .000971     LOAD CARRIED BY PATH2=  13.493
PR (PATH3)= .001421     LOAD CARRIED BY PATH3=  19.753
PR (PATH4)= .000030     LOAD CARRIED BY PATH4=    .422

FROM    3     TO    2
PR (PATH1)= .978626     LOAD CARRIED BY PATH1=  24.661
PR (PATH2)= .019846     LOAD CARRIED BY PATH2=    .500
PR (PATH3)= .001085     LOAD CARRIED BY PATH3=    .027

FROM    3     TO    4
PR (PATH1)= .978461     LOAD CARRIED BY PATH1=  42.172
PR (PATH2)= .016269     LOAD CARRIED BY PATH2=    .701
PR (PATH3)= .004780     LOAD CARRIED BY PATH3=    .206
PR (PATH4)= .000270     LOAD CARRIED BY PATH4=    .012

FROM    3     TO    5
PR (PATH1)= .747155     LOAD CARRIED BY PATH1=  83.681
PR (PATH2)= .239695     LOAD CARRIED BY PATH2=  26.846
PR (PATH3)= .004864     LOAD CARRIED BY PATH3=    .545
PR (PATH4)= .000999     LOAD CARRIED BY PATH4=    .112

FROM    3     TO    6
PR (PATH1)= .840324     LOAD CARRIED BY PATH1=  33.277
PR (PATH2)= .115870     LOAD CARRIED BY PATH2=   4.588
PR (PATH3)= .039425     LOAD CARRIED BY PATH3=   1.561
PR (PATH4)= .000653     LOAD CARRIED BY PATH4=    .026
```

```
FROM    3   [illegible]   7
PR (PATH1)= .875214     LOAD CARRIED BY PATH1=  11.028
PR (PATH2)= .120681     LOAD CARRIED BY PATH2=   1.521
PR (PATH3)= .003198     LOAD CARRIED BY PATH3=    .040
PR (PATH4)= .000226     LOAD CARRIED BY PATH4=    .003
PR (PATH5)= .000351     LOAD CARRIED BY PATH5=    .004

FROM    3    TO    8
PR (PATH1)= .926590     LOAD CARRIED BY PATH1=  10.007
PR (PATH2)= .065099     LOAD CARRIED BY PATH2=    .703
PR (PATH3)= .004353     LOAD CARRIED BY PATH3=    .047
PR (PATH4)= .000530     LOAD CARRIED BY PATH4=    .006

FROM    3    TO    9
PR (PATH1)= .882960     LOAD CARRIED BY PATH1=  41.323
PR (PATH2)= .002907     LOAD CARRIED BY PATH2=    .136

FROM    3    TO   10
PR (PATH1)= .994965     LOAD CARRIED BY PATH1=  39.401
PR (PATH2)= .004598     LOAD CARRIED BY PATH2=    .182

FROM    3    TO   11
PR (PATH1)= .860312     LOAD CARRIED BY PATH1=  61.942
PR (PATH2)= .118626     LOAD CARRIED BY PATH2=   8.541
PR (PATH3)= .018288     LOAD CARRIED BY PATH3=   1.317
PR (PATH4)= .000597     LOAD CARRIED BY PATH4=    .043

FROM    4    TO    1
PR (PATH1)= .002204     LOAD CARRIED BY PATH1=  24.697
PR (PATH2)= .001259     LOAD CARRIED BY PATH2=  14.102

FROM    4    TO    2
PR (PATH1)= .999831     LOAD CARRIED BY PATH1= 204.965

FROM    4    TO    3
PR (PATH1)= .978461     LOAD CARRIED BY PATH1=  24.657
PR (PATH2)= .014723     LOAD CARRIED BY PATH2=    .371
PR (PATH3)= .004781     LOAD CARRIED BY PATH3=    .120

FROM    4    TO    5
PR (PATH1)= .739881     LOAD CARRIED BY PATH1= 181.271
PR (PATH2)= .173426     LOAD CARRIED BY PATH2=  42.489

FROM    4    TO    6
PR (PATH1)= .749856     LOAD CARRIED BY PATH1=   6.749
PR (PATH2)= .178039     LOAD CARRIED BY PATH2=   1.603

FROM    4    TO    7
PR (PATH1)= .780990     LOAD CARRIED BY PATH1=   7.029
PR (PATH2)= .138332     LOAD CARRIED BY PATH2=   1.245

FROM    4    TO    8
PR (PATH1)= .771461     LOAD CARRIED BY PATH1=   8.332
PR (PATH2)= .168967     LOAD CARRIED BY PATH2=   1.825

FROM    4    TO    9
PR (PATH1)= .515221     LOAD CARRIED BY PATH1=   6.492
PR (PATH2)= .401407     LOAD CARRIED BY PATH2=   5.058
PR (PATH3)= .020302     LOAD CARRIED BY PATH3=    .256

FROM    4    TO   10
PR (PATH1)= .759123     LOAD CARRIED BY PATH1= [illegible].199
PR (PATH2)= .224752     LOAD CARRIED BY PATH2=   2.427
PR (PATH3)= .011367     LOAD CARRIED BY PATH3=    .123

FROM    4    TO   11
PR (PATH1)= .767692     LOAD CARRIED BY PATH1=  62.183
PR (PATH2)= .201323     LOAD CARRIED BY PATH2=  16.307
PR (PATH3)= .021614     LOAD CARRIED BY PATH3=   1.751

FROM    5    TO    1
PR (PATH1)= .002183     LOAD CARRIED BY PATH1= 188.611
PR (PATH2)= .001382     LOAD CARRIED BY PATH2= 119.375
PR (PATH3)= .000763     LOAD CARRIED BY PATH3=  65.901

FROM    5    TO    2
PR (PATH1)= .801759     LOAD CARRIED BY PATH1=  34.636
PR (PATH2)= .146650     LOAD CARRIED BY PATH2=   6.335

FROM    5    TO    3
PR (PATH1)= .947992     LOAD CARRIED BY PATH1=  54.510
PR (PATH2)= .038858     LOAD CARRIED BY PATH2=   2.234
PR (PATH3)= .010318     LOAD CARRIED BY PATH3=    .593

FROM    5    TO    4
PR (PATH1)= .739881     LOAD CARRIED BY PATH1=  42.543
PR (PATH2)= .173426     LOAD CARRIED BY PATH2=   9.972

FROM    5    TO    6
PR (PATH1)= .962242     LOAD CARRIED BY PATH1=  57.253
PR (PATH2)= .030948     LOAD CARRIED BY PATH2=   1.841

FROM    5    TO    7
PR (PATH1)= .853682     LOAD CARRIED BY PATH1= 107.564
PR (PATH2)= .135596     LOAD CARRIED BY PATH2=  17.085

FROM    5    TO    8
PR (PATH1)= .999259     LOAD CARRIED BY PATH1=  39.571
PR (PATH2)= .000625     LOAD CARRIED BY PATH2=    .025

FROM    5    TO    9
PR (PATH1)= .845532     LOAD CARRIED BY PATH1=  60.878
PR (PATH2)= .086993     LOAD CARRIED BY PATH2=   6.263

FROM    5    TO   10
PR (PATH1)= .952789     LOAD CARRIED BY PATH1=  15.435
PR (PATH2)= .039174     LOAD CARRIED BY PATH2=    .635

FROM    5    TO   11
PR (PATH1)= .942773     LOAD CARRIED BY PATH1= 179.127
PR (PATH2)= .048022     LOAD CARRIED BY PATH2=   9.124

FROM    6    TO    1
PR (PATH1)= .002101     LOAD CARRIED BY PATH1=  12.477
PR (PATH2)= .000068     LOAD CARRIED BY PATH2=    .401
PR (PATH3)= .000946     LOAD CARRIED BY PATH3=   5.613
PR (PATH4)= .000795     LOAD CARRIED BY PATH4=   4.720

FROM    6    TO    2
PR (PATH1)= .830401     LOAD CARRIED BY PATH1=   7.474
```

```
PR (PATH2)= .130843     LOAD CARRIED BY PATH2=   1.170

FROM    6     TO    3
PR (PATH1)= .840324     LOAD CARRIED BY PATH1=  30.252
PR (PATH2)= .115870     LOAD CARRIED BY PATH2=   4.171
PR (PATH3)= .002715     LOAD CARRIED BY PATH3=    .098
PR (PATH4)= .036365     LOAD CARRIED BY PATH4=   1.309

FROM    6     TO    4
PR (PATH1)= .749856     LOAD CARRIED BY PATH1=  16.197
PR (PATH2)= .119998     LOAD CARRIED BY PATH2=   2.592
PR (PATH3)= .057024     LOAD CARRIED BY PATH3=   1.232
PR (PATH4)= .028382     LOAD CARRIED BY PATH4=    .613

FROM    6     TO    5
PR (PATH1)= .962242     LOAD CARRIED BY PATH1= 197.260
PR (PATH2)= .030948     LOAD CARRIED BY PATH2=   6.344
PR (PATH3)= .004916     LOAD CARRIED BY PATH3=   1.008

FROM    6     TO    7
PR (PATH1)= .960134     LOAD CARRIED BY PATH1=  69.130
PR (PATH2)= .037543     LOAD CARRIED BY PATH2=   2.703
PR (PATH3)= .001908     LOAD CARRIED BY PATH3=    .137

FROM    6     TO    8
PR (PATH1)= .948419     LOAD CARRIED BY PATH1=  22.193
PR (PATH2)= .009994     LOAD CARRIED BY PATH2=    .234
PR (PATH3)= .038332     LOAD CARRIED BY PATH3=    .897

FROM    6     TO    9
PR (PATH1)= .633403     LOAD CARRIED BY PATH1=   4.561
PR (PATH2)= .266730     LOAD CARRIED BY PATH2=   1.920
PR (PATH3)= .022571     LOAD CARRIED BY PATH3=    .163
PR (PATH4)= .032435     LOAD CARRIED BY PATH4=    .234

FROM    6     TO   10
PR (PATH1)= .933250     LOAD CARRIED BY PATH1=    .933
PR (PATH2)= .024731     LOAD CARRIED BY PATH2=    .025
PR (PATH3)= .001751     LOAD CARRIED BY PATH3=    .002
PR (PATH4)= .036549     LOAD CARRIED BY PATH4=    .037

FROM    6     TO   11
PR (PATH1)= .958046     LOAD CARRIED BY PATH1=  86.224
PR (PATH2)= .039596     LOAD CARRIED BY PATH2=   3.564
PR (PATH3)= .000552     LOAD CARRIED BY PATH3=    .050
PR (PATH4)= .001517     LOAD CARRIED BY PATH4=    .137

FROM    7     TO    1
PR (PATH1)= .001864     LOAD CARRIED BY PATH1= 185.054
PR (PATH2)= .001024     LOAD CARRIED BY PATH2= 101.660
PR (PATH3)= .000860     LOAD CARRIED BY PATH3=  85.400

FROM    7     TO    2
PR (PATH1)= .579757     LOAD CARRIED BY PATH1=  19.063
PR (PATH2)= .335178     LOAD CARRIED BY PATH2=  11.195
PR (PATH3)= .064382     LOAD CARRIED BY PATH3=   2.150

FROM    7     TO    3
PR (PATH1)= .875214     LOAD CARRIED BY PATH1=  33.083
PR (PATH2)= .120681     LOAD CARRIED BY PATH2=   4.562

PR (PATH3)= .002828     LOAD CARRIED BY PATH3=    .107

FROM    7     TO    4
PR (PATH1)= .780990     LOAD CARRIED BY PATH1=  12.652
PR (PATH2)= .124980     LOAD CARRIED BY PATH2=   2.025
PR (PATH3)= .059891     LOAD CARRIED BY PATH3=    .962

FROM    7     TO    5
PR (PATH1)= .853682     LOAD CARRIED BY PATH1= 196.347
PR (PATH2)= .135596     LOAD CARRIED BY PATH2=  31.187

FROM    7     TO    6
PR (PATH1)= .960134     LOAD CARRIED BY PATH1=  27.652
PR (PATH2)= .037543     LOAD CARRIED BY PATH2=   1.081
PR (PATH3)= .001908     LOAD CARRIED BY PATH3=    .055

FROM    7     TO    8
PR (PATH1)= .987798     LOAD CARRIED BY PATH1=  23.114
PR (PATH2)= .010409     LOAD CARRIED BY PATH2=    .244

FROM    7     TO    9
PR (PATH1)= .659702     LOAD CARRIED BY PATH1=  20.187
PR (PATH2)= .277805     LOAD CARRIED BY PATH2=   8.501
PR (PATH3)= .023508     LOAD CARRIED BY PATH3=    .719

FROM    7     TO   10
PR (PATH1)= .972000     LOAD CARRIED BY PATH1=  19.246
PR (PATH2)= .025758     LOAD CARRIED BY PATH2=    .510
PR (PATH3)= .001824     LOAD CARRIED BY PATH3=    .036

FROM    7     TO   11
PR (PATH1)= .982972     LOAD CARRIED BY PATH1= 152.361
PR (PATH2)= .013704     LOAD CARRIED BY PATH2=   2.124

FROM    8     TO    1
PR (PATH1)= .001158     LOAD CARRIED BY PATH1=   2.711
PR (PATH2)= .001929     LOAD CARRIED BY PATH2=   4.513

FROM    8     TO    2
PR (PATH1)= .869082     LOAD CARRIED BY PATH1=   3.129
PR (PATH2)= .104887     LOAD CARRIED BY PATH2=    .378

FROM    8     TO    3
PR (PATH1)= .926590     LOAD CARRIED BY PATH1=  10.007
PR (PATH2)= .063466     LOAD CARRIED BY PATH2=    .685

FROM    8     TO    4
PR (PATH1)= .771461     LOAD CARRIED BY PATH1=  11.109
PR (PATH2)= .168967     LOAD CARRIED BY PATH2=   2.433

FROM    8     TO    5
PR (PATH1)= .999259     LOAD CARRIED BY PATH1=  57.557
PR (PATH2)= .000625     LOAD CARRIED BY PATH2=    .036

FROM    8     TO    6
PR (PATH1)= .948419     LOAD CARRIED BY PATH1=   3.414
PR (PATH2)= .049597     LOAD CARRIED BY PATH2=    .179

FROM    8     TO    7
PR (PATH1)= .987798     LOAD CARRIED BY PATH1=  42.673
```

```
PR (P[illegible])= .010409     LOAD CARRIED BY PATH2=     .450

FROM     8     TO     9
PR (PATH1)= .825443     LOAD CARRIED BY PATH1=  14.876
PR (PATH2)= .113099     LOAD CARRIED BY PATH2=   2.036

FROM     8     TO    10
PR (PATH1)= .931279     LOAD CARRIED BY PATH1=  36.879
PR (PATH2)= .065423     LOAD CARRIED BY PATH2=   2.591

FROM     8     TO    11
PR (PATH1)= .970978     LOAD CARRIED BY PATH1=  41.946
PR (PATH2)= .027341     LOAD CARRIED BY PATH2=   1.181

FROM     9     TO     1
PR (PATH1)= .001104     LOAD CARRIED BY PATH1=  13.910
PR (PATH2)= .001616     LOAD CARRIED BY PATH2=  20.364
PR (PATH3)= .001266     LOAD CARRIED BY PATH3=  15.953

FROM     9     TO     2
PR (PATH1)= .828160     LOAD CARRIED BY PATH1=   5.963
PR (PATH2)= .045275     LOAD CARRIED BY PATH2=    .326

FROM     9     TO     3
PR (PATH1)= .882960     LOAD CARRIED BY PATH1=  34.965
PR (PATH2)= .004081     LOAD CARRIED BY PATH2=    .162
PR (PATH3)= .000330     LOAD CARRIED BY PATH3=    .013

FROM     9     TO     4
PR (PATH1)= .673667     LOAD CARRIED BY PATH1=   9.701
PR (PATH2)= .199451     LOAD CARRIED BY PATH2=   2.872
PR (PATH3)= .010088     LOAD CARRIED BY PATH3=    .145

FROM     9     TO     5
PR (PATH1)= .563176     LOAD CARRIED BY PATH1=  78.845
PR (PATH2)= .369349     LOAD CARRIED BY PATH2=  51.709
PR (PATH3)= .011830     LOAD CARRIED BY PATH3=   1.656

FROM     9     TO     6
PR (PATH1)= .633403     LOAD CARRIED BY PATH1=   2.280
PR (PATH2)= .281832     LOAD CARRIED BY PATH2=   1.015
PR (PATH3)= .039878     LOAD CARRIED BY PATH3=    .144

FROM     9     TO     7
PR (PATH1)= .659702     LOAD CARRIED BY PATH1=  14.250
PR (PATH2)= .293534     LOAD CARRIED BY PATH2=   6.340
PR (PATH3)= .007779     LOAD CARRIED BY PATH3=    .168
PR (PATH4)= .000551     LOAD CARRIED BY PATH4=    .012

FROM     9     TO     8
PR (PATH1)= .826443     LOAD CARRIED BY PATH1=  20.826
PR (PATH2)= .058063     LOAD CARRIED BY PATH2=   1.463

FROM     9     TO    10
PR (PATH1)= .887428     LOAD CARRIED BY PATH1=  38.337

FROM     9     TO    11
PR (PATH1)= .648469     LOAD CARRIED BY PATH1=  36.120
PR (PATH2)= .288536     LOAD CARRIED BY PATH2=  16.071
PR (PATH3)= .021040     LOAD CARRIED BY PATH3=   1.172

FROM    10     TO     1
PR (PATH1)= .001244     LOAD CARRIED BY PATH1=[illegible].846
PR (PATH2)= .001821     LOAD CARRIED BY PATH2=[illegible]623
PR (PATH3)= .001427     LOAD CARRIED BY PATH3=[illegible].524

FROM    10     TO     2
PR (PATH1)= .933214     LOAD CARRIED BY PATH1=  13.438
PR (PATH2)= .051018     LOAD CARRIED BY PATH2=    .735

FROM    10     TO     3
PR (PATH1)= .994965     LOAD CARRIED BY PATH1=  35.819
PR (PATH2)= .004598     LOAD CARRIED BY PATH2=    .166
PR (PATH3)= .000371     LOAD CARRIED BY PATH3=    .013

FROM    10     TO     4
PR (PATH1)= .759123     LOAD CARRIED BY PATH1=   5.466
PR (PATH2)= .224752     LOAD CARRIED BY PATH2=   1.618
PR (PATH3)= .011367     LOAD CARRIED BY PATH3=    .082

FROM    10     TO     5
PR (PATH1)= .952789     LOAD CARRIED BY PATH1=  44.591
PR (PATH2)= .039174     LOAD CARRIED BY PATH2=   1.833

FROM    10     TO     6
PR (PATH1)= .933250     LOAD CARRIED BY PATH1=    .933
PR (PATH2)= .061197     LOAD CARRIED BY PATH2=    .061

FROM    10     TO     7
PR (PATH1)= .972000     LOAD CARRIED BY PATH1=   6.998
PR (PATH2)= .025758     LOAD CARRIED BY PATH2=    .185
PR (PATH3)= .001824     LOAD CARRIED BY PATH3=    .013

FROM    10     TO     8
PR (PATH1)= .931279     LOAD CARRIED BY PATH1=  80.462
PR (PATH2)= .065423     LOAD CARRIED BY PATH2=   5.653

FROM    10     TO     9
PR (PATH1)= .887428     LOAD CARRIED BY PATH1=  41.532

FROM    10     TO    11
PR (PATH1)= .955449     LOAD CARRIED BY PATH1=  17.198
PR (PATH2)= .040019     LOAD CARRIED BY PATH2=    .720

FROM    11     TO     1
PR (PATH1)= .002058     LOAD CARRIED BY PATH1= 143.447
PR (PATH2)= .001518     LOAD CARRIED BY PATH2= 105.773

FROM    11     TO     2
PR (PATH1)= .866766     LOAD CARRIED BY PATH1=  40.565
PR (PATH2)= .100709     LOAD CARRIED BY PATH2=   4.713

FROM    11     TO     3
PR (PATH1)= .860312     LOAD CARRIED BY PATH1=  61.942
PR (PATH2)= .124845     LOAD CARRIED BY PATH2=   8.989
PR (PATH3)= .012591     LOAD CARRIED BY PATH3=    .907

FROM    11     TO     4
PR (PATH1)= .767692     LOAD CARRIED BY PATH1=  55.274
PR (PATH2)= .201323     LOAD CARRIED BY PATH2=  14.495
PR (PATH3)= .021614     LOAD CARRIED BY PATH3=   1.556
```

FROM 11 TO 5
PR (PATH1)= .942773 LOAD CARRIED BY PATH1= 295.088
PR (PATH2)= .048022 LOAD CARRIED BY PATH2= 15.031

FROM 11 TO 6
PR (PATH1)= .958046 LOAD CARRIED BY PATH1= 34.490
PR (PATH2)= .039596 LOAD CARRIED BY PATH2= 1.425
PR (PATH3)= .002140 LOAD CARRIED BY PATH3= .077

FROM 11 TO 7
PR (PATH1)= .982972 LOAD CARRIED BY PATH1= 186.765
PR (PATH2)= .015663 LOAD CARRIED BY PATH2= 2.976
PR (PATH3)= .001098 LOAD CARRIED BY PATH3= .209

FROM 11 TO 8
PR (PATH1)= .970978 LOAD CARRIED BY PATH1= 48.937
PR (PATH2)= .027341 LOAD CARRIED BY PATH2= 1.378

FROM 11 TO 9
PR (PATH1)= .648469 LOAD CARRIED BY PATH1= 31.516
PR (PATH2)= .280221 LOAD CARRIED BY PATH2= 13.619

FROM 11 TO 10
PR (PATH1)= .955449 LOAD CARRIED BY PATH1= 24.077
PR (PATH2)= .040019 LOAD CARRIED BY PATH2= 1.008

ACTUAL TRUNK GROUP PERFORMANCE (BASED ON ORIGINAL ROUTING TABLE)

LINK NUMBER	OFFERED LOAD(CCS)	TRUNK GROUP ACTUAL GOS	TRUNK GROUP RELIABILITY
1	5891.7	.781701	.218299
2	543.3	.047211	.952789
3	539.3	.112572	.887428
4	345.1	.005035	.994965
5	185.4	.021374	.978626
6	3547.5	.779547	.220453
7	633.0	.000169	.999831
8	396.4	.260119	.739881
9	126.2	.000741	.999259
10	210.6	.068721	.931279
11	146.8	.066786	.933214
12	559.7	.198241	.801759
13	912.2	.057227	.942773
14	903.0	.017028	.982972
15	272.4	.039866	.960134
16	300.0	.037758	.962242
17	218.6	.012202	.987798
18	309.2	.340298	.659702
19	343.3	.028000	.972000
20	449.0	.133234	.866766
21	363.4	.219010	.780990
22	364.7	.124786	.875214
23	3143.1	.875602	.124398
24	156.1	.041954	.958046
25	1108.1	.146318	.853682
26	254.7	.429243	.570757

NETWORK PERFORMANCE (BASED ON ORIGINAL ROUTING TABLE)

SOURCE	DESTINATION	BLOCKING PROBABILITY	WEIGHTED BLOCKING PROBABILITY
1 (CON)	2 (HIN)	6.431E-01	6.431E-03

A11

1 (CON)	3 (HUM)	6.872E-01	6.872E-03
1 (CON)	4 (MAM)	6.537E-01	6.537E-03
1 (CON)	5 (FEL)	6.435E-01	6.435E-03
1 (CON)	6 (SCH)	6.453E-01	6.453E-03
1 (CON)	7 (DON)	7.153E-01	7.153E-03
1 (CON)	8 (CTO)	6.913E-01	6.913E-03
1 (CON)	9 (ATH)	7.280E-01	7.280E-03
1 (CON)	10 (NPS)	6.935E-01	6.935E-03
1 (CON)	11 (LKF)	6.424E-01	6.424E-03
2 (HIN)	1 (CON)	5.684E-01	5.684E-03
2 (HIN)	3 (HUM)	1.304E-03	1.304E-03
2 (HIN)	4 (MAM)	1.688E-04	1.688E-04
2 (HIN)	5 (FEL)	5.159E-02	5.159E-02
2 (HIN)	6 (SCH)	3.876E-02	3.876E-02
2 (HIN)	7 (DON)	2.968E-02	2.968E-02
2 (HIN)	8 (CTO)	2.603E-02	2.603E-02
2 (HIN)	9 (ATH)	8.332E-02	8.332E-02*
2 (HIN)	10 (NPS)	1.577E-02	1.577E-02
2 (HIN)	11 (LKF)	3.253E-02	3.253E-02
3 (HUM)	1 (CON)	5.420E-01	5.420E-03
3 (HUM)	2 (HIN)	4.429E-04	4.429E-04
3 (HUM)	4 (MAM)	2.213E-04	2.213E-04
3 (HUM)	5 (FEL)	7.287E-03	7.287E-03
3 (HUM)	6 (SCH)	3.728E-03	3.728E-03
3 (HUM)	7 (DON)	3.293E-04	3.293E-04
3 (HUM)	8 (CTO)	3.378E-03	3.378E-03
3 (HUM)	9 (ATH)	1.141E-01	1.141E-01*
3 (HUM)	10 (NPS)	4.367E-04	4.367E-04
3 (HUM)	11 (LKF)	2.178E-03	2.178E-03
4 (MAM)	1 (CON)	6.537E-01	6.537E-03
4 (MAM)	2 (HIN)	1.688E-04	1.688E-04
4 (MAM)	3 (HUM)	2.035E-03	2.035E-03
4 (MAM)	5 (FEL)	8.669E-02	8.669E-02*
4 (MAM)	6 (SCH)	7.206E-02	7.206E-02
4 (MAM)	7 (DON)	8.068E-02	8.068E-02*
4 (MAM)	8 (CTO)	5.957E-02	5.957E-02
4 (MAM)	9 (ATH)	6.307E-02	6.307E-02
4 (MAM)	10 (NPS)	4.758E-03	4.758E-03
4 (MAM)	11 (LKF)	9.372E-03	9.372E-03
5 (FEL)	1 (CON)	5.673E-01	5.673E-03
5 (FEL)	2 (HIN)	5.159E-02	5.159E-02
5 (FEL)	3 (HUM)	2.832E-03	2.832E-03
5 (FEL)	4 (MAM)	8.669E-02	8.669E-02*
5 (FEL)	6 (SCH)	6.810E-03	6.810E-03
5 (FEL)	7 (DON)	1.072E-02	1.072E-02
5 (FEL)	8 (CTO)	1.161E-04	1.161E-04
5 (FEL)	9 (ATH)	6.748E-02	6.748E-02
5 (FEL)	10 (NPS)	8.036E-03	8.036E-03
5 (FEL)	11 (LKF)	9.205E-03	9.205E-03
6 (SCH)	1 (CON)	6.092E-01	6.092E-03
6 (SCH)	2 (HIN)	3.876E-02	3.876E-02
6 (SCH)	3 (HUM)	4.726E-03	4.726E-03
6 (SCH)	4 (MAM)	4.474E-02	4.474E-02
6 (SCH)	5 (FEL)	1.894E-03	1.894E-03
6 (SCH)	7 (DON)	4.147E-04	4.147E-04
6 (SCH)	8 (CTO)	3.255E-03	3.255E-03
6 (SCH)	9 (ATH)	4.486E-02	4.486E-02
6 (SCH)	10 (NPS)	3.718E-03	3.718E-03
6 (SCH)	11 (LKF)	2.891E-04	2.891E-04
7 (DON)	1 (CON)	6.253E-01	6.253E-03

7 (DON)	2 (HIN)	2.969E-02	2.969E-02
7 (DON)	3 (HUM)	1.277E-03	1.277E-03
7 (DON)	4 (MAM)	3.464E-02	3.464E-02
7 (DON)	5 (FEL)	1.072E-02	1.072E-02
7 (DON)	6 (SCH)	4.147E-04	4.147E-04
7 (DON)	8 (CTO)	1.793E-03	1.793E-03
7 (DON)	9 (ATH)	3.899E-02	3.899E-02
7 (DON)	10 (NPS)	4.185E-04	4.185E-04
7 (DON)	11 (LKF)	3.323E-03	3.323E-03
8 (CTO)	1 (CON)	6.913E-01	6.913E-03
8 (CTO)	2 (HIN)	2.603E-02	2.603E-02
8 (CTO)	3 (HUM)	9.945E-03	9.945E-03
8 (CTO)	4 (MAM)	5.957E-02	5.957E-02
8 (CTO)	5 (FEL)	1.161E-04	1.161E-04
8 (CTO)	6 (SCH)	1.984E-03	1.984E-03
8 (CTO)	7 (DON)	1.793E-03	1.793E-03
8 (CTO)	9 (ATH)	6.046E-02	6.046E-02
8 (CTO)	10 (NPS)	3.293E-03	3.293E-03
8 (CTO)	11 (LKF)	1.681E-03	1.681E-03
9 (ATH)	1 (CON)	6.014E-01	6.014E-03
9 (ATH)	2 (HIN)	1.266E-01	1.266E-01*
9 (ATH)	3 (HUM)	1.126E-01	1.126E-01*
9 (ATH)	4 (MAM)	1.168E-01	1.168E-01*
9 (ATH)	5 (FEL)	5.565E-02	5.565E-02
9 (ATH)	6 (SCH)	4.489E-02	4.489E-02
9 (ATH)	7 (DON)	3.843E-02	3.843E-02
9 (ATH)	8 (CTO)	1.155E-01	1.155E-01*
9 (ATH)	10 (NPS)	1.126E-01	1.126E-01*
9 (ATH)	11 (LKF)	4.196E-02	4.196E-02
10 (NPS)	1 (CON)	5.508E-01	5.508E-03
10 (NPS)	2 (HIN)	1.577E-02	1.577E-02
10 (NPS)	3 (HUM)	6.519E-05	6.519E-05
10 (NPS)	4 (MAM)	4.738E-03	4.758E-03
10 (NPS)	5 (FEL)	8.036E-03	8.036E-03
10 (NPS)	6 (SCH)	5.553E-03	5.553E-03
10 (NPS)	7 (DON)	4.185E-04	4.185E-04
10 (NPS)	8 (CTO)	3.293E-03	3.293E-03
10 (NPS)	9 (ATH)	1.126E-01	1.126E-01*
10 (NPS)	11 (LKF)	4.532E-03	4.532E-03
11 (LKF)	1 (CON)	6.424E-01	6.424E-03
11 (LKF)	2 (HIN)	3.253E-02	3.253E-02
11 (LKF)	3 (HUM)	2.253E-03	2.253E-03
11 (LKF)	4 (MAM)	9.372E-03	9.372E-03
11 (LKF)	5 (FEL)	9.205E-03	9.205E-03
11 (LKF)	6 (SCH)	2.189E-04	2.189E-04
11 (LKF)	7 (DON)	2.664E-04	2.664E-04
11 (LKF)	8 (CTO)	1.681E-03	1.681E-03
11 (LKF)	9 (ATH)	7.131E-02	7.131E-02
11 (LKF)	10 (NPS)	4.532E-03	4.532E-03

NODE GRADE OF SERVICE (BASED ON ORIGNAL ROUTING TABLE)

NODE NUMBER	ORIGINATING LOAD (CCS)	NODE GRADE OF SERVICE	NODE RELIABILITY
1 (CON)	3398.8	.673606	.326394
2 (HIN)	694.4	.126434	.873566
3 (HUM)	540.7	.151443	.848557
4 (MAM)	720.4	.136257	.863743
5 (FEL)	1525.5	.331686	.668314
6 (SCH)	524.6	.073420	.926580
7 (DON)	1568.0	.399696	.600304

8 (CT	257.4	.072329	.927671
9 (ATH	476.5	.213472	.786528
10 (NPS)	519.8	.283361	.716639
11 (LKF)	1551.0	.294483	.705517

LARGEST WEIGHTED NNGOS(= 1.266E-01) IS FROM 9 TO 2

MAXIMUM ALLOWABLE BLOCKING PROBABILITY(BPMAX) .080

NUMBER OF WEIGHTED NNGOS EXCEEDING BPMAX IN THE ORIGNAL ROUTING TABLE= 11

NETWORK GRADE OF SERVICE IS .37810
WEIGHTED NETWORK GRADE OF SERVICE IS .01324

TIME REQUIRED TO READ IN DATA AND PERFORM ANALYSIS ON ORIGNAL ROUTING TABLE 8.047 SECONDS

CHANGES IN ROUTING TABLE REQUIRED

FINLEY, MARION R.
--A technical and economic study on the impact of the introduction of new services on existing telecommunications networks: final report.