A DISCRETE EVENT SIMULATION OF THE EUROPEAN AUTOVON USING GPSS V

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ABSTRACT

This paper presents a description of a discrete event simulation program developed to model the European AUTOVON (AUTOmatic VOice Network) of the Defense Communication System (DCS). AUTOVON is a telephone network characterized by a relatively small size, unpredictable and often fluctuating traffic loads, and a priority structure of calls and subscribers. The network is designed for survivability and proper operation in stress conditions. This paper briefly describes AUTOVON, indicates how a GPSS model was developed of the network, explains some of the logic flows involved in the model, and discusses several of the engineering and traffic control problems addressed by the simulation. And finally, the results generated by the simulation are presented. This simulation developed has not only provided valuable analysis aid for the present AUTOVON but also proved useful in designing the monitoring and control systems for the future AUTOVON.

INTRODUCTION

The European AUTOVON (Automatic Voice Network) of the Defense Communications System (DCS) is a telephone network designed for military communication for the Department of Defense. It has many unique features that do not exist in commercial circuit switched telephone networks. Its small size (few thousand subscribers compared to millions of subscribers in a typical commercial network) causes very high peak to average traffic pattern which implies high blocking rates and inefficient use of network equipment. In addition, because of the military nature of operation, many unexpected traffic patterns can occur in the case of crisis which the network has not been designed for. It is not economically and operationally feasible to design a network with enough capacity to accomodate all the possible traffic loads and shifts. Therefore, to assure acceptable operation in the case of crisis as well as normal daily operation, good traffic control is necessary. Some facilities are limited, a priority structure is adopted on calls as well as subscriber stations, and this priority structure forms a basis for traffic control. This paper presents a description of the simulation program ANDES (Autovon Network Discrete Event Simulation) developed to model the European AUTOVON, and summarizes the analyses results obtained from ANDES.

The simulation model ANDES was developed to serve a variety of purposes for the present AUTOVON system control upgrade and future AUTOVON network and control design. Specifically, this model was intended to:

- identify bottlenecks and vulnerable points in the existing network.
- provide observability of the behavior of system parameters under various traffic patterns.
- serve as a tool in identifying network parameters, as monitored by the switch control, necessary for traffic control and network performance evaluation.
- aid in designing and testing traffic monitoring and control algorithms.
- provide directions and guidelines for future network and control planning and growth issues.

To achieve the above goals, it was necessary to model accurately not only the network topology and traffic carrying capacity but also the equipment pieces and control functions at the switch. In addition, flexibility of program structure and easy access of statisitcal data are also important considerations. The model simulates AUTOVON operation on a call by call basis and was designed with modular construction with well defined interface between program segments.

DESCRIPTION OF AUTOVON

The European AUTOVON provides communication links for most parts of the European continent and the U.S. with 10 switches (nodes), each with approximately 200-500 subscribers or PBXs (Private Branch Exchanges) homin onto it. Three of the European switches are the "gateway" switches that have direct trunk groups (groups of voice and wideband channels) linking to Continental U.S. (CONUS), modeled here as the 11th switch in the network. Figure 1 shows the network topology considered and its switch locations. Each trunk group shown consists of between 7 and 35 voice and wideband channels that can be selected by either of its end switches in a talking connection. Besides its call processing control, the switch has three major common equipment groups that are essential for call set-up. These are the RSJ group for digit collection and interswitch signaling, DTMF group for subscriber dialing and 2/6 MF transceiver group for interswitch signaling. The number of pieces of equipment in each group ranges from 6 to 24 depending on the traffic and number of subscribers on each switch. As in the case of trunks in a trunk group, these switch common equipment pieces are selected from a pool of idle pieces by the switch control as needed during call processing and returned to the idle pool when the particular function has been completed.

When the originating switch attempts to set-up a talking path for a call (known as routing) it first attempts to set-up the call by selecting idle trunks on the primary route (from a routing table defined by origin and destination switch pair). When this attempt fails (all trunks busy in a group, for example), the control switch will try on the secondary route. There are 3 routing choices in most cases. This process is known as "alternate routing". In some cases, after the originating switch has successfully seized the first trunk in a route, it passes the control to the next switch (known as "spill") and the next switch will route the call as if it were its own origination. The spill control and routing table are fixed in the network and are designed so that no looping will be possible in the routing path.

Unlike the commercial telephone, some AUTOVON subscribers have an option of initiating higher priority calls than the "routine" class. This is accomplished by dialing a priority digit into the switch control. There are presently 5 priority classes, Flash Override, Flash, Immediate, Priority and Routine. In the routing process if all trunks are busy on all possible routes, the switch control will look at the priority of the call and if there is an existing call with a priority lower than the one the switch is attempting to set-up, the switch will tear down the lower priority call to give the desired trunk to the high priority call. This process is known as "preemption" on trunks.

DESCRIPTION OF MODEL

A model was developed for the AUTOVON system which attempted to reflect most of the major features of the actual network. The simulation modeled activities on a call by call basis and emulated the call processing events in both the call setup and call talking stages.

The ANDES program was developed using the discrete event simulation language GPSS-V (General Purpose Simulation System). GPSS models entities (called transactions) moving through a series of events (called blocks). In ANDES, each individual call was represented as a transaction. Each transaction has a block of data stored with it (called parameters) which were used to describe the call (its priority, type, origin, destination, control switch, route through the network if already set up, etc.) and to keep track of its current status (setup or talk stage, routing state, control spill state, etc.).

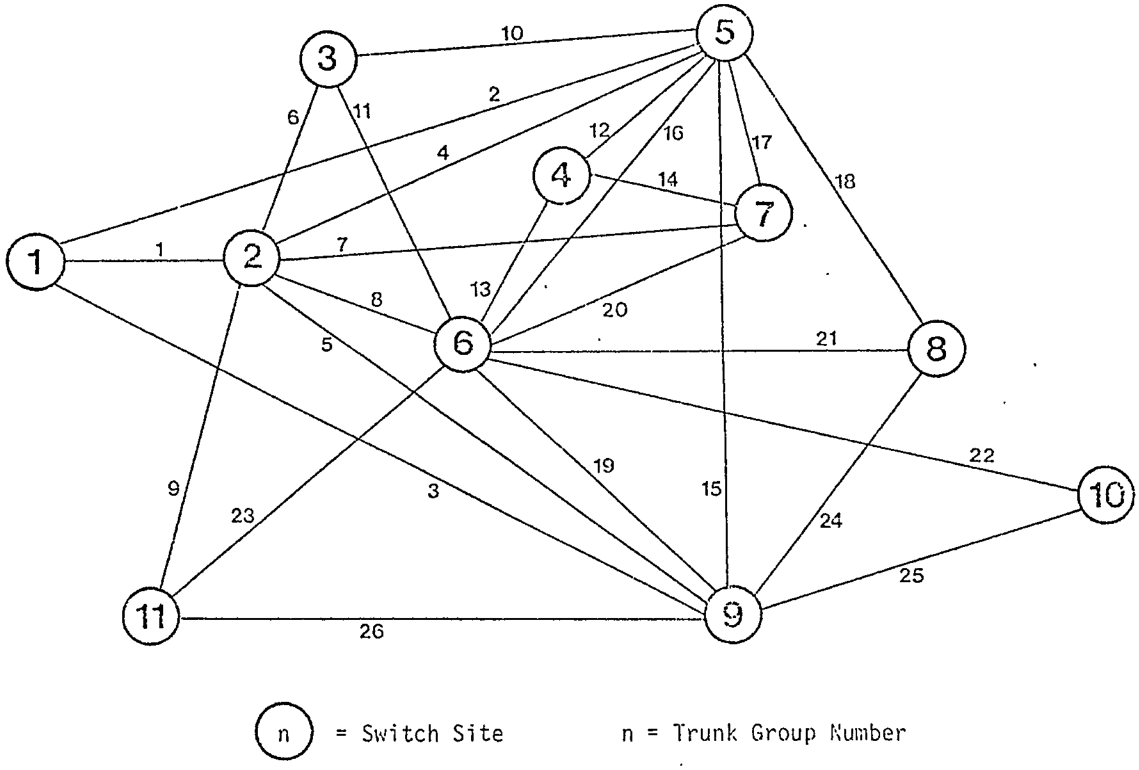
Each switch in the network was modeled as a group of three GPSS storages, one each for the RSJ, 2/6 MF transceiver and DTMF receiver groups, at the switch. Trunk groups were represented by two GPSS entities: storages and groups. Two storages and two groups were used to model each trunk group. One of each type of entity was used for the voice trunks and one for the wideband data trunks in the trunk group. Use of storages allowed the capacity of the trunk groups to be set while use of GPSS "groups" allowed an individual record of each call to be maintained. The capacities of all storages used to model both switches and trunk groups were set to mirror to the corresponding equipment in the actual AUTOVON system.

The connectivity of the network was defined by connecting each trunk group to two switches through a "table" named NODE. Reconfiguration of the network occured simply by changing the connections defined in NODE. This process could be completed before a simulation run or dynamically during the run. Matrix data arrays were also used to represent the routing tables such that entry (i,j) in the matrix represented the next link in the route between origin i and destination j. The routing tables can be defined (dynamically if desired) to change routing patterns (for example, to route traffic away from already congested portions of the network).

ANDES generates an individual stream of incoming calls at each switch by generating the inter-arrival times of the calls pseudo-randomly from an exponential distribution. The mean inter-arrival rate of the input stream can be independently defined or altered for that switch. The network traffic level can also be (dynamically) changed by proportionately increasing or decreasing the generated traffic at all switches by a proportionate amount. Upon entering the network, each call is randomly assigned a destination, priority, and a call type (voice or wideband) based on user-specified distributions.

Events in ANDES call processing sequence were designed to consider several aspects of AUTOVON's behavior. Several time delay aspects of AUTOVON were represented in the model. These include dialing time, interswitch signaling time, a queued wait for dial tone when initiating call, and time to transmit busy signal when the receiving subscriber is busy. Other features of AUTOVON which were modeled included call control and "spill" forward control, a priority structure on calls, alternate routing, preemption, two types of calls (voice and wideband data) and both local and inter-switch calling.

Through the use of GPSS's SNA's (Standard Numerical Attributed) and a number of other counters and information gathering tables defined by the authors, ANDES was able to monitor and report on a wide range of network, switch and trunk group activities. A call history was maintained on all interswitch calls which cataloged calls on an origin-to-destination basis by priority, outcome (completed, blocked, pre-empted) and by routing choice (primary, secondary, tertiary route). In addition, information was available on the length of various call types. For



1) CONUS - Continental U.S. (CONUS)
2) Hillingdon, England (HIN)
3) Martlesham Heath, England (MAM)
4) Schoenfeld, Germany (SCH)
5) Feldburg, Germany (FEL)
6) Donnersberg, Germany (DON)
7) Langerhoff, Germany (LKF)
8) Coltano, Italy (CTO)
9) Mt. Vergine, Italy (MTV)
10) Mt. Pateras, Greece (MTP)
11) Humosa, Spain (HUM)

FIGURE 1 EUROPEAN AUTOVON NETWORK CONFIGURATION

each trunk group, data was gathered on both occupancy levels and blocking rates. Similarly, for each switch, occupancy levels and blocking rate data were maintained for each type of common equipment.

DESCRIPTION OF MODELS OPERATION

The ANDES program code was developed with a modular structure consisting of a group of relatively independent subroutines. The logic flow and processing of the program were designed to be independent of the particular configuration of the network. The goal was to allow easy modification of the logic flow (for example, to allow insertion of new traffic controls) without affecting other program segments. It was also important to identify numerous parameters or variables which indicated the behavior of the network and the effect of various traffic controls upon the network. These parameters were displayed as clearly as possible to allow a wide variety of statistic gathering subroutines to access them without altering the program's logic flow.

The basic simulation program is broken into seven subroutines, each of which performs a specific function in the call processing sequence. Each call (a transaction in GPSS) moves through the logic flow defined around these subroutines. Each subroutine consists of a group of events (blocks in GPSS) and logic flow. Figure 2 provides a simplified overview of the AUTOVON simulation. Presented below are brief descriptions of each of the seven subroutines:

1) Generate Program

The GENERATE subprogram creates calls for each switch and sends them into the network. It is responsible for calculating the call arrival time and, after the call has entered the system, for defining its characterisitcs. The characterisitcs are all selected from pre-defined distributions, and include a destination, a priority, and a call type. The GENERATE routing initializes several pointers and sets the call's initial control node. GENERATE also contains a parameter for controlling the overall level of traffic in the network.

2) INIT (Initial Call Set-Up) Program

INIT starts the actual processing of the call through the network. It simulates the request for service from a subscriber. INIT assigns an RSJ, DTMF receiver pair to the subscriber to provide him with a dial tone and digit reception. If either entity is unavailable, the subscriber's call is queued until the equipment is available. After receiving a dial tone, the subscriber's dialing time is simulated and the DTMF receiver is released.

If the call is local (i.e., origin switch = destination switch), the RSJ is also released and the call is removed from the network. For purposes of the AUTOVON network model, local calls will use no additional network resources and, hence, further simulation is unnecessary.

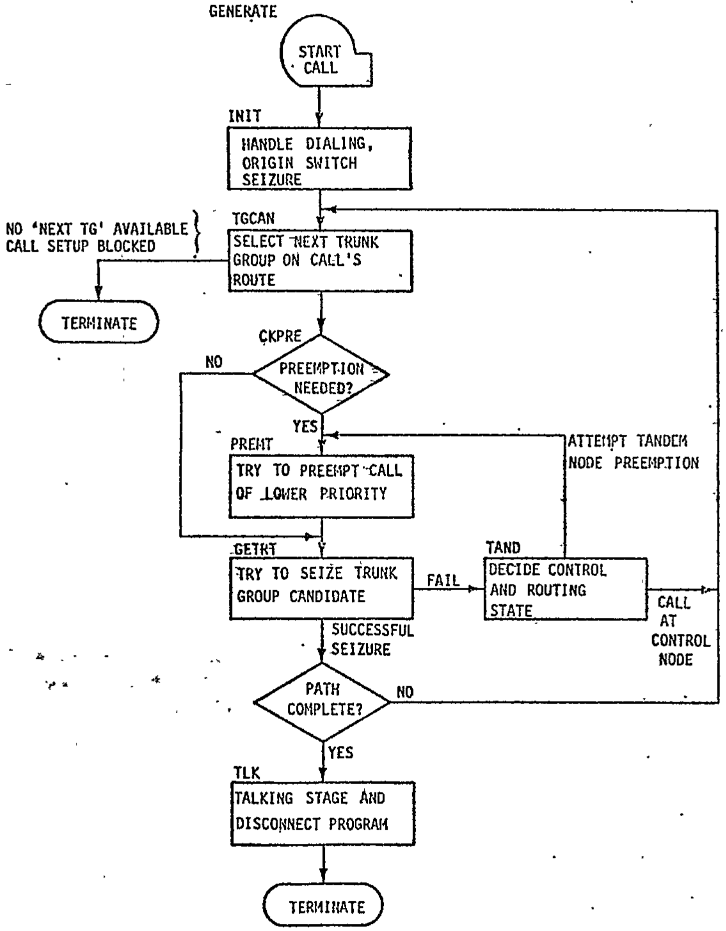


FIGURE 2 AUTOVON NETWORK SIMULATION (ANDES)

Processing of inter-switch calls continues by having them attempt to seize a 2/6 MF transceiver. If no transceiver is available, the call is terminated (blocked). Successful seizures proceed on to TGCAN where their initial route through the network is specified.

3) TGCAN (Trunk Group Candidate) Program

TGCAN selects the next trunk group over which the call will attempt to connect. The selection of this candidate trunk group is based on the state of the routing process and the origin/destination pair of the call. For calls routing from their control node, the trunk group candidate is selected from one of the three routing tables stored in the data base(primary, secondary, or tertiary route). For calls being routed from a tandem node, selections are made from the primary routing table.

If the state of routing process indicates that all possible routing alternatives have been exhausted, the call will be terminated unsuccessfully. If a potential route is available, the call then moves on to actually attempting to seize the candidate trunk and the required common equipment of the connecting switch.

4) PREEMPT (Preemption Program)

PREMPT carries out the actual pre-emption of a call in the network. A decision to attempt preemption is made based on the routing state of the call previous to the call's entry into PREMPT. PREMPT checks to see if preemption of a call occupying a particular trunk group is possible by the new call. Preemptions occur if all trunks in the trunk group are occupied and if the trunk group contains a call of lower priority than the call that is being set up. The call to be preempted is randomly picked from the group of lowest priority calls occupying the trunk group. Voice type calls can preempt on either voice or wideband trunks but traffic involving wideband transmission can preempt only other wideband calls.

5) GETRT (Get Route) Program

GETRT attempts to connect the next link on the call's route by actual seizing of the trunk group proposed by TGCAN. This is done by seizing the trunk group and the RSJ and 2/6 MF transceiver on the other end of the trunk. If any of these entities are unavailable, the entire seizure attempt fails. However, if the trunk is seized, the call out-pulses to the far end switch to establish the link. Voice communication traffic attempts to seize either a voice or a wideband trunk (although it will take a voice line if both types are available) while wideband traffic is limited to seizure attempts on wideband trunks. Various pointers and status indicators are updated. Forward "spill" of call control over the new link is carried out if appropriate.

GETRT has two exits, one to PCOM (a logic test to see if the call set up is complete) if the trunk group seizure is successful, and one to subroutine TAND if the seizure attempt fails.

6) TAND (Tandem Node) Program

TAND's primary function is to re-route a call after it has failed to seize the trunk group candidate provided by TGCAN. If the call is at a control node, it is simply sent back to TGCAN for a new candidate. If the call is at a tandem (non-control) node, it is sent to PREMPT to try to preempt a lower priority call. If the preemption has already been attempted and failed, the call "back tracks" to its control node by releasing all trunk groups and common equipment held "past" the control node. The call returns to TGCAN for a new routing plan.

7) TLK (Talking and Disconnect) Program

The call is transferred to TLK after the set-up process is complete. All common equipment (RSJ, 2/6 MF transceiver pairs) still held by the call are released. The talking stage of the call can have one of three outcomes:

1. No answer.
2. Called party busy.
3. Connection is completed and talking proceeds.

The choice of outcome is randomly selected, based on a pre-defined distribution. In all cases, time is assumed to elapse while the originating subscriber determines the call's outcome or completes his conversation. Calls involving wideband transmissions are assumed to have longer average holding ("talking") times than voice calls.

RESULTS

The AUTOVON simulation program was used to analyze several specific problems involved with analysis of traffic behavior, and switch monitoring and control. Representative of this effort are the results presented below.

1. By using available network traffic requirement data, ANDES was able to identify many of the network bottlenecks and quantify the uneven distribution of network loading which were the results of inadequate network planning, traffic forecast and unexpected subscriber calling behavior. Table 1 summarizes the daily busy hour trunk group blocking conditions. Results showed that the most long haul trunk groups were underengineered, [redacted] The over loading also appeared on some of the switch common equipment groups.

2. Some analyses of the network under traffic stress were made to identify the bottlenecks and vulnerability which might be hidden under normal conditions. When the traffic input level was increased to 140% of the average busy hour traffic, results indicated that high priority calls [redacted] could be blocked. [redacted] These blockings were caused by the blocking of RSJs and 2/6 MF transceivers at the European gateway switches. Typically during a traffic build-up, while high priority

$$\% \text{ BLOCKING} = \frac{\text{TOTAL UNSUCCESSFUL ATTEMPTS ON THE TRUNK GROUP}}{\text{TOTAL ATTEMPTS ON THE TRUNK GROUP}}$$

	1	2	3	4.	5	6	7	8	9	10	11
1. CONUS	╲	81%	╲	╲	88%	╲	╲	╲	87%	╲	╲
2. HILLINGDON	╲	╲	3%	╲	21%	56%	1%	╲	20%	╲	2%
3. MARTLESHAM	╲	╲	╲	╲	3%	28%	╲	╲	╲	╲	╲
4. SHOENFELD	╲	╲	╲	╲	1%	1%	2%	╲	╲	╲	╲
5. FELBERG	╲	╲	╲	╲	╲	2%	1%	3%	1%	╲	╲
6. DONNESBERG	╲	╲	╲	╲	╲	╲	3%	4%	5%	17%	16%
7. LANGERKOPF	╲	╲	╲	╲	╲	╲	╲	╲	╲	╲	╲
8. COLTANO	╲	╲	╲	╲	╲	╲	╲	╲	13%	╲	╲
9. MT. VERGINE	╲	╲	╲	╲	╲	╲	╲	╲	╲	2%	1%
10. MT. PATERAS	╲	╲	╲	╲	╲	╲	╲	╲	╲	╲	╲
11. HUMOSA	╲	╲	╲	╲	╲	╲	╲	╲	╲	╲	╲

TABLE 1 PERCENTAGE BLOCKING OF INTERSWITCH TRUNK GROUPS

calls were preempting their way into the European gateway switches, the effective holding time per call is short during this build up period due to the large number of preemptions. This short holding time combined with the spilled control features* at the gateway switches drastically increased the usage of the RSJs and 2/6 MF transceivers. And since no preemption-link control exists for RSJs and 2/6 MF transceivers, many high priority calls were blocked during call set-up, since they preempted a trunk but failing to seize a RSJ or a 2/6 MF transceiver. This blocking of high priority calls described above does not show up on a normal daily busy hour and happens only during traffic fluctuations. It is felt that this problem could cause serious operational hazard during a realistic military or political crisis.

3. To provide a designer an insight into the the dynamic behavior of various switch parameters as monitored by the switch control. analyses were made on the sensitivity and inter-relationship among traffic parameters under different conditions. This is an essential step in the designing of the switch and network monitoring and control system. Shown in Figure 3 is a typical behavior pattern of switch parameters under a steady traffic increase. In all cases, "average occupancy" dominated "blocking rate" for any common equipment group when the network is lightly loaded, and "pre-

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*When control is spilled to a European switch in a trans-Atlantic call set-up the European gateway switch acts an an originating switch and has to signal all tandem and terminating switches and thus increases its holding time of RSJ and 2/6 MF transceivers.

TABLE 3 TRAFFIC CONTROL SUMMARY

	CONTROL	EXISTING	NETWORK RESOURCE	IMPLEMENTATION
1.	Preemption	Yes	Trunks	Automatic, Local
2.	Alternate Routing	Yes	Trunks	Automatic, Local
3.	ATOP (Line Load Control)	Yes	RSJ	Automatic, Local (Manual)
4.	Common Equipment Denial	No	RSJ, 2/6 MF DTMF	Automatic, Local
5.	Destination Code Cancellation	Yes	Trunks*	Manual, Network
6.	Inhibit Route by Precedence	No	Trunks RSJ, 2/6 MF	Manual, Network
7.	Trunk Directionalization	Yes	Trunks*	Manual, Network
8.	Queueing for Switch Common Equipment (Changing Time-Out Parameters)	No	RSJ, 2/6 MF DTMF	Automatic, Local
9.	Alternate Routing Cancellation	No	Trunks	Manual, Network
10.	Dynamic Routing	No	Trunks	Automatic or Manual, Network

*Can also be used to relieve switch congestion

emption rate" did not show up significantly until both "occupancy" and "blocking rate" had exceded certain levels. Thus "preemption rate" provides very little statistical meaning when network loading is light. When the network was nearly at full load, the "occupancy" leveled off and "blocking rate" provided more sensitive indication of the degree of congestion. Therefore, "occupancy" parameters provide a good first indication of traffic anomaly and are the only ones which need to be monitored during normal conditions. Once "occupancy" parameters exceed a certain threshold, detection could switch to monitor "blocking rates" that provide more meaningful and quantified congestion information. In addition to these traffic parameter inter-dependency and dominance information, ANDES also provided indications of the randomness of various parameters than enables the designer to test different estimation and sampling schemes for traffic monitoring.

4. In the existing AUTOVON today, "alternate routing" and "preemption" are the two automatic controls. Simulation results indicated that in a heavily congested condition, "alternate routing" improved the traffic throughput by approximately 10% or more over the same conditions without "alternate routing". "Preemption" on trunk groups enables the switch control to give preference to high priority calls over existing lower priority calls. ANDES results indicated that "preemption" feature improved service of high priority calls by almost a factor of 3. Table 2 summarizes these results.

   In addition to the two controls mentioned above, some AUTOVON switches have the "AUTOVON Traffic Overload Protector" (ATOP) control which limits the access of lower priority subscribers into the network when the switch has 2 or less idle RSJs and stays in this condition until 5 or more RSJs are idle. Simulation of ATOP showed 30%

and 40% improvement in average tonde delay on some of the switches. High priority blocked calls were reduced by about 30%, but with significant increase of blocked low priority calls by the limited access caused by ATOP. The remaining blocked high priority calls was caused by 2/6 MF transceiver blocking which was not directly relieved by ATOP.

NORMALIZED CALL FAILURES*

Call Priority	A	B	C	D
Routine	1	0.75	0.86	0.78
Priority	1	0.77	0.82	0.91
Immediate	1	1.31	1.42	0.99
Flash	1	10.93	3.43	6.36
Flash Override	1	10.0	3.82	5.08

A - Existing Control Alternating Routing and Premptions
B - No Control
C - Preemption Only
D - Alternate Routing Only

*Call Failure is defined as the total number of "blocked" and "preempted" calls.

TABLE 2 EXISTING ALTERNATE ROUTING AND PREEMPTION PERFORMANCES

5. Because of the inability of ATOP to relieve 2/6 MF transceiver blocking for high priority calls, a new switch control has been developed and tested. "Common Equipment Denial" (CED) is a new control that independently denies usage of RSJ, DTMF and transceiver to low priority calls by monitoring the current equipment group occupancy. ANDES is currently being used to test the effectiveness of CED with various thresholds. Table 3 lists all the existing and other proposed future controls currently under consideration.

SUMMARY AND CONCLUSION

ANDES has been generally successful in serving the purposes for which it was designed. It has provided much more complete observability of the present AUTOVON system under a variety of different network and traffic conditions.

Many of the switch common equipment blocking problems discussed above occur only under abnormal traffic conditions and because ANDES models switching common equipment and switch call controls, it was able to discover many hidden network vulnerabilities. Simulation results should help point out where capacity in the network should be addes and the corresponding performance improvements.

By analyzing the dynamic behavior of various traffic parameters monitored by the local switch and identifying the inter-dependency between parameters, ANDES has served as a useful tool for the design of traffic monitoring algorithms which will be used to develop future network and traffic controls.

ANDES has the potential to be used for several other tasks for which it has, up to now, not been considered. It could be a helpful tool in long term network planning and capacity engineering. ANDES would also be useful in studying new traffic control algorithms, especially controls involving dynamic routing which are often too complex to evaluate without a model or a simulation.

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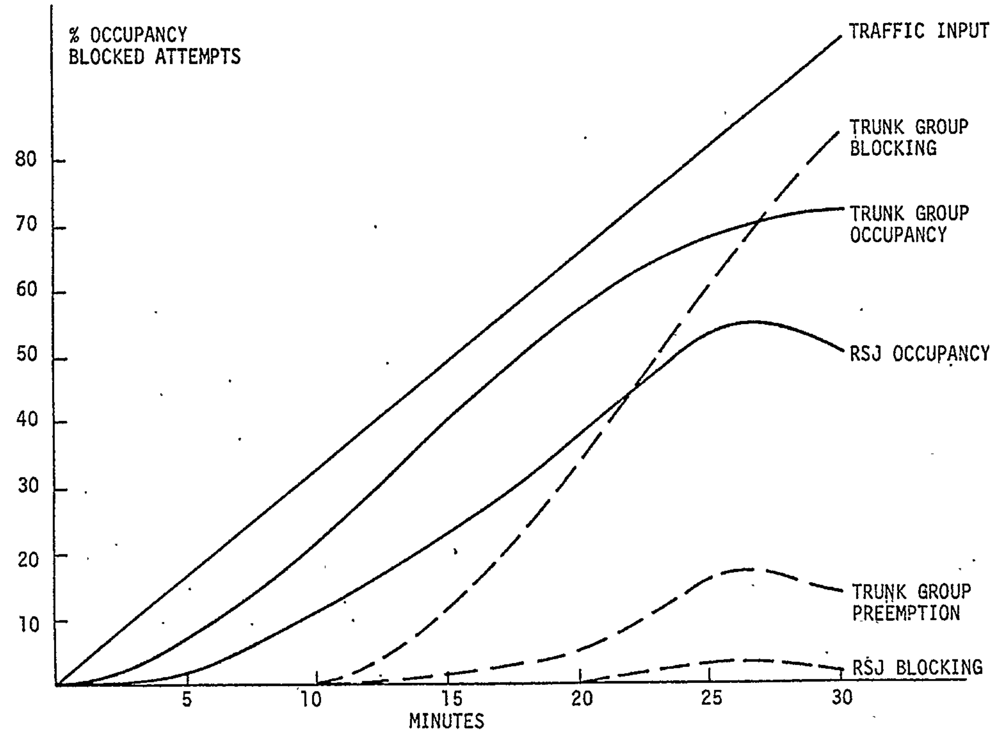

FIGURE 3   DYNAMIC BEHAVIOR OF TRAFFIC PARAMETERS