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Interpretation of Data in the Network Measurement System

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ABSTRACT

The Network Measurement System (NMS) represents an implementation of a new approach to the performance measurement and evaluation of computer network systems and services. In this report, the interpretation of data within the NMS is described. These data have been acquired by the Network Measurement Machine (NMM) component of the NMS and are then interpreted by a Data Analysis Package (DAP), which produces meaningful information concerning the quality of network service delivered to interactive terminal users as well as a characterization of user demands and network communication facility utilization.

This report traces the flow of data from the time of capture by the minicomputer-based NMM through the several phases of modeling and structuring in the DAP. Included in this description is the statistical treatment of the data which provides quantitative measures of various aspects of network performance.

Key words: Computer networks; data analysis; interactive; network service; performance evaluation; performance measurement; service.

1. Introduction

This technical note is one of a set containing detailed technical information concerning the Network Measurement System (NMS). The NMS represents an implementation of a new approach to the performance measurement and evaluation of computer network systems and services.

This report discusses the process of developing the raw data acquired by the data acquisition subsystem, known as the Network Measurement Machine (NMM), into meaningful information through the Data Analysis Package (DAP). The DAP produces reports about the quality of network service delivered to interactive terminal users as well as a characterization of user demands and network communication facility utilization.

The concept of service evaluation is discussed in Abrams and Cotton [1975]. The ways in which the NMM operates in order to obtain the raw measurement data may be found in Rosenthal, Rippy and Wood [1975]. The present technical note, along with the two just cited constitute a complete technical description of the Network Measurement System. In addition, the use of network measurement as a part of network evaluation is discussed in a Federal Information Processing Standards Guideline now in preparation under the principal authorship of Abrams, Watkins, and Cotton [1975].

1.1 Definitions, Intent, and Applicability

A computer network for the purpose of this report is defined as one or more computers connected to one or more interactive terminals via a communications facility. (Pyke and Blanc [1973] and Blanc [1974] present a discussion of computer network technology). When discussing service delivered by a network, the computers and communications facility are often considered as one by the network user.

Computer installation managers, procurement specialists, performance evaluation specialists, and computer users can benefit from utilization of the NMS. Of course, their interests in the details of its operation will vary widely. This report is intended to convey conceptual information about the functioning of the data analysis and report generation parts of that system. It does not contain implementation detail at the program level suitable for replication of the effort. It also provides information about the functional structure of the NMS to others working in the network measurement field. In most cases it may be assumed that a small group of individuals in an organization would have major responsibility for operation of the NMS and the presentation of its outputs to other interested parties. The term "analyst" is applied to those most closely associated with the NMS operation. The level of detail contained in this report is important to the analyst who must interpret the NMS reports and present them to others.

This report traces the flow of data from the time of capture by the minicomputer-based NMM through several phases of modeling and structuring in the DAP. Included in this description is the statistical treatment of the data which provides quantitative measures of various aspects of network performance.

The NMS provides a quantitative basis for Federal agencies and other network users and operators to select and improve computer networks and network services. After the procurement of a network service, the NMS provides a means to assure that service continues to be provided at an acceptable level. For example, a network serving a certain number of customers may provide the best service during the selection portion of a procurement action and therefore be awarded the contract; however, several months later the number of customers served by the network may double or triple, causing the network to perform at an unacceptable level. Periodic application of the NMM to network services would assure that service continues to be provided at a contractually agreed upon level.

1.2 The Service Approach

The approach to measurement represented by the NMS is service-oriented. By focusing on the service delivered to the network customers at their terminals, rather than on the internal mechanics of network operation, measurements can be obtained which are directly relevant to user needs and management concerns. As discussed by Abrams and Cotton [1975], a network user at an interactive terminal is concerned with service rather than total system efficiency. It is of little concern to the user that the network is serving other users. This only becomes a concern when the user is forced to wait longer than usual for the network to answer a request. At that point the user is aware that service has degraded for some reason. The user does not care that the Central Processing Unit (CPU), or input/output devices are over-burdened or why they are; the user only knows that the service being delivered by the network is unsatisfactory.

1.3 System Overview

The Network Measurement Machine (NMM), the data acquisition component of the NMS, is a minicomputer-based system which captures all characters transmitted between a user at a terminal and the computer network serving the user. The NMM associates a time-tag (the time a character occurs) and the source of the character (user or network) with each character transmitted.

Data is not structured or analyzed during acquisition. Time-tagged characters and other pertinent information are written on magnetic tape as rapidly as possible as a consequence of the design criterion to avoid any activity in the NMM which might possibly compromise the accuracy of the timing.

Once recorded, the data are processed by the DAP. Briefly, the processing proceeds as follows: The multiple conversations on the tape are separated into individual conversations by demultiplexing the recording. Each individual conversation is then processed to remove character echos, and scanned to build a structure file which contains pointers to the user and network messages. The network software resources utilized by each message are identified and noted in the structure file. Individual conversations may be analyzed, reports generated, a file written for additional data processing by independent statistical packages, and another file created for use in the analysis of multiple conversations.

1.4 The NBS Implementation

The NMM is implemented on a Digital Equipment Corporation PDP 11/20 and has the capacity to acquire data on eight simultaneous, independent, character asynchronous user/network interactions. The standard hardware includes a high precision programmable clock and a set of communications interfaces. Special hardware connects the NMM to the network to be measured. This special hardware includes an automatic calling unit and line selector system for computer-controlled originating and answering of data calls via common carrier communications facilities.

The NMM has a special operating system which is a real-time interrupt driven scheduler incorporating various device drivers and handlers. The user and network characters and related information acquired during application of the NMM are stored on a seven track magnetic tape. Detailed information concerning NMM hardware and software is presented in Rosenthal, Rippy and Wood [1975].

The Data Analysis Package (DAP) processes the data acquired by the NMS. The DAP is implemented on a Digital Equipment Corporation DECSystem 10. The magnetic tapes generated by the NMM are transferred to the analysis machine for subsequent processing.

2. Transformation of the NMM Data

Each NMM-generated magnetic tape may contain data acquired on one or several days of NMM operation; or one day of operation may produce a multi-reel file. In any case, the DAP creates an independent disc file for each day represented on the tapes. The naming convention for files on the DAP machine is:

FILE.EXT

where FILE is the filename and may consist of six or less alphanumeric characters, and EXT is the filename extender and may consist of three or less alphanumeric characters. Following this convention, a disc file which represents one day's accumulation of data is referenced as a .DMT file.

The name of the .DMT file, specified by FILE above, is the Julian date on which the conversation was recorded. (This information is contained in the data supplied by the NMM which will be described in the next section.) Consistent with the Federal Information Processing Standards for the specification of representations of the years, months, and days of the Gregorian Calendar (FIPS 4 [1968]), the form of the date is: the first 2 digits represent the units and tens identification of the year, and the third, fourth and fifth digits represent the three digit ordinal number descriptive of the day of the year (beginning with 001 for January 1 and progressing to 365 for December 31 except progressing to 366 in leap years). For example, conversational data obtained on June 14, 1975, is stored in the file 75165.DMT.

2.1 Description of the NMM Data

The magnetic tape produced by the NMM is organized into information records (1). There are five record types which define the 1) configuration of the user/NMM connection, 2) time and date when the data was acquired, 3) software version number of the NMM, 4) destination network to which user was connected, and 5) the user/network characters with associated time-tags.

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(1) A record is a collection of related items of data treated as a unit. See FIPS 11 [1970].

The configuration record contains information related to the hardware configuration of the user's connection to the NMM at the time of the recording. Such details as the type of interface, the type of connection, and the transmission rate of the interface are contained in this record.

The NMM uses a 24 bit clock which is incremented 10,000 times per second. Therefore, approximately every 20 minutes a clock overflow occurs. Each time there is a clock overflow a time/date record which contains the current time of day and Julian date is generated.

The version record insures that the analysis routines treat the data appropriately for the version of the NMM software which was used in acquiring the data. Thus compatibility between the NMM and the DAP is preserved.

The destination record specifies the network to which the user is connected. The information contained in this record is used in the separation of conversations process and will be discussed in the next section.

When the data is acquired by the NMM, every character transmitted by the user or the network is tagged with the current time in clock ticks. A record containing a character and time-tag is called a character record.

Every record contains a unit number indicating the source of the information contained in the record. A conversation or dialogue has associated with it two unit numbers, one for the user portion and one for the network portion. All even unit numbers refer to the user portions of conversations, while odd refer to the network portions. Once a conversation is initiated, the unit numbers associated with that conversation are constant. When the conversation is terminated, those units become available for another user/network dialogue.

2.2 Demultiplexing Conversations

Records are ordered on the magnetic tape in the same sequence as they arrive at the NMM. This implies that multiple conversations are interleaved on a tape.

The .DMT files are scanned by a routine, RAW, which creates a new set of disc files referenced as .RAW files. There is one .RAW file created for each dialogue represented on the .DMT file. RAW demultiplexes the interleaved dialogues by recognizing pairs of unit numbers and creating an individual file for each pair. Global information such as configuration details, version, and destination network is placed in a header to the .RAW files reserved for such information. When the 24-bit clock employed by the NMM overflows, the DAP extends the time-tag to 27 bits. Overflow of a 27 bit time-tag does not occur for approximately two and three-fourths hours. When the 27 bit clock overflows, timing adjustments are made and the clock is reset. The integrity of the time-tags is not compromised in this process.

Each character with associated time-tag and source (user or network) is placed in one word of the .RAW file (7 bits reserved for the character, 27 for the time-tag and 1 for the source). The time and date information requires two consecutive words in .RAW. Character and time/date records in the .RAW files are distinguished by a flag bit: if the flag equals zero then the record is a one word character record, if the flag equals one then the next two words contain a time/date record. Figure 1 illustrates the three types of information found in a .RAW file.

The naming convention for the .RAW files is as follows:

DDDNNN.RAW

where

DDD is the ordinal number of the day,
NNN is the conversation position on .DMT

All conversations occurring within a given decimal year are maintained in a directory which incorporates that year in its name. For example, the third conversation recorded on June 14, 1975, is stored in the file 165003.RAW in the directory for 1975.

HEADER

0	35
Address of Beginning of Data	
Number of Words of Data	
Communication Speed	
Version of NMM	
Destination Network	
Address of 1st Free Word in File	
Date File Written	
Time File Written	
ooo	
oooo	
ooooo	
oooooo	

TIME/DATE RECORD

0	35
1 Time	
Date	

CHARACTER RECORD

0	1	7	8	9	35
0	Character		S		Time-Tag

where S indicates the source

if S = 0 user character

if S = 1 network character

Figure 1. Elements of a .RAW File

Figure 2 illustrates the reconfiguration of a hypothetical .DMT file into its component .RAW files. The first word of each file diagram shows the format of the data contained in the file.

2.3 Recognition of Conversation Boundaries

There are five general categories of NMM interconnection of user and network. 1) Local is the simplest connection form. User and network devices are in the immediate vicinity of the NMM and the use of modems is not required for their interconnection. 2) A dial-in connection involves only one modem which is logically connected to the user device. 3) Dial-out utilizes a computer controlled automatic calling unit and line selector. 4) Dial-through requires two modems and is effectively a combination of dial-in and dial-out. 5) Remote connection utilizes specialized interconnection hardware. For detailed explanations of these categories of interconnection see the Hardware Operating Environment Section of Rosenthal, Rippy, and Wood [1975].

These interconnection forms have a direct effect on the "separation of conversations" process in the DAP. When a .DMT file is separated into independent dialogue files (.RAW), the routine RAW must be able to recognize a completed dialogue in order to initiate the .RAW file termination process which includes entering information (as the number of data words in .RAW, etc.) into the headers of the .RAW files. In the case of the dial-out user the detection of an end-of-conversation is trivial because it is marked by a disconnection of the phone circuit. However, the other possible connections are continuous; that is, once a connection has been initialized, various users may initiate and terminate conversations without any physical termination of the line. For such connections, the destination record acts as the key to the separation of conversations on the .DMT files.

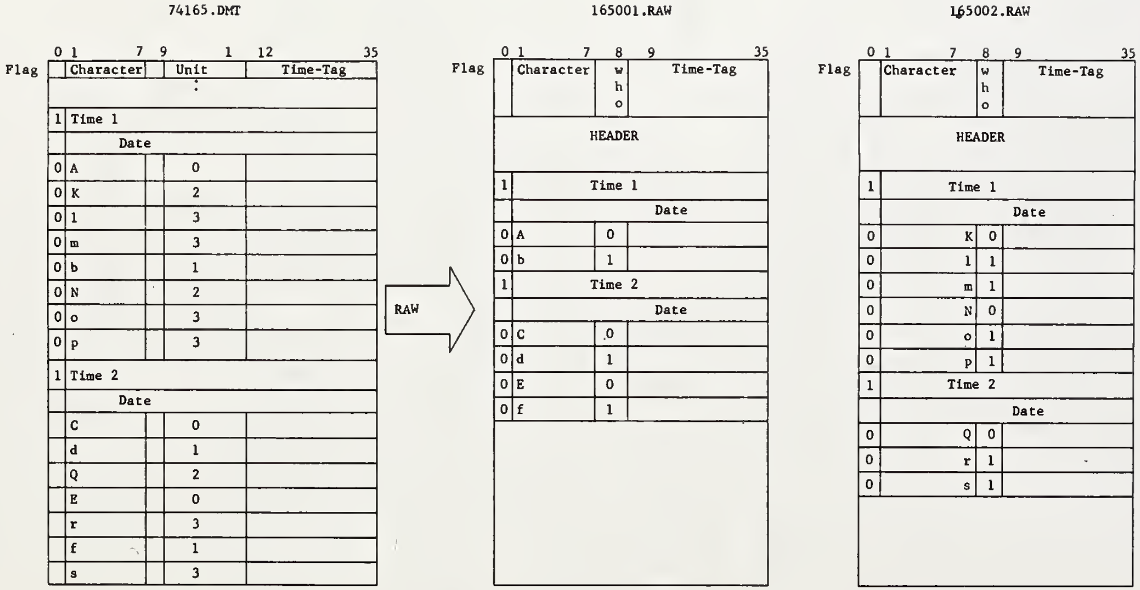

Figure 2. .DMT to .RAW Transformation

The destination record contains an integer code designating the network connection made. Each connection has a distinct log-in and log-out procedure. Therefore, all that is necessary is to search for the string of characters that represents the termination of a conversation for the network which indicates that the .RAW file is complete. To include the case of a network crash or unplanned disconnect, the string of characters representing a log-in request is included in the search, the occurrence of which indicates that the preceding .RAW file should be terminated and a new .RAW file begun. This search procedure is accomplished by a sliding character string match against the data being processed. This match is implemented in software as a finite state machine.

The conversation being scanned during the generation of a .RAW file is considered to be in any one of several states during the scan. Based on the current state of the conversation, network, and current character, a decision is made whether to proceed to the next state, continue in the current state, or revert back to the first state. This procedure requires specification of conversation states prior to processing data for that network. Additions to the DAP library of known networks require the intervention of one who is well versed in the syntax of the network to be added in order to insure the accurate specification of conversation states.

Currently the possible states are:

< -3	testing for beginning of conversation
-3	accept any character as a beginning
-2	terminate current .RAW file; begin a new .RAW
-1	terminate .RAW file
0	between conversations
1-999	conversation in progress

To illustrate, Figure 3 is the procedure for one of the current network connections specified in a destination record, the TIP (2). TIP commands always start with the symbol @ and end with either a carriage return (optionally linefeed) or a rubout, depending on whether the user wishes the command to be issued or be aborted. The exception is

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(2) The Terminal Interface message Processor is the communications interface to the Advanced Research Projects Agency Network (ARPANET). See BBN [1974].

the specific command @@ which causes the TIP to insert one @ in the data stream to the host computer. Normally, TIP connection to a host computer is requested by an "@L", an "@O", or an "@H," while termination of a connection is initiated by an "@C." The state is initialized at 0 and remains there until a beginning of conversation is signaled; upon receipt of an "@" the state moves to -3. If the next character is a "C," the state becomes -1. After termination of the current raw file, the state becomes 0. If the "@" is followed by an "L", an "O", or an "H," the next state becomes -2. After termination of the current raw file and opening of a new one, the state becomes 1 to indicate the processing of a conversation. Once at state 1, an "@" is the only character that can signal an exit. Upon receipt of an "@" the next state is 2. If another "@" is received, the state goes back to 1; otherwise, the state becomes -3.

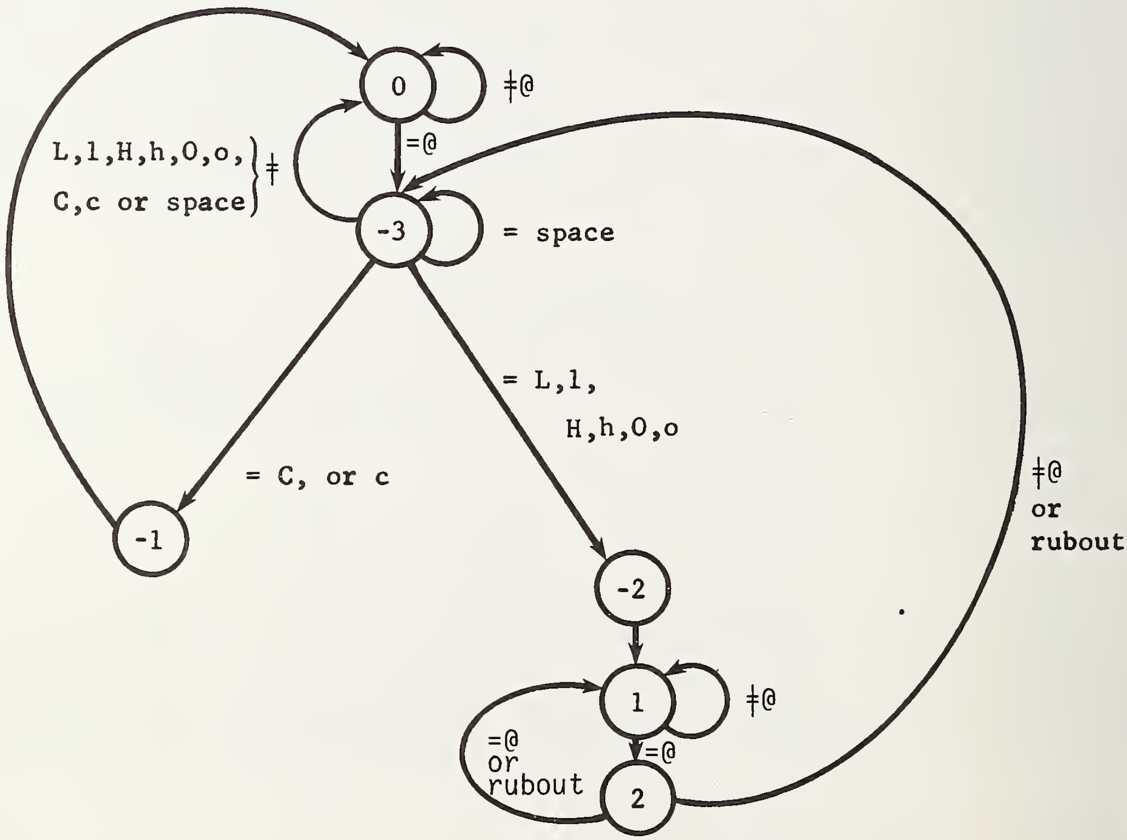


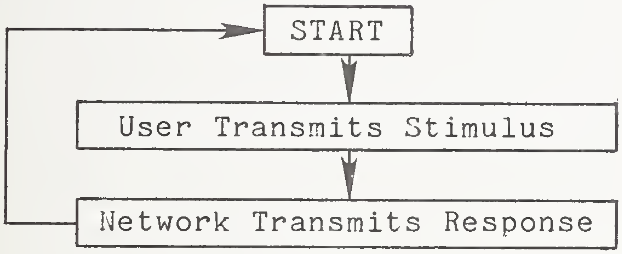
Figure 3. End-of-Conversation Search for TIP

3. Models and Their Parameters

A model was formulated to represent the dialogue in such a manner as to readily extract meaningful measurement information. As data were acquired and interpreted by the model, it was necessary to refine the model to adequately account for new types of data and provide for their meaningful interpretation relative to the measurement objectives.

3.1 Definition of the SAR Model

The first model employed by the DAP was a simple iterated stimulus-response situation (Scherr [1966]) of the form



Of course the text transmitted varies for each iteration of the model.

This model presumes that the user is the "driver", that is, the stimulus is the catalyst which elicits a response from the network. In reality just the opposite may be true or the "driver" may alternate during a dialogue. However, the stimulus-response form appears adequately consistent with the "service" orientation of the NMS.

In certain circumstances utilization of the stimulus-response model led to anomalous interpretations of data. Although the user observed a long elapsed time between the end of a stimulus and a meaningful response, the data as interpreted by the model produced a very short elapsed time. This inconsistency was caused by the network immediately acknowledging the receipt of the stimulus say, by a carriage return/line feed sequence, before processing it. A new model was required to account for the presence of this "acknowledgement" condition. The new model is accordingly known as the stimulus-acknowledgement-response (SAR) model. (See Abrams, Lindamood and Pyke [1973].) A stimulus with its corresponding acknowledgement and response is termed a "message group", with the stimulus, acknowledgement and response being the components of a message group.

While the presence of a stimulus and response in a message group may be assumed, the network output must be tested to ascertain the presence of an acknowledgement. It should be noted that differentiation between acknowledgement and response is semantic and time dependent, that some networks issue no acknowledgement, that some networks are inconsistent in their acknowledgement, and that in some cases the acknowledgement constitutes the only response.

To determine if an acknowledgement is present, three algorithms are used. At the beginning of an analysis session, the analyst using the DAP has the option to specify which of these acknowledgement definitions is to be used or to specify a new definition. The first algorithm requires the specification of a set of acknowledgement characters; this character set (the match set) is used for string matching. An acknowledgement is delineated by comparing the match set with the beginning of the character string from the network. The comparison begins with the first network character and continues until the last character of the match set or until a "no match" is encountered. If the end of the match set is successfully reached, an acknowledgement is present; otherwise, the entire network output comprises the response.

A second algorithm is based on timing information. If a delay in the network output is encountered greater than a fixed multiple of the character duration, then the output is divided into an acknowledgement and a response. A character duration is the time interval needed for one character to be transmitted and is calculated by dividing the number of bits required for each character (including start and stop bits) by the speed of the interface in bits-per-second. The interface speed information is available in the configuration record described earlier. The default parameter is set at 50 character durations; however, the analyst may redefine this parameter.

The third algorithm defines the existence of an acknowledgement based on network output beginning with nonprinting ASCII control characters rather than printing characters. All nonprinting characters occurring at the beginning of network output until the occurrence of a printing character are considered within the acknowledgement.

These three algorithms may be applied individually or in combination.

3.2 Parameters of the SAR Model

Using the SAR model, several variables characterizing the dialogue can be identified. These variables fall into two broad classes: those concerned with character count, and those concerned with elapsed time. The character count is the number of characters occurring in each message group component. Stimulus character count (SC) refers to the total number of characters in the stimulus, while acknowledgement character count (AC) and response character count (RC) refer to the number of characters for these respective portions of the network output.

Each message group component is delimited by two events -- the arrival times of the first and the last characters. Using these two events to measure elapsed time, transmission and delay times are calculated. Figure 4 represents the definitions of the elapsed time intervals. Transmission time is the time between the first character in a message group component and the last character of that component. Stimulus transmission time (ST) refers to the interval between the first character of a stimulus and the last, while acknowledgement transmission time (AT) and response transmission time (RT) refer to that interval for the respective portions of the network output.

The delay time is the elapsed time between the last character of a message group component and the first character of the next component (which may occur in the same or the next message group). Stimulus delay time (SD) is the elapsed time between the last character of the network response of the previous message group and the first character of the stimulus of the current message group. Acknowledgement delay time (AD) is the interval between the last character of the stimulus and the first character of the acknowledgement, while response delay time (RD) is the interval between the last character of the acknowledgement and the first character of the response.

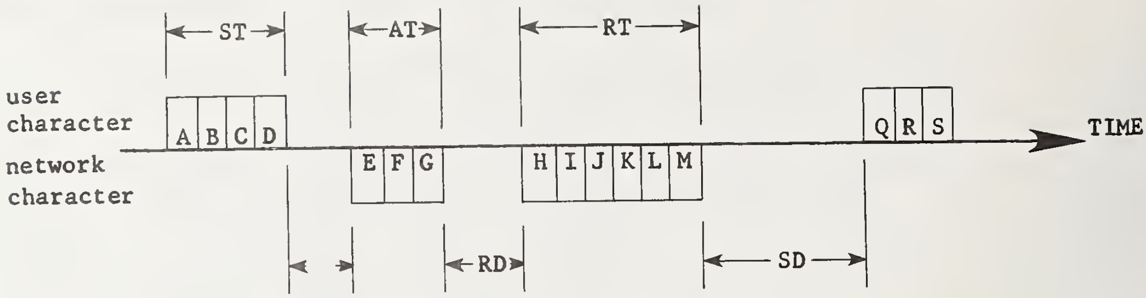


Figure 4. Time Intervals During and Between Transmissions

Since transmission and delay times are measured by the elapsed time between two events, there are numerous measurements which may be made by selecting different events. Examining the literature on measurement techniques (Agajanian [1975]), it is apparent that experimenters do not agree on the significance of events, especially related to network output. Because of the multiplicity of definitions about to be introduced, the names of events will explicitly state the interval being measured.

Using the more complete (and verbose) name, the delay time referenced above as RD is termed the "end of acknowledgement to beginning of response" delay. Determination of the point at which a meaningful response has occurred has long been a topic for debate in the measurement world. The next three response definitions are consequences of this debate. The time between the end of the acknowledgement to the point at which the arithmetic average of the total number of response characters for that message group occurs is the "acknowledgement to mean of response" delay. The time between the end of the acknowledgement to the point at which the arithmetic median of the total number of response characters for that message group occurs is the "acknowledgement to median of response" delay. Finally, the time between the end of the acknowledgement and the last character of the response is the "acknowledgement to end of response" delay. In dealing with networks that do not issue acknowledgements, the network delay time definitions would be the same as above except for the substitution of stimulus for every occurrence of acknowledgement. The most commonly used measure of delay, conventionally called "response time," is the elapsed time from the end of the stimulus to the beginning of the network's output. (The acknowledgement/response distinction is not recognized.) This is termed the "stimulus to response" delay.

3.3 Communications Conventions

In fitting the conversational data to the appropriate model, the communications conventions had to be considered in order that the data be interpreted correctly. The simplest computer communications convention to implement and understand is half-duplex. In half-duplex there may be only one source of transmission at a time, the network or the user. As a consequence, the printer mechanism on the user's terminal is directly connected to the keyboard.

An alternate convention is full-duplex in which transmission can occur in both directions simultaneously. In sophisticated implementations of full-duplex the user is allowed to type ahead; that is, the user does not have to wait for the network to respond before entering the next stimulus. A major consequence of full-duplex transmission is that there is no connection between printer and keyboard on the user's terminal. If characters transmitted by the user are printed, it is by virtue of traveling into the network and being retransmitted back to the user terminal printer. This process of retransmission is called echoing. Retransmission may be performed by a communications processor in the network or by a remote computer connected to the network. While the communications conventions used may have implications for network efficency, the concern of the service approach to measurement is network performance as viewed by a user at a terminal, not the internal functioning of components of the network.

There are several elements which complicate analysis of full-duplex usage. Transformation of a nonprinting character into a sequence of printing characters is common. For example, end of text or ETX (which on many keyboards is transmitted by depressing the CONTROL key and the letter C simultaneously) may cause the transmission back to the user terminal of the two characters "^C" in sequence. Type ahead also introduces complexities. Since the user is not constrained to waiting for a network response before entering another stimulus, stimuli may be queued by the network until it processes them. At that time a series of responses may be printed on the user's terminal. Interleaving of responses is another complication that type-ahead may introduce. In this case a response does not necessarily immediately follow the stimulus to which it is associated. Figure 5 illustrates these type-ahead related complications in contrast to the normal user-network sequence expected.

Full-duplex transmission has two major effects on the analysis. First, it increases network utilization by virtue of echoes. Second, it makes more difficult the demarcation between user and network transmission segments.

In many, but not all, cases the representation of a full-duplex conversation may be reduced to an equivalent half-duplex case. This transformation makes it possible to employ the same data reduction techniques to both transmission types. The implementation of this transformation records sufficient data to reflect the increased network utilization of full-duplex operation.

Semantic content analysis is required to reduce the full-duplex record to an equivalent half-duplex case whenever character transformation and type-ahead occur. The current DAP does not provide this capability. Since half-duplex mode is the dominant convention for the interactive use of networks and is the simplest to understand and analyze, a half-duplex model containing the meaningful points of this mode has been created. Whenever possible, data obtained from a full-duplex conversation are transformed according to the half-duplex model.

The program which performs the transformation from the .RAW file to a half-duplex model is HDMOD which produces a corresponding .HDX file. The naming convention of the .HDX files is identical to that for the .RAW files. Figure 6 defines the elements of the .HDX files.

(a) Normal Sequence

User:	5 + 7 <CR>
Network:	12
User:	1 + 2 <CR>
Network:	3
User:	9 + 9 <CR>
Network:	18

(b) Queued Sequence

User:	5 + 7 <CR>
User:	1 + 2 <CR>
User:	9 + 9 <CR>
Network:	12
Network:	3
Network:	18

(c) Interleaved Sequence

User:	5 + 7 <CR>
User:	1 + 2 <CR>
Network:	12
User:	9 + 9 <CR>
Network:	3
Network:	18

where <CR> indicates carriage return

Figure 5. Full-Duplex Possibilities

HEADER

0	35
Address of Beginning of Data	
Number of Words of Data	
Communication Speed	
Version of NMM	
Destination Network	
Number of Echoes Removed	
Per Cent of User Non-Printing Characters	
Per Cent of Network Non-Printing Characters	
Address of 1st Free Word in File	
Date File Written	
Time File Written	
ooo oooo ooooo oooooo	

TIME/DATE RECORD

0		35
1	Time	
Date		

CHARACTER RECORD

0	1	7	8	9	35
0	Character		S	Time-Tag	

where S indicates the source

if S = 0 user character

if S = 1 network character

Figure 6. Elements of an .HDX File

3.4 Echo Removal

The echo removal algorithm produces an approximation for the half-duplex representation of a full-duplex conversation. While the sequence of the characters is preserved in an echo, the timing is not. As illustrated in Figure 7, any number of user characters may be interposed between a user character and its echo. The problem is to identify when a character transmitted from the network is an echo and when it is the beginning of a network output sequence. The algorithm utilized requires that the beginning of the user stimulus be identified. This was accomplished by defining any character from the user as terminating a network transmission. Likewise, any character from the network which is not an echo terminates the user transmission. The procedure involves placing user characters into a buffer, maintaining pointers to the end of the buffer and to the current user character. Each network character received is an echo candidate and has to be compared with the current user character. As long as a match exists, the pointer is advanced and the process repeated. When the end of the buffer is reached, the user transmission is terminated. If there is a nonmatch before the end of the buffer, the remaining user characters end the network transmission and begin the next user transmission, the exact location being independent of the time at which the various characters occurred. By this definition, endings and beginnings are strictly determined by time sequence.

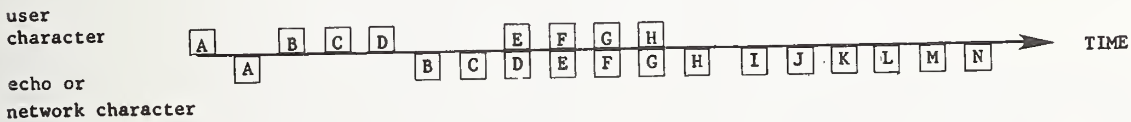


Figure 7. Intermixing of User Input and Network Output

One exception is made for a nonexact match. There is a DAP option to treat an upper case character output from the network as a match to the corresponding lower case character input from the user. The presence of this option was indicated by the observation that this mode of echoing exists. The historical precedence of upper case only terminals may explain its existence.

3.5 Conversation Record

The hard copy representation of the conversation is that of the half-duplex SAR model. The format of the printed record is given in Figure 8. Each message group in the conversation is subdivided into its three components, and the characters belonging to each one of these components appear to the right of the corresponding label.

Control characters are optionally represented by their standard abbreviation enclosed in corner brackets. For example, a carriage return would appear as <CR>. For the sake of readability the space character is treated as a special case. If a space is the first or last character on a line, it appears as <SP>; otherwise, a blank character is printed. Multiple occurrences of control characters are indicated by printing an asterisk followed by the count of repetitions , followed by a closing corner bracker. For example, seven linefeeds would appear as <LF>*7>.

The .HDX file, from which the SAR model is derived, contains time/date records in addition to the character/time-tag information. The occurrence of a time/date record is preserved in the conversation record by the printing of the message:

Recording Time: XXXX

where XXXX represents the hour. The execution of the analysis routines does not necessitate a hard copy reproduction of the conversation, but if a reproduction is requested, the user specifies the terminal being used. The program maintains pertinent statistics (i.e., the number of rows and columns per page and per inch) for a variety of terminals.

The user of the DAP has the ability to designate that any or all of the previously described model parameters be calculated. Further, the analyst has the option to have these parameters printed. The format is that each message group is printed followed by its corresponding parameters.

```
CONVERSATION RECORD OF FILE 184003.HDX

####                            LEGEND                                   ####
        S=Stimulus          R=Response          A=Acknowledgement
####                                                                     ####

S    1 @
A    1 <CR><NUL>*5><LF>*6>
R    1 OMNUS AUTOBAUD. <SP> *2>RATE = 3 (300) ON PORT 33.<CR><NUL>
       *5><LF>*5>PLEASE ENTER SITE-ID.<CR><NUL>*5><LF>*6>

RECORDING TIME:        JULY  3, 1975        44160SEC

S    2 XXXXXX
A    2 <CR><LF><DEL><CR><DEL>*6>
R    2 ENTER USERID/PASSWORD:<DEL><CR><LF><DEL>*6>><DEL>

S    3 *xxxxxx/yyyyy<CR>
A    3 <CR><LF><DEL>*7>
R    3 ><DEL><CR><LF>*9><DEL>**>*DESTROY USERID/PASSWORD ENTRY
       <DEL><CR><LF><DEL><CR><DEL>*6>*UNIVAC 1100 OPERATING SYSTEM <SP>
       *2>VER. 31-244 UPD D(RSI)* <SP> *2><DEL>"2><CR>*2><LF>*2><DEL>*2>

S    4 @@tty 1,_,c,",w,80<CR>
A    4 <CR><LF><DEL><CR><DEL>*6>
R    4 * @@ PROCESSING COMPLETE * <SP> *2><DEL>*2><CR>*2><LF>*2><DEL>*2>

S    5 @run xxxxxx,12345-xxxxxx,yyyyyy,8,800<CR>
A    5 <CR><LF><DEL><CR><DEL>*6>
R    5 DATE: 070375 <SP> *6>TIME: 121858 <SP> *2><DEL>*2><CR>*2><LF>
       *2><DEL>*8>><DEL>

S    6 @add setup.<CR>
A    6 <CR><LF><DEL><CR><DEL>*6>
R    6 READY <SP> *3><DEL>*3><CR>*3><LF>*3><DEL>*3><CR>*3><DEL>*8>R
       EADY <SP> *3><DEL>*3><CR>*3><LF>*3><DEL>*8>READY <SP> *3><DEL>
       *3><CR>*3><LF>*3><DEL>*8>READY <SP> *3><DEL>*3><CR>*3><LF>
       *3><DEL>*8>READY <SP> *3><DEL>*3><CR>*3><LF>*3><DEL>*8>R
       EADY <SP> *3><DEL>*3><CR>*3><LF>*3><DEL>*8>READY <SP> *3><DEL>
       *3><CR>*3><LF>*3><DEL>*8>READY <SP> *3><DEL>*3><CR>*3><LF>
       *3><DEL>*3><CR>*3><DEL>*8>FURPUR NS26H-07/03-12:19<DEL><CR>
       <LF><DEL><CR><DEL>*6>CSDACCTTEST*TPF$(0),F4,T<DEL><CR><LF>
       <DEL>*6>CSDACCTTEST*SETUP(1),F2,A <SP> *2>SYM$$001016,(
       ADD) <SP> *3><DEL>*3><CR>*3><LF>*3><DEL>*8>DINES*UOM(0),DUMM
       Y <SP> *2>Q, <SP> *2><DEL>*2><CR>*2><LF>*2><DEL>*7>CSDAC
       CTTEST*GEORGE(1),F2,A <SP> *2>G, <SP> *2><DEL>*2><CR>*2><LF>
       *2><DEL>*7>CSDACCTTEST*BASE(1),F2,A <SP> *2>B,<DEL><CR>
       <LF><DEL>*6>CSDACCTTEST*UPDATE(1),F2,A <SP> *2>U, <SP>
       *2><DEL>*2><CR>*2><LF>*2><DEL>*7>CSDACCTTEST*GG(1),F2,A <SP>
       *2><DEL>*2><CR>*2><LF>*2><DEL>*7> <SP> *2>END PRT <SP>
       *3><DEL>*3><CR>*3><LF>*3><DEL>*9>><DEL>
```

Figure 8. Sample Conversation Record

4. Data Structuring

Once the message groups and their corresponding components are identified, this identification is retained in order that the process need not be repeated in future analysis sessions. An index (.INX) file which contains pointers (addresses) into the half-duplex (.HDX) data file was implemented so that specific message groups may be accessed without reprocessing the entire data base. The program which produces the .INX files is SARTST and the naming convention for the .INX files is identical to that for the .RAW and .HDX files. Figure 9 represents the flow of data from the original .DMT file to the .INX file.

4.1 Type of Structure

The index file has been organized to best represent the form of the conversational data and to take advantage of the random file addressing capability of the computer employed for data analysis. This organization facilitates the efficient retrieval of data. The structure employed is a series of linked lists some of which are doubly linked. The base of the structure contains, explicitly or via pointers, descriptive information concerning the conversation. This descriptive information includes the date of recording, the network and user participating, the length of the half-duplex file, etc. Since the index file is implemented on a random access medium, this descriptive information may be modified or expanded at any time. A utility program provides this capability.

As shown in Figure 10 the base also contains a pointer to the first message group. These message group headers are represented in a doubly linked list. Each message group header is numbered and contains the address in the half-duplex file of the beginning of the stimulus, acknowledgement, and response for that message group. If a time/date record occurs, a pointer to that record is placed in the message group header.

Access to structured data is provided through a set of interface subroutines which serve to insert and retrieve data by message group. Subroutines have been written to

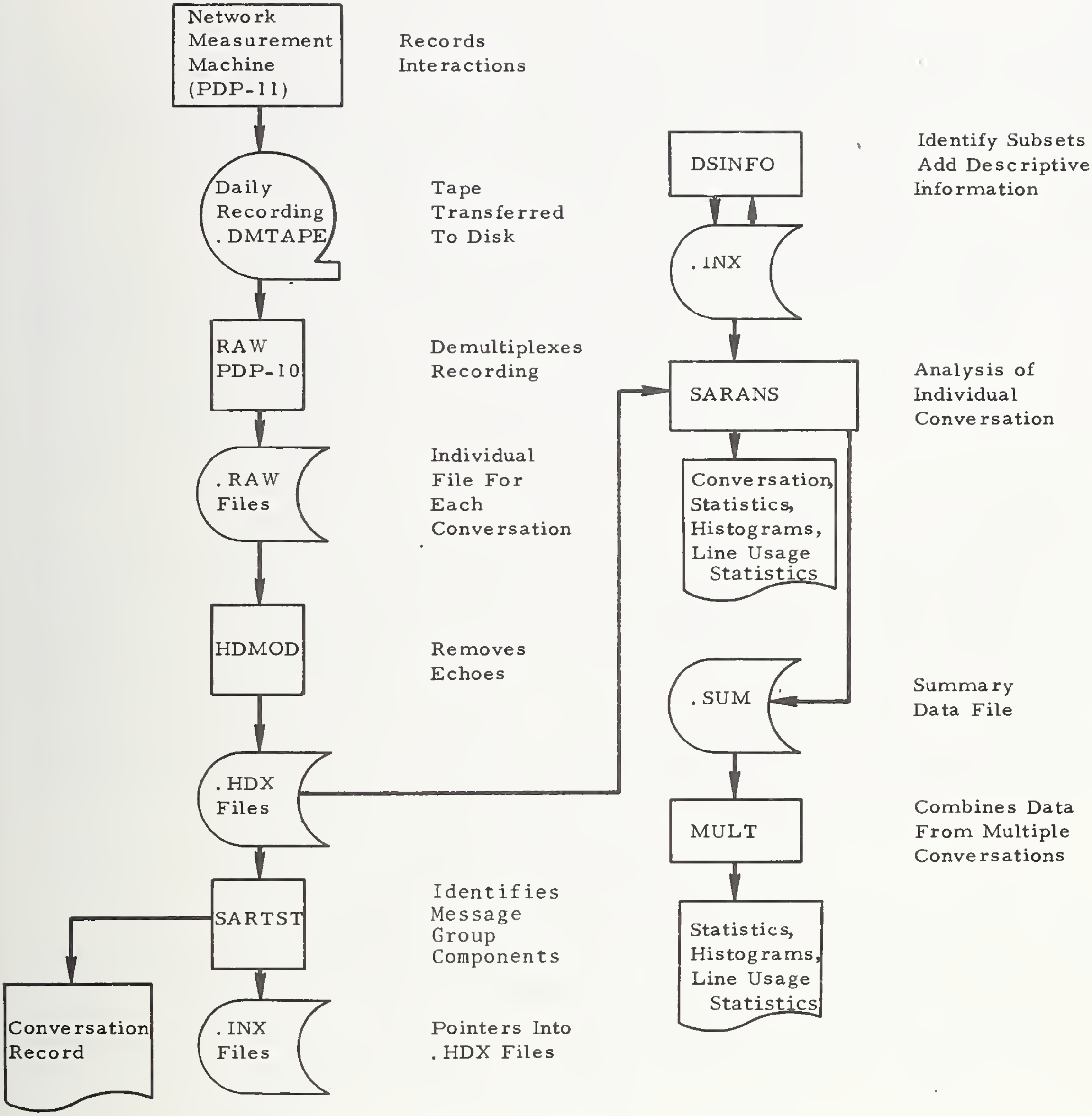
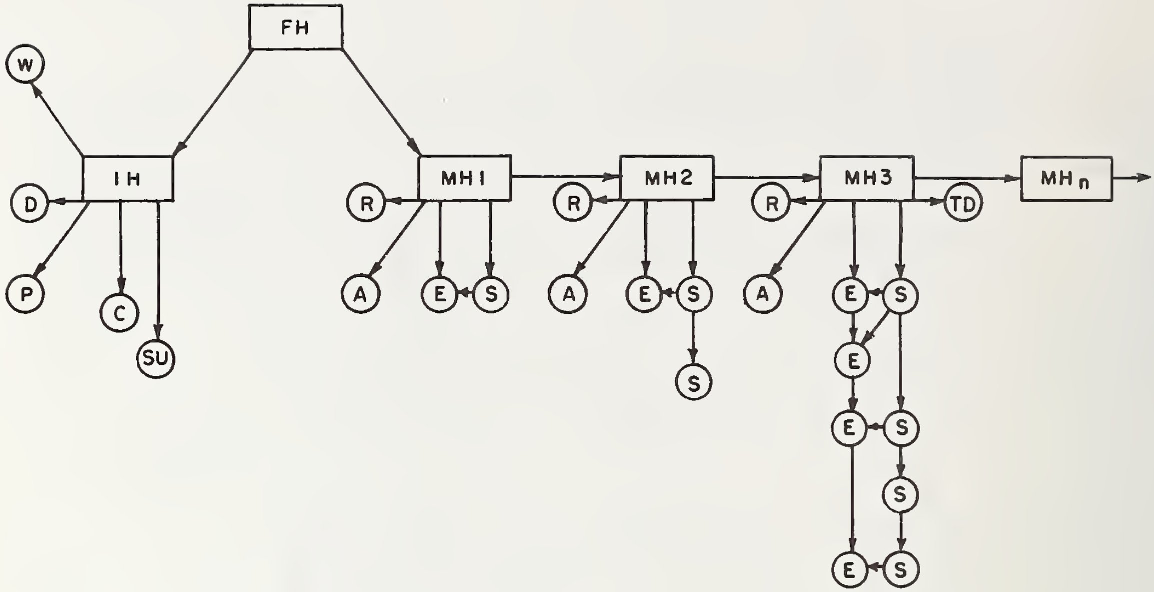


Figure 9. Data Flow in Network Measurement System



FH = File header
S = Stimulus
E = Echo
A = Acknowledgement
R = Response
TD = Time/date indicator
MH = Message group header
IH = Information header
W = Who did the conversation
D = Date of the conversation
P = Place of conversation
C = Computer and network used in conversation
SU = Subset description

Figure 10. Directed Graph of Full-Duplex Data Index File Structure

4.2 The Structured File

Each word in the half-duplex file is examined by SARTST during the creation of the index file. Information records which are identified by bit zero being set at one (1) are handled separately as discussed below.

4.2.1 Treatment of Character Records

Only the character and the bit indicating source are of interest for purposes of identifying the stimulus, acknowledgement, and response. As a matter of fact, the character is only of interest in identifying the acknowledgement. The stimulus beginning is identified by the change of source from network to user. This beginning address and the number of stimulus characters are sufficient input to the creation of the index file.

The change of source from user to network identifies the end of the stimulus and the beginning of either the acknowledgement or response. The algorithm to determine the number of characters in the acknowledgement is coded in a separate subroutine which was described in section 3.1. The acknowledgement may consist of any non-negative number of characters, including zero. The algorithm defining the acknowledgement is compiled as a table for each network identified in the half-duplex file headers. The analyst has the option of changing the acknowledgement definition.

4.2.2 Treatment of Information Records

Information records are signaled by bit zero being set to one (1). Counting from left to right, bits one through seven contain a one's complement negative identification number. Implicit in the identification is the number of words which contain the information. Presently, the only information record defined in the data structure file is the time/date record.

A time/date record is not associated with a character; rather it is associated with an entire message group. More than one time/date record within a message group is not atypical, especially when excessive stimulus delay time (i.e., think time) indicates user distraction. Provision is therefore made for associating multiple time/date records to a message group by chaining.

Reading of the .INX file proceeds sequentially from beginning of the stimulus, acknowledgement, or response and continues for the number of characters indicated by the count in the message group header. Since sequential reading may encounter information records, the subroutines which do the actual file reads skip over information records automatically.

5. Statistical Treatment of the Data

Thus far a variety of techniques for the defining and structuring of data has been discussed. Now the procedures for analyzing the described data will be explained (3). The program responsible for the statistical treatment of individual conversations is SARANS.

5.1 Measured Data and Derived Data

The characters with associated time-tags obtained by the NMM constitute the measured data. The DAP introduces derived data which are arithmetic combinations of the measured data. These derived data are basically the counts of characters occurring in the stimulus, acknowledgement and response, or the time delays between the boundaries of one or more of these message group components. More complicated arithmetic is employed for some of the derived data in the form of ratios and perhaps, ratios of sums. The percentage of printing and nonprinting characters, the percentage of network characters, and the transmission rates are all examples of such derived data. The statistics must be accumulated and processed individually for each of the derived data parameters. It is unlikely that all of the derived data parameters will be of interest to all users of the DAP. Therefore, the DAP user is presented with a choice of the parameters to have computed. While it may be more convenient to give this choice at the time of execution, implementation constraints require a compile time selection.

5.2 Standard Sampling Interval

The intent of the DAP is the measurement of activity typical of a user/network dialogue, not the measurement of anomalies; therefore, it is reasonable to eliminate outliers for the calculation of the statistics. For

----

(3) The reader unfamiliar with any statistical terms used is referred to Mathematics Definitions (pp. 504-532), and Statistics Definitions (pp. 533-560) of Sippl [1967].

example, it is possible for an on-line network user to become distracted by and involved in an activity totally unrelated to network usage. It is also possible for a network to crash at any point during a conversation. Such events produce distorting data. While the number of times a network unexpectedly disconnects (crashes) over a given period may be interesting, one such crash could give an unrealistic slant to a given set of statistics by producing an abnormally long response time. To recognize the presence of these data, upper and lower limits must be used. These limits determine the standard sampling interval. Data must fall within the interval to be considered in the statistics. The acknowledgement and response delay time limits should be set high enough to assure that the network has crashed and is not just heavily loaded. The acknowledgement and response transmission time limits are based on the average character speed.

The upper limits of stimulus delay and transmit times are set with the purpose of eliminating the data reflecting a user become involved in activities unrelated to network usage.

5.3 Frequency Count Distribution

By dividing the standard sampling interval into a number of subintervals it is possible to characterize the distribution of the derived parameters by counting the number of occurrences of a parameter value in each of the subintervals. These equal class intervals may be directly utilized in statistical analysis, as discussed in section 5.5 below. The finer the division, the greater the number of subintervals, and the more accurate the representation of the distribution. This subdivision of data is necessary for the production of histograms. Practical programming considerations limit the number of subintervals; it is, therefore, desirable to make the standard sampling interval as small as possible. By this criterion the upper and lower limits on the standard sampling interval should be carefully chosen to exclude uninteresting, as well as anomalous values. Since there is a minor conflict between these two preceding criteria for establishing the standard sampling interval, this selection should be done very carefully and the results of the analysis studied to detect a possible bias introduced by the interval choice.

Figure 11 is a sample of the histograms currently produced. The vertical axis is divided into intervals, called frequency classes, which reflect the values of the data; this may be time in seconds or number of characters. The horizontal axis represents the number of occurrences. The exact number of occurrences for a class appears in parentheses next to the base class value, which represents the smallest value a data item may have to be represented in the class. The total number of occurrences in all classes appears at the bottom of the histogram.

5.4 Analysis Results

In addition to the histograms, statistical measures of the data including the mean, standard deviation, median (50th percentile), and the 90th and 95th percentiles are provided.

The mean and standard deviation of the derived parameters may be calculated from the frequency count distribution. As a check, the mean and standard deviation are also calculated on a cumulative basis as each observation is recorded. A comparison of these two methods for calculating the moments produces an independent confirmation of the intervals used in the frequency count distribution.

In the analysis of data the appropriate statistical measures depend on the underlying distribution. The statistical quantities shown in Figure 11 should therefore be regarded as typical examples to be replaced by other quantities as desired. The mean and standard deviation are included in the statistical quantities currently calculated; however, due to the non-normal distribution of the data, the median, 90th and 95th percentiles may be more informative. The user must also be mindful of the fact that for some performance parameters each of these runs and its summary constitute a single "event." Variations in repetition of the same basic event should therefore also be investigated to gain a better understanding of the uncertainties in the network.

```
        RESPONSE-STIMULUS DELAY (THINK) TIME (IN SECONDS)
    0.0 (10)   !----------------
    1.2 (30)   !------------------------------------------------
    2.4 (22)   !-----------------------------------
    3.6 (12)   !-------------------
    4.8 (9)    !--------------
    6.0 (3)    !----
    7.2 (3)    !----
    8.4 (9)    !--------------
    9.6 (6)    !---------
   10.8 (4)    !------
   12.0 (2)    !---
   13.2 (6)    !---------
   14.4 (3)    !----
   15.6 (2)    !---
   16.8 (3)    !----
   18.0 (1)    !-
   19.2 (3)    !----
   20.4 (1)    !-
   21,6 (3)    !----
   22.8 (0)    !
   24.0 (1)    !-
   25.2 (1)    !-
   26.4 (2)    !---
   27.6 (0)    !
   28.8 (0)    !
   30.0 (0)    !
   31.2 (0)    !
   32.4 (0)    !
   33.6 (1)    !-
   34.8 (1)    !-
   36.0 (1)    !-
   37.2 (0)    !
   38.4 (1)    !-
   39.6 (1)    !-
   40.8 (1)    !-
   42.0 (0)    !
   43.2 (0)    !
   44.4 (0)    !
   45.6 (1)    !-
   46.8 (1)    !-
   48.0 (0)    !
   49.2 (0)    !
   50.4 (0)    !
   51.6 (0)    !
   52.8 (0)    !
   54.0 (0)    !
   55.2 (1)    !-
   56.4 (1)    !-
   57.6 (0)    !
   58.8 (1)    !-
 FREQUENCY CLASS BASE VALUE   (NUMBER OF OCCURRENCES)
GROUP FREQUENCY RANGE      1.2
 TOTAL NUMBER OF OCCURRENCES=  147
MEAN=        10.0   STANDARD DEVIATION=      12.0
MEDIAN=       3.5   90%=      21.6   95%=      37.9
```

Figure 11. Sample Histogram

Following the printing of the histograms with accompanying statistics for the designated model parameters is a conversation summary. The summary begins with a review of the statistics associated with each parameter. The speed of the connection (recorded in the configuration record), the number of occurrences of anomalous data (values occurring outside the standard sampling interval), and the total time of the conversation are printed. In addition, a number of measures concerning utilization of the connection line are listed. All characters are generated by either the user or the network; further, they are either printing or nonprinting. A variety of percentages relative to these character groupings are calculated. These percentiles serve as a guideline concerning usage of a connection. For example, in order to compensate for varying speeds in carriage control for different transmission rates, a network may always send a given number of nonprinting characters at the beginning of each new line based on the fastest available speed. This technique avoids line dependent calculation of delays but may cause the user to pay for transmittal of unnecessary characters.

Communications or line utilization reflects the actual use of a transmission line relative to the potential use of that line. In other words, how many characters were sent on the line during a given transmission period by the user or network relative to the number that the line could have transmitted during that time period. Two measures of line utilization are given. One defines the potential time interval as beginning with the first character of a message sent by the source of transmission and ending with the last character of that message. The other measure incorporates in its calculation of the potential time interval the delay time imposed by the source. These statistics help to indicate if the user has chosen an unrealistic connection speed. See Figure 12 for a sample of that part of the summary describing utilization of the connection line.

A .SUM file which contains the frequency distribution array obtained from the analysis is created by SARANS. This file conforms to the same naming convention as .RAW, .HDX, and .INX. The analysis of multiple conversations is performed by the program MULT which creates a composite frequency distribution by totaling the contents of the .SUM files selected.

LINE UTILIZATION STATISTICS VERSION 750411 4140#10-1108.HDX;1

300.0 BITS PER SECOND TRANSMISSION LINE RATE
11 OCCURRENCE(S) OF ANOMALOUS DATA

	NUMBER	% OF TOTAL	% OF SUBTOTAL
TOTAL NUMBER OF CHARACTERS	8523	100	
USER	872	10	100
PRINTING	729	9	84
NON-PRINTING	143	1	16
SYSTEM	7651	90	100
PRINTING	6854	80	90
NON-PRINTING	797	10	10
SUBTOTAL # OF PRINTING CHARS	7583	89	100
USER	729	9	10
SYSTEM	6854	80	90
SUBTOTAL # OF NON-PRTING CHRS	940	11	100
USER	143	1	15
SYSTEM	797	10	85

LINE UTILIZATION (MEAN)
DURING TRANSMISSION ONLY (BURSTINESS)

USER	4.1%
ACKNOWLEDGEMENT	8.0%
RESPONSE	49.5%

LINE UTILIZATION (MEAN)

USER	1.3%
SYSTEM	25.5%

43.2 MINUTES TOTAL CONNECT TIME

Figure 12. Sample Line Utilization Statistics

5.5 Statistical Analysis Support

In the implementation of the statistical analysis portions of the DAP, every effort was made to avoid duplication of existing available programs. A subroutine from the machine-independent Scientific Subroutine Package (SSP [1968]) was used to calculate moments for grouped data on equal class intervals. As discussed in section 5.4, a confirmation of the results is provided by calculation of the mean cumulatively from the ungrouped observations.

Since reliable, sophisticated statistical analysis is available in OMNITAB (Ku [1973]; Hogben, Peavy, and Varner [1971]), the DAP produces files of the derived data which may be input to OMNITAB.

5.6 Verification of the Statistical Results

It is possible to test the accuracy of the algorithms employed in the DAP by calculating the statistics by hand, and then comparing the hand calculations with those from the DAP. However, this proves tedious for a sample of any appreciable size, and there is the probability of human error .

It was decided that the best way to test the statistical package was to execute it using a data base of known statistical distributions of the parameters of the SAR model. A program, BLDRAW, was developed to create such data. The output of BLDRAW is a file in the format of the .RAW files described previously; because the program produces only half-duplex conversations, the file is also identical to the .HDX files. The analyst specifies the distributions for nine of the parameters calculated by the analysis routines: character count, transmit time and delay time for the stimulus, acknowledgement and response. Values for these parameters may be specified as a constant or in terms of a mean and standard deviation. The program also asks the analyst to supply the following information:

- i) name of the file to contain generated data,
- ii) number of message groups in generated conversation, and
- iii) speed of the connection line for generated conversation.

If the analyst chooses a transmit time too small with respect to the corresponding character count and the capacity of the chosen line, the program warns the analyst and requests a new transmit time.

Available in SSP is a Gaussian number generator, GAUSS, which produces a series of random numbers which conform to a specified distribution. BLDRAW makes use of this routine to calculate appropriate time-tags and number of characters in each message group component to produce the analyst-defined data file.

The data files produced by BLDRAW did indicate the existence of several minor errors in the statistical routines which were corrected. It also enabled the creation of potential problem situations never encountered in previous recordings.

A set of statistics generated using a file built by BLDRAW is used as a comparison basis for future acceptance testing of the analysis routines. When changes are made to the analysis package, statistics will be produced using the test data file in order to assure that the routines are still functioning properly. Before processing a major portion of data files, it is advisable to run the test data file through the analysis routines to insure that the DAP computer is behaving normally. Thereby BLDRAW's test data file provides a basis for acceptance criteria for the analysis routines.

6. Subsets

The working unit in the interaction between the user and the network is the message group which may be considered a generalization of a transaction in special purpose transaction-oriented networks such as reservation networks. Employing set terminology, the conversation is the ordered set of all message groups. Many other sets of message groups can be defined. The set concept may also be extended beyond the boundary of a single conversation, where the upper limit (i.e., the universe of discourse) is the entire data base obtained by the NMM. For example, when all of the usage of a given network during a period of time such as a month is considered, the set encompasses multiple conversations.

In the present context the interest is in sets which encompass less than a conversation; that is to say subsets of a conversation. Two criteria have been developed for the identification of subsets. One criterion is the meaningfulness of the information obtained from the message group. Data screening techniques may be applied to the message groups to identify those falling outside of a standard sampling interval. From an entirely different point of view, message groups may be identified according to the functional objective with which they are associated. The use of an identifiable software resource or service is a criterion for membership of a message group in an identified subset. For example, in a programming environment the use of the various language translators, the editor, the linking loader, and the execution of debugging tools each constitute a subset. There is no requirement that the subset definitions be mutually exclusive; it is therefore possible that an individual message group may satisfy the definition of, and therefore belong to, multiple subsets. In the present implementation, the pointer to each message group in the index file also contains an identification of subsets of which that message group is a member.

Subset identification makes it possible to take various samplings or cross sections through the data base, depending upon the objective of the analysis. Using the editor as an example, it is possible to identify what percentage of the message groups or the elapsed time is spent in the use of this resource. It is also possible to limit the attention to this editing resource and to perform all of our statistical analyses on it. The user demands and network responses associated with the use of the editor are interesting in themselves and may be substantially different from the network assemblage statistics.

6.1 Subset Assignment

The resources and services for a given computer network are, in general, fixed and well defined. They are usually enumerated in user literature provided by the network operators. It is, therefore, straightforward to identify the subsets describing usage of a particular network. The process of identifying the subset to which a message group belongs begins with the identification of the computer and network involved in the conversation. Implicit in the identification is the selection of the possible subsets, the union of which describes the utilization. For the convenience of the analyst, the subsets are identified by name whenever analyst interaction is possible. Of course, internal identification by name would be inefficient, so a coded mask is employed in the message group header to identify the subset or subsets to which each individual message group belongs.

6.2 Assignment of Message Groups to Subsets

Automation of assigning a message group to one or more subsets is accomplished by a specially written program. The program is strictly dependent on the network and network computer being analyzed. This program must incorporate recognition of the software services available, the syntax of the command language, and the local editing conventions. At this time one such special program, called TT1108, has been implemented to identify subsets used on the Univac 1108 operating under Exec 8. The program employs a sliding character string match technique, similar to that used to detect the end of a conversation and the end of an acknowledgement, to identify the subset to which each message group belongs.

After subsets have been identified by this program, it may be necessary to make changes to account for anomalies or to correct errors. These changes must be performed manually by the analyst. The analyst works with a list of the conversation which was previously prepared and interactively assigns one or more subsets to each message group through the program DSINFO.

6.3 Analysis of Data by Subsets

The statistical routines described earlier -- histograms, statistics, summary -- are available for operation on the subsets. They may be applied to individual subsets or to logical combinations of subsets. Therefore, it is possible, for instance, to analyze the response delay time experienced in invoking an editor at various points in a conversation.

Although the analysis of subsets within a given conversation may prove sufficient to some users, analysis of corresponding subsets within a variety of conversations is necessary for others. For example, statistics may be obtained on network performance during a specified time period over a number of days to verify the time dependent variation in network utilization. This analysis of multiple .SUM files is done with the previously described program MULT. To assure compatibility in the analysis of .SUM files such information as subset definitions is maintained in headers to the .SUM files.

7. Applications Areas

The NMS can be used in the design, selection, and improvement of computer networks and network services. This section specifies how the NMS can help Federal agencies in these three network related areas. This subject is discussed in detail by Abrams, Watkins and Cotton [1975].

7.1 Design

In the design of a computer network the measurement of external performance is useful in specifying service design goals. The NMS can be used by designers for such specification and later for the testing of the design to determine if design goals are being met; that is, that the service specified is being provided. This procedure also provides a common ground for network designers and those for whom they are designing the network. It is often difficult for agencies to explicitly state the service they expect from a proposed network. By applying the NMS to known networks the analyzed data provides agencies with a basis for service specification.

7.2 Selection

The selection of computer networks and network services provides three areas of application of the NMS. The NMS can be used to determine user requirements. When the NMM is applied to a current network, the analysis of the data acquired instructs agencies as to current service capabilities. The agencies can then specify their requirements with current service levels as a comparison base for determining the minimum service level required.

Once user requirements are determined, a selection among networks must be made. The NMM is applied to each candidate network during execution of a specified benchmark. For a computer evaluation of network performance, it is recommended that this procedure be conducted during both high and low network load periods. A variety of aspects of the network can be analyzed: degradation during high load periods, utilization of the communication lines, the time the network requires to process stimuli, and the time needed to output responses.

The third application occurs after selection and is especially pertinent to the selection of network services. The NMS is periodically applied to a network service during the execution of the same benchmark used in the selection process. The analysis of acquired data will assure that service is not degrading below an acceptable level.

7.3 Improvement

The NMS can be used to measure the effect on service caused by a change within the network. For this application, the NMM should be applied before and after the change is made.

The NMS can also be used relative to the operation of computer networks by characterizing user habits and the communications characteristics of the network. The data will show which facilities of the network are most heavily used, thus indicating which optimization efforts should receive priority. Efficient multiplexing and concentrating in a network are key factors; the analysis of data will indicate such statistics as the users' average transmission rate which will help in the design of multiplexors and concentrators for specific networks.

The NMS data can be used in determining the overhead introduced by the communications portion of a network. When the network charging algorithm incorporates the number of characters transmitted, the overhead of nonprinting characters (which do not convey useable information to the user) becomes more significant. Another area of investigation is the transmission rate of the communications facility. Arguments concerning the desirability of asymmetrical transmission rates, with a high transmission rate from computer network to user, may find support in these statistics. By providing such data as line utilization, the NMS-produced statistics can indicate to Federal agencies areas of inefficient network functioning.

8. Summary

This report has described the Network Measurement System (NMS) with particular attention to the interpretation of data by the Data Analysis Package (DAP) component. The processing necessary to produce meaningful service measurements from the data acquired by the Network Measurement Machine (NMM) has been explained. Various processing by the DAP -- including format reconfiguration, structuring, and statistical treatment -- has been discussed.

The intent in the design of the DAP was to present the NMM data in such a form as to permit the most flexible use. The index structure allows selective access to any portion of the half-duplex representation of the conversational data. The subset capability enables the user of the DAP to concentrate analysis on one specific network function or set of functions, even across conversation boundaries.

The statistics calculated by the current DAP should be regarded as typical and may be replaced or supplemented by others desired by users of the DAP. Among the statistics calculated, the median and 90th and 95th percentiles may be more informative in the comparison of two networks or network services due to the non-normal distribution of the data.

The NMS was designed to provide a quantitative basis for the evaluation of a computer network and computer network service for the purposes of improvement and selection. It is hoped that this work will prove useful to Federal agencies operating their own networks or in the process of selecting a network or network service.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The Network Measurement System (NMS) represents an implementation of a new approach to the performance measurement and evaluation of computer network systems and services. In this report, the interpretation of data within the NMS is described. These data have been acquired by the Network Measurement Machine (NMM) component of the NMS and are then interpreted by a Data Analysis Package (DAP), which produces meaningful information concerning the quality of network service delivered to interactive terminal users as well as a characterization of user demands and network communication facility utilization.

This report traces the flow of data from the time of capture by the mini-computer-based NMM through the several phases of modeling and structuring in the DAP. Included in this description is the statistical treatment of the data which provides quantitative measures of various aspects of network performance.

17. KEY WORDS *(six to twelve entries; alphabetical order, capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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