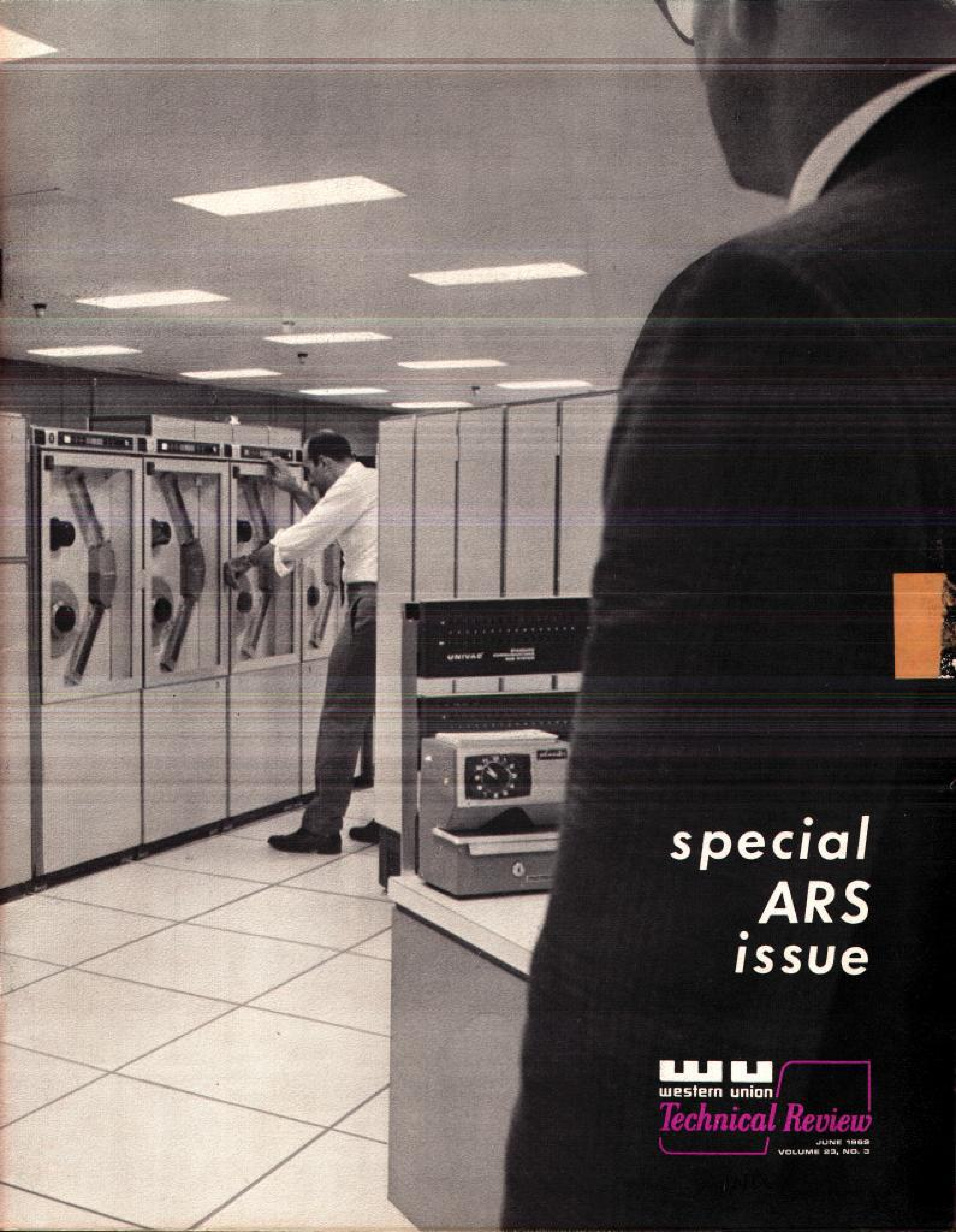

special ARS issue

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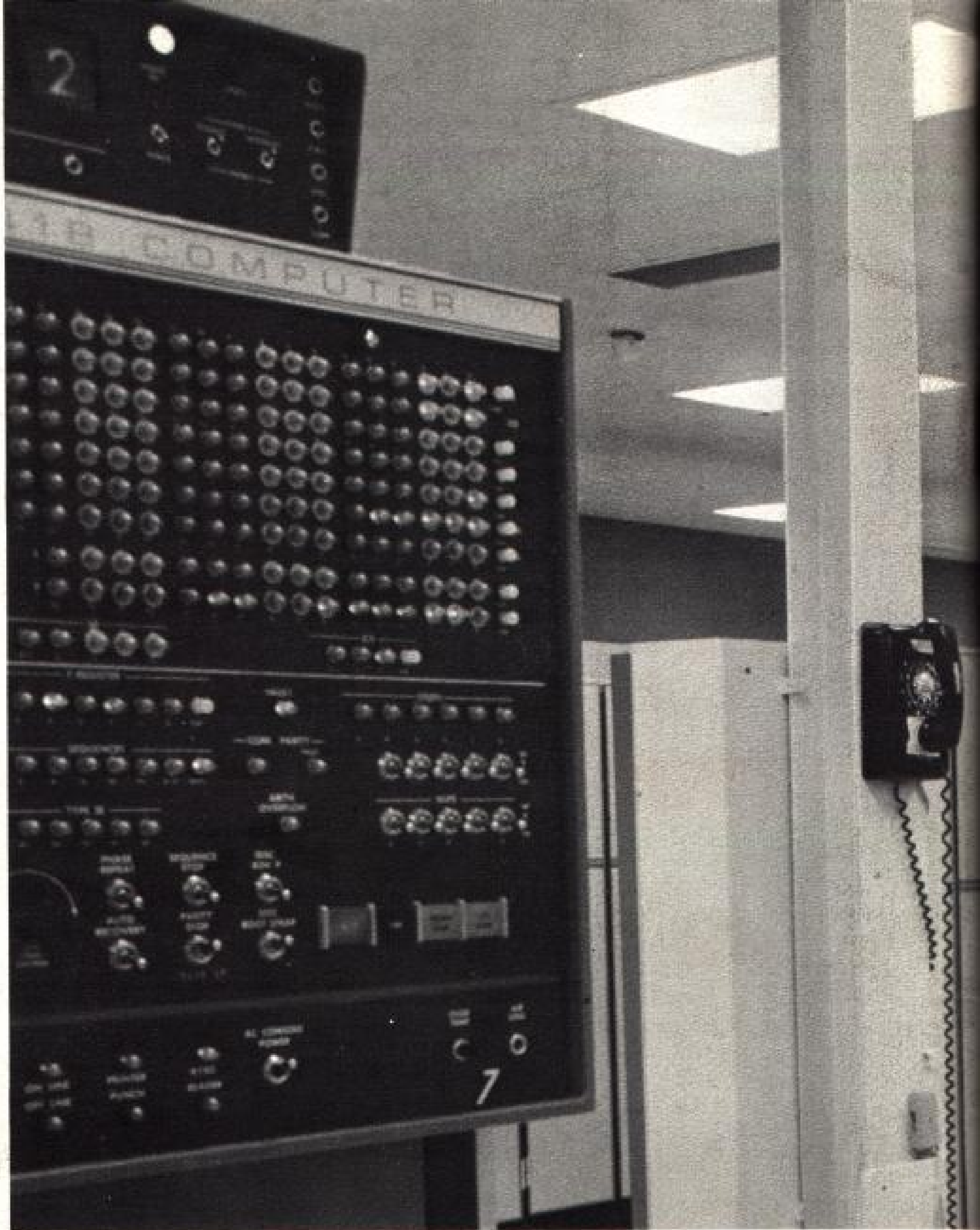

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Foreword

The articles that follow in this special ARS issue of the TECHNICAL REVIEW present some new ideas and techniques relating to the combination of circuit and message switching systems. By a circuit switching system we mean one in which a terminal is connected directly to another terminal for the purpose of handling traffic. A message switching system is one in which a message is transmitted into some form of storage, where it is held until a connection can be established to the destination point for the delivery of the message.

To some of our readers it may appear that the problems for which solutions are proposed should have been resolved long ago. However, it may be well to review the genesis of some of the arts of circuit and message switching. The first circuit switching "system" probably appeared in the early days of the telephone, when it was recognized that some system of interconnecting subscribers, even in a very small "exchange," was necessary. Early systems used simple combinations of switches to make these interconnections; following this—jacks, connected by plug cords, were used. As the industry progressed connections were no longer made by simple cords, instead "trunking" was used between switchboards to permit increasing numbers of subscribers to be handled.

It is well to point out that circuit switching by machines, rather than by human operators, came into use in the telephone industry around 1900. It provided theoretical advances which were not entirely attained because their advantages could not be realized by the mechanical and electrical equipment then available.

The early telegraph industry was the first in the communications field to use the technique of message store and forward systems. Telegraph circuits did not permit and were not capable, in those days, of reaching from one location to many locations in the country. As a result Morse operators, operating the more important trunk circuits, would send a message from destination A to destination B, where it was hand copied, stored in the form of a written message on a blank, and delivered to another operator who would forward it from destination B to destination C.

Until the early 30's circuit switching had little application in the telegraph industry but was primarily confined to the telephone systems. Message switching systems have been principally the province of the telegraph industry, and various forms of it have been used for some 40 or 50 years.

It may be surprising that only within the last decade or so have we seen these two well established basic types of switching systems brought together to perform functions that neither can do as well operating separately.

W. S. W. Edgar, Jr

Assistant Vice President
Private System Projects
P and E Operation

A Fundamental Record Communication System Problem . . .

The ARS Solution

by J. Acunis, Director
GSA/ARS Project Engineering

Several articles describing various functional aspects of the Advanced Record System designed for the General Services Administration have appeared in previous issues of the "Technical Review." The articles in this special June 1969 issue deal with solutions to different parts of the same fundamental record communications system problem.

The problem is one which must be faced when a system is configured to include both message and circuit switching centers exchanging traffic with each other. The rewards of such a system can be high since the combination of the two switching modes can offer advantages in services which neither one can provide by itself. However, a design for such a system which does not adequately consider the peculiarities of each of the two switching disciplines can prove to have a very great negative effect on system performance and service to the subscriber.

Conventional circuit switching systems are designed to provide a satisfactory grade of service for users who exhibit an established statistical pattern of demands on the system. An understanding of these statistics allows for an efficient allocation of shared equipment in the switching exchanges and an economical distribution of shared trunks in the network. The circuit switching network design is therefore based on the habits of people using subscriber equipment.

The output traffic of message switching center computers, on the other hand, is usually statistically different from the kind of traffic which a circuit switching exchange expects to receive on its input trunks. Consequently, when message switching center computers having such characteristics are connected directly to circuit switching exchanges certain problems arise. The circuit switching exchanges invariably yield to the insistent demands of the computers and unfairly allocate shared equipment and trunks to the computers. As a result, service to subscribers frequently suffers a severe degradation.

Theoretically, one could program the computer output so that the offered traffic to the circuit switching exchange statistically resembles the traffic appearing on input trunks from other circuit switching exchanges. This would prevent the computer from overloading the exchange and the network and would permit the circuit switching systems engineer to intelligently design for the required grade of service. In ARS, however, this would have involved an unrealistic programming redesign for a system which was already operational. Furthermore, the computer would have been stripped of much of its throughput capacity by reducing its behavior to that of people in the way it offered traffic.

The approach which finally evolved established controls over the computer output traffic in a way which enhanced its own throughput capability while limiting its access to common circuit switching elements. This was accomplished entirely through programming redesign which forced the computer to, in effect, police itself with the help of programs containing much more system intelligence. The computer was made to observe strict output limitation rules when necessary but was allowed to relax these constraints during those intervals when the network traffic conditions could tolerate the additional computer load. A dynamic determination of network conditions has made this flexibility possible. The results show definite improvements in both circuit switching network grade of service and in message switching center throughout.

The article entitled "Service Improvement Through MSC Program Control" describes the programming constraints imposed on the computers to prevent them from 1) seizing more than their fair share of common exchange equipment and trucks, and 2) from attempting calls when a priori knowledge indicates that such calls would be aborted if placed.

A further examination of system performance showed that while the demands on the circuit switching common equipment were greatly reduced and grade of service greatly improved, the constraints on the message switching centers seemed unduly severe and rigid. The second article deals with "Improved Trunk Allocation in a Congested Network." Instead of programming the computer to limit itself to fixed maximum numbers of trunks, the software design was improved to allow the computer to control its demand on trunks in a dynamic fashion. This allowed almost unlimited seizure of trunks by the computers during idle network conditions but placed constraints on such seizures during periods of busy activity. This was made possible by utilization of current status of trunk usage and resulted in performance improvements in both the circuit and message switching elements of the system.

The knowledge gained through the implementation of the programs described in the first two articles led to the work described in the third article entitled "Throughput Improvements in Message Switched Traffic." As a result, the computers are now able to organize the processing of multiple address messages so efficiently that the delivery time has been reduced to about one-sixth of what it was before these changes were made. This signifcant improvement in message processing was achieved without degrading performance in the circuit switching network.

Finally, in the fourth article an off-line computer tool, NETSIM—NETwork SIMulation, was developed which permits one to conveniently determine "End-to-End Grade of Service Through Circuit Switching Network Simulation." Its usefulness lies in the ability to determine the end-to-end grade of service for any hypothetical variation of service factors in the individual system elements. ■ ■ ■

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SERVICE IMPROVEMENT THROUGH MSC PROGRAM CONTROL

J. C. PARR
and
A. M. EISNER

The circuit switching network is a commonly accepted method of providing communication services to subscribers whose individual needs do not justify dedicated communication facilities and equipment. The economic advantage to these subscribers is they can satisfy their communications needs by sharing a limited amount of common control equipment and facilities. In a circuit switching network subscribers obtain communications service by bidding for the common control equipment and facilities. In the conventional circuit switching network this competition is usually not detrimental but in a unique system such as ARS, where automatic message switches are competing with teleprinter stations for service, special steps must be taken to insure that the service provided to all subscribers is consistent with their communications requirements.

The Advanced Record System is a hybrid telecommunication system consisting of a Circuit Switching Network (CSN) and three dispersed Message Switching Centers (MSCs). The CSN is the backbone of the system in the sense that it provides the basic ARS service, i.e., it provides, on dialing, point-to-point connections, by direct or alternate routes, for real time exchange of communications traffic or data between ARS subscribers. The MSCs enhance the system capability by providing additional services to the subscribers beyond the capability of the CSN. These additional services include store and forward handling, data collection and distribution, message exchange, and multiple address handling. Subscribers request these special services by transmitting appropriately formated messages through the CSN to the MSCs. The MSCs provide these services by performing the required processing and transmitting messages through the CSN to the appropriate subscribers. In effect, the MSCs are in competition with the subscribers for the available common control equipment and facilities in the CSN.

This competition is not, in itself, undesirable or detrimental to system performance. However, an examination of system operation and performance, several months after cutover of the initial phase, revealed two basic facts. First, a considerable amount of network congestion and an inordinate number of incompleted calls resulted from the

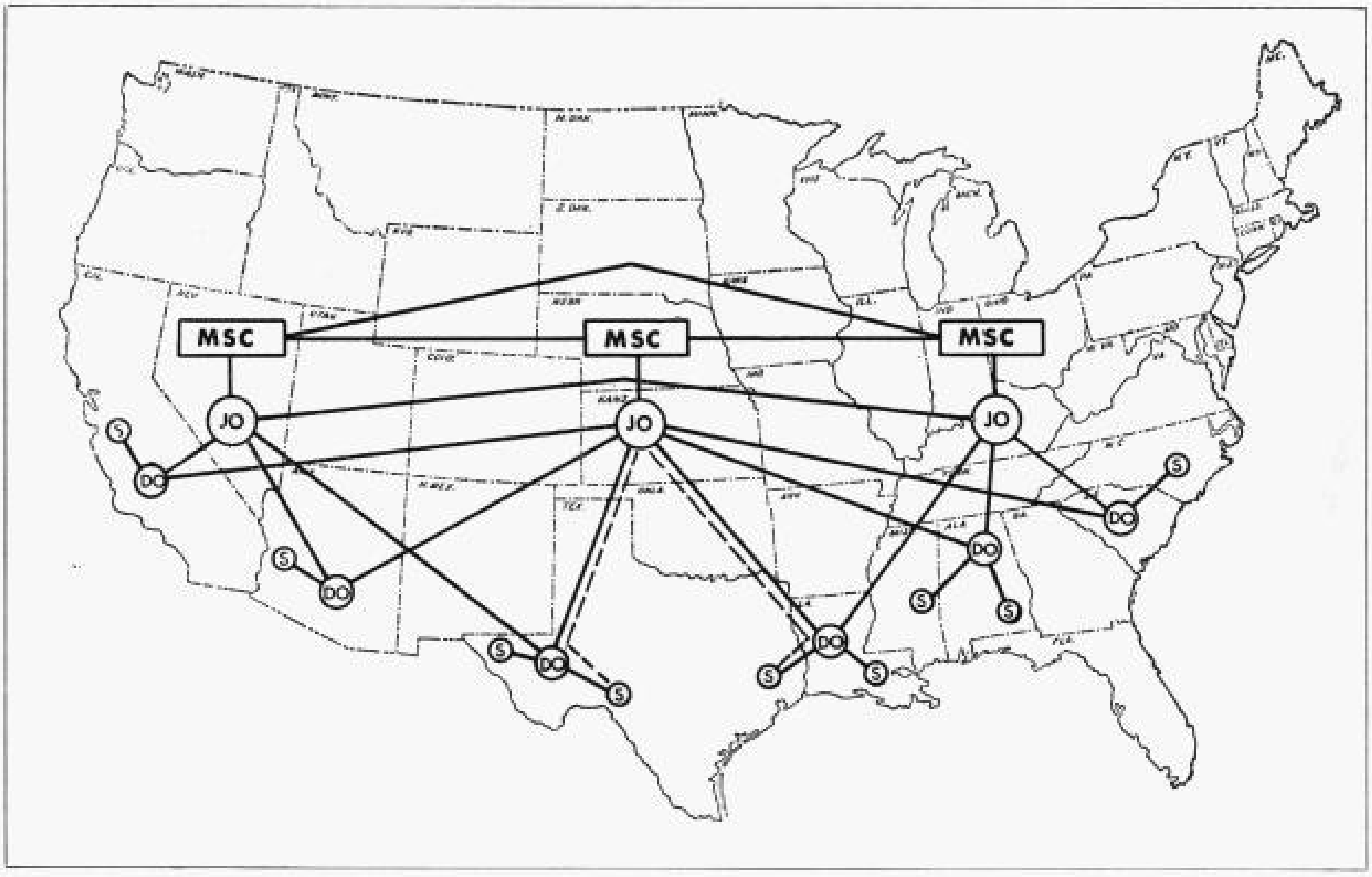

Figure 1—Network Diagram of ARS

competition for common control equipment and facilities. Second, the MSCs were prime contributors to the network congestion.

The Problem of System Configuration

The network diagram of ARS, shown in Figure 1, indicates that the MSCs have privileged access to the CSN. Traffic from an MSC enters the CSN through its collocated Junction Office (JO). Traffic from a subscriber enters the CSN through the subscriber's District Office (DO). The impact on system performance due to this privileged access given to the MSCs can be demonstrated by comparing CSN operation for subscriber originated traffic and for MSC originated traffic.

A Subscriber Call

A subscriber-to-subscriber call proceeds through the originating subscriber's DO, through one of the JOs and finally through the called subscriber's DO. The use of the registers in the DOs and the JO in this procedure is of particular significance. The register is a unit of common control equipment found in both DOs and JOs. One of its functions is to accept, store and forward the dial digits supplied by the calling subscriber. In a subscriber-to-subscriber call, the calling subscriber sends a service request signal to the associated DO. The DO recognizes the service request by attaching one of its registers to the subscriber's line and signalling back over the subscriber's line. The subscriber responds by sending the five dial digits to the DO where they are stored in the DO register. The DO analyzes the dial digits to determine the required destination, seizes an appropriate outgoing trunk to a JO and determines a path through the DO matrix. The JO responds to the trunk seizure at the DO by attaching one of its registers to the seized trunk and signalling back over the trunk to the DO. The DO responds by sending the five dial digits in the DO register to the JO where they are stored in the JO register. The first two dial digits uniquely identify the destination DO and are used by the JO to set up the necessary circuit. The JO analyzes the dial digits, seizes an appropriate outgoing trunk to the destination DO and determines a path through the JO matrix. The destination DO responds to the trunk seizure at the JO by attaching one of its registers to the seized trunk and signalling back over the trunk to the JO. The JO then completes the path between the originating DO register and the destination DO register, releases the JO register for use in setting up other calls and signals the originating DO. The originating DO sends the five dial digits to the destination DO where they are stored in the DO register. The destination DO analyzes the dial digits to determine the required subscriber, seizes the circuit to that subscriber, determines a path through the DO matrix and signals the originating DO. At this point the end-to-end connection has been made and the originating DO sends a "Who Are You" signal to the destination DO. If the answerback received by the originating DO is valid, both DOs release their registers. In a typical subscriber-to-subscriber call the DO registers will be in use for an average of five seconds and the JO register will be in use for approximately two seconds.

An MSC Call

Register usage is somewhat different in an MSC-to-subscriber call. The MSC requests service by seizing one of its output trunks to the collocated JO. The JO recognizes the service request by sending a "trunk seized" signal to the MSC. After connecting one of its registers to the seized trunk, the JO sends a "register attached" signal to the MSC. The MSC responds by sending the five dial digits to the JO where they are stored in the JO register. The JO analyzes the dial digits to determine the required destination DO, seizes an appropriate outgoing trunk to the destination DO and determines a path through the JO matrix. The destination DO responds to the trunk seizure at the JO by attaching one of the DO registers to the seized trunk and signalling back over the trunk to the JO. The JO then sends the five dial digits to the destination DO where they are stored in the DO register. The DO analyzes the dial digits to determine the required subscriber; it then seizes the circuit to that subscriber, determines a path through the DO matrix and signals back to the JO. At this point the end-to-end connection has been made and the registers in the JO and DO can be released. For this type of call the JO register is required to perform all JO register functions required in a subscriber-to-subscriber call and also to perform the function of a DO register since there is no originating DO. In a typical MSC-to-subscriber call the registers in the DO and the JO will each be in use for approximately five seconds.

The critical difference between the two types of calls is the amount of time the JO register is in use. In a subscriber-to-subscriber call the JO register is in use for approximately two seconds. In an MSC-to-subscriber call the JO register is in use for approximately five seconds. Since more than half the traffic handled by ARS flows through the MSCs, this difference in JO register usage is significant. It indicates that the operation of the interface between the MSC and the JO is a potential area for improving CSN performance, at least in terms of register usage.

Problem of Program Control

Two basic programs are used by the MSC to deliver a message in storage in the MSC to the ARS subscriber. The first program, Precedence Message Selection (PMS), periodically reviews the messages in storage and determines whether any messages require delivery to the CSN. If a message requiring a CSN delivery is found, it is given to the second program, Initiate Call (INC), which controls the exchange of signals and message data with the CSN and causes the message delivery to take place. A review of these two programs performed prior to the addition of the MSC programming changes described in this article, indicated that the only criterion for selection and delivery of a message to the CSN was MSC output trunk availability. If a message in storage required delivery to the CSN and an output trunk from the MSC to the CSN was available, the MSC would select this message and attempt to deliver it regardless of the CSN traffic load.

The inefficient operation which can result when the MSC to CSN interface is controlled only by MSC to CSN trunk availability can be demonstrated using the simplified network diagram shown in Figure 2. This network diagram was generated by taking part of the ARS network and scaling down the number of registers and trunks. Special care was taken in scaling down the network in order to insure that conclusions reached in examining the scaled down network also apply completely in the actual network. Three cases can be examined, using the simplified network diagram, which will demonstrate the problem of MSC program control.

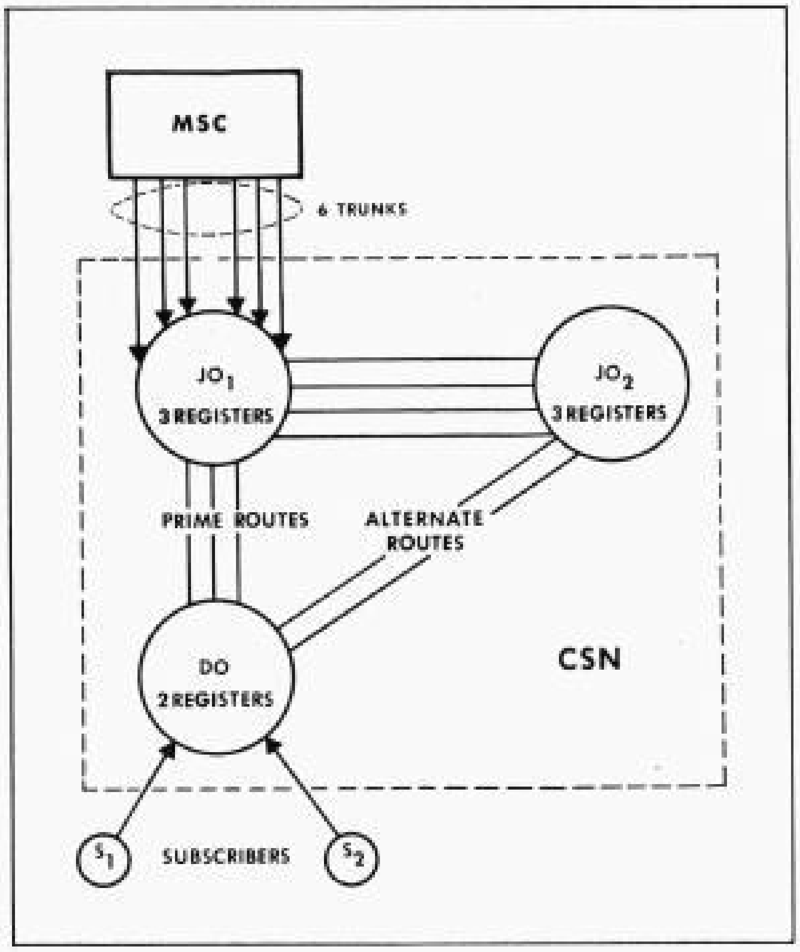

Figure 2—Simplified ARS Network

1) Register Usage

The first case involves register usage. Suppose that the MSC schedules six calls to the DO and that at the same time the DO receives two service requests from its subscribers for calls to the MSC. The three registers in the JO are attached to three of the six MSC to JO trunks requesting service. The two registers in the DO are attached to the two subscriber lines. The JO and the DO begin seizing trunks to each other and determining matrix paths. The worst condition occurs when the DO is successful in seizing two trunks to the JO collocated with the MSC. In this case all JO to DO trunks are seized, with two JO to JO trunks seized as alternate routes. Neither the JO nor the DO can honor any incoming trunk seizures by attaching registers since all registers are acting as originating registers. This is an unfortunate communications standoff and none of the five calls can be extended until one of the registers times out and releases. The JO register releases in twelve seconds and the DO register releases after eight seconds. Whether the MSC calls will be extended to the DO, depends on the other outstanding requests for registers at the DO. It is also interesting to note that three MSC originated calls are waiting for JO registers and may prevent DO originated calls from receiving register service. Two conclusions may be drawn from this case. First, no calls are completed through the JO or the DO for eight seconds. Second, if one of the five registers had been available, all calls might have been completed.

2) Trunk Usage

The second case involves the use of JO to DO trunks. Suppose that two of the three prime JO to DO trunks are occupied with subscriber-to-subscriber calls, that all registers are available and that the MSC schedules six calls to the DO. Three of these calls cause the JO to attach registers. Two of these three calls are serviced by the two DO registers. When one of these two calls is extended to the subscriber and the DO register released, the third call is serviced by the DO register. Ultimately all registers are released. However, there are still three outstanding MSC originated calls awaiting service in the JO and all JO to DO trunks are occupied. The JO honors the three outstanding MSC originated calls by attaching registers. Since all trunks to the DO are occupied, the JO must route the calls to the next JO. Only two of these outstanding calls can be alternately routed since only two trunks are available to the next JO. The collocated JO responds to the third outstanding call by sending a "busy trunk" signal to the MSC which causes the MSC to abort the call. The second JO responds to the two alternate routed calls with "busy trunk" signals since all trunks from the second JO to the DO are occupied. These signals are returned to the MSC which causes the MSC to abort these two calls also. Therefore, of the six MSC calls, three are completed and three are terminated in busy trunk conditions. Again two conclusions can be drawn. First, the MSC not only scheduled its traffic without regard for the existing CSN traffic but actually scheduled more traffic than the CSN was physically equipped to handle. Second, the aborted calls used common control equipment and facilities which might have been needed to handle other calls.

3) Subscriber Equipment Usage

The third case involves the use of subscriber equipment. Suppose that the simplified network is not handling any traffic and that the MSC schedules six calls to the DO. Further assume that all six calls are destined to the same subscriber and that this subscriber has only one teleprinter. In this case five of the six calls reach the DO. The sixth call is extended to the second JO and then aborted due to a busy trunk condition. One of the five calls reaching the DO is completed to the subscriber and the remaining four calls are aborted due to a busy station condition.

Since more than half of the large number of busy station conditions encountered by the MSC occur because of MSC traffic to the station, the inefficient use of common control equipment and facilities resulting from this aspect of MSC traffic scheduling is significant.

New MSC to CSN Interface Criteria

The three cases cited above indicated that three basic changes were necessary in the MSC programs, which control the selection and scheduling of traffic from the MSC to the CSN.

a) The *number of JO registers in use simultaneously for MSC traffic should be limited* to some reasonable share of the available registers.
b) The *number of simultaneous calls to a DO by the MSC should be limited* such that the MSC traffic does not occupy more than its fair share of the JO to DO trunks.
c) The *number of simultaneous calls to an individual subscriber by the MSC should be limited* such that the MSC traffic does not exceed the number of pieces of subscriber equipment and, in the case of subscribers with more than one piece of equipment, does not occupy more than its fair share of the subscriber's equipment.

The exact nature of the program changes and the system considerations involved in imposing these limitations can best be understood by examining the manner in which the MSC program caused a delivery to be made to the CSN.

Original Rules of Interplay

Prior to the inclusion of the MSC programming changes described in this article, the rules of interplay between MSC and CSN were as follows. When the MSC decided that a message was to be delivered to the CSN and that a trunk to the JO was available, the output area associated with the selected trunk was "initialized" with all data necessary to make the delivery and control was given to the Initiate Call (INC) program. This program controls the exchange of signals with the CSN in order to obtain the desired end-to-end connection with the subscriber, verifies the identity of the connected subscriber, transmits the message and finally terminates the connection after again verifying the identity of the subscriber. The interval between the time at which INC is given control and the time at which message transmission begins is called pre-message interplay. Interplay is of particular significance since the majority of the controls necessary to implement the criteria cited above had to be implemented in interplay.

To begin interplay, the INC program seized the trunk to the JO and began a 500 millisecond timeout waiting for a "trunk seized" signal from the JO. If the "trunk seized" signal was received before the expiration of the timer, INC stopped the timer and started a second timer of twelve seconds waiting for a "register attached" signal from the JO. If either timer expired before the expected signal was received from the JO, the seized trunk was released and interplay was restarted over another trunk or if no other trunk was available, over the same trunk.

When the "register attached" signal was received from the JO, INC stopped the twelve second timer, transmitted the five dial digits to the JO and started a fifteen second timer waiting for connection status digits from the JO. The connection status digits can specify any one of four conditions: station connected, station busy, trunk busy or deranged. If the "station connected" signal was received, INC sent a "who are you" signal and verified the answerback received from the connected station. If the answerback was correct, premessage interplay was complete and message transmission began. If the answerback was incorrect, the error path was similar to that taken when the connection status digits specified a condition other than station connected or when no connection status characters were received and the fifteen second timer had expired.

Five functions were performed in this error path. A printout was made on the MSC high speed line printer which specified the time of the error, the message number, the dial digits, a unique code indicating the type of error, the connection status digits received, and the trunk number. An error journal was also made on magnetic tape and contained the same basic information. A disconnect signal was sent over the trunk to the CSN. The aborted message delivery was entered in the busy table which automatically delayed the next attempt to deliver the message for 60 seconds. Finally, the output area was released. The only exception in this error handling was the processing of a "Z" or flash precedence message. In this case the message delivery was not placed in the busy table and the output area was not released. Instead, interplay was restarted on another trunk or on the same trunk if no other trunk is available.

Necessary Programming Changes

Two programming changes had to be made in the MSC program to implement the three criteria cited above. The first change, Register Usage Control, limits the MSCs share of the JO registers and prevents the communications standoff that can occur when the MSC seizes all JO registers. The second change, Trunk and Subscriber Equipment Usage Control, limits the MSCs share of the JO to DO trunks and its share of the subscriber's equipment. This change, in effect, permits the MSC to attempt only those deliveries which have a high probability of successful completion. Those deliveries with a low probability of successful completion are sent directly to the busy table without incurring the associated unnecessary use of CSN common control equipment and facilities.

Both changes made in the MSC program will be discussed from two points of view. First, the tables and data necessary to provide the required control will be described. Then the control logic and the manner in which it was incorporated as part of the improved design in the MSC program will be defined.

Register Usage Control

Program control of register usage by the MSC depends on the three word Register Table added as part of the design improvement to the MSC program. The first word is the current registers-in-use counter and contains the actual number of registers currently in use. The second word contains a number specifying the maximum number of registers which can be used by the MSC during peak hour operation. The third word contains a number specifying the maximum number of registers which can be used by the MSC during non-peak hour operation. Two values are necessary since there is a substantial difference between peak hour and non-peak hour CSN originated traffic.

When the Precedence Message Selection (PMS) program finds a message delivery for the CSN, it makes two checks before scheduling INC. First, it checks the precedence level of the message. If the message is a "Z" or flash precedence message, INC is scheduled regardless of register usage. If the message is not a flash message, PMS checks register usage. If the registers-in-use counter is less than the maximum permitted, INC is scheduled to deliver the message. If the register-in-use counter is not less than the maximum permitted, PMS will not schedule the message delivery to the CSN on this selection cycle.

The maximum value selected for comparison with the register-in-use counter is done by the program in conjunction with a console skip switch which is under the control of the MSC operator. If the skip switch is in the normal position, the peak hour maximum value will be used. If the skip switch is in the set position, the non-peak hour maximum value will be used. The programming change is designed such that the program automatically adjusts whenever the console skip switch setting is changed.

The registers-in-use counter is modified at five points in the program. It is incremented by one whenever a "register attached" signal is received from the CSN. It is decremented by one whenever connection status digits have been received from the CSN and whenever the MSC timer expires before connection status digits have been received. It is also incremented and decremented as part of the trunk and subscriber equipment usage control described below.

This programming change eliminates the register problem cited earlier. With the appropriate choice of a peak hour maximum value, the MSC will not be permitted to seize all JO registers simultaneously. Consequently, the communication standoff which can result when the MSC seizes all JO registers cannot occur.

Trunk and Subscriber Equipment Usage Control

Program control of JO to DO trunk usage by the MSC depends on the District Office Table (DOTAB). DOTAB contains twenty four entries, one for each DO in ARS. Each entry contains two words. The first word contains the first two dial digits which uniquely identify the DO and a trunks-in-use counter which specifies the number of deliveries in progress (and therefore the number of trunks in use) to the DO. The second word contains two maximum values; one for peak hour operation and one for non-peak hour operation.

Program control of subscriber equipment usage by the MSC depends on the Multiple Equipment

Table (XTAB) and on the Current Connections Table (DCTAB). XTAB is basically a table of those subscribers who have more than one piece of equipment. It contains 200 three-word entries which is sufficient to permit all multi-equipped subscribers to be included and to provide sufficient room for system growth. The first two words of the XTAB entry contain the five dial digits which uniquely identify the subscriber and a subscriber equipment-in-use counter which specifies the number of deliveries in progress (and therefore the number of pieces of equipment in use) to the subscriber. The third word contains two maximum values; one for peak hour operation and one for non-peak hour operation. DCTAB is a table containing 16 two-word entries and is used to record the five dial digits of the subscribers currently receiving traffic from the MSC. Its size is sufficient to contain an entry for each output trunk.

Modified Interplay

The three tables are used by the INC program after the PMS program has selected a CSN message delivery, verified that a register can be requested, assigned an available trunk to this delivery, "initialized" the output area associated with the trunk and scheduled INC. Before seizing the output trunk and starting interplay, INC must perform a number of checks. First, the message precedence is checked. If the message is a "Z" or flash precedence message, INC immediately begins interplay by seizing the output trunk to the CSN. If the message is not a flash message, then the tables must be used to check the delivery. The first two dial digits stored in the output area are used to search the DOTAB to find the appropriate entry. When the appropriate DOTAB entry has been found, the number of calls in progress to the DO, as specified by the trunks-in-use counter (the first word of the entry) is compared to the maximum number permitted (the second word of the entry). If the number of calls in progress is less than the maximum number permitted, the trunks-in-use counter is incremented by one and a subscriber check is made. If the number of calls in progress is greater than or equal to the maximum number permitted, interplay will not be attempted for this delivery and a special error path must be taken since a simulated busy trunk (a busy trunk without interplay) has occurred.

If a trunk is available, all five dial digits are used to search XTAB to determine if the subscriber has more than one piece of equipment. If the subscriber is found in the table, the number of calls in progress to the subscriber as specified by the subscriber equipment-in-use counter (second word of the entry), is compared to the maximum number permitted (the third word of the entry). If the number of calls in progress to the subscriber is less than the maximum number permitted, the subscriber equipment-in-use counter is incremented by one, the five dial digits are placed in an available entry in DCTAB and INC begins interplay by seizing the output trunk to the CSN. If the number of calls in progress to the subscriber is not less than the maximum number permitted, interplay will not be attempted for this delivery, the trunks-in-use counter in the DOTAB entry is decremented by one and a special error path must be taken since a simulated busy station (a busy station without interplay) has occurred. The trunks-in-use counter in the DOTAB entry is decremented by one because a simulated busy station error condition has occurred and no DO trunks will be used for this call.

If the subscriber is not found in XTAB, the five dial digits are compared to the dial digits in the active entries in DCTAB. If no active entry with identical dial digits is found in DCTAB, the five dial digits are placed in an available entry in DCTAB and INC begins interplay by seizing the output trunk to the CSN. If an active entry with dial digits identical to those being checked is found in DCTAB, interplay will not be attempted for this delivery, the trunks-in-use counter in the DOTAB entry is decremented by one and the simulated busy station error path must be taken.

In checking the DOTAB or XTAB entry, the selection of the maximum value for comparison with the trunks-in-use counter or the subscriber equipment-in-use counter is done by the program in conjunction with the same console skip switch which controls the maximum register value chosen. If the skip switch is in the normal position, the peak hour maximum values will be used. If the skip switch is in the set position, the non-peak hour maximum values will be used. As is the case with the maximum register values, the programming change is designed to adjust automatically whenever the console skip switch setting is changed.

A message can terminate normally at the end of message, prematurely due to an error encountered in interplay or in message transmission or prematurely due to preemption by a "Z" message. Whenever a message terminates, the various tables are updated. The current trunks-in-use counter in the appropriate DOTAB entry and the subscriber equipment-in-use counter in the appropriate XTAB entry are decremented and the entry in DCTAB is removed.

Simulated Error Path

The special error path taken for the simulated busy conditions is analagous to the normal error path used for interplay errors with two basic exceptions. The error mnemonic is different and the trunk is not disconnected since it was never seized. A printout of a trunk busy condition encountered in interplay contains an identifying mnemonic OBZT (Output Busy Trunk). A busy station error printout due to an interplay error contains the mnemonic OBZS (Output Busy Station). The error mnemonics for the pseudo busy conditions encountered in checking the control tables are, respectively, SBZT, (Simulated Busy Trunk) and SBZS (Simulated Busy Station). These printouts indicate to the MSC operator that the associated delivery has been placed in the busy table by program decision and no attempt has been made to make the delivery to the CSN.

The average time spent in interplay is approximately five seconds. This time is even higher if only those calls which encounter interplay errors are considered. The decision to take the simulated busy error path is made in a matter of microseconds. In order to give the subscriber the full benefit of the equipment and facility usage saved by these program controls, the simulated busy error path is not entered for seven seconds after the simulated busy condition is discovered. This holds the output area associated with this trunk for seven seconds and prevents the MSC from processing another delivery using this output area or its associated trunk. In addition, the registers-in-use counter is incremented by one when the simulated busy condition is discovered and decremented by one, seven seconds later, when the simulated error path is taken. This, in effect, gives the register usage saved by taking the simulated error path to the subscriber rather than the MSC. Neither one of these special provisions alters MSC operation over what it was prior to these program changes. They simply insure that the efficiency in the use of common control equipment and facilities is reflected in improved performance for subscribers.

The trunk and subscriber equipment control programming change eliminates two problems. First, with the appropriate choice of the peak hour maximum value, the MSC is limited to its fair share of the JO to DO trunks and can no longer schedule more traffic to a DO than the CSN is equipped to handle. This eliminates the trunk problem cited earlier. Second, the MSC cannot attempt to transmit more than one message at a time to subscribers with one piece of equipment. This eliminates the subscriber equipment problem cited earlier.

Choice of Limits

One of the most difficult aspects of limiting the MSCs share of common control equipment and facilities is to choose numbers to represent these limits. The non-peak hour limits are straightforward. They are equivalent to the maximum equipment and facilities available in the CSN. The peak hour limits, however, must be examined on an individual basis.

In the case of registers, the peak hour values chosen for the Romney, Berwick and Mount Aukum MSCs were respectively four (of six), four (of six), and three (of four). Performance data indicated that these limits, while conservative, would provide significant CSN service improvement at little expense in MSC thruput or performance.

In the case of trunks the peak hour values were chosen equivalent to the number of direct trunks from the JO collocated with the MSC to the DO in question. This rule does not cover all cases since the JOs in Romney and Mount Aukum are not connected to all DOs. This is simply a reflection of CSN connectivity rules under which each DO is connected to two of the three JOs. In this case the peak hour trunk value was chosen equivalent to the smaller of the peak hour trunk values in those MSCs whose collocated JO is directly connected to the DO. This choice was based on the rationale that the MSC without direct connection via its collocated JO, would only transmit messages to this DO in the event that one of the MSCs with direct connection was off-line and in this case can be permitted to use a number of trunks equivalent to the smaller of the two peak hour values used at the other MSCs. Performance data again indicated that these limits, while also conservative, would provide a significant service improvement at little expense in the MSC thruput or performance.

It should be noted that the choice of peak hour values equivalent to the number of direct trunks does not mean that an MSC call cannot take an alternate route. The decision to take the direct route or an alternate route is strictly under the control of the JO.

In the case of subscriber equipment the peak hour maximum values were chosen identical to the non-peak hour maximum values. This was because information on subscriber traffic characteristics was not available. Even here service improvement would occur since, prior to this change, the MSC calls to a subscriber were limited only by the number of output trunks to the CSN.

Operator Control

Two console skip switches are programmed into these program modifications in order to permit operator intervention. One console skip switch permits the operator to select either of two equipment values as the maximum value available for MSC use. If this skip switch is in the normal position, the MSC will be limited to the peak hour maximum value of registers, JO to DO trunks and subscriber equipment. If this skip switch is in the set position, the MSC will be limited to the non-peak hour maximum equipment values which in effect permits the MSC to use all CSN equipment. This ability is particularly useful when the MSC reads in high speed tapes during non-peak hours and distributes the messages on these tapes to various subscribers.

The second console skip switch controls the SBZT and SBZS printouts. If this skip switch is in the normal position, the SBZT and SBZS printouts will occur on the line printer whenever the simulated error path is taken. If this skip switch is in the set position, the SBZT and SBZS printouts will be eliminated. All other functions including error journalling will still take place and no other printouts will be affected. This flexibility is added because in certain cases the number of SBZS and SBZT printouts can become quite large and the printouts do not reflect true CSN activity since the calls are not being attempted.

Performance Improvement

A number of valid methods can be used to compare performance before and after the programming modifications described above. One method is to analyze the journals created during the on-line operation of the MSCs before and after the programming changes. Table 1 is a synopsis of the data obtained by running the IOSTAT and BZSTAT programs, two off-line journal processing programs. IOSTAT supplies the actual message data and the actual error data while BZSTAT supplies the actual error data and the simulated error data. All data shown in the columns labeled BEFORE is a straight averaging of data derived from journals for the period from March 6 to March 10, 1967 and from March 13 to March 17, 1967, a period of two calendar weeks prior to the implementation of these programming changes. The data shown under the columns labeled AFTER is a straight averaging of data derived from journals for the period from January 15 to January 19, 1968 and from January 22 to January 26, 1968, again a period of two calendar weeks, following the implementation of these programming changes.

Results of Program Changes

The data in Table 1 indicates that MSC thruput has increased significantly in every case and in most cases the increase is more than fifty percent. The data also indicates that the real busy trunk and real busy station error conditions decreased significantly in all cases and in all but one case the decrease was more than fifty percent. However, this data ony indicates that MSC operation was more efficient. The real question is whether or not this MSC efficiency was reflected in a CSN service improvement. The data on simulated busy station and simulated busy trunk errors indicates that a considerable amount of register usage time was released for use by ARS subscribers. Based on an average use of five seconds, the average daily register time released for use by the Berwick JO was 3.7 hours.

Another method of estimating system performance is to compare the number of JO register seizures for incompleted calls to the number of JO register seizures for completed calls. Prior to the programming modifications this ratio was 1.6 to 1.0. Following the programming modifications the ratio was 0.6 to 1.0. To be specific the Berwick JO required, on the average, 14,630 register seizures per day to handle its traffic during the two week period in March cited in Table 1 and required, on the average, 10,709 register seizures per day to handle the traffic during the two week period in January cited in Table 1.

The final method is to examine the performance reports supplied by subscribers themselves. The

Table I

Comparison of MSC—CSN Interface Performance Data before and after programming changes

		at ROMNEY			at BERWICK			at MT. AUKUM		
		BEFORE	AFTER	% CHANGE	BEFORE	AFTER	% CHANGE	BEFORE	AFTER	% CHANGE
Messages	Daily Input	2475	4281	+73.0	2371	3198	+34.9	1000	1526	+52.6
Messages	Peak Hour Input	411	776	+88.8	358	567	+58.4	176	272	+54.5
Messages	Daily Output	1486	2652	+78.9	1644	2585	+57.2	794	1296	+63.2
Messages	Peak Hour Output	244	402	+64.8	417	485	+16.3	140	200	+42.9
Errors	Busy Trunk (OBZT)	219	85	−61.2	384	148	−61.5	681	261	−61.7
Errors	Busy Station (OBZS)	1184	660	−44.3	3799	394	−89.6	1607	140	−91.3
Errors	Simulated Busy Trunks (SBZT)	—	262	—	—	253	—	—	101	—
	Simulated Busy Stations (SBZS)	—	1253	—	—	2425	—	—	352	—

NOTE: Unless otherwise specified all figures are daily averages.

Social Security subscribers who constitute about 40 percent of the total subscriber population, publish daily reports containing performance figures of merit for the traffic sent to the MSCs. These figures of merit are, in essence, ratios of incompleted calls to completed calls. These daily reports indicated that the programming changes had cut these ratios in half.

Summary

The programming modifications described above have given the MSC the necessary logic and data to recognize the size of the CSN and to operate efficiently using its share of the CSN. The performance improvements that resulted and the application of this approach to systems with similar problems depend on two considerations. The MSCs handle fifty percent of the traffic and consequently, a significant increase in MSC to CSN operating efficiency has a measurable effect on overall system performance. Also the relatively limited size and the simple organizational structure of the CSN lend themselves to the type of technique implemented.

The future work in the MSC to CSN interface will fall into two categories. The limits selected are conservative and, as more system performance data becomes available, further refinements will be made. In addition the picture of the CSN which has been programmed into the MSC is a static one representing the best interpretation of system behavior at the time the programming changes were made. Should the CSN equipment configuration change or the traffic pattern shift, changes will be necessary in order to keep this picture up to date.

Acknowledgement

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* * * *

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IMPROVED TRUNK ALLOCATION IN A CONGESTED NETWORK

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The primary purpose of a circuit switched network is to provide circuit switched communication paths for real time exchange of traffic between its subscribers. When a circuit switching network is also required to provide communications paths for store and forward traffic, the classic problem of allocating the limited common control equipment and facilities between this traffic and the real time circuit switched traffic occurs. In many cases this allocation problem is avoided by procedurally scheduling the delivery of store and forward traffic during non-peak traffic hours on the rationale that speed of service for this traffic is not critical. However, the store and forward traffic in ARS must be serviced during peak traffic hours along with the real time circuit switched traffic. The ARS solution to the resultant allocation problem is to permit the circuit switching network to assign its common control equipment and facilities on a "first come first serve" basis and to regulate the store and forward traffic by placing limits in the message switch on the amount of common control equipment and facilities which the message switch can use in delivering its traffic. In the case of the allocation of trunks in a trunk bundle this regulation is performed by limiting the message switch to a certain fixed maximum number of trunks in the trunk bundle. An improved design has been implemented which makes it possible to allocate the trunks within trunk bundles on a real time dynamic basis as a function of both the store and forward traffic and the real time circuit switched traffic load on the trunk bundle by placing the appropriate decision making control in the message switch.

The Advanced Record System is composed of a Circuit Switching Network (CSN) and three dispersed Message Switching Centers (MSCs). The CSN provides the basic service, real time point-to-point communication paths between the ARS subscribers. The MSCs provide the advanced services to these subscribers such as store and forward handling, data collection and distribution, multiple address processing and message exchange. Since these advanced services are requested by the subscribers and are provided by the MSCs using communication paths supplied by the CSN, the MSC is a CSN user.

THE PROBLEM

Both the MSCs and the subscribers use the CSN to provide communications paths for their traffic. As a result the CSN must handle an intermix of real time point-to-point circuit switched traffic, originating from the subscribers, and store-and-forward traffic originating from the MSCs. The CSN services requests for communications paths in the order of their appearance and, in allocating its limited common control equipment and facilities, it makes no distinction between store-and-forward traffic and real time circuit switched traffic. In effect, the CSN allocates its common control equipment and facilities on a "first come, first serve" basis. However, the MSC controls this traffic intermix since it is the source of the store-and-forward traffic. This control is accomplished by limiting MSC usage of CSN common control equipment and facilities to predetermined maximum limits[1].

Two sets of limits are provided, one for peak hour MSC operation and one for non-peak hour MSC operation. These limits are imposed on MSC traffic to accomplish two objectives: 1) to prevent the MSC from using more than its fair share of the CSN common control equipment and facilities and thereby lowering the service provided to the subscribers, and 2) to minimize the use of common control equipment and facilities by the MSC in unsuccessful attempts to transmit its traffic. While the concept of predetermined fixed maximum limits on MSC usage of CSN common control equipment and facilities meets the first objective traffic situations can arise where controls based on static limits do not satisfy the second objective. The special traffic situations arise, whenever trunk bundles in the CSN become saturated with traffic, and the MSCs can still request trunks in these saturated bundles without exceeding their programmed trunk limits.

STATIC TRUNK ALLOCATION

The concept of controlling the CSN traffic intermix on CSN trunk bundles using fixed maximum limits in the MSC can be best described using the simplified ARS network shown in Figure 1. This simplified diagram was generated by selecting a limited part of the ARS network and proportionally reducing the number of trunks between the three major system components: the MSC, the CSN Junction Office (JO) and the CSN District Office (DO). The selection and trunk reduction used to create the simplified network was done such that any conclusions reached in examining traffic flow through the simplified network are also true in the actual ARS network.

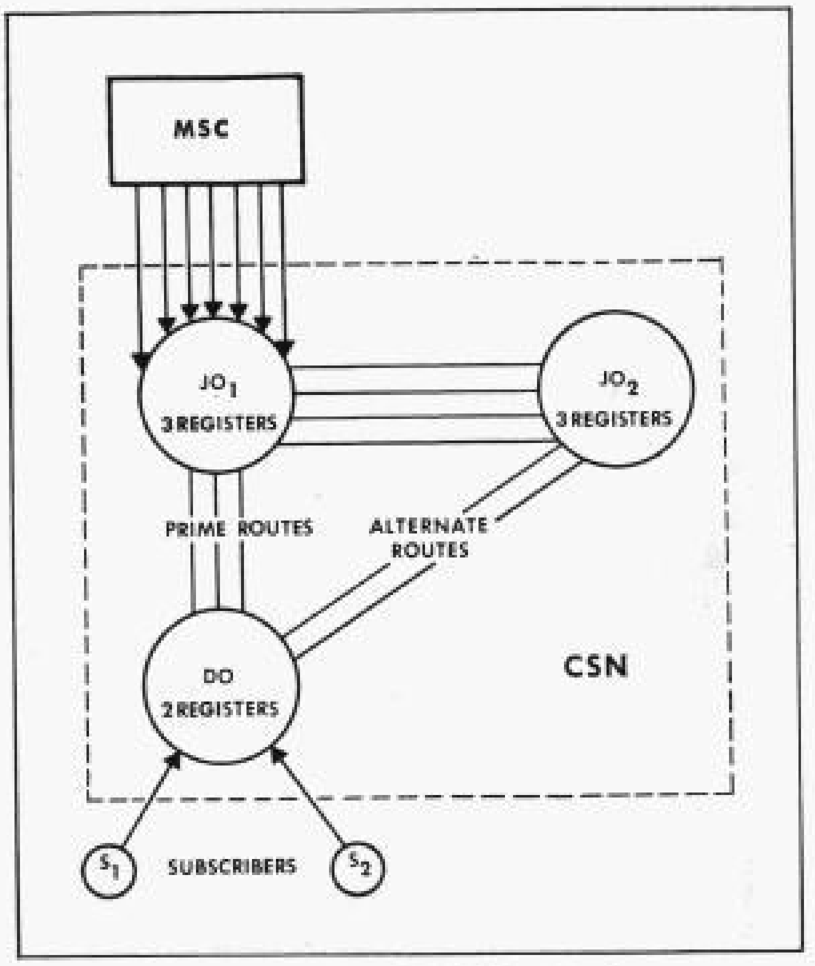

Figure 1—Simplified ARS network.

The trunks from the two JOs, JO_1 and JO_2 to the DO are of particular interest. The three trunks from JO_1 to the DO constitute a trunk bundle, and are labeled primary routes, since traffic originating from the MSC for subscribers on this DO would use trunks in this trunk bundle as a first choice path. If all trunks in the prime or first choice trunk bundle are busy, the trunk bundle is saturated; consequently traffic originating from the MSC must use alternate routes. In the simplified network the two trunks from JO_2 to the DO constitute another trunk bundle and provide possible alternate routes to the subscribers on the DO. If all trunks in both the prime route trunk bundle and the alternate route trunk bundle are busy, then trunk saturation has occurred for that DO.

The fixed trunk limits programmed into the MSCs apply directly to MSC usage of these JO to DO trunks. The number of simultaneous calls, which an MSC can make to subscribers on a particular DO during peak traffic hours, is limited to the maximum number of trunks in the prime route trunk bundle. In Figure 1, the MSC is limited to three simultaneous calls to subscribers on the DO during peak traffic hours. The three calls can take place over any of the five possible routes (JO to DO trunks) since the decision to go prime or alternate route is under the control of JO_1. The two remaining trunks are available for real time point-to-point circuit switched traffic. During non-peak traffic hours the number of simultaneous calls from the MSC to subscribers on the DO is limited to a maximum value, equivalent to the total number of trunks in both the prime route trunk bundle and the alternate route trunk bundle. In Figure 1, the simplified network diagram, the MSC is limited to five simultaneous calls to subscribers on the DO during non-peak traffic hours. In this case no trunks are left for real time point-to-point circuit switched traffic, under the assumption that this traffic is negligible during non-peak traffic hours.

Program Control

Program control of the usage of JO to DO trunks is accomplished by means of a District Office Table (DOTAB). DOTAB contains 24 entries, one for each DO in the CSN. Each DOTAB entry contains the dial digits which uniquely identify the DO, a counter which records the number of calls in progress (and therefore the number of JO to DO trunks in use) from the MSC to subscribers on the DO and two maximum limits, one for peak hour operation and one for non-peak hour operation. Each time the MSC is required to deliver a message to a subscriber the status of the DOTAB entry for the DO serving that subscriber is checked. In this check, the MSC verifies that the number of calls in progress to subscribers on the DO, as specified in the counter, is less than the maximum value permitted before attempting to make the call over the CSN to the subscriber. The choice of the peak hour maximum value or the non-peak hour maximum value for use in this check is automatically made by the MSC as a function of the setting of a console skip switch which is under the control of the MSC operator. In the event that the number of calls in progress to subscribers on the DO is more than the maximum permitted, the MSC does not attempt to make the call over the CSN to the subscriber. The call has encountered a simulated busy trunk condition, a busy trunk by program decision, and is placed in the MSC busy table in the same manner as a real busy trunk; that is, a busy trunk which would be encountered after dialing. The significant difference is that the simulated busy trunk condition is internal to the MSC and does not use any CSN common control equipment and facilities. The advantage of this program control can be seen from the following example.

Example 1—An Ideal Traffic Situation

Suppose that the following traffic conditions exists in the simplified network, in Figure 1, during a peak traffic hour. Two trunks to the DO are occupied with real time circuit switched traffic from two subscribers on the DO to two subscribers on other DOs not shown on the network diagram. One occupied trunk belongs to the prime route trunk bundle and the other is in the alternate route trunk bundle. The MSC, which is limited to a maximum of three calls to subscribers on the DO (the peak hour limit is equivalent to the number of trunks in the prime route bundle), is not transmitting any messages to the CSN but six messages requiring delivery to subscribers on the DO have been received by the MSC.

Under these conditions the MSC will assign the six messages to the six output areas associated with the six trunks from the MSC to JO_1. Since no trunks to the DO are in use in DOTAB, the MSC will process the first call by transmitting the dial digits of the called subscriber to JO_1. JO_1 will extend the call to the DO and ultimately to the called subscriber by using one of the two trunks remaining in the prime route trunk bundle. The MSC now has one trunk in use to the DO. Since the MSC is permitted, by program control, to use up to three trunks to the DO, the MSC will process the second call by transmitting the dial digits of this called subscriber to JO_1. JO_1 will extend the call to the DO and ultimately to the called subscriber by using the remaining trunk in the prime route trunk bundle. At this point, the MSC has two trunks in use to the DO. Since the upper limit is three calls to subscribers on the DO, the MSC will place a third call by sending the called subscriber's dial digits to JO_1. Since the prime route trunk bundle is saturated, JO_1 extends the call through JO_2 to the DO and finally to the called subscriber by using the second and last trunk in the alternate route trunk bundle. At this point all trunks to the DO are in use and any further attempted calls to subscribers on the DO from the MSC or from a subscriber will be aborted (terminated prematurely) with a busy trunk response.

However, the MSC has reached its program limit for calls to the subscribers on the DO and will not attempt to place any of the three remaining calls to the subscribers on the DO. These three calls will be aborted for simulated busy trunk conditions and placed in the MSC busy table, where they are held for a fixed time period before transmission attempts are made. The program decision to abort these calls, due to simulated busy trunk conditions, is completely internal to the MSC and no common control equipments or facilities in the CSN are used.

This example demonstrates a situation where both objectives in the control of MSC trunk usage are satisfied. First, the MSC is limited to its share of the JO to DO trunks (three) and is not permitted to lower the service provided to the subscribers (two calls). Second, the MSC does not use CSN common control equipment and facilities in unsuccessful attempts to transmit its traffic (three calls are aborted internally).

However, in a less than ideal traffic situation, control of MSC trunk usage based on static or fixed limits will give less than ideal results as the following example demonstrates.

Example 2—A Congested Traffic Situation

Suppose that the following traffic conditions exist in the simplified network during a peak traffic hour. Three trunks to the DO, one in the prime route trunk bundle and two in the alternate route trunk bundle, are occupied with real time circuit switched traffic from three subscribers on the DO to three subscribers on other DOs not shown on the network diagram in Figure 1. Three of the six trunks from the MSC to JO_1 are occupied with store-and-forward traffic from the MSC to three subscribers on DOs not shown on the network diagram. The remaining three trunks from the MSC to JO_1 are available and the MSC, which is limited to a maximum of three calls to subscribers on the DO of interest, has received six messages requiring delivery to subscribers on that DO.

In this situation the MSC will assign three of the six messages, for the subscribers on the DO, to the output areas associated with the three remaining trunks from the MSC to JO_1. The remaining three messages for subscribers on the DO must wait until output areas and trunks to JO_1 become available. Since the DO entry in DOTAB indicates that no trunks are in use by the MSC to the DO, the MSC processes the first call to a subscriber on the DO by transmitting the dial digits of the called subscriber to JO_1. JO_1 extends the call to the DO and ultimately to the called subscriber by using one of the two trunks remaining in the prime route trunk bundle. The MSC now has one trunk to the DO in use and is permitted, in accordance with its program limit for the DO, to process a second call through JO_1. JO_1 extends this call to the DO and ultimately to the called subscriber by using the last trunk in the prime route trunk bundle. All trunks to the DO are now occupied. The MSC has two calls in progress to subscribers on the DO, has one call for a subscriber on the DO in an output area which can be sent to the CSN without violating the program trunk limit for the DO, and has three calls for subscribers on the DO awaiting assignment to output areas and trunks to JO_1.

Since DOTAB indicates that, for this DO, the number of trunks in use (two) is less than the peak hour maximum allowed (three), the MSC processes the third call to the subscriber on the DO by transmitting the dial digits of the called subscriber to JO_1. JO_1 cannot directly extend the call to the DO, since all prime route trunks to the DO are occupied; therefore it extends the call through an alternate route to JO_2. JO_2 cannot extend the call to the DO since all alternate route trunks to the DO are occupied and returns a busy trunk signal to JO_1 and ultimately to the MSC. The MSC aborts the attempted call, places it in the MSC busy table and releases the output area and trunk to JO_1 assigned to the aborted call. The MSC immediately assigns the fourth call to the newly available output area and trunk to JO_1. Since only two calls are in progress to subscribers on the DO, the MSC is permitted, without exceeding its DO trunk limit, to process the fourth call to a subscriber on the DO. This call follows the same path through JO_1 to JO_2 as the third call where it is also terminated with a busy trunk signal returned to the MSC. The MSC aborts the fourth call, places it in the MSC busy table and releases the output area and trunk to JO_1 assigned to the aborted call. The process is repeated in the same fashion for the fifth and sixth calls to subscribers on the DO. Ultimately all six calls have been attempted with two calls completed and four calls terminated due to busy trunk responses from the CSN.

In this case the program control of MSC usage of JO to DO trunks is not effective. This is demonstrated by the fact that the handling of the six calls from the MSC to the subscribers on the DO in this example is the same, regardless of whether or not the MSC operates in accordance with trunk limits. The first objective of trunk control is satisfied since the MSC is limited to its share of the JO to DO trunks (actually less than its share) but this is due to the traffic environment not the program control of MSC trunk usage. The second objective of trunk control is not met since four of the six calls from the MSC to subscribers on the DO were attempted using CSN common control equipment and facilities and were aborted due to busy trunk responses from the CSN.

The MSC delivery requirements to subscribers on the DO and the MSC program limit for the traffic to subscribers on the DO are the same in this second example as they were in the first example for ideal traffic. The difference between the two examples lies in the traffic environment which exists in the network when the MSC is required to make the six deliveries. Several conclusions can be reached based on the results of these two examples. First, MSC program control based on fixed trunk limits is completely effective when the CSN can supply the number of JO to DO trunks necessary to handle the number of calls permitted by the program trunk limit. The ideal traffic example demonstrates the effectiveness of program control for this case. Three of the six calls from the MSC to subscribers on the DO were transmitted successfully and three were processed internally without using CSN common control equipment and facilities. Second, MSC program control based on fixed trunk limits is partially effective when the number of output trunks available from the MSC to its collocated JO exceeds the number of calls permitted by the program trunk limit. If all six trunks from the MSC to JO_1 were available in the congested traffic example, the handling of the six calls from the MSC to subscribers on the DO would have resulted in two completed calls, one call terminated due to a real busy trunk condition and three calls terminated internally in the MSC due to simulated busy trunk conditions. Finally, MSC program control, based on fixed trunk limits, is ineffective when the number of output trunks available from the MSC to its collocated JO is equal to or less than the number of calls permitted by the program trunk limit; and when the CSN cannot supply the number of JO to DO trunks necessary to handle the number of calls which the MSC can attempt to transmit over its output trunks. The congested traffic example demonstrates this problem. The number of output trunks available from the MSC to JO_1 (three) equals the number of calls specified by the program trunk limit and the number of JO to DO trunks which the CSN can supply (two) is less than the number of calls which the MSC can attempt to transmit over its output trunks (three).

The primary problem with program control using fixed trunk limits is that the MSC processes its traffic for subscribers on a DO based only on an evaluation of the amount of MSC store and forward traffic to subscribers on the DO and neglects information concerning the CSN real time traffic to and from subscribers on the DO. In order to consider the full traffic load in the DO, the MSC must do special processing whenever a busy trunk response is received from the CSN.

DYNAMIC TRUNK ALLOCATION

The special processing which the MSC must do, when a busy trunk signal is received from the CSN, is based on the interpretation of the meaning of a busy trunk signal. The receipt of a busy trunk signal at the MSC, for a call to a subscriber on a DO, is not just an indicator that the traffic to subscribers on the DO has reached a saturation condition. It also indicates, that the real time circuit switched traffic of the subscribers on this DO has reached a level which requires the use of trunks which the MSC is normally permitted to use. It also suggests that unsuccessful attempts are being made by subscribers to transmit real time circuit switched traffic to subscribers on the saturated DO. These unsuccessful attempts on the part of the subscribers and the MSC to transmit traffic to subscribers on the saturated DO can adversely affect CSN operation in other DOs by inefficient use of common control equipment in the JO. This congestion problem can be substantially reduced by controlling MSC traffic to subscribers on the DO, as a function of the CSN traffic load in the DO or, more specifically, as a function of busy trunk signals received from the CSN in attempting to transmit traffic to subscribers on the DO.

Concept of a Lower Threshold

The control of MSC traffic to subscribers on a DO as a function of busy trunk signals received from the CSN on calls to subscribers on the DO is based on the concept of a lower threshold, in addition to the two upper thresholds already provided. This lower threshold specifies the maximum number of calls which the MSC can place or attempt to place to subscribers on the DO regardless of the traffic situation in the DO. The upper thresholds (peak hour and non-peak hour) specify the maximum number of calls which the MSC can place to subscribers on the DO, provided that the traffic situation in the DO does not cause busy trunk signals to be returned from the CSN to the MSC. In effect, the lower threshold specifies the maximum traffic level from the MSC to subscribers on the DO, which the MSC is permitted to maintain in congested traffic situations; while the upper threshold specifies the maximum traffic level from the MSC to subscribers on the DO, which the MSC is permitted to attain in non-congested traffic situations.

When the number of calls in progress, from the MSC to subscribers on the DO, lies between the lower and upper thresholds for the DO, MSC trunk usage will be controlled as a function of busy trunk signals received from the CSN. In this case a busy trunk signal will cause any additional MSC traffic to subscribers on the DO to be delayed regardless of the fact that the MSC is permitted, in accordance with the upper threshold, to transmit additional messages to subscribers on the DO. This delay will continue until one of the calls in progress from the MSC to a subscriber on the DO terminates. During this delay which varies as a function of MSC traffic to subscribers on the DO, any new traffic from the MSC to subscribers on the DO is terminated internally in the MSC due to simulated busy trunk conditions. Depending on the amount of traffic awaiting delivery from the MSC to subscribers on the DO and the number of output trunks available from the MSC to its collocated JO, this procedure can significantly lower unnecessary and inefficient use of CSN common control equipment and facilities. This "wait one message" philosophy is used in terminating the delay of MSC traffic to subscribers on the DO because it permits the MSC to terminate its delay at the earliest point at which JO to DO trunk availability has been recognized in the MSC. At this point the MSC is permitted to place as many calls to subscribers on the DO as its upper threshold permits, provided that a busy trunk signal is not received from the CSN in attempting to place one of these calls to a subscriber on the DO. In this case the MSC must check its lower threshold against the number of calls in progress to subscribers on the DO and decide whether or not a delay of traffic from the MSC to subscribers on the DO is required.

Dynamic Trunk Control

The process of trunk usage control in the MSC, under the rules described above, can be demonstrated using the Trunk Allocation Diagram, shown in Figure 2. At time t_0, during a peak hour, the number of calls in progress from the MSC to subscribes on a DO is four. The upper threshold for calls from the MSC to subscribers on this DO during the peak traffic hour is six and the lower

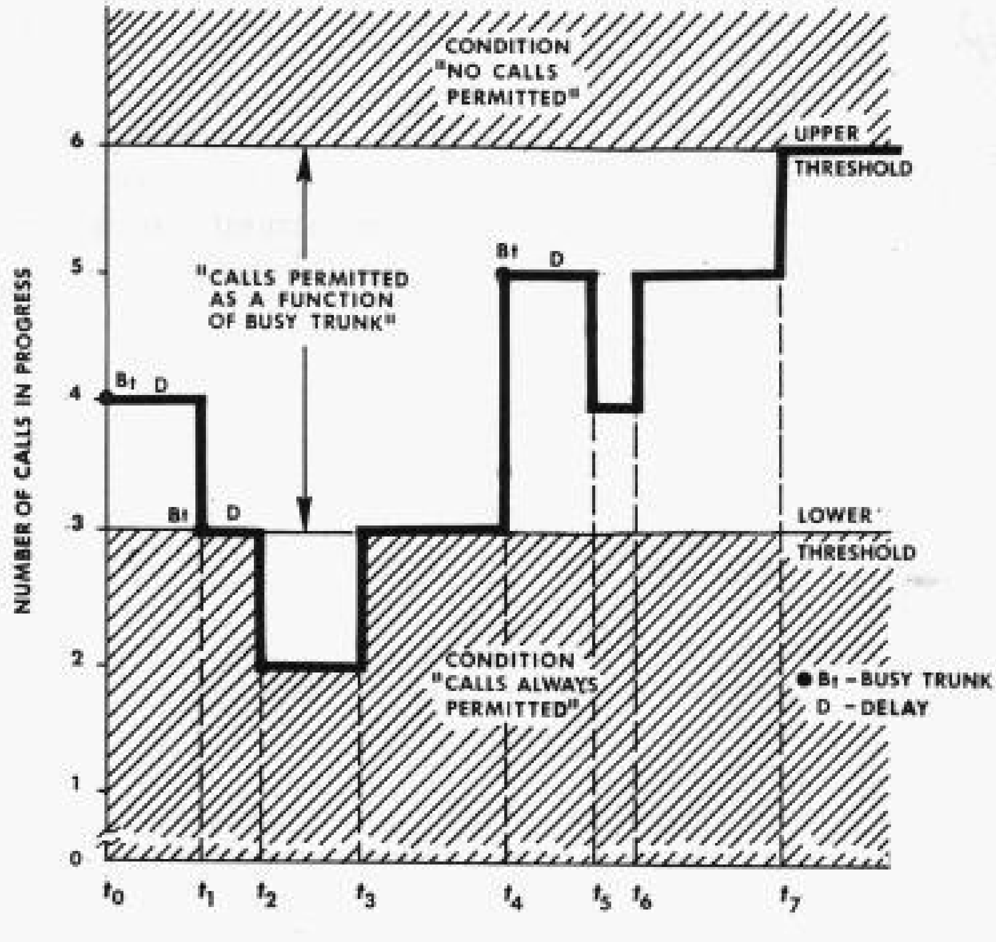

Figure 2—Trunk Allocation Diagram.

threshold is three. At time t_0, the MSC begins processing a large queue of messages requiring delivery to subscribers on the DO. In attempting to place the fifth call to a subscriber on the DO, the MSC receives a busy trunk signal from the CSN. Since the number of calls in progress from the MSC to subscribers on the DO is between the upper and lower threshold, the MSC must wait until one of its four calls to a subscriber on the DO terminates. Any calls processed by the MSC for subscribers on the DO during the delay period are terminated due to simulated busy trunk conditions and placed directly in the MSC busy table. When one of the MSC calls to a subscriber on the DO terminates at time t_1, the MSC attempts to place a fourth call to a subscriber on the DO (only three calls are now in progress). The MSC receives another busy trunk from the CSN and must again delay its traffic for subscribers on the DO since the number of calls in progress (three) is between the two threshold values. The receipt of a busy trunk in this case indicates that the JO to DO trunk, released when the MSC call to a subscriber on the DO terminated at time t_1, was assigned by the CSN to a real time, circuit switched call to or from a subscriber on the DO. When one of the three calls now in progress from the MSC to a subscriber on the DO terminates at time t_2, the number of calls from the MSC to subscribers on the DO is below the lower threshold and the MSC can attempt to place calls to subscribers on the DO regardless of busy trunk signals received from the CSN. At time t_3 the MSC is successful in placing a third call to a subscriber on the DO. At time t_4 the MSC places three calls in succession to subscribers on the DO. The first two of these calls are successful and the number of calls in progress increases to five. The third call results in a busy trunk signal from the CSN. This causes the MSC to delay its traffic for subscribers on the DO until one of the five calls in progress from the MSC to a subscriber on the DO terminates. At time t_5 one of these calls terminates and at time t_6 the MSC successfully places a fifth call to a subscriber on the DO. Finally, at time t_7 the MSC places a sixth call to a subscriber on the DO. MSC traffic to subscribers on the DO has reached the upper threshold of six and no further attempts can be made by the MSC to place calls to subscribers on the DO until one of the calls in progress terminates.

In effect this control permits the MSC to adjust its traffic to subscribers on a DO in accordance with the overall traffic load in the DO, not just according to the MSC originated traffic load in the DO. The traffic delay inherent in this control is minimized by requiring the MSC to wait only if the number of calls in progress to subscribers on the DO is equal to or greater than the lower threshold; and by requiring the MSC, in this case, to wait only until one of its calls in progress to a subscriber on the DO terminates. One other approach to controlling the delay can be used. This approach, which can be termed "wait till threshold," results in less unnecessary use of CSN common control equipment and facilities but increased MSC delay. The "wait till threshold" approach requires the MSC to delay its traffic to subscribers on the DO for a busy trunk response from the CSN until the number of calls in progress is less than the lower threshold. In the example cited above, a "wait till threshold" approach would have eliminated the unnecessary use of CSN common control equipment and facilities that occurred at time t_1 but would have unnecessarily delayed MSC traffic for the busy trunk response at time t_4. The "wait one" approach was selected over the "wait till threshold" approach because it minimizes delay without prohibitive use of CSN common control equipment and facilities.

IMPLEMENTATION OF DYNAMIC TRUNK CONTROL

The implementation of this dynamic trunk control is based on a modification of the two-word DOTAB entry. The first word contains the dial digits unique to the DO and the counter which specifies the number of calls in progress (or trunks in use) and remains unchanged. The second word, which formerly contained only the peak hour maximum trunk limit and the non-peak hour maximum trunk limit (the upper thresholds), has been modified to include a control bit and a lower threshold in addition to the two upper thresholds.

Whenever the MSC assigns a message to an output area and its associated trunk, it performs a series of checks before attempting to deliver the message to the CSN. One of those checks involves the use of DOTAB to verify that a JO to DO trunk is available for the call. This trunk check requires the MSC to verify that the number of calls in progress to subscribers on the DO (as specified in the first word of the appropriate DOTAB entry) is less than the number allowed (as specified by the appropriate upper threshold in the second word of the DOTAB entry). If this check fails, the MSC sends the message to the MSC busy table without attempting to deliver the message to the CSN. Dynamic trunk control requires an additional check which must be made before the trunk check. This additional check is made on the control bit in the second word of the DOTAB entry. If this control bit is set, the MSC is in the delay mode for traffic to subscribers on this DO and the message is sent to the MSC busy table without performing the trunk check and without attempting to deliver the message to the CSN.

This control bit is set whenever a busy trunk signal is received from the CSN on an MSC call to a subscriber on a DO and the number of calls in progress from the MSC to subscribers on this DO lies between the lower and the upper threshold. This control bit is reset whenever a message transmission from the MSC to a subscriber on this DO is terminated.

The actual values used for the lower thresholds in the various DOTAB entries have been arbitrarily selected as equal to half the number of trunks specified by the peak hour upper threshold. This arbitrary selection was necessary, since exact system performance data was not available at the time the dynamic trunk control modification was made.

SUMMARY

The dynamic trunk control modification permits the MSC to adjust its usage of JO to DO trunks as a function of the total traffic load in the DO. This adjustment minimizes the unnecessary use of CSN common control equipment and facilities at a time when efficient usage is most important, namely, during periods of congestion. The resultant improvement in overall system performance has an associated penalty, the delay of traffic from the MSC to subscribers on the DO. But this traffic delay is minimal since delay periods only occur in periods of network congestion and these delay periods terminate as soon as the MSC releases a JO to DO trunk to the DO.

The future work in this area will be primarily concerned with the adjustment of the lower thresholds and the upper thresholds based on system performance data. The lower thresholds are conservative and, in addition, the use of a lower threshold could, under the proper performance conditions, permit an increase in the upper threshold to expand the range in which dynamic trunk control operates.

* * * *

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J. C. Parr (left) and A. M. Eisner, Engineers, shown in our laboratory, checking the dynamic trunk control program.

THRUPUT IMPROVEMENT in MESSAGE SWITCHED TRAFFIC

J. C. PARR
and
A. M. EISNER

The processing of multiple address and group code messages is a standard service offered by message switching systems. It permits a user to input a single message and obtain multiple deliveries. The multiplicity factor associated with this type of traffic can present thruput problems in message switching systems and quite often restrictions are placed on the number of deliveries that a subscriber can request in a single message. The problem of providing this service in ARS is even more severe than in most message switching systems. There are, effectively, no restrictions placed on the number of deliveries the ARS subscriber can request. In addition the deliveries must be made by the message switch using the circuit switching network and sharing the available common control equipment and facilities with the subscribers. The severity of this problem in ARS was indicated by performance data taken on ARS operation. These data indicate that the actual delivery time for multiple address traffic exceeded the theoretical delivery time by a factor as high as six. The adjustments made in the operation of the message switch effectively changed this factor to one.

The Advanced Record System (ARS) is a nationwide telecommunications system composed of a Circuit Switching Network (CSN) and three dispersed Message Switching Centers (MSCs). The CSN offers the ARS subscribers the real time subscriber-to-subscriber communication paths available in conventional circuit switching systems. The MSCs offer the subscribers the special services normally found in message switching systems such as store and forward handling, data collection and distribution, message exchange, and multiple address processing. The availability, in ARS, of the services found in each of these communications disciplines is noteworthy but the unique feature in ARS is the manner in which these disciplines are integrated into a single system.

The CSN is the essential system element in ARS and provides the basic communication service. The CSN is composed of two basic types of circuit switching offices, the Junction Office (JO) and the District Office (DO). The JO is the high level office in the two-level CSN hierarchy and is primarily responsible for providing communication paths between DOs. The DO is the low level office in the two-level CSN hierarchy and is primarily responsible for interfacing the subscribers to the CSN. The CSN provides the circuit switched communication paths between subscribers in a conventional manner. The subscriber's call is made through his DO, through the appropriate JO and finally, through the called subscriber's DO to the called subscriber.

Unique Feature of ARS

The uniqueness of ARS becomes apparent when MSC traffic flow is examined. There are no dedicated trunks or circuits between the MSCs and the subscribers. The three MSCs are collocated with and connected to the three JOs in the CSN. Subscribers use the special services offered by the MSCs by sending appropriately formated messages over the CSN to the MSCs. The MSCs provide the special services by performing the required processing and transmitting messages over the CSN to the appropriate subscribers.

In effect, the CSN is providing communications paths for two types of traffic: 1) the real time circuit switched traffic originating from the subscribers, and 2) the store-and-forward traffic originating from the MSCs. The ability of the CSN to provide the communication paths for the traffic intermix is severely taxed when the MSC is required to provide multiple address processing. In many cases, traffic constriction results in the MSC because the CSN is unable to provide the quantity of communications paths required for MSC multiple address traffic. This should not be interpreted as an indication that the CSN is inadequate. The CSN is configured and equipped to handle a poisson distributed traffic load. The traffic distribution which results, due to multiple address traffic, is not poisson distributed and represents the abnormal system case. If the CSN were designed to meet this abnormal traffic situation, a grossly overdesigned CSN would result.

MULTIPLE ADDRESS PROBLEM

Messages sent to the MSC by subscribers must conform to the message format rules, as specified in JANAP 128 [B]*. JANAP format is a fixed-field format, specifically designed for automatic processing by digital computer message switches. One of the fields defined by this format, the routing field, is used to specify the destination to which the message is to be delivered. The MSC will deliver a message received from the subscriber, in accordance with the seven character routing indicator, found in this routing field. This seven character routing indicator uniquely identifies the required destination. If only one routing indicator is specified in the routing field, only one delivery is required; and the message is termed a single address message. If more than one routing indicator is specified in the routing field, multiple deliveries are required; and the message is termed a multiple address message. The multiple address message is a traffic multiplier. This multiplicity factor can become quite high since there is no program restriction on the number of routing indicators permitted in the routing field.

Group code processing is a special case of multiple address processing. In this case, the subscriber specifies a group code or collective routing indicator in the routing field. The MSC recognizes the routing indicator as a group code and delivers a copy of the message to every subscriber specified in the MSC group code tables for the given group code. An individual group code routing indicator is limited to 625 deliveries, but there is no program restriction on the number of group code routing indicators permitted in the routing field of a message. An example of an ARS group code message is the "all points Social Security" group code message. This message contains eleven group code routing indicators in the routing field and requires 745 deliveries. In this case while only one message is received in the MSC, 745 messages must be transmitted by the MSC.

The minimum theoretical time required to deliver a multiple address or group code message can be computed by multiplying the number of required deliveries by the number of bits in the message and then dividing the result by the capacity of the output trunks in bits per second. The multiple address or group code message cannot be delivered in the theoretical time computed because this computation does not consider overhead time in the MSC and also the fact that other messages are being delivered. However, test data taken on MSC performance indicated that the actual time, required by the MSC to deliver a group code or a multiple address message, could exceed the theoretical time required by a factor as high as six.

This difference between actual time and theoretical time was due primarily to two basic factors: equipment and facility availability in the CSN and program design criteria in the MSC and their interaction on each other. In effect, the processing of multiple address traffic in the MSC places unrealistic demands on the CSN; and when these demands are not satisfied, the MSC reacts such that delivery of the multiple address traffic is inefficient. This interaction can best be understood by

* Joint Army Navy Air Force Procedures, JANAP 128 [B], 15 November 1967

examining the manner in which the MSC program processed message transmissions to the CSN prior to the programming modifications described later in this article.

Message Queueing

The software in the MSC can be divided into three functions: input processing, message selection and output processing. The primary function of the input processing program is to validate the incoming message, record it on the reference journal, place it in in-transit storage and queue it for message selection and output processing. The queueing function is to make an appropriate entry, called a QTRA entry, in the message queue table. The message queue table is a list of the messages in storage that are awaiting selection and output processing. The QTRA entry is a two-word entry which contains the drum address of the first segment of the message in the in-transit storage, the core address of the next QTRA entry in the message queue table and a definition of the output equipment requirements of the message. The output equipment requirements define which output interface(s) of the nine possible output interfaces is required to deliver the message. The nine possible output interfaces in the MSC are MSC2, MSC1 (the other two MSCs), CSN8 (ASCII subscribers), CSN5 (Baudot subscribers), OIP (the Output Intercept Position), AU (the AUTODIN system), VA (the Veterans Administration data collection tape), Telex/TWX (the Telex and TWX systems), and SS (the Social Security data collection tape). The output equipment requirements are specified in the QTRA entry using the EQRQ (equipment requirements) format. This format uses nine bits, one per output interface, to specify the equipment requirements of the message. If an EQRQ bit is set in the QTRA entry, then the message has output equipment requirements for the output interface associated with that EQRQ bit. It should be noted that the terms equipment requirements and output interfaces are interchangeable.

In order to make a message available for selection and output processing, the input processing programs must perform a twofold function. First, the input processing programs must analyze all routing indicators in the routing line in order to identify the output interfaces required for the message and set the corresponding EQRQ bits in the QTRA entry for the message. Second, the input processing programs must place the QTRA entry in the message queue table in accordance with the message precedence and time of arrival.

For example, in the case of the "all points Social Security" group code the input processing programs will construct a QTRA entry with the MSC2, MSC1 and CSN8 EQRQ bits set. This is a reflection of the fact that all three MSCs participate in making the required 745 deliveries to the subscribers. The CSN8 EQRQ bit indicates that the MSC receiving the message has equipment requirements for this message on its CSN8 output interface. The MSC2 and MSC1 EQRQ bits indicate that the MSC receiving the message has equipment requirements for this message on its output interfaces to the other two MSCs. However, the input processing programs have not identified which specific deliveries of the 745 required deliveries are to be handled over these three output interfaces. This is a function performed by message selection.

Message Selection

The message selection programs examine the message queue table for each output interface, in turn, and select a message for a given interface based on the status of the EQRQ bit associated with that output interface in the QTRA entry for the message. If the EQRQ bit is not set, the message selection programs must examine the next QTRA entry in the queue table. If the EQRQ bit is set, the message has equipment requirements for the output interface being serviced and a message delivery must be scheduled over this output interface.

Since more than one delivery of a message may be required over a given interface, the message selection routines must specify which delivery is to be made by the output processing programs. The first time that a message is selected for any interface, the entire routing line is analyzed and a three-word Message Dial Header (MDH) is constructed for each required delivery. Each MDH contains information on subscriber status, the equipment requirements for the associated delivery in EQRQ format and the drum address of the subscriber dial code. When the message selection programs select a message for processing over a given interface, an MDH for a specific delivery over this interface for this message is given to the output processing program. Selection finds an appropriate MDH for a given interface by examining the EQRQ bits in each MDH in the string of MDHs constructed for the message.

In the case of the "all points Social Security" group code message the message selection programs will build a string of 745 MDHs. Since all deliveries will ultimately be made to ASCII subscribers, each MDH will contain the appropriate status information unique to the subscriber and will contain the drum address of the unique dial code to be used in delivering the message to the subscriber. The EQRQ format in each MDH will be one of three types. The EQRQ format in an MDH, for a delivery over the CSN8 interface at the MSC which originally received the message, will have only the CSN8 bit set. The EQRQ format in an MDH for a delivery to one of the other MSCs will have the appropriate MSC bit set and, in addition, will have the CSN8 bit set. This indicates that the delivery associated with the MDH is to be made to the specified MSC, where it will be delivered over that MSC's CSN8 interface.

Output Processing

The primary responsibility of the output processing programs is to perform the necessary interplay and coordination to establish the transmission path, transmit a copy of the message as found in in-transit storage and record the completion of the delivery on the reference journal. In the case of a message delivery to a subscriber via the CSN5 or CSN8 interfaces, output processing and message selection are closely interrelated.

Once a message has been selected by the message selection programs for either one of the CSN interfaces and one of its deliveries has been scheduled for output over one of the MSC to CSN trunks, the delivery will be transmitted successfully or will be terminated due to an output error or trouble condition. A busy trunk or a busy station response from the CSN for a delivery attempted by the MSC are two examples of output errors or trouble conditions which will cause a delivery from the MSC to the CSN to be terminated. When an MSC delivery to the CSN is terminated due to an output error or trouble condition, another attempt is made to deliver the message after a delay of 60 seconds. This delay is accomplished by making an entry for this message in the Subscriber Busy Table (SBT).

Busy Table Operation

The efficient operation of the MSC-to-CSN interface depends to a large extent on the SBT function. Stated simply, the SBT function makes the transmission retry of a message delivery occur after a fixed time delay regardless of the length of the message queue. The importance of this feature can be demonstrated by considering the case of a busy station response from the CSN for an attempted delivery. Analysis and theoretical computations, using performance data taken on ARS operation, indicated that the expected waiting time, before a busy subscriber will terminate the connection and therefore be available for an MSC message delivery, is approximately 60 seconds. From a statistical point of view, therefore, the optimum time to retry a message delivery to the CSN, which has been previously terminated due to a busy station response, is 60 seconds after the terminated attempt. Without an SBT function it would be impossible to take advantage of this statistical property.

The busy table is a circular table capable of holding 50 three-word entries. The first word of the entry, QTRADD, contains the core address of the QTRA entry in the message queue table associated with the message being placed in the busy table. The second word, EQRQP, contains, in EQRQ format, the output interface over which the delivery was attempted and also contains a count of the number of extra cycles of 60 seconds each that the entry must make before leaving the busy table. In the case of a Telex or a TWX message entering the busy table, this count was set at three. For the CSN interfaces the count was set at zero. The third word, TWAIT, contains the time at which the entry is to be removed from the busy table. The use of TWAIT to specify the time that an entry is to be removed permits the MSC to implement the statistical property associated with the busy station response.

The control logic associated with the busy table performs four basic functions: 1) it builds or makes an entry in the table when required, 2) it maintains the time scheduling necessary to remove the oldest entry in the table when its time delay has expired, 3) it removes an entry from the table when required, and finally, 4) it requeues the message for selection when the associated entry has left the table. Figure 1 shows the basic busy table functions and their interrelationships.

The requirement to build an entry can arise from two sources. It can be caused by an output error occurring on an attempted message delivery or it can be caused by the requirement to reinsert an entry which has been removed and has a non-zero cycle count. If it is caused by an output error, it can cause the premature removal of the oldest entry if the table is full. In this case, the oldest entry is removed regardless of its time scheduling

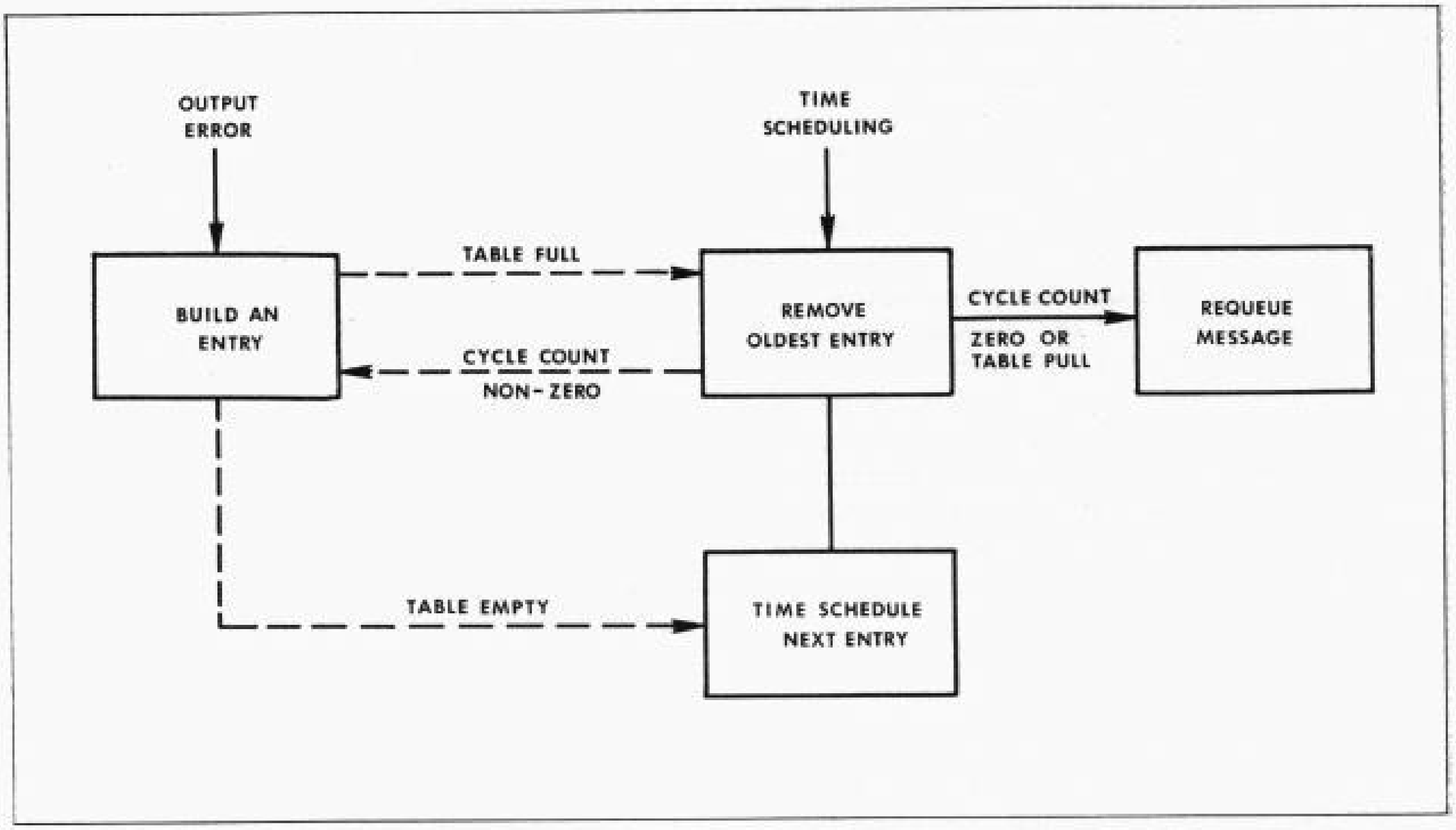

Figure 1—Functional Block Diagram of the Busy Table Operation

or its cycle count. The requirement to remove an entry can also arise from two sources. It can occur due to the time scheduling of the oldest entry or it can be caused by the requirement to add an entry to a full table. If it occurs due to time scheduling, the cycle count is inspected. If the cycle count is not zero, the entry is placed back in the table using the build function. If the cycle count is zero, the message associated with the entry is requeued, making it available to message selection. This is done by restoring the EQRQ bit in the QTRA entry associated with the output interface over which the message delivery encountered trouble. The fact that this EQRQ bit must be restored points out the critical problem in the operation of selection, CSN output processing and SBT processing.

BASIC DESIGN LIMITATION

While the concept and implementation of the Busy Table gave the MSC to CSN interface a critical and necessary capability, the overall integration of selection, CSN output processing and SBT processing had two significant drawbacks. First, any message which encountered an output error or trouble condition, in one of its scheduled deliveries over an output interface and required SBT processing, could not be further selected as a message candidate by the message selection programs for that output interface, until the suspended delivery left the busy table. In effect, one delivery encountering trouble on an output interface and entering the busy table suspended any new delivery attempts for this message over the given output interface. The output processing routines inhibited further selection of this message and subsequent scheduling of its deliveries over the given output interface by setting the EQRQ bit associated with this output interface in the QTRA entry to zero. The primary reason for inhibiting selection for this condition was to prevent the selection of the MDH associated with the delivery being placed in the busy table. Since every bit in the MDH is already used and no bit has been dedicated to storing the status information that the delivery is in the busy table, the method of preventing a second selection of the MDH was to prevent the selection of any MDH for that message for the given output interface.

This design approach can significantly delay message deliveries in a group code or multiple address message. Most group codes require deliveries to only a few DOs in the CSN and the MSC group code tables are usually arranged in a non-optimum fashion with the deliveries ordered by DO. A typical group code message might have 75 deliveries to three DOs arranged internally such that the first 25 deliveries are to the first DO, the second 25 deliveries are to the second DO and the final 25 deliveries are to the third DO. MDHs are built in the order in which the deliveries are specified in the MSC group code table and MDHs are scanned for selection in the order in which they are built. This causes selection to schedule calls on every available output trunk to the same DO. The trunks from the JO to the DO become saturated and busy trunk signals are returned. Some MSC to CSN trunks begin message deliveries but others are released due to busy trunk conditions. No further deliveries of the message can be scheduled over these idle MSC to CSN trunks since one of the previous deliveries required SBT processing. Deliveries to the second or third DO cannot be made even though no trunks to these DOs are in use by the MSC and the MSC has available output trunks to its collocated JO.

This basic problem is illustrated in Figure 2. Selection finds message X and, upon examination of the MDH string, finds an appropriate delivery, delivery Y, for the output interface being serviced. Delivery Y is attempted and the CSN responds with a busy trunk signal. Output processing removes the EQRQ bit associated with this output interface in the QTRA entry for message X and SBT processing makes an entry for message X for the given output interface. Delivery Z, which also requires output processing over that output interface, cannot be scheduled since the EQRQ bit in the QTRA entry for that output interface has been removed and selection cannot find message X when searching the message queue table for that output interface. The basic design goal of the programming change to be described later in this article can be stated with reference to this example. The scheduling of any delivery for output, e.g., delivery Z, should be independent of the status or outcome of any previously attempted delivery of the message, e.g., delivery Y.

A Second Limitation

The second drawback in the overall integration of selection, CSN output processing and SBT processing is that all output errors on a given interface which require SBT processing place the message

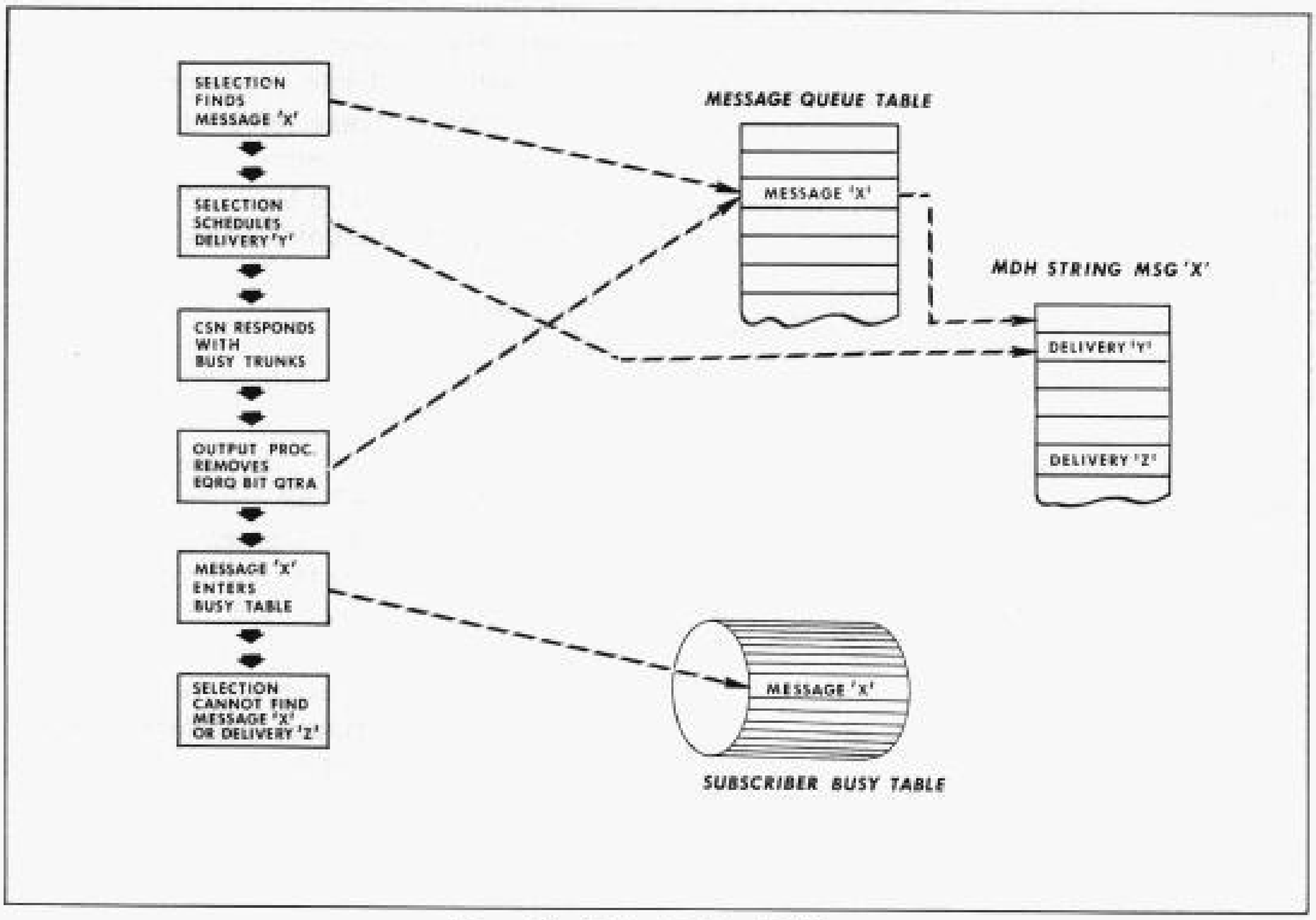

Figure 2—Basic Design Problem

in the busy table for the same amount of time. While this is not as serious as the first problem, the errors are different and should be handled differently. For example, a delay of 60 seconds, which is optimum for a busy station response, is not optimum for a busy trunk response.

An Alternate Design Approach

The basic problem in the processing of multiple address or group code messages is that a message delivery over a given output interface, which encounters an error requiring SBT processing, causes the suspension of the selection of any other deliveries of the message over the given output interface. One solution is to suspend only the delivery which has encountered trouble and permit all other deliveries in the message for the given output interface to be selected and scheduled for output. This is a more efficient solution with respect to multiple address and group code handling, but is more likely to lead to the undesirable operation associated with a full busy table. When the busy table is full and a requirement arises to make an entry, the SBT routines will make the additional entry by prematurely removing the oldest entry. In effect, a problem delivery is placed in the busy table but at the penalty of prematurely releasing another potential problem delivery for selection. The dynamics of the busy table in the case where there are more than 50 deliveries which are encountering trouble or error conditions and require SBT processing can lead to situations, where MSC processing time is very inefficiently used in making busy table entries and processing problem deliveries released as a result of making these entries. This full busy table condition can arise for large group codes if selection of message deliveries is permitted to continue as long as any deliveries remain to be made. Therefore, one extreme—the original design, is inefficient with respect to output processing but reasonable with respect to program operation and MSC time usage; and the other extreme—the alternate design, which is efficient with respect to output processing but can lead to situations where MSC time usage is excessive and inefficient.

The alternate design approach is a tradeoff between the two extremes described above in the following sense. In general, when a message delivery over a given output interface encounters an error or trouble condition requiring SBT processing, only that delivery will be suspended. Other deliveries of the message will be selected and scheduled for the given output interface. The exception to this general rule occurs when the occupancy (number of entries) in the busy table reaches a given threshold. In the event that a message delivery over a given output interface encounters a trouble condition requiring a busy table entry and the busy table contains 35 or more entries, the EQRQ bit will be removed from the QTRA entry associated with the delivery. This suspends all further deliveries of this message over the given output interface. This approach permits message selection, in most cases, to examine additional deliveries in a message for a given output interface even though a trouble condition has been encountered for one of the message deliveries over this output interface. It also minimizes the probability that a full busy table condition will be encountered. The choice of 35 as the threshold parameter is governed by two considerations. It is high enough to permit message selection to search the group code deliveries in a message to a sufficient extent to keep the output trunks busy transmitting deliveries. It is low enough to minimize the probability of entering the full busy table mode of operation.

The Implementation of the Tradeoff

The problem which arises in attempting to implement this tradeoff solution is to make it compatible with the basic message selection rules. The first time message selection finds a candidate message for a given output interface it will cause a string of MDHs to be built for the message. This string will contain a unique MDH for each delivery required in the message. The string will be scanned, on this first selection and on every subsequent selection of the message, to select a specific MDH for the given output interface. Three items of information are of particular interest in the MDH during this scan: the output interface required for the delivery; the "done" bit which, if set, indicates that the associated message delivery has been made; and the "in-transmission" bit which, if set, indicates that the associated message delivery has already been selected and is being transmitted. Each time message selection selects a given message for a given output interface, the string of MDHs is scanned and the first MDH found for the given output interface with neither its "done" bit nor its "in-transmission" bit set will be selected. Therefore, if the tradeoff solution described above is implemented, message selection will reselect and reschedule the same message delivery which had encountered trouble over the given output interface.

Busy Table Modifications

To prevent this repeated selection and scheduling of the same message delivery, some indicator must be used in the MDH to tell message selection that the message delivery is in the busy table and should not be selected. The indicator chosen is the "in-transmission" bit. This is the only available indicator in the MDH which can be used without drastically altering the basic structure of message selection. In effect the "in-transmission" bit is given two meanings: the message delivery is in transmission or the message delivery is in the busy table.

This programming change permits the message delivery rather than the message itself to be placed in the busy table. Since the "in-transmission" bit in the MDH is used to indicate that the message delivery is in the busy table, this bit must be turned off when the message delivery leaves the busy table. Therefore, the busy table entry must contain two additional words of information. The modified busy table entry is now a five-word entry instead of three. The first word, QTRADD, contains the core address of the QTRA entry for the message whose delivery is being placed in the busy table. The second word, MDHENT, is the first word of the MDH associated with the message delivery being suspended. It contains the subscriber status bits (including the "done" bit and the "in-transmission" bit) and, in EQRQ format, the output interface over which the message delivery was attempted. The third word, TWAIT, contains the time at which the entry is to be removed from the busy table. The fourth word, MDHAD, contains the drum address of the MDH associated with the message delivery being suspended. The fifth word, CNTRP, contains the number of extra cycles that the entry must make before exiting from the busy table.

The two new words, MDHENT and MDHAD, are necessary in order to enable the SBT routines to turn off the "in-transmission" bit in the MDH thereby making it available to message selection. This process is done by writing the contents of MDHENT on the drum at the address specified by MDHAD at the time the delivery is removed from the busy table.

A second major change made to the SBT programming routines was the reduction of the basic busy table time delay from 60 to 20 seconds. Using the basic busy table design described earlier this reduction permits entries to be made for any multiple of 20 seconds as a function of the cycle count associated with the particular entry. The third major change made to the SBT routines was to make this cycle count, which specifies the number of extra cycles of 20 seconds that an entry must make before leaving the table, a function of the error or trouble condition requiring the busy table entry. Formerly, this cycle count was solely a function of the output interface over which the message delivery was attempted.

Table I lists the various output errors and defines the cycle counts and the total time spent in the busy table for each type of error condition. As indicated in Table I, the finer resolution in terms of the basic busy table cycle time permits a specification of 20 seconds for a busy trunk error condition and a specification of 60 seconds for a busy station error condition.

Table I also indicates that a group code message delivery encountering a simulated busy trunk error condition[1] receives unique treatment. In this case the number of extra cycles in the busy table is a function of the length of the message. This special handling for group code message deliveries is based on the observation that simulated busy trunk error conditions encountered on group code message deliveries usually occur when most of the MSC output trunks and most of the JO to DO trunks handling MSC traffic are occupied with deliveries of the group code message. Under these conditions considerable trunk efficiency can be gained by processing the group code message as a function of its length.

Operator Control

The basic program decision to inhibit selection of deliveries for a given message over a given interface is based on the busy table occupancy level. However, this program modification also provides for MSC operator intervention and control through the use of a console skip switch. If this console skip switch is in the normal position, the program will inhibit further selection of deliveries of the given message over the given output interface if the busy table contains 35 or more entries. If this console skip switch is in the set position, the program will inhibit further selection of deliveries of the given message over the given output interface regardless of the number of entries in the

TABLE 1 • BUSY TABLE DELAY FOR VARIOUS TYPES OF OUTPUT ERROR

Output Error	Mnemonic	Extra 20 sec. Cycles	Total Delay Time (Seconds)
Real Busy Trunk	OBZT	ø	20
Real Busy Station	OBZS	2	60
Deranged (Rec'd)	ODER	2	60
Pre-Message Answer-back Invalid	OABE	2	60
Circuit Disconnect	ODSC	ø	20
Post-Message Answer-back Invalid	OSUS	2	60
Non-Letters Response to Dial Digit (Telex)	ORDB	8	180
Disconnect At End Of Dial Sequence (Telex)	ODSA	8	180
No V Response on End of Dialing (Telex)	ONOV	8	180
Deranged (Assumed)	ODER	ø	20
Simulated Busy Trunk	SBZT	See note 1	
Simulated Busy Station	SBZS	2	60

Note 1: For a non group code message the number of additional cycles is Ø and the total delay time is 20 seconds. For a group code message the number of additional cycles and the total delay time are respectively, (0, 20), (1, 40) or (2, 60) depending on the length of the message.

busy table. In effect, setting the console skip switch restores the selection rules to what they were prior to the program modification. The other improvements, the reduction of the basic busy table cycle time and the use of the output error condition to determine the time in the busy table, remain in force.

The reason for this operator control can be best explained by examining the handling of other messages in the system when a group code message is being delivered. Under the old selection rules, selection of deliveries of the group code message was repeatedly suspended and restored as the group code message was being processed. During periods when the selection of the group code message deliveries was suspended, other messages of the same or lower precedence were selected and delivered. Under the new selection rules the suspensions which permitted other messages to be serviced are almost non-existent and these other messages must wait until the group code message has been delivered. In some cases this means a delay in excess of one hour.

The console skip switch permits the MSC operator to invoke the old selection rules, if the group code message content and the number of messages waiting in queue behind the group code message justify such a procedure.

ARS Performance Improvement Tested Successfully

A number of tests have been run by the authors, shown in Fig. 3, using actual group code messages with results which proved to be far better than those initially envisioned. All tests indicated significant system performance improvement. The group code messages are being processed in slightly more than the minimum theoretical time. Group code messages which formerly required more than six hours to deliver are being delivered in slightly more than one hour. In processing group code messages maximum possible use is being made of the output trunks from the MSC to the CSN. Group code deliveries which formerly used only half the available output trunks are using all output trunks. Selection of the deliveries of the group code message is never suspended as long as an active MDH is available for selection. Busy table occupancy is minimal under the new selection rules. In tests of the threshold and of the full busy table mode of operation it was necessary

Figure 3—J. C. Parr (left) and A. M. Eisner (right) engineers run the tests in the Laboratory.

to artificially lower the threshold to three and the table size to five. Finally, the error printouts associated with the delivery of a group code message have also decreased significantly.

Summary

This programming modification implements a simple concept. The processing of an errored message delivery should suspend that delivery only. Its implementation permits message selection to continue the examination of message deliveries in multiple address and group code messages beyond the errored delivery. The MSC trunk and subscriber controls[1] effectively sort these additional message deliveries into two classes: those which have a high probability of successful delivery and should be attempted and those which have a low probability of successful delivery and should be sent directly to the busy table.

In effect this program change makes optimum use of the busy table and of the trunk and subscriber controls, to keep all output trunks busy with message deliveries and to drastically reduce the overall time required to deliver multiple address and group code traffic.

The resulting improvement in performance was significantly enhanced by making the time delay in the busy table entry a function of the error or trouble condition encountered and, in the special case of a group code message delivery encountering a simulated busy trunk trouble condition, by making the busy table time delay a function of the length of the group code message.

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END-TO-END GRADE OF SERVICE THROUGH CIRCUIT SWITCHING NETWORK SIMULATION

Theresa Sullivan

The design of a circuit switching network is primarily a trade-off between quantities of equipment provided and the customer service required for a defined traffic load. The parameter generally used in specifying service required by a customer or a subscriber is called "Grade of Service." This parameter, expressed as a ratio of busy calls to calls attempted, is usually applied to components of a network such as trunk bundles and switching matrices rather than to the overall network. In the Advanced Record System (ARS) the concept has been extended to include all the components in combination and is called End-to-End Grade of Service.

End-to-End Grade of Service is not only a function of the circuit switching network with its multiple paths, alternate routes and complex switching rules but also a function of the origin and the destination of the traffic flowing through the network. Manual computation of End-to-End Grade of Service for the various origin and destination types is very complex particularly when the objective is to measure the sensitivity of end-to-end grade of service to changes in the grade of service in the various components of the system. A more practical approach to the computation of End-to-End Grade of Service is to simulate the circuit switching network by means of a computer model and to measure the End-to-End Grade of Service which results, when this model is exercised. In the simulation of the ARS circuit switching network, the computer model used is based on the use of random numbers and is a Monte Carlo model.

The Advanced Record System is primarily a Circuit Switching Network (CSN) augmented by three Message Switching Centers (MSC). The CSN is the basic system component in ARS in that it provides the communication paths for traffic from the ARS subscribers and from the three Message Switching Centers. The simplified diagram of the ARS network, shown in Figure 1, indicates that the CSN comprises two types of offices, higher level and lower level. The Junction Office (JO), the higher level office in the CSN hierarchy, performs the high level switching functions normally associated with a regional or tandem office. It interconnects various District Offices and provides automatic alternate routing of traffic as required. In addition, the JO provides the interface between the MSCs and the CSN. The District Office (DO) is the lower level office in the CSN hierarchy; it performs the low level switching functions normally associated with a local office. It provides the interface between the subscribers and the CSN and performs automatic alternate routing of traffic as required.

Communication paths in the CSN are provided in a standard manner. A subscriber-to-subscriber call proceeds from the calling subscriber through the calling subscriber's DO, through an appropriate JO to the called subscriber's DO and ultimately to the called subscriber. In proceeding from the calling subscriber to the called subscriber, the call uses various units of common control equipment and facilities. It uses trunks in trunk bundles between offices and matrix paths and other common office equipment, such as registers and path selectors in the offices. It will be assumed, in the following example, that the term matrix path includes the actual matrix as well as all pertinent common office equipment. In designing the CSN, these trunk bundles and matrices were selected so that a call entering any trunk bundle or matrix is assigned a certain level or grade of service. This grade of service is expressed as a ratio of busy calls to calls attempted, and is usually applied to the various units of common control equipment and facilities used, such as a matrix or a trunk bundle. Basically, grade of service for a trunk bundle or a matrix defines the probability of getting a busy call on that trunk bundle or matrix for an assumed traffic load. However even if the grades of service associated with the various units of common control equipment and facilities are known, the problem of computing the end-to-end or subscriber-to-subscriber grade of service is formidable. This problem is complicated by two factors: 1) the choice of calling subscriber (origin) and called subscriber (destination) can change and 2), the CSN can set up the required communication path in a number of ways. The following example demonstrates this problem.

Problem: A Typical Subscriber-to-an-MSC Call

A basic type of call made in ARS is a call from a subscriber to any MSC. A subscriber places a call to an MSC, using any one of four dial sequences. Three of these dial sequences address the three unique MSCs, one dial sequence for each MSC. The fourth dial sequence is a common dial sequence and requests a connection to the "nearest available" MSC. Most calls to the MSC are made using the common dial sequence since the probability of completing the call is increased and the MSC handling the call is immaterial. When a subscriber places a call to an MSC using the common dial sequence, the call is termed a "subscriber-to-any-MSC" call.

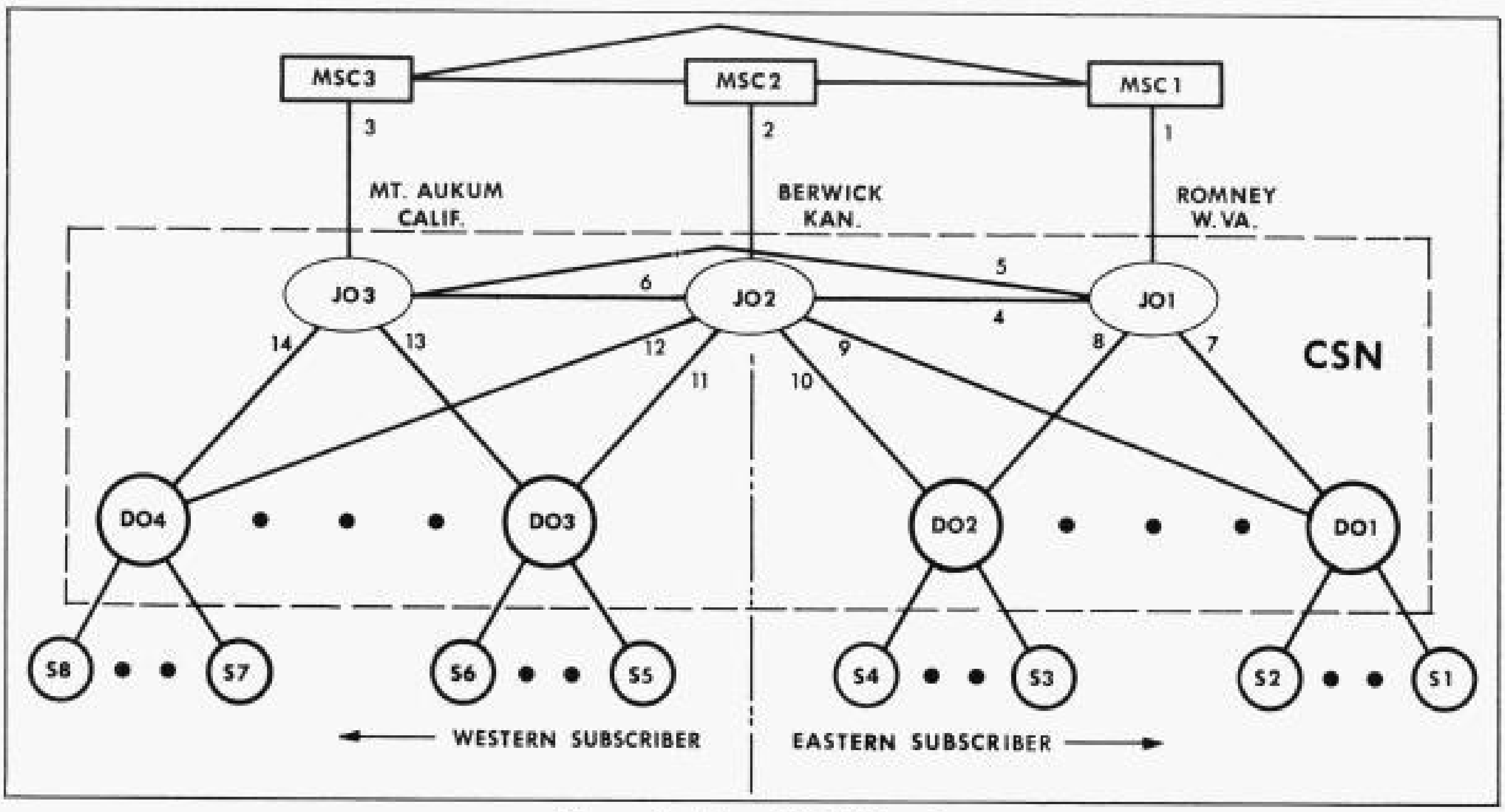


Figure 1—The ARS Network

Possible Paths

In Figure 1, the Eastern subscriber S_1 on DO_1 places a call to any one of three MSCs. In this case any one of six different paths or routes may be used. The first path is from S_1 to DO_1, through the DO_1 matrix to JO_1, via a trunk in trunk bundle #7 and through the JO_1 matrix to MSC1, via a trunk in trunk bundle #1. The second path is from S_1 to DO_1, through the DO_1 matrix to JO_1, via a trunk in trunk bundle #7, through the JO_1 matrix to JO_3 via a trunk in trunk bundle #5 and through the JO_3 matrix to MSC3 via a trunk in trunk bundle #3. The third path is from S_1 to DO_1, through the DO_1 matrix to JO_1 via a trunk in trunk bundle #7, through the JO_1 matrix to JO_2 via a trunk in trunk bundle #4, and through the JO_2 matrix to MSC2 via a trunk in trunk bundle #2. Paths 1, 2 or 3 represent the prime route out out of DO_1 and the prime secondary and tertiary routes, respectively, out of JO_2.

The fourth possible path permits a call from S_1 to DO_1, through the DO_1 matrix to JO_2 via a trunk in trunk bundle #9, and through the JO_2 matrix to MSC2, via trunk bundle #2. The fifth path is from S_1 to DO_1, through the DO_1 matrix to JO_2 via a trunk in trunk bundle #9, through the JO_2 matrix to JO_3 via a trunk in trunk bundle #6 and through the JO_3 matrix to MSC3 via a trunk in trunk bundle #3. The sixth path is from S_1 to DO_1, through the DO_1 matrix to JO_2 via a trunk in trunk bundle #9, through the JO_2 matrix to JO_1 via a trunk in trunk bundle #4 and through the JO_1 matrix to MSC1 via a trunk in trunk bundle #1. Paths 4, 5 or 6 represent the alternate route out of DO_1 and the prime secondary and tertiary routes, respectively, out of JO_2.

Path Selection

The actual path chosen for a call from S_1 to any MSC is determined by the originating DO and the first JO reached. When the call from S_1 enters DO_1, DO_1 will attempt to seize a prime route to JO_1, a trunk in trunk bundle #7. If a prime route trunk is available, DO_1 will attempt to build a path through its matrix between the input line from S_1 and the output trunk to JO_1. If a DO_1 matrix path is available, the call is extended to JO_1 and JO_1 is responsible for the further extension of the call. If the DO_1 matrix blocks (that is no path is available) between the input line from S_1 and the available output trunk to JO_1, then DO_1 will terminate the call with a busy signal. If all prime route trunks are busy, DO_1 will attempt to seize an alternate route to JO_2, a trunk in trunk bundle #9. If an alternate route trunk is available, DO_1 will attempt to build a path through its matrix between the input trunk from S_1 and the output trunk to JO_2. If a DO_1 matrix path is available, the call is extended to JO_2 and JO_2 is responsible for all further extension of the call. If the DO_1 matrix blocks between the input line from S_1 and the available output trunk to JO_2, DO_1 will terminate the call with a busy signal. If all alternate route trunks are busy, DO_1 has failed to extend the call to a high level office, a JO, and the call is terminated with a busy signal.

In this first phase of "call extension," the DO makes the logical switching decisions. Any one of three possible results can occur: 1) The call can be extended to the prime JO, JO_1, and enter the next phase, 2) It can be extended to the alternate JO, JO_2, and enter the next phase, and finally, 3) the call can be terminated when the DO is unable to extend the call to either JO because of busy conditions.

Prime Route Paths

In the second phase, the JO makes the logical switching decisions. If the call is extended to JO_1, the prime route JO, it will first attempt to extend the call to MSC1 using a prime route trunk in trunk bundle #1 and an appropriate JO_1 matrix path. If a trunk in trunk bundle #1 and a JO matrix path are available, the call is completed to MSC1 over communication path 1. If the JO_1 matrix blocks, JO_1 will terminate the call with a busy signal. If all trunks in trunk bundle #1 from JO_1 to MSC1 are busy, JO_1 will attempt to extend the call to JO_3 using a secondary route trunk in trunk bundle #5 and an appropriate JO_1 matrix path. If a trunk in trunk bundle #5 and JO_1 matrix path are available the call is extended to JO_3 and JO_3 is responsible for extending the call to an MSC. If the JO_1 matrix blocks, JO_1 will terminate the call with a busy signal. If all secondary route trunks to JO_3 in trunk bundle #5 are busy, JO_1 will attempt to extend the call to JO_2 using a tertiary route trunk in trunk bundle #4 and an appropriate JO_1 matrix path. If a trunk in trunk bundle #4 and a JO_1 matrix path are available, the call is extended to JO_2 and JO_2 is responsible for extending the call to an MSC. If the JO_1 matrix blocks or if all tertiary route trunks to JO_2 are busy, JO_1 will terminate the call with a busy signal.

If the call is extended from JO_1 to JO_3, JO_3 will attempt to extend the call to MSC3 using a trunk in trunk bundle #3 and an appropriate JO_3 matrix path. If a trunk in bundle #3 and a JO_3 matrix path are available, the call is completed to MSC3 over communication path 2. If the JO_3 matrix blocks, JO_3 will terminate the call with a busy signal. If all trunks from JO_3 to MSC3 are busy, JO_3 will return control to JO_1. In this case JO_1 will attempt to extend the call to JO_2.

If the call is extended from JO_1 to JO_2, JO_2 will attempt to extend the call to MSC2 using a trunk in trunk bundle #2 and an appropriate JO_2 matrix path. If a trunk in trunk bundle #2 and a JO_2 matrix path are available, the call is completed to MSC2 over communication path 3. If the JO_2 matrix blocks, JO_2 will terminate the call with a busy signal. If all trunks from JO_2 to MSC2 are busy, JO_2 will return control to JO_1 and JO_1 will terminate the call with a busy signal.

In this second phase of call extension, JO_1 makes the logical switching decisions and one of four possible results will occur: 1) The call can be completed over primary route to MSC_1 (communication path 1), or 2) over the secondary route to MSC3 (communication path 2), or 3) over the tertiary route to MSC2 (communication path 3) or finally, 4) the call can be terminated due to busy conditions.

Alternate Route Paths

In the first phase of "call extension," DO_1 can extend the call to JO_2 the alternate route JO. In this case, JO_2 handles the call extension in a manner analogous to that described above for JO_1. Again one of four possible results can occur: 1) The call can be completed over the primary route to MSC2 (communication path 4), or 2) over the secondary route to MSC3 (communication path 5), or 3) over the tertiary route to MSC1 (communication path 6) or finally, 4) the call can be terminated due to busy conditions.

The "subscriber-to-any-MSC" call is only one of a number of basic calls which can be made in ARS. However, the problem inherent in computing end-to-end grade of service in ARS can best be appreciated by developing a mathematical expression for grade of service for this type of call.

Mathematical Expression

A mathematical expression for end-to-end grade of service for a "subscriber-to-any-MSC" call can be developed using Figures 2 and 3. Figure 2 is that part of Figure 1 which illustrates only a call from subscriber S_1 to any MSC. This network, called network 1, is a series-parallel combination of links from node A, the entrance

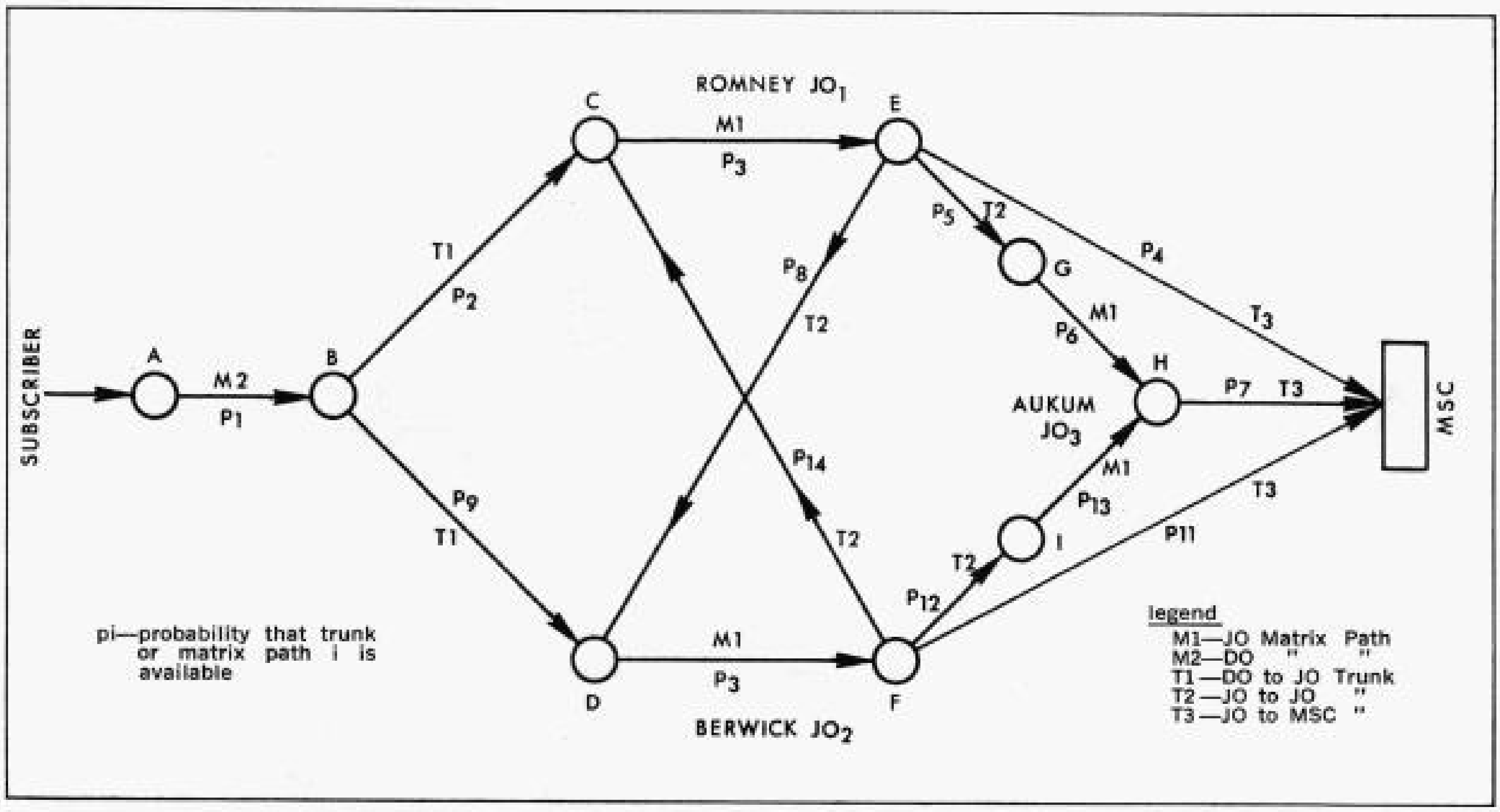


Figure 2—ARS Network Path for a Subscriber-to-any MSC Call

to the DO_1 matrix, to node J, the exit to any one of the three MSCs. The circuit from the subscriber S_1 to DO_1 is not included since the grade of service on the subscriber circuit is zero (i.e. his circuit is always available). The various links in Figure 2 are identified as matrix paths or inter office trunks using the key given on Figure 2. Associated with each link is a probability figure, p_i, which gives the probability of link availability. Link availability, p_i, and grade of service, g_i, are related by the simple formula:

$$p_i = 1 \cdot g_i \quad \text{for all}_i \tag{1}$$

Communication Path Availability

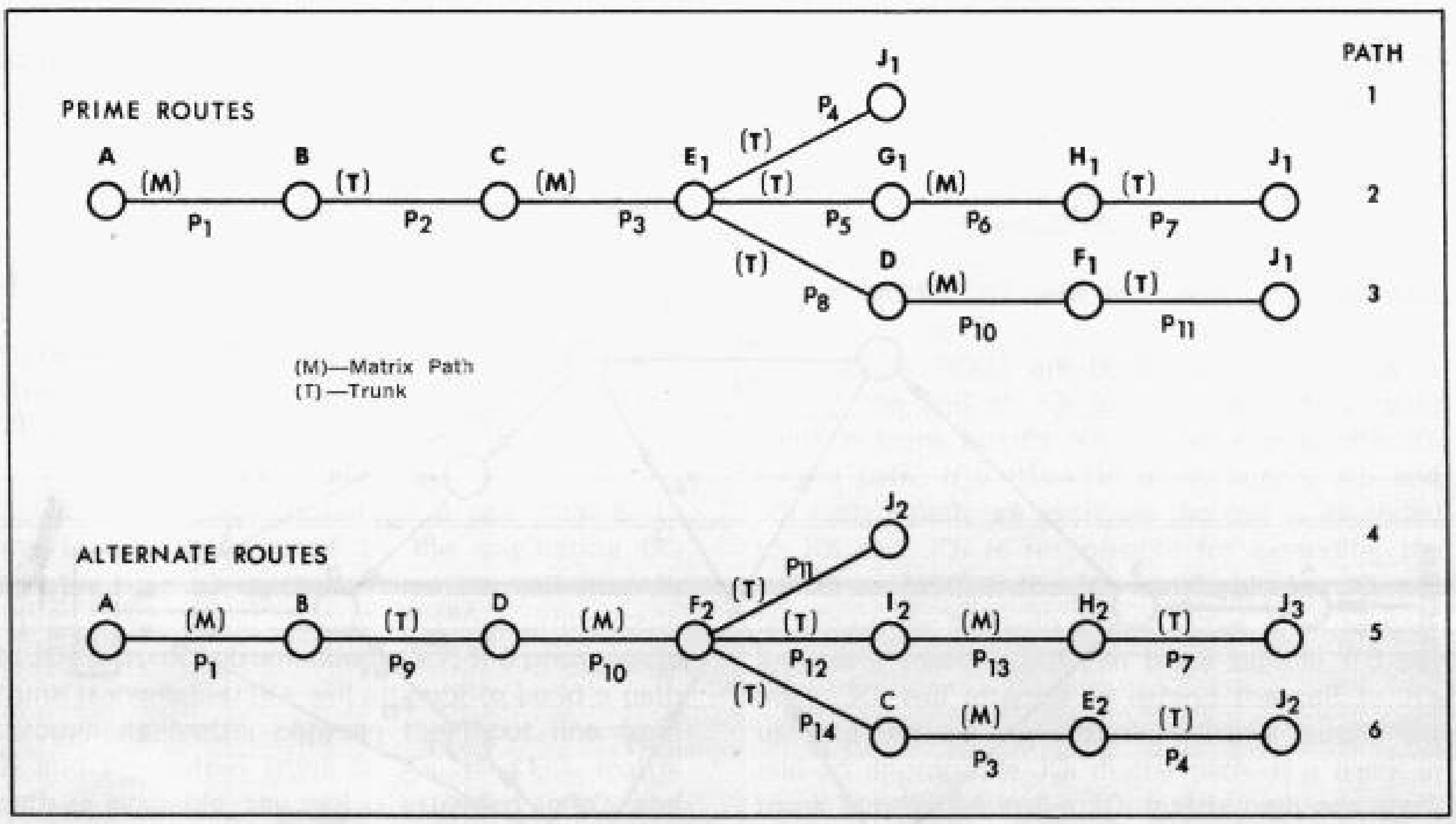
The six communication paths described earlier for a call from S_1 to any MSC are composed of the links, shown in Figure 2 and are the only valid paths which can be used in this network. Figure 3 defines these six communication paths in terms of the link notation used in Figure 2. It should be noted that there are a number of possible paths in the network of Figure 2, that are not included in Figure 3. These paths are not possible valid paths and the design of the CSN prevents the use of these paths. The first three paths, as stated earlier, are prime routes with respect to DO_1. The second three paths are alternate routes with respect to DO_1. The mathematical expression for end-to-end grade of service, G, can be derived using Figure 3, and the following formula:

$$G = 1 - \sum_{i=1}^{6} P_i \tag{2}$$

where the P_is are the probabilities that the various communication paths are available. The probability that communication path 1 will be available is:

$$P_1 = p_1\, p_2\, p_3\, p_4 \tag{3}$$

where p_1, p_2, p_3 and p_4 are the probabilities that each link in path 2 will be available. The probabil-



Notes:
1. Alternate routes taken if trunk BC in prime routes is not available
2. pi is the probability that trunk (or matrix path) i is available
3. In designating a particular link the numerical subscripts, if any, associated with the first letter in the link designation will not be used, e.g., in path 1 the links are designated AB, BC, CE and EJ

Figure 3—Type of Communication Path for a Subscriber to any MSC Call

ity that communication path 2 will be available, if required, is:

$$P_2 = p_1\, p_2\, p_3\, (1\text{-}p_4)\, p_5\, p_6\, p_7 \qquad (4)$$

where p_1, p_2, p_3, p_5, p_6, p_7 are the probabilities that each link in the path will be available and $(1\text{-}p_4)$ is the probability that the link EJ_1, in communication path 1, is busy. The probability that communication path 3 will be available, if required, is:

$$P_3 = p_1\, p_2\, p_3\, (1\text{-}p_4)\, (1\text{-}p_5\, p_7)\, p_8\, p_{10}\, p_{11} \qquad (5)$$

where p_1, p_2, p_3, p_8, p_{10}, p_{11} are the probabilities that each link in the path will be available and $(1\text{-}p_4)$ and $(1\text{-}p_5\, p_7)$ are the probabilities, respectively, that the link EG_1 in communication path 1 is busy and that either the link EG_1 or the link HJ_1 (or both) in communication path 2 are busy. The link GH_1 and its associated probability, p_6, is not included since GH_1 is a matrix path. If GH_1 is not available (busy), the call would be terminated, and communication path 3 would not be examined. The probability that communication path 4 will be available, if required, is:

$$P_4 = p_1\, (1\text{-}p_2)\, p_9\, p_{10}\, p_{11} \qquad (6)$$

where p_1, p_9, p_{10} and p_{11} are the probabilities that each link in the path will be available and $(1\text{-}p_2)$ is the probability that link BC in communication path 1 is busy. The probability that communication path 5 will be available, if required, is:

$$P_5 = p_1\, (1\text{-}p_2)\, p_9\, p_{10}\, (1\text{-}p_{11})\, p_{12}\, p_{13}\, p_7 \qquad (7)$$

where p_1, p_9, p_{10}, p_{12}, p_{13} and p_7 are the probabilities that each link in the path will be available and $(1\text{-}p_2)$ and $(1\text{-}p_{11})$ are the probabilities, respectively, that the link BC in communication path 1 is busy and that the link FJ_2 in communication path 4 is busy. The probability that communication path 6 will be available if required, is:

$$P_6 = p_1\, (1\text{-}p_2)\, p_9\, p_{10}\, (1\text{-}p_{11})(1\text{-}p_{12}\, p_7)\, p_{14}\, p_3\, p_4 \qquad (8)$$

where p_1, p_9, p_{10}, p_{14}, p_3 and p_4 are the probabilities that each link in the path will be available and $(1\text{-}p_2)$, $(1\text{-}p_{11})$ and $(1\text{-}p_{12}\, p_7)$ are the probabilities, respectively, that the link BC in communication path 1 is busy, that the link FJ_2 in communication path 4 is busy and that either the link FI_2 or the link HJ_3 (or both) in communication path 5 are busy. The link, IH_2 and its associated probability, p_{13}, is not included since IH_2 is a matrix path. If IH_2 is not available (busy), the call would be terminated and communication path 6 would not be examined.

The probability that a call is completed in network 1 of Figure 2 is:

$$P = \sum_{i=1}^{6} p_i = p_1 + p_2 + p_3 + p_4 + p_5 + p_6 \qquad (9)$$

End-to-End Grade of Service

The end-to-end grade of service for a call from a subscriber to any MSC can be computed using equation (2) and is as follows:

$$G = 1 - \{\, p_1\, p_2\, p_3\, [p_4 + (1\text{-}p_4)\, p_5\, p_6\, p_7 + (1\text{-}p_4)\, (1\text{-}p_5\, p_7)\, p_8\, p_{10}\, p_{11}] + p_1\, (1\text{-}p_2)\, p_9\, p_{10}\, [p_{11} + (1\text{-}p_{11})\, p_{12}\, p_{13}\, p_7 + (1\text{-}p_{11})\, (1\text{-}p_{12}\, p_7)\, p_{14}\, p_3\, p_4]\} \qquad (10)$$

The computation problems associated with this mathematical expression become apparent if the following calculations of interest are attempted:

- Determine G given all p_is
- Determine the sensitivity of G to p_k given all p_is except p_k
- Determine some p_is given G and the remaining p_is

These calculations indicate that more than a mathematical expression is required to solve the end-to-end grade of service problem. Some efficient and flexible method of handling all the variables and their interrelationships is needed.

The Solution—The Monte Carlo Simulation

In many cases where mathematical descriptions of physical systems are difficult to manipulate, it is possible to construct a model of the physical system and use this model to evaluate the performance of the physical system. In this case, the model is an analog of the physical system and the results which occur when this model is exercised are used to predict the performance of the physical system. This technique of evaluating or testing a physical system using a model of the system, is called simulation. When the model includes the concept of randomness or random processes, the technique is referred to as a Monte Carlo simulation.

A Simple Example

The concept of a Monte Carlo simulation, as it applies to the End-to-End Grade of Service problem, can be demonstrated by a simple example. Suppose, that it is necessary to determine the grade of service in the simple network shown in Figure 4. This network consists of two links, AB and BC, with origin A and destination C. Both links must be available in order to complete a call from A to C. The End-to-End Grade of Service is expressed as:

$$G = 1 - P = 1 - (p_1 \, p_2) \tag{11}$$

where p_1 and p_2 are the probabilities, respectively, that links AB and BC are available. Once the p_is are given, it is a relatively easy matter to compute G. For example, when both p_1 and p_2 are assigned the value of 0.5, P is equal to 0.25 and G is equal to 0.75.

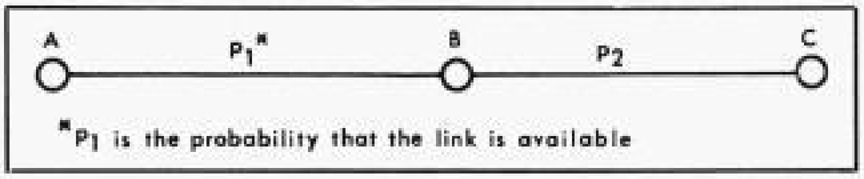


Figure 4—A Simple Network

However, there is another approach to solving this problem which is highly significant to the computation of End-To-End Grade of Service in ARS. This approach is Monte Carlo simulation. Suppose that it were possible to generate a random variable for the availability or non-availability of link AB, such that AB would be available fifty percent of the time. In other words, in the long term average of a large number of random variables generated, AB would be available consistent with a value of $p_i = 0.5$ even though any specific random variable generated would make AB available or not available. The toss of an unbiased coin would be a suitable random generator which meets these requirements.

If the outcome of heads on the flip of the unbiased coin is equated to link available and the coin is flipped twice, once for link AB and once for link BC, a trial has been performed. If the result is heads, heads, the trial is a success, i.e., the call is completed. If not, the trial is a failure, i.e., one or both of the links are busy. A number of trials can be performed and the number of busy conditions divided by the number of trials gives an estimate of G.

Table I, shown in Fig. 5, contains the results of 50 tosses of an unbiased coin. These outcomes can be grouped into sets of two, and used to determine call success or failure. Table I indicates that 7 out of 25 trials are successful since there are 7 out of 25 sets of two heads (HH). This yields a P of 0.28 and a G of 0.72. This approximates the results calculated using equation (11) which yields a P of 0.25 and G of 0.75.

TABLE I

HT	TT	TT	HH*	HT
TH	TT	HH*	TT	TH
HH*	TH	TT	TH	HH*
TH	TH*	TH	TT	HT
HH*	HT	HH*	HT	TT

*Successful trial—HH

Figure 5—Matrix of Successful Trials Using an Unbiased Coin

In effect, the determinate problem, equation (11), has been replaced by a game of chance (the tossing of an unbiased coin) and the solution to the determinate problem by the results of playing the game of chance. This approach is called the Monte Carlo method.[1]

Simulation of a Subscriber-to-any-MSC Call

The Monte Carlo method has its true value in dealing with a large number of variables. In the simulation of ARS, and the evaluation of end-to-end grade of service, the Monte Carlo method accommodates the greater number of variables without significantly increasing the amount of work required.

Network 1, given in Figure 2, is basically the same type of network as the simple network. It has more than two links in any given path. However, as in the simple network, each link in the path must be available in order for the call to be completed. It has a number of paths but the availability of each path is determined in the same manner as that of the simple network. Therefore, in dealing with network 1 or any similar ARS network, the method used is identical to that used in the simple network. However, the particular rules and requirements governing choices of paths in the ARS network must be incorporated in the Monte Carlo simulation.

In the ARS network, the link grades-of-service may theoretically range from 0.000 to 0.999. Therefore a random process that can deal with this range is needed. In effect, a random number generator capable of generating three digit random numbers is required. The random number generated can be compared to the given link grade of service (probability of being unavailable, i.e., busy). As a result of this comparison, a determination of the availability or non-availability of a link can be made. If the random number is greater than or equal to the link grade of service, the link is available. If the random number is less than the link grade of service, the link is busy. When all links in a given path have been evaluated in terms of availability, a determination of the call success or failure can be made. If all links in a given path are available, the call is successfully completed on this path. If one or more links in a given path are busy, the call cannot be completed on this path. If a matrix link in any path is busy, the call is terminated due to busy conditions. If a call is completed on any path in the network, the call is a success. If a call cannot be completed on any path in the network, the call is terminated due to busy conditions.

Table II contains a list of the links in network 1, in the order of their appearance in Figure 3, where the six basic communication paths are defined. Associated with each link in Table 2 is the link grade of service and a random number. The random number is part of a set of random numbers generated to perform a trial on network 1. The set of random numbers has been adjusted to yield results which illustrate the Monte Carlo method as applied to network 1.

Using this set of random numbers an evaluation of link availability in path 1 shows that links AB, BC, and CE_1 are available and link EP_1 is busy. Therefore, path 1 is busy and the next alter-

TABLE II
Test Data for NETWORK 1—SUBSCRIBER-TO-ANY MSC CALL

Link	Grade of Service*	Random Numbers	Communication Paths**					
			1	2	3	4	5	6
AB	1	356	X	X	X	X	X	X
BC	10	915	X	X	X			
CE_1	1	478	X	X	X			
EJ_1	10	4***	X					
EG_1	10	614		X				
GH_1	1	189		X				
HJ_1	10	9***		X				
ED	10	349			X			
DF_1	1	935			X			
FJ_1	10	524			X			
BD	10	923				X	X	X
DF_2	1	532				X	X	X
FJ_2	10	146				X	X	X
FI_2	10	763					X	
IH_2	1	384					X	
HJ_3	10	767					X	
FC	10	638						X
CE_2	1	271						X
EJ_2	10	907						X

*Grade of Service is expressed as the number of busys in 1,000 trys.

**An X identifies a specific link as a member of the given communication path.

***These random numbers are less than the link grade of service, and the comparison of these two values will result in a link busy.

nate path, path 2, must be examined. A comparison of random numbers and link grades of service for links in this path indicates that links AB, BC, CE_1 and GH_1 are available and that link HJ_1 is busy. Therefore, path 2 is busy and the alternate path, path 3, must be examined. The random number and grade of service comparisons for the links in path 3 show that links AB, BC, CE_1, ED, DF_1 and FJ_1 are available. Therefore, path 3 is available and the call is successfully completed. If path 3 had been busy, no alternate path could have been tried and the call would have been terminated unsuccessfully due to busy conditions. Therefore, trial 1 of network 1 using the set of random numbers results in a successful call completion through the network.

Table 2 also indicates that the call could have been completed over path 4, 5 and 6 if link BC in the prime paths had not been available.

If additional sets of random numbers are generated and used to perform additional trials on network 1, an estimate of End-to-End Grade of Service for network 1 can be obtained by dividing the number of times the call is unsuccessful due to busy conditions by the number of trials.

NETSIM

The Monte Carlo approach described above has been incorporated into a computer program called NETSIM (Network Simulation). This program has been designed for use on the Univac 418. NETSIM automatically simulates the placing of a given type of call in ARS and after a repeated number of trials computes the end-to-end grade of service associated with this type of call. NETSIM is programmed to test trunk bundles and matrix paths in a manner identical to that used in the CSN. All switching rules and alternate routing capabilities in the CSN are included in the NETSIM model. NETSIM is actually a collection of six network models each of which deals with a specific origin and destination associated with a specific type of CSN call. One of these models is network 1, a subscriber to any MSC call. These six models are as follows:

1. Network 1—Subscriber to any MSC
2. Network 2—Eastern Subscriber to Eastern Subscriber
3. Network 3—Subscriber to one MSC
4. Network 4—Any MSC to a Subscriber
5. Network 5—Eastern Subscriber to Western Subscriber
6. Network 6—Subscriber to two MSCs

These models can be illustrated by using Figure 1. The first type deals with calls from a particular subscriber, S_1, to any MSC where the subscriber uses the common MSC dial code. The model for this call type is entitled "Network 1—Subscriber to Any MSC." This model tests all links in a subscriber to any MSC call. These links include DO matrix paths, DO to JO trunk bundles, JO matrix paths, JO to JO trunk bundles and JO to MSC trunk bundles.

The second type covers calls from subscriber to subscriber. The model for this call type is entitled "Network 2—Eastern Subscriber to Eastern Subscriber." This model simulates calls from a subscriber such as S_4 serviced by both JO_1 and JO_2 to another subscriber such as S_1 serviced by these JOs. This model tests all links in a subscriber to subscriber call and also covers a call from a western subscriber to a western subscriber, such as a call from subscriber S_5 to subscriber S_8.

The third basic call type handles calls from a particular subscriber such as S_7 to a particular MSC such as MSC3 using the unique MSC dial sequence. The model for this call type is entitled "Network 3—Subscriber to One MSC" and requires that all links in a subscriber to one MSC call be tested.

The fourth call type is a call from a particular MSC such as MSC2 to a subscriber serviced by both JO_2 and JO_3 such as S_6. The model for this call type is entitled "Network 4—Any MSC to a Subscriber" and requires that all links be tested.

The fifth call type deals with a call from an eastern subscriber such as S_3 to a western subscriber such as S_5. The model for this call type is entitled "Network 5—Eastern Subscriber to Western Subscriber". This model which requires that all links be tested also includes a call from a western subscriber to an eastern subscriber such as a call from subscriber S_8 to subscriber S_1.

The sixth call type covers calls from a subscriber such as S_6 to either of two MSCs such as MSC2 or MSC3 using the common MSC dial sequence. The model for this call type is entitled "Network 6—Any Subscriber to Two MSC" and requires that all links be tested.

Each of these models is a composite of those matrix paths and trunk bundles which can be used to establish a valid call path from the given origin to the given destination.

Random Number Generation

NETSIM uses the Monte Carlo method in examining a network or model and arriving at a network grade of service for the type of call represented by the model. The random numbers used by NETSIM to test the network model are provided by a random number generator.

The multiplicative congruential method is used to generate random numbers to be used in a comparison with the link grades of service. The random number generator algorithm [2,3] used is:

$$u_{n+1} = (2^9+1)\ u_n + 1 \ (\text{modulo } 2^{17}) \qquad (12)$$

where u_n is the random number generated on cycle n of the random number generator and u_{n+1} is the random number generated on cycle $_{n+1}$. The random number generated on any given cycle is formed in accordance with equation 12 using the random number generated on the previous cycle. The initial value, u_0, is taken from the Univac 418 incremental real time clock, a value which is a variable. This algorithm is used modulo 2^{17} in order to obtain a non-negative 18 bit word which can be compared to the grades of service which have been converted to 18 bit words. (The word size of the UNIVAC 418 is 18 bits.)

Network 1 Model

The basic element in a network model is the Network Link Table which contains the data necessary to form valid paths and determine call success or failure. This table contains a separate entry for each link in the network each time it appears as an alternate link in a different path. Each entry is composed of six words. The first word contains the link identification. The second word contains the link grade of service, i.e., the number of times this link is likely to be busy out of 1000 tries. The third word contains a pointer to the next link in this path provided the link being tested is available. If this word contains zero, the call has been completed successfully and the counter of successful calls must be incremented. The fourth word contains a pointer to the alternate link to be tried provided the link being tested is busy. If this word contains zero, there is no alternate path. The call cannot be completed and the counter of busy calls must be incremented. The fifth word is used to maintain a count of the number of times this link was available. The sixth word is used to maintain a count of the number of times this link was busy.

Table III shows the Network Link Table for Net-

TABLE III
ANY SUBSCRIBER TO ANY MSC CALL—NETWORK 1 LINK TABLE

Link	Grade of Service	Next Link Success	Next Link Busy	Success Counter	Busy Counter	Path No.
AB	1	BC	**			
BC	10	CE1	BD			
CE1	1	EJ1	**			
EJ1	10	***	EG1			1
EG1	10	GH1	ED			
GH1	1	HJ1	**			
HJ1	10	***	ED			2
ED	10	DF1	**			
DF1	1	FJ1	**			
FJ1	10	***	**			3
FI1*	10	—	—			
IH1	1	—	—			
HJ2	10	—	—			
BD	10	DF2	**			
DF2	1	FJ2	**			
EJ2	10	***	FI2			4
FI2	10	IH2	FC			
IH2	1	HJ3	**			
HJ3	10	***	FC			5
FC	10	CE2	**			
CE2	1	EJ2	**			
EJ2	10	***	**			6
EG2*	10	—	—			
GH2*	1	—	—			
HJ4*	10	—	—			

* These entries are not used on any of the presently existing paths in the model and represent possible paths not used at present in the CSN.
** Call terminated.
*** Call completed.

work 1—Subscriber to Any MSC. This link table contains twenty-five entries. When a call is simulated using Network 1, NETSIM tests AB, the first entry in the Network Link Table. If the comparison of the link grade of service and the generated random number shows that this link is available, the success counter for this link is incremented and NETSIM tests the next link in this path, BC. If AB is not available, the busy counter for this link is incremented. Since no alternate route exists (the next link pointer contains zero), the counter of busy calls is incremented and a new trial call is simulated on the network.

NETSIM tests BC by comparing the grade of service of BC to a generated random number. If BC is available, its success counter is incremented and NETSIM tests the next link in this path, CE_1. If BC is not available, its busy counter is incremented and NETSIM tests the alternate route link, BD.

NETSIM tests CE_1 using its grade of service and a generated random number. If CE_1 is available, its success counter is incremented and NETSIM tests the next link in this path, EJ_1. If CE_1 is not available, its busy counter is incremented. Since no alternate path exists, the counter of busy calls is incremented and another trial call is simulated on the network.

NETSIM tests EJ_1 using its grade of service and a generated random number. If EJ_1 is available, its success counter is incremented and since the next link pointer contains zero, this call has been completed successfully via communication path 1. NETSIM increments the counter of successful calls and simulates another trial call on the network. If EJ_1 is not available, its busy counter is incremented and NETSIM tests the link, EG_1, of an alternate path.

NETSIM tests the remaining communication paths, if necessary, in network 1 using the Network 1 Link Table shown in Table 2. The testing of these paths proceeds in exactly the same manner as described above for communication path 1.

Sample Results

When the NETSIM program is initiated, the operator specifies the data on which the program runs are to be made. This data includes the date of the run, the network number, the total number of calls to be tried on this network and the grade of service for each link in the network. The printout which results at the completion of the pro-

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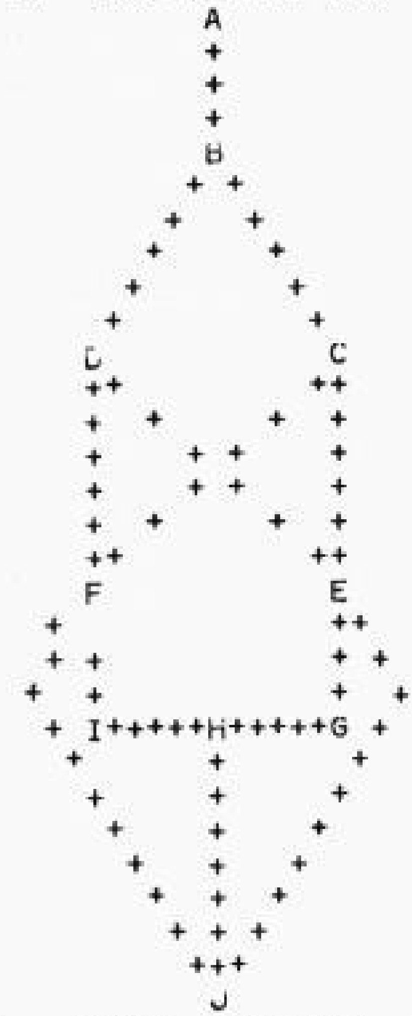
1 SUB TO ANY MSC



LINK	PROB	SUCCTR	FALCTR
AB	1	9993	7
BC	10	9879	114
CE1	1	9867	12
EJ1	10	9745	122
EG1	10	121	1
GH1	1	121	0
HJ1	10	120	1
ED	10	0	1
DF1	1	0	0
FJ1	10	0	0
FI1	10	0	0
IH1	1	0	0
HJ2	10	0	0
BD	10	112	2
DF2	1	112	0
FJ2	10	112	0
FI2	10	0	0
IH2	1	0	0
HJ3	10	0	0
FC	10	0	0
CE2	1	0	0
EJ2	10	0	0
EG2	10	0	0
GH2	1	0	0
HJ4	10	0	0

CALLS COMPLETED 9977
CALLS NOT COMPLETED 23
TOTAL OF X:0<X<=333 13473
TOTAL OF X:333<X<=666 13485
TOTAL OF X:666<X<=999 13484

Figure 6—Typical NETSIM Printout

gram run contains the operator specified data as well as the results of the program run.

Figure 6 represents a typical printout at the end of a program run. The first line of the printout in Figure 6 contains the data on which this run was made. The second line contains the network number and name. The following lines are a diagram of the network being simulated. Following the diagram is a list of four columns. The first column contains the identification of the link. The second column contains the particular link's grade of service, i.e., the calculated number of times the link will fail out of 1,000 tries. The third column contains the number of times the given link was available. The fourth column contains the number of times the link was busy in the particular path being tested. For example, link AB has a probability of being busy once in a thousand times. It was available 9,993 times and busy 7 times in this program run. Link BC has a probability of being busy ten out of a thousand times. It was available 9,879 times and busy 114 times.

Following the results for each link, the printout specifies the number of calls which were successfully completed. In this particular network run, the number of calls completed was 9,977. The next entry of the printout specifies the number of calls which were terminated unsuccessfully due to busy conditions. In this particular network run, the number of calls which could not be completed was 23.

The following three entries contain the quantity of random numbers generated that lie within each of three prescribed ranges: 000 to 333, 334 to 666 and 667 to 999. These three entries are printed out to maintain a simple check on the random numbers being generated.

The results of the program run associated with the printout of Figure 6 indicate that P is equal to 0.9977 and that G is equal to 0.0023. In other words, the simulation model has determined that the grade of service for this particular call type is 0.0023 or 23 busy responses in 10,000 calls attempted. Some care should be taken in interpreting these results. They depend directly on the link grades of service specified in the simulation run. These link grades of service depend, in turn, on the operating condition of the actual equipment. As an example, suppose that a trunk group is equipped with six trunks to provide a grade of service of 0.01 for the assumed traffic load. If one of these trunks is not operational due to equipment failure, the grade of service on the trunk group for the same assumed traffic load is greater than 0.04. The simulation model only predicts end-to-end grade of service based on link grade of service and can only provide an end-to-end grade of service measurement in a network with equipment failures if the link grades of service in the network model have been appropriately adjusted to reflect the change in link grades of service due to these equipment failures.

SUMMARY

The NETSIM program is significant for two basic reasons. First, it provides an effective method of determining end-to-end grade of service in ARS. It permits the examination of six basic ARS call types and includes, in its six network models, the alternate routing capability and switching rules found in the CSN. Second, it uses a simple but effective simulation technique, the Monte Carlo method.

Some comments must be made on the problems ineherent in a Monte Carlo simulation. As in all simulations, the results are a function of the degree to which the model represents the actual system. The NETSIM model, by design and by results obtained, seems to be an excellent analog of the CSN. The role of a random number generator is critical in a Monte Carlo simulation. The particular algorithm used in the NETSIM program has proved to be completely satisfactory. The final problem which is probably the most serious one in a Monte Carlo simulation involves the determination of the number of repetitions or trials required in order to develop a dependable result. In the case of NETSIM it was found that a number of program runs (ten) with the number of repetitions in each run, an order of magnitude larger (10,000) than link grade of service accuracy gave consistent and accurate results. The accuracy of these results was checked by manually computing end-to-end grade of service using mathematical equations.

Despite these problems application of the Monte Carlo method should be investigated whenever a performance evaluation of a physical system, which behaves in accordance with probabilistic laws, is required.

* * * *

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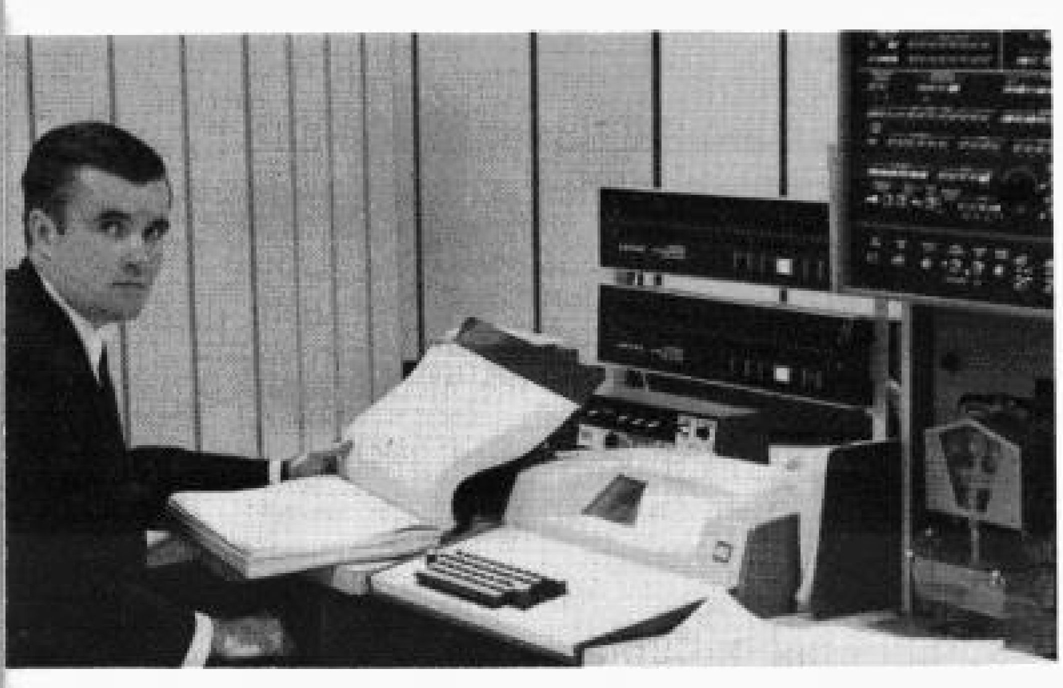
The Authors in this



John C. Parr, a Manager in the Advanced Record System Project for General Services Administration, is responsible for computer systems analysis and engineering on all computers in the Advanced Record System.

Mr. Parr joined Western Union in 1957 to design and implement the Plan 57 Switching Center. From 1960 to 1966 he was a Senior Engineer with R.C.A. where he was involved in the communications aspect of Command and Control Systems. When he rejoined Western Union in 1966, he was involved with the systems engineering of the NASA 311 project.

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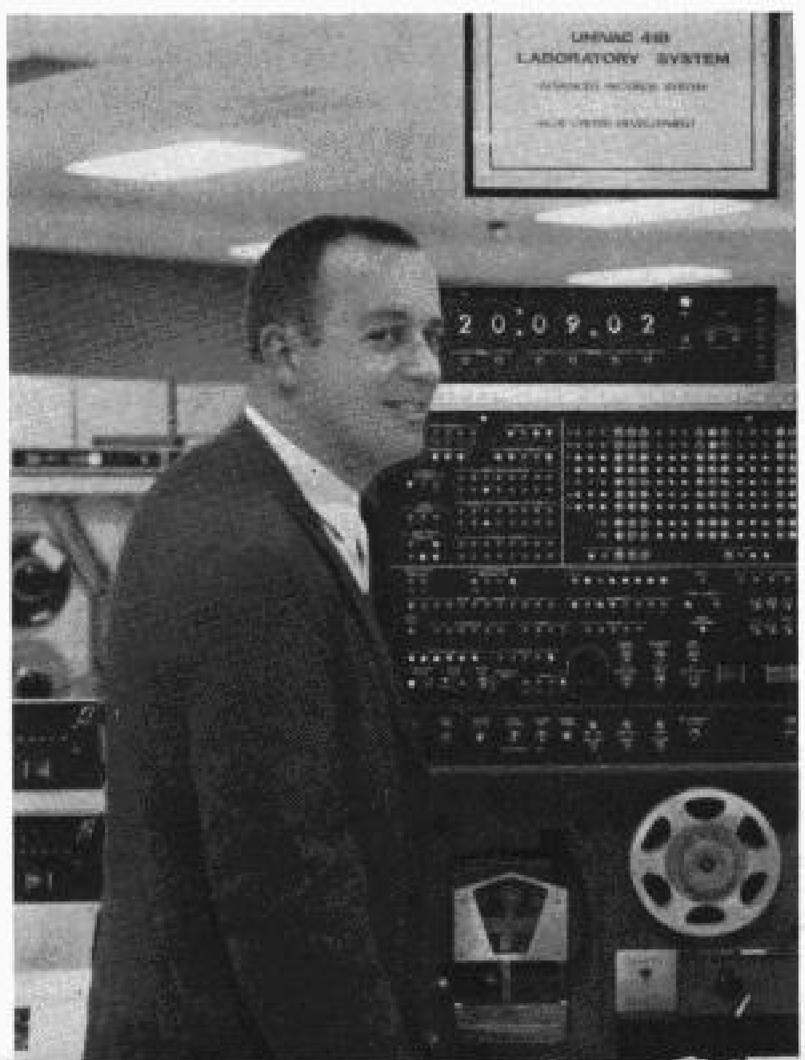
Mr. Eisner joined Western Union in 1957 and participated in the design and implementation of cross-office control of the Plan 57 Switching Center. He participated in the software design and implementation of the laboratory model of the 301 Switching System. He also was concerned with the system engineering of the NASA 311 Switching Center and the Advanced Record System.

Mr. Eisner received his B.E.E. in 1957 from City College of New York where he has taken graduate courses toward an M.S.E.E.



ssue

Theresa Sullivan, a programmer in the Private System Projects division of the Planning and Engineering Operations department, has been responsible for developing NETSIM. She joined the department in 1967 as a member of the Advanced Record System project technical staff and was assigned to software analysis and design on ARS. She wrote the article in this issue, prior to her leaving Western Union early in 1969.

Mrs. Sullivan received a Bachelor of Science degree in mathematics from Fordham University in June 1967.

ABSTRACTS OF ARTICLES IN THIS ISSUE

Advanced Record System
Service Improvement
Program Control

Parr, J. C. and Eisner, A. M.: Service Improvement Through MSC Program Control

Western Union TECHNICAL REVIEW, Vol. 23, No. 3 (June 1969 pp. 86 to 95 Special ARS Issue)

Several programming modifications were made by Western Union in the Advanced Record System, designed for G.S.A., which gave the MSC the necessary logic and data to recognize the size of the CSN and to operate efficiently using its share of the CSN. This article describes the program control which made possible this service improvement.

Message Switching
Busy Table Design
Advanced Record System

Parr, J. C. and Eisner, A. M.: Thruput Improvement in Message Switched Traffic

Western Union TECHNICAL REVIEW, Vol. 23, No. 3 (June 1969 pp. 104-113 Special ARS Issue)

An improvement in performance of delivery of multiple messages was developed. By making the time delay in the Busy Table entry a function of the error or of the trouble conditions encountered, this improvement was effected.

This article describes the basic design limitations and the alternate design approach.

Program Control
Trunk Allocations
Traffic Load

Parr, J. C. and Eisner, A. M.: Improved Trunk Allocation in a Congested Network

Western Union TECHNICAL REVIEW, Vol 23, No. 3 (June 1969, Special ARS Issue)

The dynamic trunk control modification permits the MSC in the Advanced Record System to adjust its usage of JO to DO trunks as a function of the total traffic load in the DO. This article describes the static trunk allocation, the Program Control and the Dynamic Trunk Control and how it was implemented for this system designed for G.S.A.

End-to-End Grade of Service
Network Simulation
Circuit Switching

Sullivan, Theresa: End-to-End Grade of Service Through Circuit Switching Network Simulation

Western Union TECHNICAL REVIEW, Vol. 23, No. 3 (June 1969 pp. 114-125 Special ARS Issue)

The NETSIM, Network Simulations program, is a simple simulation technique, which provides an effective method of determining End-to-End Grade of Service in the Advanced Record System. This article identifies the problem in a typical Subscriber-to-a MSC Call and how it was solved by the Monte Carlo simulation technique. A sample printout of a program run is included.