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A COMPUTER SIMULATION ANALYSIS OF CONVENTIONAL AND TRUNKED LAND MOBILE RADIO SYSTEMS AT WRIGHT PATTERSON AIR FORCE BASE

THESIS

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THESIS

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Preface

My interest in land mobile radio (LMR) began in Europe when, as an additional duty, I became our unit's Site Security OIC. Subsequent exercises and real world events demonstrated the need for reliable intra-base communications, and how easily the communication systems (public telephone, field phone, and radio) could become saturated with calls in an emergency.

Hybrid trunked LMR should go a long way to solving these problems. Although this thesis explores the effects of some increases in loading on fleets of a trunked system, more research on LMR loads during exercises would be profitable. Of particular interest would be the probability distributions and statistics (described in Chapter V) of various LMR nets currently in use at Air Force bases during exercises.

In conducting this research I have been helped by many people. In particular, I would like to express gratitude to my sponsor, Mr Gardner, who provided much of the background information about LMR systems and answered many questions, and to my committee, Maj Prescott, Maj Norman, and CPT Shaw. CPT Shaw deserves special thanks for the time he spent and advice he gave, both on the queueing aspects of this thesis, and on good engineering practices in general. I would also like to thank my parents who, through example, demonstrated the benefits of academic discipline and self motivation. Finally, I would like to thank the technical people I have known, and learned from, who are serving in the United States armed forces around the world.

Thomas C Farrell

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Abstract

Trunked land mobile radio systems, currently being developed by several companies, allow many groups of land mobile radio (LMR) users to share a set of channels dynamically, reducing the total number of channels needed to support these groups. These systems also support "dynamic regrouping", reassigning individual users to different groups through software in the controlling computer. Hybrid trunked systems (HTSs) have the added advantage of being able, in the event of controlling system failure, to default to certain channels, adding a degree of robustness to the system. HTSs seem to be an answer to many of the Air Force's intra-base communications needs. These needs include the ability to support an ever increasing number of users with a minimal increase in allocated channels, a very high level of system reliability under extremely adverse conditions, and an ability to manage users under a variety of contingencies (base attack, aircraft crash, etc.) In order to determine the number of channels a HTS will require for a specific facility, information about traffic loading, and how the system reacts to it, is needed.

This paper discusses a computer model of existing LMR networks on Wright Patterson Air Force Base (WPAFB), and a model of a possible trunked system for the base. Data was collected from off the air monitoring of LMR nets, and was used to determine numerical values for various parameters. These values were input to the computer models to determine the time required for a user to obtain a channel while

traffic load and (for the trunked model) user grouping were varied to simulate various conditions.

A 5 (1 data, 4 voice) channel HTS was found to adequately support WPAFB, even with a loss of one repeater and an increase in LMR traffic. With proper user grouping, trunked system performance is shown to be superior to the existing conventional system while using fewer channels.

A COMPUTER SIMULATION ANALYSIS OF CONVENTIONAL AND TRUNKED LAND MOBILE RADIO SYSTEMS AT WRIGHT PATTERSON AIR FORCE BASE

I. Introduction

Background

Land Mobile Radios (LMRs) (also called "walkie-talkies" or "bricks") are small, hand held radios used by police, fire departments, and other organizations desiring portable, rapid communications. Because of the LMR's decreasing cost and increasing availability, many organizations on Air Force bases now have, or want, their own LMR network (net). Because of this, the Air Force now faces the problem of obtaining allocation of a larger number of channels from the Federal Communications Commission (FCC) and host nations.

Trunked LMR systems reduce this problem by allowing users to share a set of channels dynamically. In one type of trunked system, all of the radios are originally tuned to a digital channel monitored by a computer driven central controller. If a user, a fireman for example, wants to talk with his department, he keys the radio, which sends a digital signal to the central controller. The controller examines the set of allocated voice channels and, if it finds one not currently in use, it sends a digital signal to every radio on the fireman's net (called "fleet" in trunked systems) re-tuning them to the channel. When the fireman de-keys his radio all the radios in the fleet re-tune back to the digital channel. Normally this whole procedure occurs so quickly the user doesn't notice any difference from a conventional system. However, if all of the voice channels are in use, other users trying to get a channel are queued on a priority basis by the controller.

Trunked systems have several advantages over conventional systems:

1. As mentioned above, the primary advantage is in requiring fewer channels to satisfy more users. This is based on the observation that transmissions usually take place on a conventional net for only a small percentage of time.

2. Individual radios in a trunked system can be reallocated to different fleets based on programs stored in the central controller. This has great advantages on an Air Force base, particularly during contingencies when individuals are performing different missions, reporting chains are changed, and some conventional LMR nets would become saturated.

3. Assuming compatibility between Air Force trunked systems, deployed units can communicate with other units at their new location. For example: national guard units deployed overseas can integrate their LMR system with that of their host base.

4. Individual radios can be "turned off" of a system. This is an advantage in situations such as a hostage scenario where the hostage's captured radio can be taken off of the fleets used by the rescue force and, if desired, assigned to its own fleet for use by the negotiating team.

Hybrid trunked systems are trunked LMR systems with the added advantage that, if the central controller goes down, radios automatically re-tune to preallocated channels. This is vital in the military environment, where loss of one element of the system shouldn't completely eliminate communications.

The 1842 Electronics Engineering group, Scott AFB, Il is developing Air Force requirements for the hybrid trunked LMR systems described above and needs data to determine the number of channels necessary to provide reliable communications in a contingency situation. They would like to have a computer model developed which will simulate a trunked system and determine its performance characteristics during various contingencies.

Problem and Scope

The objective of this thesis is to design and build a computer simulation model of a trunked system for a specific Air Force base, determine appropriate values for input parameters for both day to day and contingency operations, and use the model to determine the number of channels needed to provide the base LMR users with a reasonable time to access a channel.

Approach

Computer Models. A computer model of a conventional LMR system was built as a baseline for measuring performance differences between it and the trunked model. In a conventional system there are two possible reasons a user would have to wait for a channel: 1) someone else on the user's net is already talking, or 2) someone on another net (sharing the channel) is talking. The computer model measures these conditions for a given load and presents curves of the percent of transmissions delayed vs. the amount of time they are delayed.

On a trunked system, delays in granting a user a channel can be due to somebody else talking on the same fleet, all of the voice channels being in use, and mechanical delay in the system (which includes delay in accessing the controller on the digital channel and delay in the controller itself). The computer model of the trunked system assumes a constant mechanical delay and measures the other two delay conditions for a given load. Like the conventional model, the results are plotted as the percent of transmissions delayed vs. the amount of time they are delayed.

Both computer models were built using SLAM II, a FORTRAN based simulation tool (7:vii). The models were verified by setting the input parameters to match simple mathematical models and comparing results.

Collection of Data. Data was collected from off the air monitoring of nets in use at Wright-Patterson Air Force Base (WPAFB). The data was used to determine, for each net, the number of messages per hour, the mean transmission length, the mean time between transmissions (within a message), and the mean number of transmissions per message. (Usually a conversation over LMRs consists of several transmissions making up a message. For example, a dispatcher asks for a police officer's location, the officer tells him, and the dispatcher responds. This is considered one message and consists of three transmissions: one by the police officer and two by the dispatcher.) The data was also used to verify the legitimacy of the various distributions used in the computer models.

Normal Configuration Runs. The data collected by off the air monitoring was put into the computer models and they were set up to simulate the existing conventional system, and a hypothetical trunked system, at WPAFB. The models were run for various loads, and for different numbers of channels in the trunked model. The curves obtained were then compared to determine how many channels a trunked system would need to provide performance comparable to the existing system.

Contingency Runs. Various contingencies were also examined. Contingencies can affect an LMR system in at least three ways:

1. In certain circumstances, load might increase disproportionately for a few nets (or fleets). For example, an automatic fire alarm going off in a hospital storeroom might cause increased activity on the fire net, the hospital net, and the security police net, but would not affect the load on other nets at all.

2. On a computer controlled trunked system, fleets might be reallocated during certain contingencies. Most notably, if the base is located in an area that could become a war zone, contingency plans probably call for reallocating resources (manpower and equipment) from non-essential functions to areas vital to the base's wartime mission.

3. Certain contingencies might affect the LMR system itself. For example, a fire in the room housing a repeater would not only increase traffic load, but might take the repeater off the air.

These situations were examined with the trunked model.

Assumptions

There appears to be no published data on call inter-arrival distribution and call length distribution specifically taken from Air Force LMR nets. The assumption was made that these distributions, in general, are similar to commercial nets as described in the literature review. This assumption was checked to some extent through off the air monitoring of WPAFB nets (see Chapter V).

In off the air monitoring of WPAFB nets to determine mean call inter-arrival times and mean call lengths, the statistical fluctuation over periods of time greater than several days was assumed to be negligible. This was necessary due to the time constraints of the research.

The nature of the LMR users on WPAFB led to an assumption that traffic intensity is fairly constant throughout the day, and equal or heavier (depending on the specific user) during daytime than at night. This assumption was checked through off the air monitoring (see Chapter V).

The Air Force will require an adjustable 0 to 6 second "drop out" time for its hybrid trunked systems (16). Drop out time is an intentional delay in releasing a channel after a user de-keys, and allows a user to complete a transmission if he inadvertently de-keys for a moment. This is not modelled in the simulation and the effects on the measured results are assumed to be negligible. (Actually, the simulation models a trunked system with a drop out time set to 0 seconds. Any other drop out time would require modifying the trunked computer model.)

Equipment

A VAX/VMS computer system owned by the Air Force Institute of Technology (AFIT) was used to run the simulation models. Data was collected using a Realistic PRO-2004 programmable scanning receiver and recorded on a Realistic VSC-2000 variable speed cassette tape recorder, both owned by the researcher.

II. Literature Review

Trunking Schemes

Reeves (8:3) discusses several trunking schemes. One of these, the simplest in terms of hardware required, includes a repeater for each channel and a number of mobile (or portable) radios, assigned to specific nets. Each radio automatically scans through the channels, stopping when it finds a signal indicating a call is about to start on the channel for that radio's net. A radio making a call finds an idle channel and sends a signal indicating which net the radio belongs to and telling other radios on the net to monitor that channel.

Another technique (8:3) involves connecting a computer driven controller to the repeaters and broadcasting an idle tone on an unused channel. Each mobile radio scans the channels until it finds the tone. When a call is made, the controller has the channel's repeater send a signal indicating which net is involved. Radios not on that net then continue scanning until they find the idle tone again, which the central controller has moved to another idle channel.

A third technique discussed by Reeves, and described by Thro (11:302), uses a computer to control the repeaters, as with the system previously discussed, but uses one of the channels exclusively for signalling. When radios are idle, they monitor the signalling channel. When a call is made, the calling radio sends a digital signal to the central controller, indicating which fleet the radio is on. The central controller then sends a digital signal over the signalling channel telling each radio in the fleet to tune to an idle channel.

When the call is over, each radio re-tunes back to the signalling channel and continues monitoring. This technique gives the system fast access time and good reliability.

Air Force Requirements

As in the civilian sector, the Air Force faces an increasing number of LMR users (about 30 nets on one base, for example) (1:K-2-1) and a limited number of channels available for their use. In addition, the Air Force requires a robust system capable of withstanding harsh conditions while performing reliably. The ability to inter-net (transfer a radio from one net or fleet to another) is also highly desirable, as is the ability to deploy radios from one location to another and use them with an existing system at the new location. An Air Force Communications Command (AFCC) technical report (12:7) examined several conventional and trunked LMR systems based on these requirements and concluded a hybrid trunked system would best meet Air Force needs.

As explained in the report, the hybrid trunked system operates like the trunked system with a central controller and dedicated signalling channel as described above, with the added advantage of allowing each radio to operate in a conventional mode if the central controller is disabled.

Air Force specifications for hybrid trunked portable radio transceivers (15), hybrid trunked mobile transceivers (14), hybrid trunked control station transceivers (13), and trunked system central controller equipment (16) are currently being written.

Description of the Hybrid Trunked System

Zdunek describes an existing hybrid trunked system built by Motorola Inc. for use in the United States (17) and a similar proposed system for use in the United Kingdom (18). Both of these systems can support between 5 and 20 channels and any of the four highest in frequency can be used as the data channel. Since the radios automatically scan until they find the data channel, there is protection against system failure should the data channel's repeater fail: the controller simply picks another channel and the radios quickly find it. Each channel consists of two frequencies, one used as an inbound link from the broadcasting radio to the repeater, and the other used as the outbound link from the repeater to the radios in the fleet. These are often referred to as the "inbound channel" and "outbound channel" in the literature, even though both make up the channel.

Motorola's trunked system can operate so either the whole message is assigned a channel, or each transmission is assigned a channel, which may, or may not, be the same channel used in the last transmission. Zdunek shows better performance is realized with the transmission trunked mode (17:195).

The transmission trunked mode is easy to implement, because a transmission is indicated to the central controller through the push to talk (PTT) switch on the transmitting radio. A transmission starts when the radio's user keys the PTT switch and ends when the PTT switch is de-keyed. A desirable modification to this scheme is to allow a small amount of "drop out" time after de-keying. This gives the broadcasting radio's user a chance to complete a transmission if he inadvertently de-keys for a moment. The Air Force will require a drop out time of 0 to 6 seconds (adjustable through the central controller) (16). On a busy system channels might not always be immediately available, and this might cause a delay in the middle of a message on a transmission trunked system. This condition is very undesirable, and is taken care of with a "recent user" queue which gives fleets completing a transmission recently first priority in obtaining a newly available channel. The Air Force will require a queue allowing recent users to remain in it for between 0 and 90 seconds (adjustable through the central controller) and operating on a last-in-first-out discipline (16).

In the Motorola system, when the user keys the PTT switch on his radio, the radio sends a 78 bit digital signal to the central controller via the 3600 BPS inbound signalling channel (17:198). The radio coordinates these signals in time with received signals from the central controller, so the 78 bit signal always begins at the start of a fixed length time slot (18:14). There is a chance two or more radios may try to send signals at the same time, and, because these signals are synchronized in time with the signals coming from the outbound signalling channel (the scheme is a modification of slotted ALOHA) the usable capacity of the inbound channel is about $1/(3e) = 0.123$ of the total capacity on a fully loaded system (where e is the base of the natural logarithm) (17:197). A fully loaded system, in this case, is a 20 channel system with 3000 radios making an average of one call each an hour. On a fully loaded system, taking into account the usable capacity/total capacity ratio, a total capacity of 34 slots/second is required for the inbound channel (17:197).

When the central controller receives a request for a voice channel, it checks and, if a channel is available, a digital signal is sent over the outbound signalling channel telling all of the radios on the requesting radio's fleet (including the requesting radio itself) to re-tune to the available channel. In the Motorola system, a 3600 BPS handshaking signal is sent over the outbound voice channel until the requesting radio re-tunes, recognizes the signal, and responds over the inbound voice channel with an 1800 Hz tone. Both the radio and the controller continue to send sub-audible signals over the voice channel for the duration of the transmission (digital data from the central controller and a constant tone from the radio) (18:14-15). On the proposed United Kingdom trunked system, access time, the time between the channel request and achieving the voice channel, is estimated to take about 460 msec when a channel is available (18:13). For the Air Force system, a 350 msec access time will be required (16).

When the user finishes a transmission, he de-keys the PTT switch, and, after the appropriate drop out interval, his radio re-tunes to the signalling channel. The other radios on the fleet detect the transmission is over and also re-tune to the signalling channel. The central controller detects the transmission is over and assigns the channel to another user as necessary.

Load Analyses

The obvious drawback to trunked systems is that a channel may not always be available when needed. If nineteen users, from nineteen different fleets, are using a twenty channel system (nineteen voice channels and one signalling channel) at a given time, other users will have to wait to obtain a channel. (When they attempt to make a call, they are said to be "blocked".) It is important for trunked system designers to be able to predict, for a specific system with a certain number of channels, what the probability of this occurring will be. Also of interest is the average wait time for a blocked user, and the wait time cumulative distribution function (CDF).

Another issue is whether users tend to talk longer on trunked systems than on conventional shared repeater systems (systems in which two or more distinct user groups share a common frequency). The concern is, where users on a conventional system can hear each other and may have a natural channel discipline (short, concise, transmissions), trunked users, not being able to hear other fleets, may tend to transmit longer (11:305).

Many analyses have been done on these issues, using at least three different approaches: evaluation of systems already in operation, mathematical modelling, and computer simulation.

Davis and Mitchell (2:345) point out that in LMR systems the traffic statistically has large inherent fluctuations. They show the measurement of mean traffic loads on existing systems can be inaccurate and an unreliable predictor.

Two General Electric systems in Chicago, one trunked and one conventional, with shared repeaters, and both supporting commercial users, were analyzed using automatic recording equipment (8:4). No significant differences in transmission length were found. However, in a study presented a year later, Motorola analyzed two trunked systems their own and another company's, and one of their own conventional systems, all located in Chicago (4:269). They found significant differences in transmission lengths between the trunked and conventional systems. The trunked systems' transmission lengths were approximately 50% longer. Motorola used human monitoring off the air. They noted the human monitoring provided more conclusive results than earlier studies they conducted with automatic recording equipment.

Many mathematical models based on queueing theory have been developed to analyze trunked systems. Using the Erlang C model the probability of blocking can be found (8:2), as can the average waiting time for a blocked transmission (4:271). Formulas for peak load and variation in load have been found based on an observation that in trunked systems used by businesses, peak hours are not correlated (5:331).

The third approach to analyzing load on trunking systems, computer simulation, is sometimes advantageous. Most mathematical models deal with a situation where fleets all have identical call inter-arrival and call length distributions. Haslett and Bonney (3:28) point out that for public service systems (systems whose users include police departments, fire departments, etc.) this is not usually the case. Since the number of fleets on a public service system usually isn't much more than the total number of channels on the system, mathematical models assuming an infinite number of fleets are, in this case, invalid. Haslett and Bonney could find no mathematical model to handle both a finite number of fleets and unequal loading by the fleets for a system in which blocked calls are queued rather than lost, so computer simulation was used.

Motorola used computer simulation as an aid in developing their trunked systems (11:305). Based on observations of conventional systems, they characterized message traffic to have a Poisson arrival time with a mean of 1.9 messages per mobile per hour, an exponentially distributed transmission length with a mean of 2.5 seconds, an exponentially distributed pause between transmissions with a mean of 2 seconds, and a truncated normal distribution of transmissions per call with a mean of 4.

Philips Research Laboratories, UK, built computer simulation models comparing several types of trunked systems using a Pascal based simulation package (10:122). They included the time it takes the controller to provide a channel once it is available, and modelled this as an exponentially distributed random variable with a given mean (T2) and distorted to have a given minimum (T1). They modelled a message trunked system with call length exponentially distributed with a mean of 20 seconds and distorted to have a minimum of 1 second. They had new calls generated with a Poisson distribution with a mean corresponding to the traffic level (one of their independent variables). They compared the results of this model with data collected from a real system and found the model to be accurate for systems of 15 channels and less. They present results as curves of number of channels vs. traffic/channel given various values for T1 and T2, and as curves of time vs. probability of delay for given values of T1, T2, and number of channels available on the system.

III. Conventional Model

Introduction

There are two reasons a user may have to wait to make a call on a conventional LMR system. First, other users on the caller's net may already be involved in a conversation. Second, other users on another net sharing the caller's channel may be involved in a conversation. In practice, the distinction between the two can become fuzzy on some Air Force nets, because groups of users sharing the same channel may sometimes talk between each other as if they were one large net, and other times act as two or more independent nets. The computer model measures a single wait time for each call, regardless of the reason for the wait, based on the total traffic on the channel. In the case where most of the calls on the channel being modelled are to or from a single base station, statistics on the average number of users making a call or wishing to make a call at a time can be collected.

The model was designed to simulate up to thirty channels. During the design of the model, all of the users sharing a channel were considered to belong to one net, and the model is described in this way throughout the chapter. The next section provides a physical description of the model itself and the section following relates it to the real world. The final section of the chapter describes a mathematical verification that indicates the model does indeed appear to work as expected.

Description of the Computer Model

Both the computer model of the conventional LMR system and the computer model of the trunked system were built using the SLAM II programming language. SLAM II is a language developed for simulation and, for descriptive purposes, uses its own unique set of flow charting symbols (7:inside front cover). These symbols are used in Figure 1.

Figure 1 is a diagram of the conventional LMR model. The diagram shows the modelling for a single net and, with the exception of the node labeled MC, the SLAM code is replicated 30 times in the complete model. The nets are numbered 1 through 30 in the complete model, and these numbers are represented by I in Figure 1.

Entities are created at a rate that is random with an exponential distribution, and the time of an entity's creation is assigned to its ATRIB(4). The net number is assigned to the entity's ATRIB(1) and, if a unit of resource NETI is available, the entity proceeds to an AWAIT node. (If not, it is terminated.) The entity seizes one unit of resource NETI in the AWAIT node, and then values are assigned to ATRIB(3), based on a normal distribution (with a mean of MTPMI and standard deviation of SDTMI), and ATRIB(2), which is set equal to ATRIB(3) and is used later in the model as a counter. The entity then moves to a second AWAIT node, where the one unit of resource CHANI is assigned when available. The entity may have to wait in this node for a certain length of time, and that time is collected, along with the wait times of the other entities in that net, and is presented in the SLAM output under the label WAIT TIME NET I. The entity then proceeds to the node labeled MC, the only node common to all of the nets in the

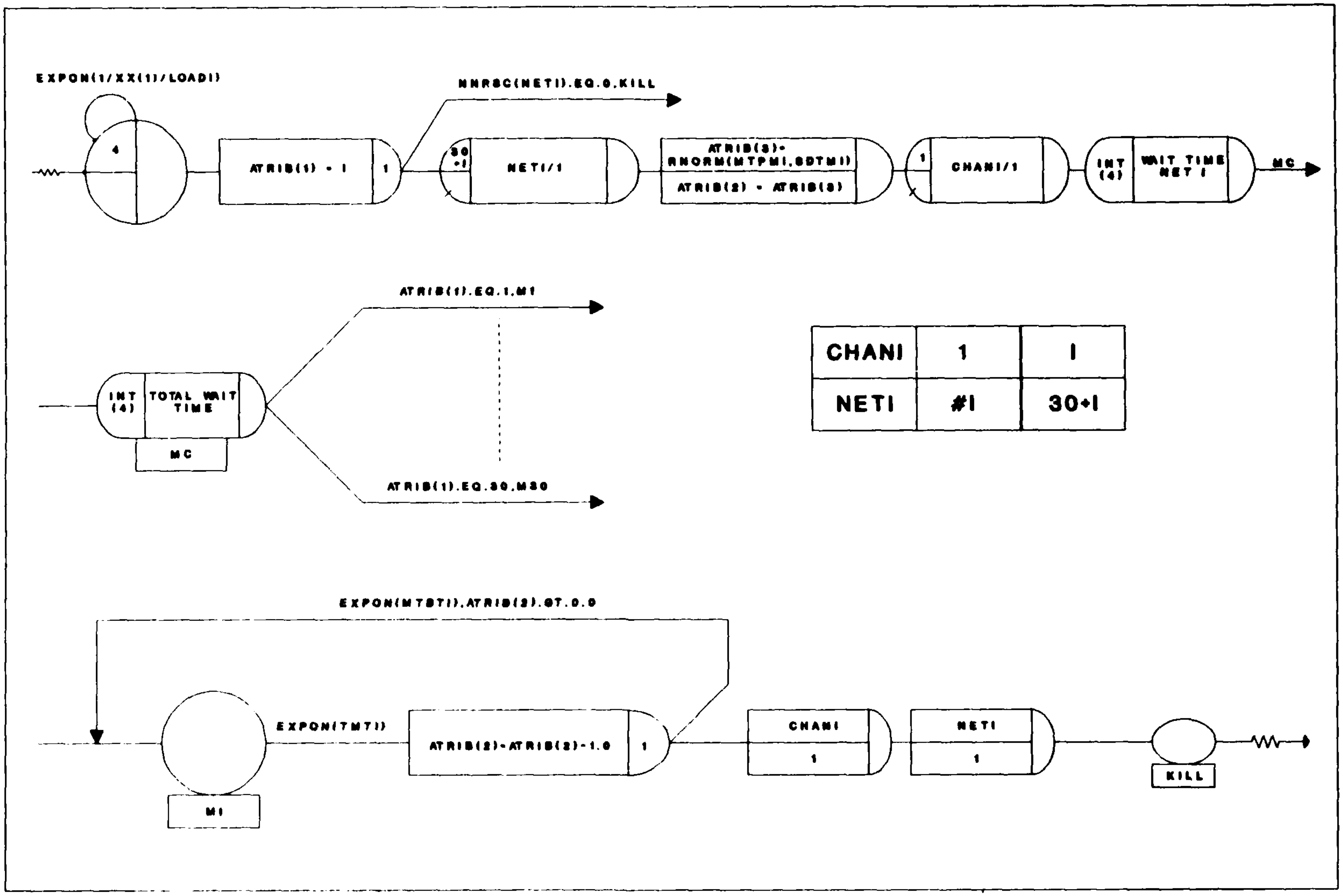

Figure 1. Conventional Land Mobile Radio Model

model. In this node the wait times for all of the entities of the model are collected for presentation in the SLAM output under the label TOTAL WAIT TIME. The entity then proceeds to the node labeled MI and, from there, is delayed by a random amount of time distributed exponentially with a mean of TMTI. ATRIB(2) is then decremented by 1.0 and, if ATRIB(2) is greater than 0.0, the entity is sent back to the node labeled MI with a random, exponentially distributed, delay with a mean of MTBTI. If ATRIB(2) is less than 0.0 after being decremented, the entity flows through two nodes, freeing the units of resources CHANI and NETI held by the entity. The entity is then terminated.

The shell program for this model is presented in Appendix A. Before running the model, numerical values are substituted for the variables in boldface (using a word processor's "replace" feature).

Discussion of the Model

In this model, an entity represents a call on the LMR system. A call is considered to be generated when an LMR user decides he wants to communicate, regardless of whether he can begin right away or must wait for the channel to become free. Calls are generated randomly in time with an exponential distribution and a mean rate equal to

$$\lambda = XX(1)*LOADI \qquad (1)$$

where

λ = the mean call rate (messages/sec)

LOADI = the load on net I (messages/sec)

XX(1) = load constant

(For all equations in this document, "*", when used, represents multiplication.) The mean call rate is calculated independent of the number of radios available for communications (ie: radios of users not already making a call or waiting to make a call) on a net. This is easy to apply to a real LMR system because LOADI can be determined from off-the-air monitoring without knowing how many radios are on the system, or what each radio's individual call rate actually is. (A more sophisticated model could scale the mean call rate by the number of radios available to make a call, but, because of the uncertainty of estimating individual radios' call rates, it is doubtful a significant improvement in results would be obtained.) XX(1), in Eq (1), is unitless and can be used between runs to change the load on all of the nets without changing the 30 LOADI variables.

Each unit of resource NETI represents a radio on net I. Since each entity seizes one unit, statistics collected on this resource indicate, on average, how many users on a net are making a call, or wish to make a call, at a given time (assuming calls on the net are only made to or from a base station). Entities created when there are no units of NETI available are destroyed. (This is most likely on nets with few radios, under heavy load conditions.) To avoid this, the number of radios on a net can be set artificially high. (The statistics collected on NETI would then be invalid, of course).

The number of transmissions in a message is assigned randomly with a normal distribution. The number assigned is not an integer, but the counter is decremented by 1.0 and tested as to whether it is greater than 0.0. The effect of this is to take negative infinity to 1.0 to be one transmission/message, 1.0^+ to 2.0 to be two transmissions/message, etc. The normal distribution was picked because that is what was used in a Motorola model (8:305). This distribution was checked with off the air monitoring (see Chapter IV).

CHANI is a resource and is used to represent the channel. Only one unit per net exists (because only one call can take place on the channel at a time) and the amount of time a caller has to wait for this resource is the primary parameter of interest. The model collects data on this wait time for each net and for the entire system. The model assumes a caller will wait for a message to be completed before initiating a new message on the net.

Both transmission length and time between transmissions within a message are taken randomly, with an exponential distribution, in the model.

Mathematical Verification of the Model

A simulation model can be tested by adjusting parameters to make the system one for which a mathematical solution is known, and then comparing the simulation results against the mathematical results.

The conventional LMR SLAM model was tested by comparing wait times for a channel with the wait times in the queue of an $M/E_n/1$ mathematical model. This model has a random, exponentially distributed, inter-arrival rate, a single server, and a series of n service stages each of which takes a random, exponentially distributed, amount of time to complete. An entity can not begin to be served until the preceding entity is completely served.

For verification of the SLAM model, both the mean transmission time and the mean time between transmissions for all nets are taken as 2.0 seconds and the mean number of transmissions/message is taken as 4 with a standard deviation taken as 0.0 (making all messages have exactly 4 transmissions). In effect, this creates a seven stage server with a mean service rate of

$$\mu = 1/(2.0*n) = 1/14 \text{ (messages/sec)} \quad (2)$$

(6:123). *LOADI* is set as 0.0014 messages/second for all nets and XX(1) is changed for each run, so the inter-arrival rate is

$$\lambda = 0.0014*XX(1) \text{ (messages/second)} \quad (3)$$

from Eq (1). (Infinite radios per net are assumed.) The mean wait time, in seconds, in the queue of an $M/E_n/1$ system can be calculated as

$$W = \frac{n+1}{2n} * \frac{\lambda}{\mu(\mu - \lambda)} \quad (4)$$

(9:120), and the utilization factor can be calculated as

$$\rho = \lambda/\mu \quad (5)$$

(6:18). The SLAM model was run with various values of XX(1) and the total wait times were recorded. Only one run per value of XX(1) was considered necessary because the total wait time is actually an average of the wait times for the 30 independently operating nets. (The code shown in Appendix A is written to make 3 independent runs for each input. For these tests, the code was altered appropriately.) The measured results were compared with the mathematically predicted results and close agreement was found. These results are presented in Table I and Figure 2.

TABLE I

Predicted and Measured Wait Times (Conventional Model)

XX(1)	ρ	PREDICTED (SECONDS)	MEASURED (SECONDS)
2	0.039	0.326	0.325
4	0.078	0.681	0.7526
6	0.118	1.066	0.9389
8	0.157	1.488	1.607
10	0.196	1.950	1.806
12	0.235	2.460	2.382
14	0.274	3.025	2.851
16	0.314	3.655	3.861
18	0.353	4.361	4.609
20	0.392	5.158	5.255
22	0.431	6.065	6.477
24	0.470	7.106	7.082
26	0.510	8.313	8.632
28	0.549	9.730	9.269
30	0.588	11.417	11.60
32	0.627	13.459	12.42
34	0.666	15.981	15.17
36	0.706	19.174	19.58
38	0.745	23.348	22.16
40	0.784	29.037	29.47
42	0.823	37.249	34.32
44	0.862	50.140	51.29

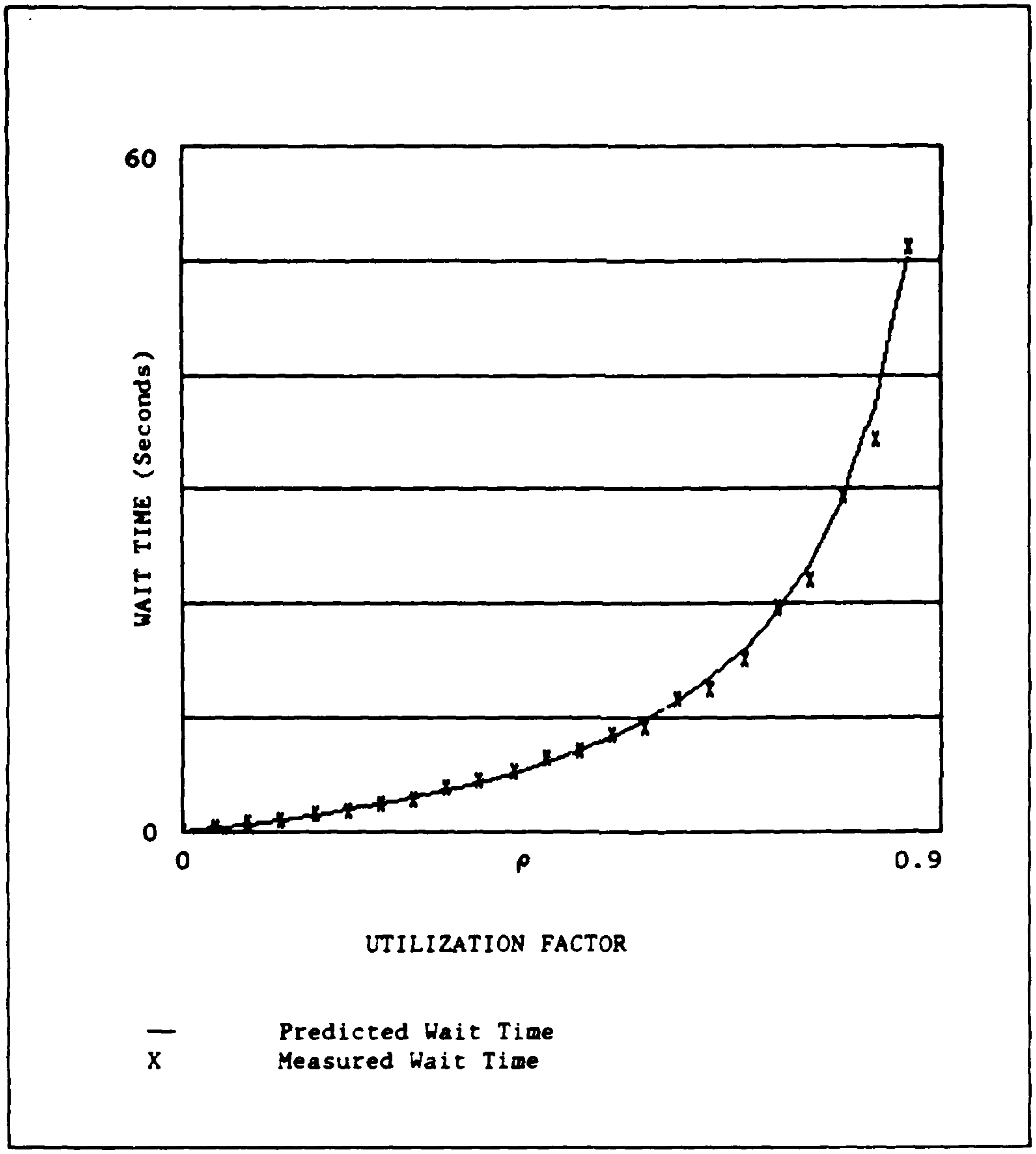

Figure 2. Predicted and Measured Wait Time (Conventional Model)

IV. Trunked Model

Introduction

There are two reasons a user may have to wait to begin his call on a trunked system. First, as in the conventional system, others on the user's fleet may already be making a call. Second, all of the channels on the trunked system may be in use handling traffic from users on other fleets. Another source of delay on the conventional system, the wait time a user of one net must endure while a user on another net sharing the same channel is making a call, has no equivalent on the trunked system simply because unrelated users would generally be assigned to separate fleets. The computer trunked system model measures both the wait time for the fleet to become free and the wait time for a channel.

The next section in this chapter gives a physical description of the trunked system model and the section after that relates the model to the real world system. The final section of the chapter describes a mathematical verification of the model which indicates the model does indeed appear to operate as expected.

Description of the Computer Model

Figure 3 shows the flow of entities for each fleet. The trunked system model was designed to handle up to 30 fleets, so the SLAM code for Figure 3 is replicated 30 times in the program. The parameter I in the figure is replaced by the fleet number in the program. Entities are created at a random rate, with an exponential distribution, and

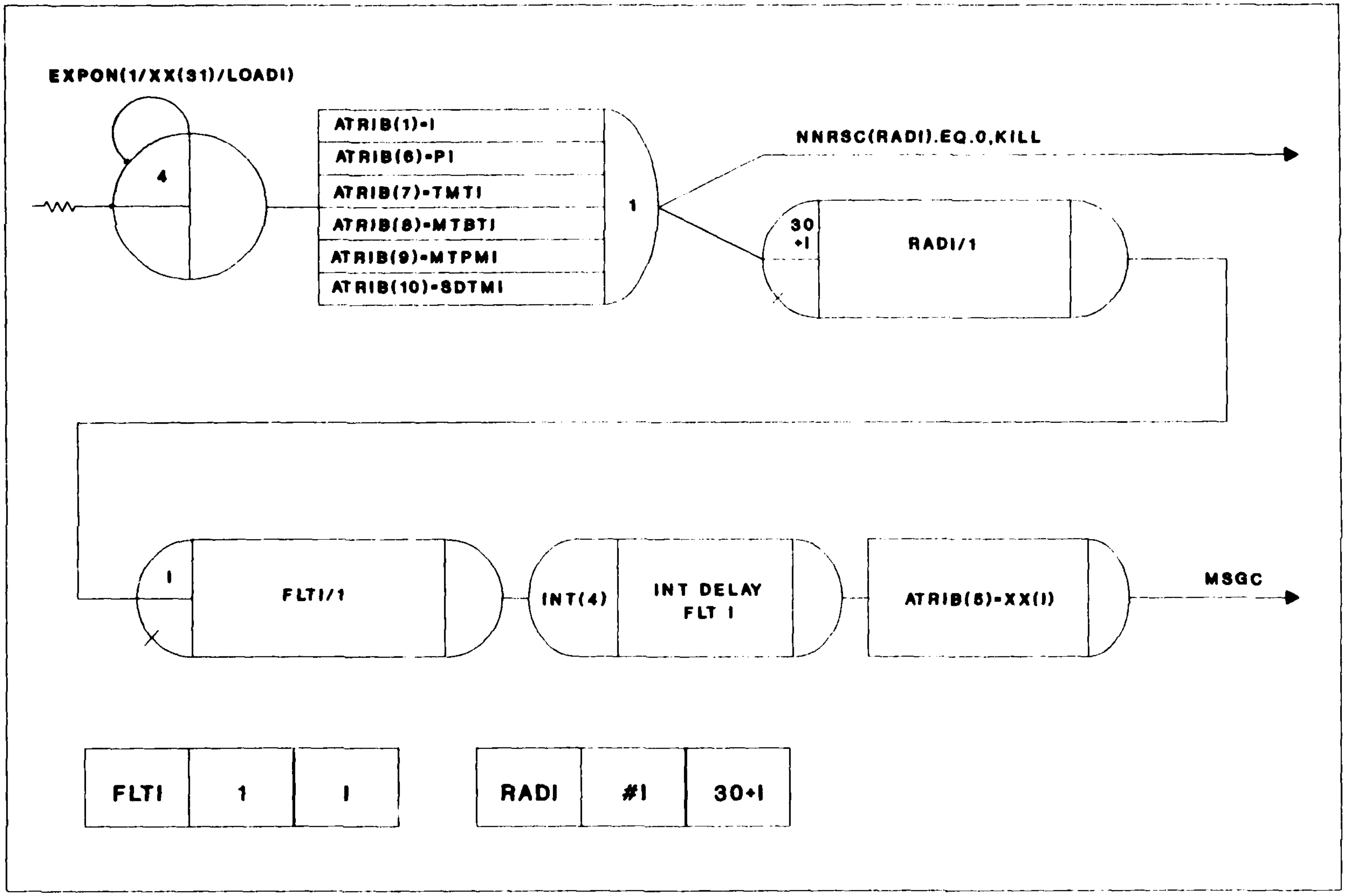

Figure 3. Trunked System Model (Part 1)

each entity is assigned the time of its creation to its ATRIB(4). An entity then has its fleet number assigned to ATRIB(1), the fleet's priority to ATRIB(6), the fleet's transmission mean time (TMTI) to ATRIB(7), the fleet's mean time between transmissions (MTBTI) to ATRIB(8), the fleet's mean transmissions per message (MTPMI) to ATRIB(9), and the fleet's standard deviation of transmissions per message (SDTMI) to ATRIB(10). The entity is then terminated if no resources of RADI are available, or passed to an AWAIT node if at least one unit of the resource is available. The entity seizes one unit of resource RADI in the first AWAIT node and moves on to a second AWAIT node, where it waits until the one unit of resource FLTI becomes available and seizes it. The entity passes through a COLCT node, where the time it spent waiting for FLTI is recorded, and then flows into an assign node, where the value of XX(I) is assigned to ATRIB(5). The entity then passes to the node labeled MSGC, shown on Figure 4.

Figure 4 shows the flow of entities after fleet specific actions have been performed. Entities from all 30 fleets flow into the node labeled MSGC, where each entity's ATRIB(3) is assigned a random number, based on a normal distribution with a mean of the entity's ATRIB(9) and standard deviation of the entity's ATRIB(10). ATRIB(2), which is used later as a counter, is assigned to equal ATRIB(3). The entity then flows to the node labeled TRAN and from there flows to either B1 or B2, depending on whether the current time in the model is greater than the time in the entity's ATRIB(5) plus RU. In either case, the entity then has the current time assigned to its ATRIB(5), and flows into an AWAIT node to wait for a unit of resource CHAN to become available. When a

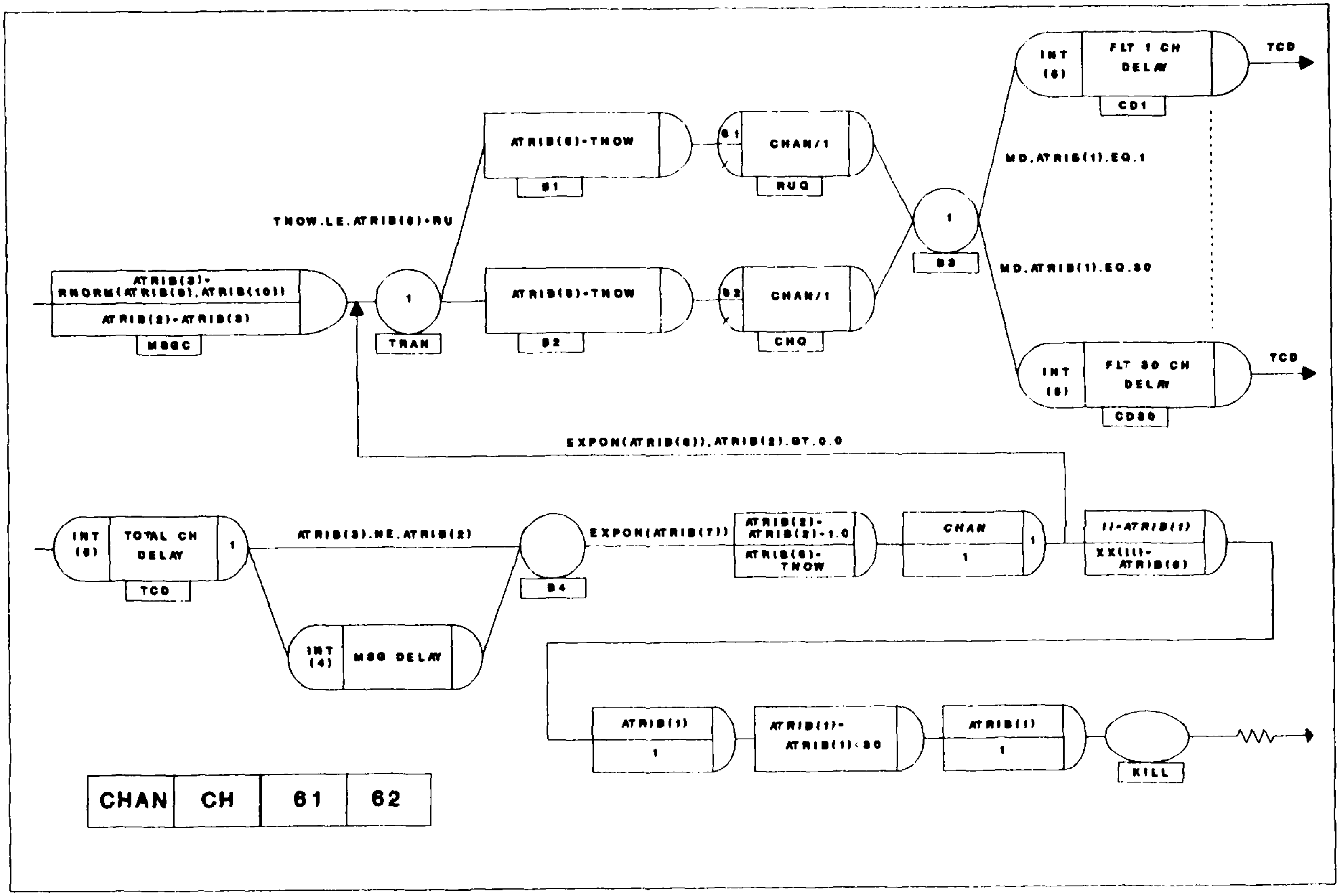

Figure 4. Trunked System Model (Part 2)

unit of the resource does become available, the entity flows through the node labeled B3 and then to a COLCT node specifically for the entity's fleet. On its way to the COLCT node, the entity is delayed by the amount of time MD. In the COLCT node, the amount of time the entity was delayed in the previous AWAIT node plus MD is collected and the entity flows to the node labeled TCD. TCD is another COLCT node which also collects the amount of time the entity was delayed in the previous AWAIT node plus MD. (The difference between the first and second COLCT nodes is, of course, the first collects data for a specific fleet while the second collects it for the entire system.) The entity then has its ATRIB(2) and ATRIB(3) compared and, if they are equal, the total delay of the entity to that point is collected. The entity then flows through B4 and is delayed by a random amount of time with an exponential distribution and a mean equal to the entity's ATRIB(7). The entity is then passed to an ASSIGN node, where ATRIB(2) is decremented by one and ATRIB(5) is assigned the current time. The entity then passes through a FREE node where the unit of resource CHAN is released, and, if ATRIB(2) is greater than 0.0, the entity flows back to the node labeled TRAN with a random delay which is distributed exponentially with a mean equal to the entity's ATRIB(8). If ATRIB(2) is less than or equal to 0.0, the entity flows to an ASSIGN node, where the global variable used to indicate the time the last transmission on the entity's fleet ended is set equal to ATRIB(5). The entity then flows through a FREE node, where the unit of the resource FLTI is released, through an ASSIGN node, where ATRIB(1) is set equal to itself plus 30 (its original value no longer being needed), and through another FREE node, where the unit of resource RADI [whose associated file number is now equal to ATRIB(1)] is released. The entity is then terminated.

The shell program for this model is presented in Appendix B. As with the shell for the conventional model, numerical values are substituted for the variables in boldface before running.

Discussion of the Model

Many parts of the conventional model have counterparts in the trunked system model, and usually the discussion of these (in Chapter III) also applies here. For example, in the trunked system model, calls are represented by entities, as in the conventional model, and, just as in the conventional model, a call is considered to be generated when a user first wishes to communicate. The call generation rate is distributed exponentially with a mean of

$$\lambda = XX(31)*LOADI \tag{6}$$

where

λ = the mean call rate (messages/sec)

LOADI = the load on fleet I (messages/sec)

XX(31) = load constant

The global variable XX(31) here plays a role analogous to XX(1) in the conventional model. It is used to change the load on all of the fleets without changing the 30 LOADI variables. The call generation rate is calculated independent of the number of radios on the fleet.

The resource RADI in the trunked system model plays a role similar to NETI in the conventional model by representing the radios on fleet I. As in the conventional model, an entity is destroyed if a unit of the resource is not available.

The transmission length and time between transmissions are calculated based on exponential distributions and the number of transmissions per message is calculated based on a normal distribution in the trunked system model, just as they are in the conventional model. On both models, it is assumed a caller will wait for a message in progress to conclude before beginning a new message.

Some parts of a trunked system have no counterpart in a conventional model. Entities waiting for a channel in the trunked system model are assigned to one of two queues, depending on how recently the last transmission on the entity's fleet took place. If the last transmission took place less than RU seconds ago, the entity is assigned to the recent user queue (labeled RUQ in the model). RU is adjustable in the model, as it is in the real world system (16). The recent user queue is served on a last-in-first-out (LIFO) basis. If the last transmission took place more than RU seconds ago, the entity is assigned to the channel queue (labeled CHQ in the model). This queue is served on a priority basis, with priority assigned to each entity based on its fleet. Entities with the same priority are served on a first-in-first-out (FIFO) basis. Entities in the recent user queue always have priority for a channel over entities in the channel queue. The ability of emergency calls to preempt other calls on the real world system is not modelled in the simulation since the use of this priority should be rare enough that it will not significantly influence statistical results.

Two types of wait times are recorded in the trunked system model. The first is the wait to begin a message, due to other people talking on the caller's fleet before he even keys the PTT switch, and is recorded by fleet under the statistic INT DELAY FLT I. After other users on the caller's fleet are finished, and after he keys the PTT switch, he must still wait for a free voice channel before beginning each transmission. This wait time is recorded by fleet under the statistic FLT I CH DELAY, and for the system as a whole under the statistic TOTAL CH DELAY. The total wait time to begin the first transmission of a message is collected for the system as a whole under the statistic MSG DELAY and can be used for comparison with the conventional model's TOTAL WAIT TIME statistic.

There are CH units of the resource CHAN in the trunked system model. Each unit represents a voice channel and, of course, the value of CH is set to equal the number of voice channels being modelled.

The delay in assigning channels in the real word system due to mechanical delays and contention on the digital channel is modelled with the constant: MD. A constant, rather than a random distribution, was picked for this because the mechanical delays are much greater than the contention delay (18:13), and mechanical delays are not expected to vary by much from one transmission to the next.

Drop out time, the time the system keeps a channel with a fleet after a caller releases the PTT switch, is not modelled in the trunked system model.

Another aspect of the trunked system not modelled is the Air Force requirement to automatically release a channel if a PTT switch is depressed for more than one minute (16). This is used to counter the possibility of a stuck switch in the real world system, a situation not simulated in the model. The number of cases in which a transmission in the model exceeds one minute is expected to be rare enough not to affect results significantly, so the added complexity was not considered to be worthwhile.

Mathematical Verification of the Model

The trunked system model is more difficult to verify mathematically than the conventional model because entities in the trunked system model have to queue for a channel before each transmission. Figure 5

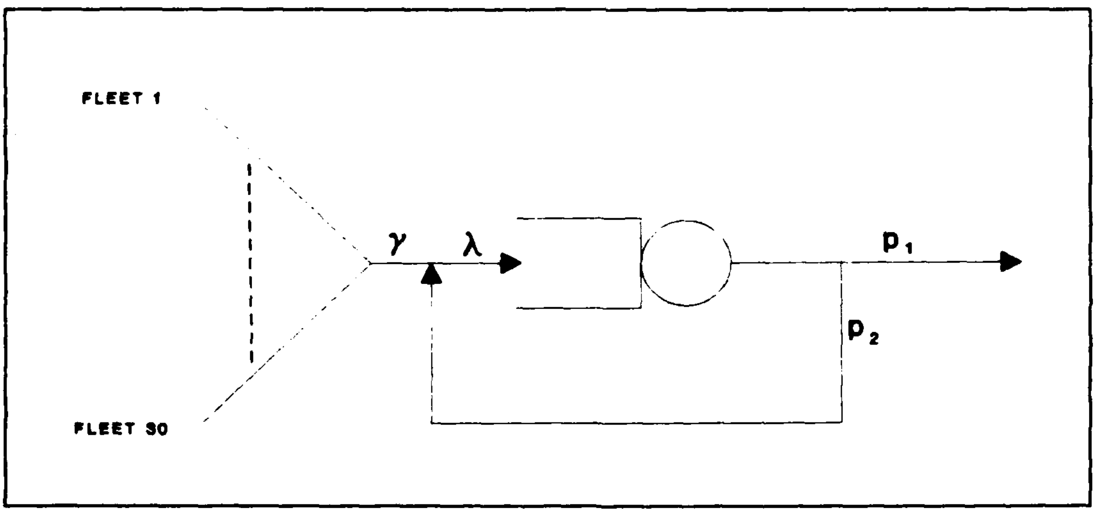

Figure 5. Flow of Entities in The Modified Trunked System Model

shows the path entities take in the trunked system model after fleet specific activities have been performed. To simplify analysis, only one unit of the channel resource and a 0.0 second wait time between transmissions within a message are used in the verification (and shown in the figure). γ, in Figure 5, is the sum of mean inter-arrival rates from the fleets, λ is the mean inter-arrival rate of entities entering the queue for the channel (note this is not the same λ used in Eq (6)), μ is the mean channel service rate (which is the inverse of the mean transmission time), p_1 is the probability the transmission in progress is the last of the message, and p_2 is the probability it is not.

This system can be analyzed mathematically if the inter-arrival rates of entities are distributed exponentially for each fleet, and the channel service rate is exponential (6:149). The second condition occurs naturally in the trunked system model, and the first can be made to occur if enough units of resource RADI are available so entities are never terminated prematurely and if the program is modified by removing the AWAIT nodes in which entities wait for resource FLTI.

Of course, the trunked system model no longer simulates a real world system with this modification. The objective here is to verify the program works as desired. If the modified program produces results similar to those predicted mathematically, the unmodified program can be assumed to produce meaningful results.

For the verification tests, LOADI was set to equal 0.0014, transmission mean time (TMTI) was set equal to 2.0 seconds, the mean time between transmissions (MTBTI) was set equal to 0.0, the mean number of transmissions per message (MTPMI) was set equal to 4, and the standard deviation of transmissions per message (SDTMI) was set equal to 0.0, for every fleet. Given the value for LOADI, the value of γ, in Figure 5, can be calculated. It is 30 times the results of Eq (6), or

$$\gamma = 30*XX(31)*LOADI = 30*0.0014*XX(31)$$
$$= 0.042*XX(31) \text{ (Entities/sec)} \quad (7)$$

where XX(31) is changed for different runs of the model, to change the utilization factor. The numbers listed for MTPMI and SDTMI above cause every message to consist of four transmissions, so

$$p_1 = 1/4 \quad (8)$$
$$p_2 = 1 - p_1 = 3/4 \quad (9)$$

and the mean channel service rate is just the inverse of the transmission mean time, or

$$\mu = 1/TMTI = 1/2.0 = 0.5 \text{ (Entities/sec)} \quad (10)$$

The value for λ, in Figure 5, can then be calculated using the equation

$$\lambda = \gamma + \lambda * p_2 \text{ (Entities/sec)} \quad (11)$$

(6:149). From this, the utilization factor for the queue can be calculated as

$$\rho = \lambda/\mu \quad (12)$$

(6:18) and the average length of the queue can be calculated as

$$L = \rho^2/(1 - \rho) \text{ (Entities)} \tag{13}$$

(9:64). To determine this value in the computer model, a modification was made routing all of the entities to the recent user queue (instead of letting some enter the recent user queue and the rest enter the channel queue), and the average length of the queue was recorded from each run's output file.

Three simulation runs were made for each value of the utilization factor tested. (The random number streams in the SLAM code were not reset between the three runs for the results reported in this chapter.) Results of the three runs, and the mathematical predictions, are compared in Table II and Figure 6. (The dispersion of results for

TABLE II

Predicted and Measured Channel Queue Length
(Modified Trunked System Model)

XX(31)	ρ	PREDICTED	RUN 1	RUN 2	RUN 3
0.2	0.067	0.005	0.0017	0.0037	0.0079
0.4	0.134	0.021	0.0221	0.0137	0.0137
0.6	0.202	0.051	0.0602	0.0340	0.0447
0.8	0.269	0.099	0.0640	0.0897	0.0852
1.0	0.336	0.170	0.1533	0.1526	0.1765
1.2	0.403	0.272	0.1793	0.2505	0.2426
1.4	0.470	0.418	0.4672	0.3802	0.3519
1.6	0.538	0.625	0.5853	0.4319	0.5664
1.8	0.605	0.926	0.9013	0.6658	0.9770
2.0	0.672	1.377	1.4356	2.1332	1.2827
2.2	0.739	2.095	2.0159	3.1307	2.0149
2.4	0.806	3.359	1.9223	4.7260	3.6926

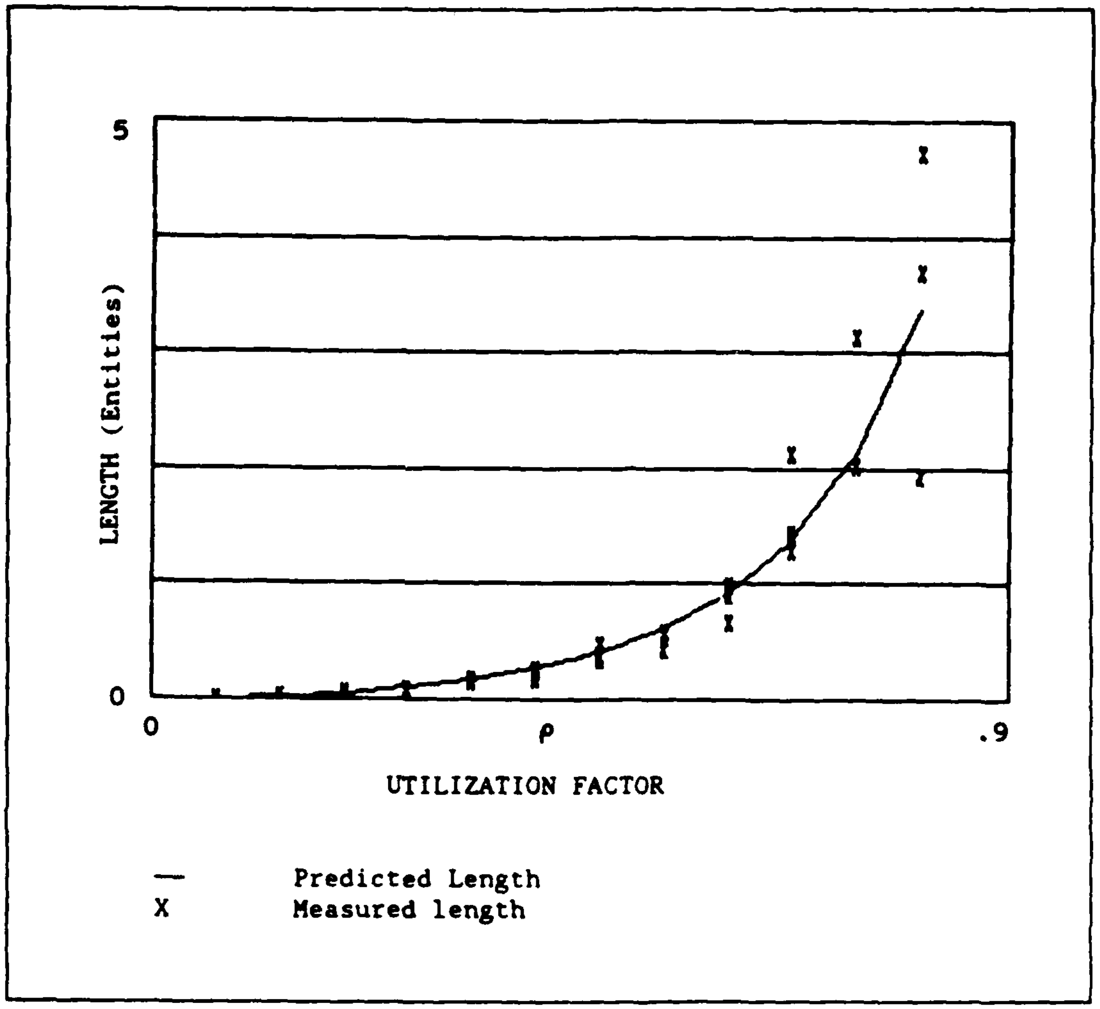

Figure 6. Predicted and Measured Channel Queue Length (Modified Trunked System Model)

higher utilization factors is due to an increase in variance, and is a common occurrence in queueing models.) The close agreement of these results indicates the model works as expected.

As a further verification, simulation runs were made for different values of MTPMI. This changes the values of p_1 and p_2 in Eqs (8) and (9), and tests the assumptions about the model upon which Eq (11) is based. During these runs, XX(31) was made equal to 1.0 and the other variables were left unchanged from the earlier test. Results of the simulation runs are compared with the mathematically predicted results in Table III and Figure 7. The close agreement of these results is a

TABLE III

Predicted and Measured Channel Queue Length as the Number of Transmissions Per Message is Varied (Modified Trunked System Model)

MTPMI	P_1	PREDICTED	RUN 1	RUN 2	RUN 3
1	1.000	0.0077	0.0076	0.0059	0.0062
4	0.250	0.17	0.1533	0.1526	0.1765
8	0.125	1.377	0.9965	1.4624	1.4608

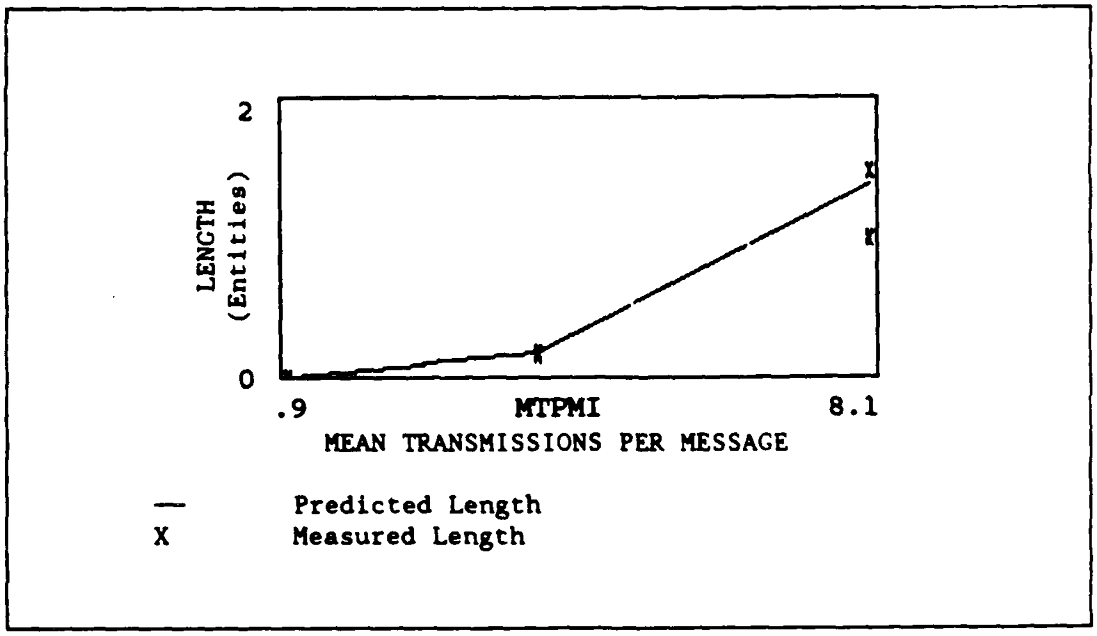

Figure 7. Predicted and Measured Channel Queue Length as the Number of Transmissions Per Message is Varied (Modified Trunked System Model)

further indication of the probable accuracy of the simulation model.

V. Analysis of Data Collected Via Monitoring

Objectives

LMR channels in use at WPAFB were monitored, and traffic data was collected and analyzed to obtain input values for the computer model. Parameters evaluated for each channel were: mean transmission length, mean time between transmissions, the number of transmissions per message, and the number of messages per hour during each channel's busy hour.

Another parameter checked was whether the channel contained any traffic at all. Some channels were either unused during normal conditions, or were so lightly loaded that no messages were detected.

It should be emphasized the goal of this phase of the research was simply to obtain estimates accurate enough to model the base's normal LMR traffic. Although the amount of time spent monitoring each channel was short (due to research time constraints), the sensitivity of the computer models to input variance was checked (see Chapter VI) and found to be reasonably small.

Procedure Used to Collect Data

Channels were monitored using a Realistic PRO-2000 receiver located about half a mile from the base. Although in some instances only a single party of a message could be heard (generally the base station), transmissions from mobiles located at the far end of the base (about 5 miles from the receiver) were often heard clearly. The limited range of portable and mobile radios dictates that, unless an LMR net operates over a very limited area or uses a repeater, calls on the net must go through the base station. Since base stations could be heard on all of the channels monitored in which traffic was detected, the number of undetected messages must have been small.

A listing of LMR users and channel frequencies was obtained from the WPAFB Base Reception Plan (1:K-2-1 to K-2-3). According to this document, three of the nets used repeaters. (Traffic was detected on only one of these.) Although the plan lists frequencies for these channels, the repeater's transmission and reception frequencies are not clearly identified. Therefore to monitor each channel, the receiver was set up to scan through all of the channel's frequencies. Other nets, using single frequency channels, were monitored by keeping the receiver locked on the channel's frequency.

Channels were monitored for approximately an hour at a time and recorded on a cassette tape recorder specially designed to play back at variable speeds. In order to properly measure lengths of time while the tape recorder was in the variable speed mode, a one minute calibration signal was recorded at the beginning of each tape.

Monitoring: Phase I

Monitoring was divided into two phases. The purpose of the first phase was to learn enough about each channel to carry out the second phase. Specific objectives of Phase I were to:

1. Determine which channels carry enough traffic, during normal operations, to consider in the computer models.

2. Determine, roughly, the time of day each channel carries the most traffic.

3. Determine how much traffic each channel carries during its busy time, and, from this, decide how long each channel should be monitored during Phase II.

Monitoring was done from 1200 to 2400 hours during weekdays (Monday through Thursday). Traffic on each channel was recorded for two or three time periods during the day. A mechanical tape counter was set to 000 at the beginning of each tape and the number of messages to 700 on the tape counter (3107.5 seconds) were noted. (700 was picked merely for convenience. It was necessary to measure for a time period consistent between channels, and, due to the length of the cassette tapes, a period slightly less than one hour was desired.) Results are shown in Table IV.

Of the 19 channels monitored, no traffic at all was detected on 10. 5 channels were found to have traffic heavy enough that, during Phase II, only three days of monitoring would be necessary to obtain sufficient data. The remaining 4 channels were found to carry light traffic and would be monitored for six or seven days during Phase II.

The nature of the users of the LMR channels on WPAFB leads to an assumption that traffic intensity is probably fairly constant throughout the day, and equal or heavier (depending on the specific user) during daytime than at night. This tends to be confirmed by the data collected during Phase I. Therefore, during Phase II, channels were monitored from 1100 to 1900 hours.

Monitoring: Phase II

During the second phase of monitoring, data on each channel was collected and analyzed for use in the computer models. Each channel

TABLE IV

Number of Messages Noted During Various Times of the Day (Measured During Weekdays For 3107.5 Seconds of the Hour)

CHANNEL	TIME OF DAY											
	1200 1300	1300 1400	1400 1500	1500 1600	1600 1700	1700 1800	1800 1900	1900 2000	2000 2100	2100 2200	2200 2300	2300 0000
EXPLOSIVE ORDINANCE DISPOSAL				0					0			
EXPLOSIVE ORDINANCE DISPOSAL				0					0			
OFFICE OF SPECIAL INVESTIGATIONS			0					0				
HQ AFLC/CC CH 1		0					0				0	
HQ AFLC/CC CH 2				0					0			
MEDICAL CENTER		0					0				0	
MOBILITY		0					0				3	
AIR TERMINAL		0					0				4	
CIVIL ENGINEERS CH 1			25					11				
CIVIL ENGINEERS CH 2			23					1				
SPECIALIST DISPATCH/POL/BASE OPS	49					47						8
SUPPLY			3					0				
MAINTENANCE EXPEDITE	0					0						0
FIRE/CRASH	3					35						0
SECURITY POLICE CH 1	32					26						19
SECURITY POLICE CH 2				0					0			
DISASTER PREP/2750 ABW	0					0						0
TAXI		29					3				2	
MUSEUM			0					0				

was monitored for about one hour a day at the same time each day. The Security Police, Motorpool, Special Dispatch/POL/Base Operations, and both of the Civil Engineering channels were monitored for three days each, the Mobility channel was monitored for six days, and the Fire/Crash, Air Terminal, and Base Supply & Distribution C channels were monitored for seven days each. As during Phase I, channels were only monitored during weekdays (Monday through Thursday). During this phase, so little traffic was detected on the Mobility and Air Terminal channels they were not included in the computer models for analysis of normal operations.

After monitoring and recording the channels, the tapes were played back twice; once at high speed (about twice the recording speed) to count the number of messages and the number of transmissions per message, and then at slow speed (about 0.8 times the recording speed) when the length of each transmission and the time between each transmission (within a message) was measured with a stop watch. The measured times were then corrected for the difference between the recording and playback speeds. The time between each transmission was measured only when both sides of the conversation were detected.

Results

The means and standard deviations of transmission length and time between transmission for each channel are shown in Table V. In an exponentially distributed sample, the mean will equal the standard deviation. Since the means are fairly close to the standard deviations, these parameters are adequately modelled with exponential distributions.

The means and standard deviations of the number of transmissions per message for each channel are shown in Table VI. Histograms showing frequencies of transmissions per message for each channel are presented in Appendix C. Although it is difficult to detect a specific distribution from which these values could be drawn, testing of the models indicates the standard deviation is not as critical as the mean and,

TABLE V

Measured Characteristics of Transmission Length and Time Between Transmissions (Within a Message)

CHANNEL	TX LENGTH (seconds)		TIME BTWN TX (seconds)	
	MEAN	ST DV	MEAN	ST DV
SECURITY POLICE	2.915	3.844	2.054	2.141
MOTORPOOL	1.596	1.260	1.385	1.836
BASE SUPPLY & DIST. C	1.793	1.346	2.088	2.558
FIRE/CRASH	2.726	2.371	2.135	1.985
CIVIL ENGINEERS CH 1	2.312	2.134	1.611	1.655
CIVIL ENGINEERS CH 2	2.781	3.488	2.375	2.660
SPECIAL DISPATCH/POL/ BASE OPERATIONS	1.986	2.006	1.557	1.686

therefore, the specific sample distribution used is probably not too critical, as long as the mean is chosen accurately. Normal distributions are used in the models.

The channel loading to be used in the computer models are shown in Table VII (rounded to the nearest whole number of messages per hour). To determine these numbers, the number of messages noted between 000 and 700 on the tape counter (3107.5 seconds) for each tape was recorded and the number of messages per hour was calculated. With one exception, the worst case (highest loading) for each channel was chosen. On the Fire/Crash channel, on one day 23.17 messages per hour were noted while the next highest value was only 8.109 messages per hour. Since, on other days, the numbers of messages per hour noted for this channel

TABLE VI

Measured Characteristics of the Number of Transmissions Per Message

CHANNEL	TRANSMISSIONS/MESSAGE	
	MEAN	ST DEV
SECURITY POLICE	3.940	1.786
MOTORPOOL	3.091	1.881
BASE SUPPLY & DIST. C	2.744	2.181
FIRE/CRASH	2.806	1.506
CIVIL ENGINEERS CH 1	2.857	1.807
CIVIL ENGINEERS CH 2	2.710	2.003
SPECIAL DISPATCH/POL/ BASE OPERATIONS	3.533	2.093

TABLE VII

Channel Load Used in the Computer Models to Simulate Normal Conditions

CHANNEL	MESSAGES/HOUR
SECURITY POLICE	49
MOTORPOOL	44
BASE SUPPLY & DIST. C	14
FIRE/CRASH	8
CIVIL ENGINEERS CH 1	22
CIVIL ENGINEERS CH 2	49
SPECIAL DISPATCH/POL/ BASE OPERATIONS	47

were even less, the 8.109 value was chosen as being representative. (One contingency scenario discussed in Chapter VII deals with an increase in traffic on this channel.)

VI. Normal Configuration Runs

Overview

This chapter reports on results of computer runs designed to explore characteristics of the existing conventional LMR system and a hypothetical trunked system at WPAFB, during normal day to day operations. (Contingency operations are examined in the next chapter.)

The main characteristic explored in this chapter is the wait time to begin a message. Wait times for both the conventional system, and for trunked systems with different numbers of available voice channels, are measured and compared while parameters of the model are varied. Also explored is the effect of the recent user's queue on wait times for a channel.

All runs were 48 hours long (simulation time). For each set of input parameters, three runs were made. Unless otherwise noted, the results of the three runs were averaged to give the results reported in this chapter.

Comparison of Conventional and Trunked Systems

Most of the inputs to both the conventional and trunked models for this series of runs were derived from the data evaluated and reported on in Chapter V. Only the seven most active nets were considered, as the rest do not have enough traffic to seriously affect the results of the models during normal operations. Fleet priorities for the trunked model were set (somewhat arbitrarily) so emergency services were highest (Priority 2), flightline and essential base services were next

(Priority 3), and other users were lowest (Priority 4). (Priority 1 was not used.) Fleet and net inputs are summarized in Table VIII. In

TABLE VIII

Fleet and Net Inputs Used in the Computer Simulation Models to Compare the Conventional and Trunked Systems

FLEET OR NET	FLEET OR NET #	LOAD (MSGS/ SEC)	TRANSMISSION MEAN TIME (SECONDS)	MEAN TIME BETWEEN TRANSMISSIONS (SECONDS)	MEAN TRANSMISSIONS PER MESSAGE	STANDARD DEVIATION PER MESSAGE	PRIORITY (TRUNKED SYSTEM ONLY)
SECURITY POLICE	1	.0136	2.915	2.054	3.940	1.786	2
MOTORPOOL	2	.0122	1.596	1.385	3.091	1.881	4
BASE SUPPLY & DIST. C	3	.0039	1.793	2.088	2.744	2.181	4
FIRE CRASH	4	.0022	2.726	2.135	2.806	1.506	2
CIVIL ENGINEERS CH 1	5	.0061	2.312	1.611	2.857	1.807	3
CIVIL ENGINEERS CH 2	6	.0136	2.781	2.375	2.710	2.003	3
SPECIAL DISPATCH/POL/ BASE OPERATIONS	7	.0131	1.986	1.557	3.533	2.093	3

the trunked model mechanical delay of the system, MD, was set to 0.350 seconds (the worst case delay allowed in the Air Force specifications) (16), the time allowed in the recent user's queue, RU, was set to 5 seconds, and the number of voice channels, CH, was varied. XX(1) in the conventional model and XX(31) in the trunked model were varied to vary the load of all the channels proportionally.

Runs were made using the conventional model, and the trunked model with CH set from 1 to 7 channels (any more than 7 would necessarily give similar results since only seven fleets were used). Load was varied from 0.75 to 3.00 times the measured load for WPAFB (in increments of 0.25).

Sample SLAM outputs from the conventional and trunked models are shown in Appendices D and E. For these runs, only the average wait time to begin a message for the whole system was measured (labeled TOTAL WAIT TIME in the conventional model and MSG DELAY in the trunked model). These are shown in the histograms presented in the outputs where percentage is shown across the horizontal axis while seconds delay is shown down the vertical axis. The "C" curve represents the cumulative percentage of callers who have obtained a channel by the time shown on the vertical axis. To summarize this data for each run the following values were recorded:

1. The percentage of calls completed immediately in the conventional model and within the first second in the trunked model. (This is a fair comparison since, due to MD, no calls can be immediately completed in the trunked model.)

2. The time the "C" curve reached 80%. (Due to round off error when the histogram was made, this is not exactly when 80% of the callers have obtained a channel. It is, however, close, and consistent for all of the runs. This also applies for 3 and 4, below.)

3. The time the "C" curve reached 90%.

4. The time the "C" curve reached 98%.

The results are shown in Figures 8-11.

Interpretation of Results

For this series of runs, fleets on the trunked system were made identical to nets on the conventional system, with each fleet experiencing the same load as its corresponding net, and without any division of fleets into sub-fleets. Under these conditions, the wait

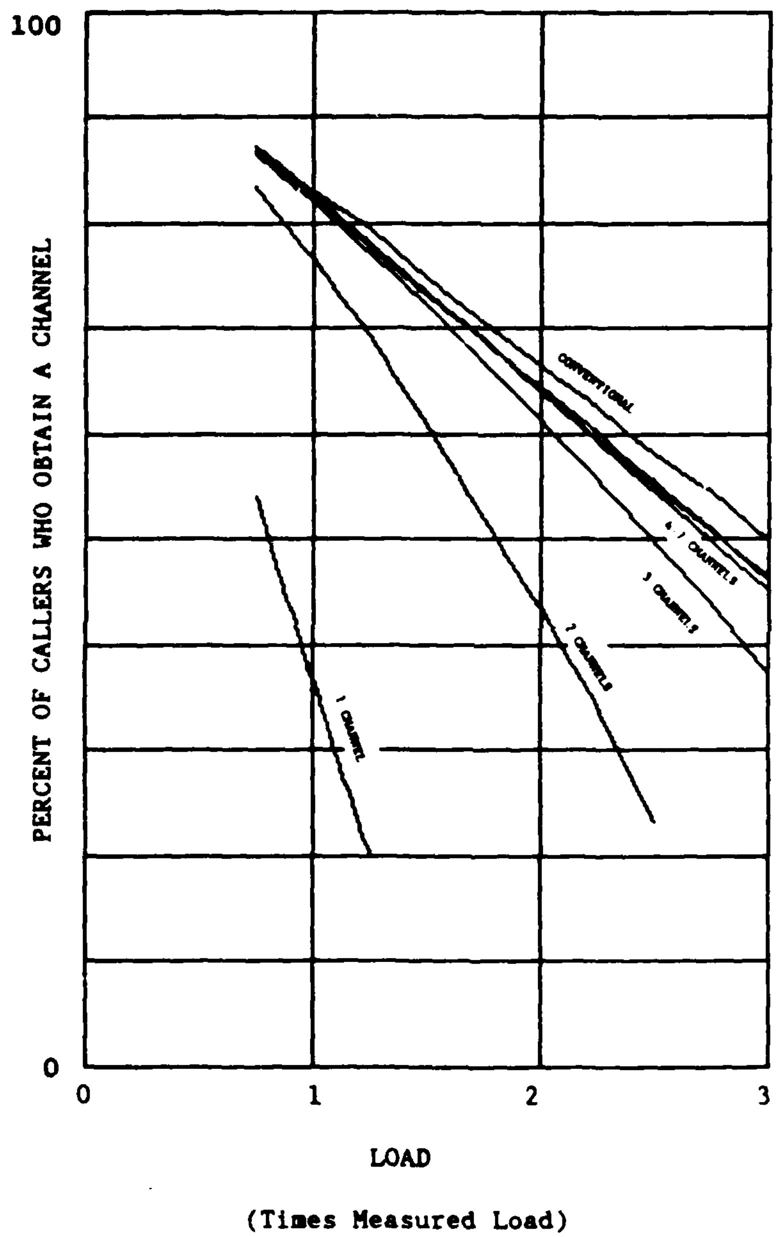

Figure 8. Percent of Callers Obtaining a Channel Within 1 Second

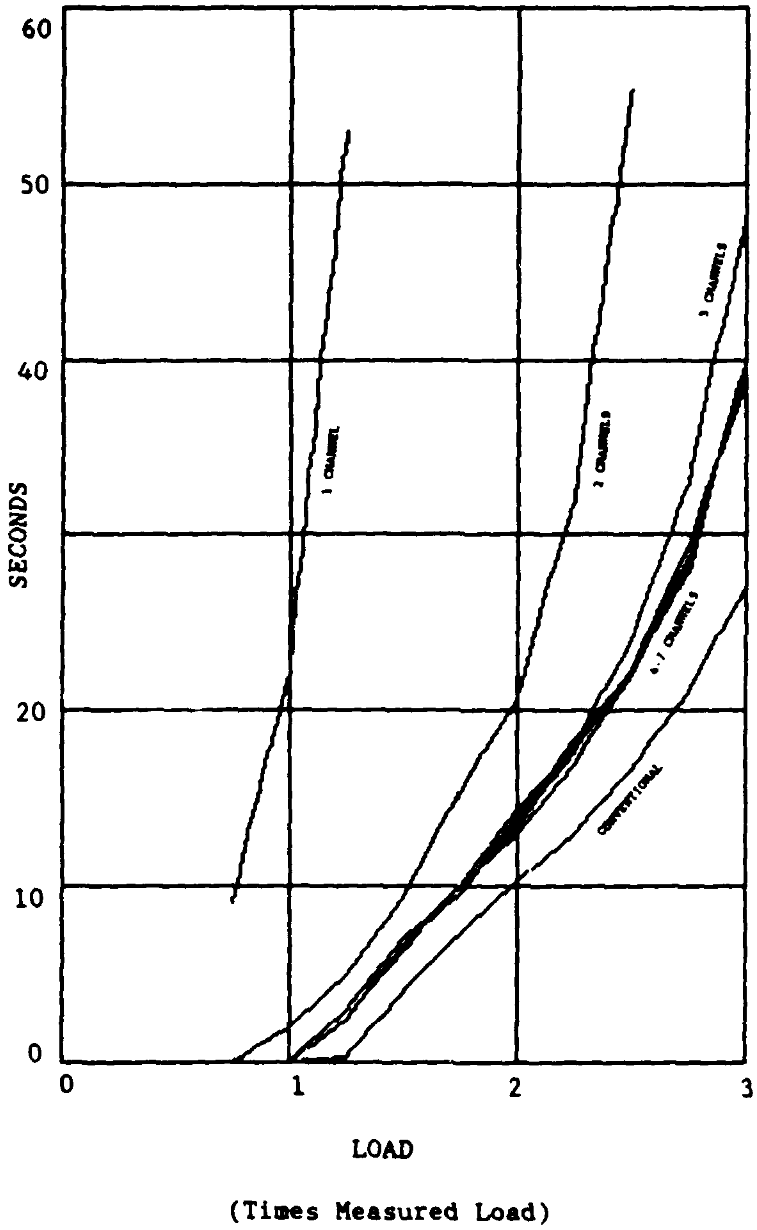

Figure 9. Wait Time Until 80% of Callers Obtain a Channel

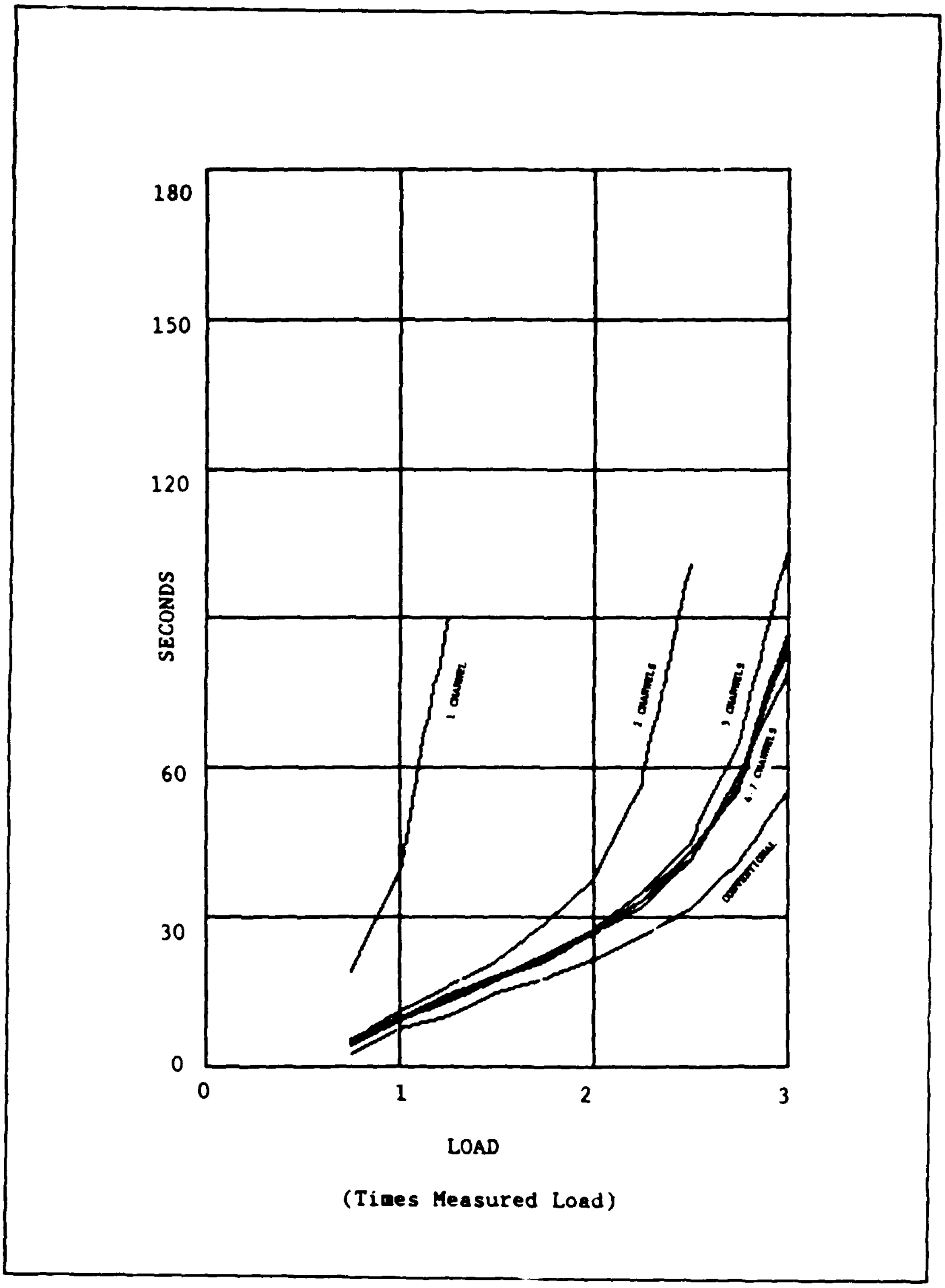

Figure 10. Wait Time Until 90% of Callers Obtain a Channel

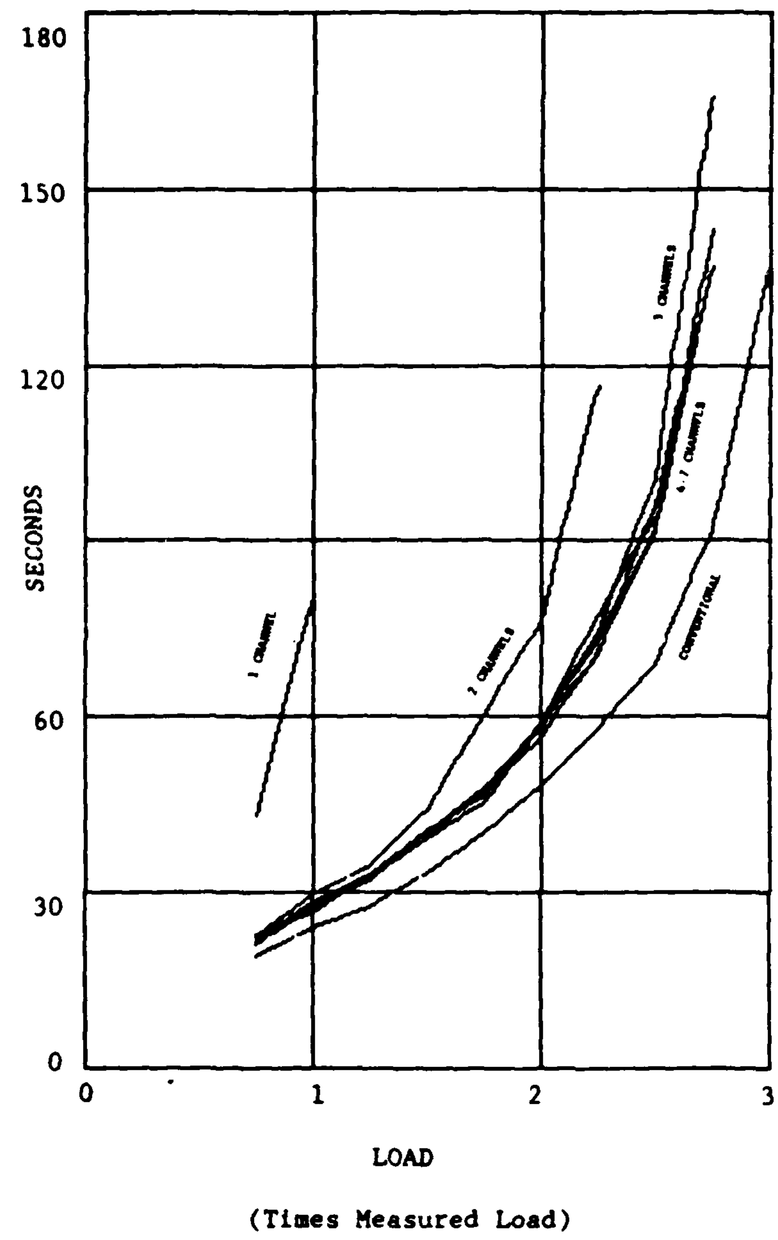

Figure 11. Wait Time Until 98% of Callers Obtain a Channel

time to begin a message cannot be any better for the trunked system than for the conventional system. Wait time on the conventional system is dictated solely by the time a user must wait for someone else on his net to conclude a message. The trunked system user must wait for this (which will be about the same, given the same number of users and same loading on the fleet as on the net) and then wait for a free voice channel.

As shown in Figures 8-11, for the loads examined on the trunked system, there is not a lot of difference in wait time between a 7 channel and a 4 channel system. Also, for light loading, wait times on 2 and 3 channel systems are comparable to the 7 channel system. This indicates that, under light loading, the delay in beginning a message is primarily due to other users on the caller's fleet. As load increases, the delay due to channels not being available becomes more significant.

Figures 9-11 show that, as with almost every queueing system, the wait times in the conventional and trunked systems approach infinity as the load increases to an asymptote (6:99). For 1, 2, and 3 channel trunked systems, the asymptote is determined primarily by the number of channels. For trunked systems with more channels, it appears to be determined primarily by loading within the fleets. Of course, the wait time to obtain a channel in these systems becomes unacceptable long before approaching infinity, but the curves can be kept lower, for higher loads, by moving the asymptote as far to the right as possible. It can be seen that increasing the number of channels in a system past a certain point provides no improvement in performance, unless something is also done to decrease the loading within fleets, such as dividing fleets into sub-fleets (described below).

Except for MD, the wait time for the 7 channel model should be about the same as for the conventional model. The difference due to MD can be seen in Figures 8-11 to increase as load increases. To confirm this delay was due to MD, the trunked model was run with 7 voice channels, MD set equal to zero, and loads set to 1 and 3 times the load measured at WPAFB. Results are compared, in Table IX, with the

TABLE IX

Comparison Of 7 Channel/7 Fleet Trunked Model (With MD Set To 0) and the Corresponding Conventional Model

XX(1) = 1 IN CONVENTIONAL MODEL XX(31) = 1 IN TRUNKED MODEL	CONVEN-TIONAL MODEL	TRUNKED MODEL
% CALLS COMPLETED IMMEDIATELY IN CONVENTIONAL MODEL AND AFTER 1 SEC IN TRUNKED MODEL	83.5 82.9 82.5	82.6 82.9 83.1
TIME WHEN 90% OF CALLERS OBTAINED A CHANNEL	7 8 8	8 8 8
TIME WHEN 98% OF CALLERS OBTAINED A CHANNEL	23 25 24	25 26 24
XX(1) = 3 IN CONVENTIONAL MODEL XX(31) = 3 IN TRUNKED MODEL	CONVEN-TIONAL MODEL	TRUNKED MODEL
% CALLS COMPLETED IMMEDIATELY IN CONVENTIONAL MODEL AND AFTER 1 SEC IN TRUNKED MODEL	49.5 50.8 49.3	50.2 49.3 50.3
TIME WHEN 80% OF CALLERS OBTAINED A CHANNEL	27 26 28	28 29 26

conventional model results. In this table, results of each of the three runs per set of input parameters are presented separately (instead of being averaged like the other results presented in this chapter) to indicate the variability of results in the simulations.

Sub-fleets

As discussed above, the user of a trunked system must still wait for other users on his fleet to finish before he can begin his message, and, therefore, if the fleets on a trunked system are configured identically to a conventional system, the wait time of the trunked system must be slightly worse (although, of course, fewer channels are needed). Trunked system performance can be dramatically improved by dividing fleets into sub-fleets, creating, essentially, more fleets with less loading on each. (For this analysis, sub-fleets are considered to be independent of each other; there are no fleet-wide calls to several sub-fleets.)

Unfortunately from the view of analysis, it is unlikely a base's LMR users will be divided into sub-fleets based on wait time performance (unless, of course, performance of a desired configuration becomes unacceptable, forcing the LMR manager to reconfigure the system). More likely will be a logical division of fleets based on users' functions, personnel available to man base stations, etc. For this reason, the trunked model was not set to simulate a particular situation, but was instead used to examine the overall wait times of several extreme cases of sub-fleet configuration.

In one series of runs, the original 7 fleets were divided into 30 independent fleets/sub-fleets, each with a load (when XX(31) = 1) of about 8 messages/hour. (For example, the original Security Police fleet with 49 messages/hour was divided into 6 sub-fleets with 8 messages/hour each. All other characteristics of the sub-fleets were kept the same as in the original fleet.) Although it might be expected that, at some point, the increased delay in obtaining a channel in a system with many sub-fleets would overcome the decrease in delay due to other users on the sub fleet, this did not occur, for the loads measured, on the 30 fleet/sub-fleet system, except for the 1 channel XX(31) = 1 case, in which the system became unstable (calls came in too frequently for the system to handle).

Two other series of runs were made. One of these examined the division of the busiest fleet of the original configuration (the Security Police fleet) into two equally loaded sub-fleets, while the other examined the division of the lightest fleet (the Fire/Crash fleet) into two equally loaded sub-fleets. With XX(31) set equal to 2, the configuration with the divided Fire/Crash fleet showed slightly worse performance than the original configuration. For that case, the increase in delay in obtaining a channel did offset the improvement due to fewer users on the sub-fleet. For all three series of runs, MD was set equal to 0.350 seconds and RU was set equal to 5 seconds.

The amount of time it took 98% of the callers to obtain a channel in each of the three cases examined, are shown in Table X for both one and two times the measured load at WPAFB. Runs were not made for systems with certain numbers of channels if runs made with fewer channels gave results similar to the system with the maximum number of channels. For example, both the 4 channel and the 30 channel 30 fleet

TABLE X

Comparison of the Effects of Division Into Sub-fleets of the Original Seven Fleet Trunked System
(Time For 98% of Callers to Obtain a Channel)

XX(1) = 1 IN CONVENTIONAL MODEL XX(31) = 1 IN TRUNKED MODEL			CONVENTIONAL SYSTEM: 24 SEC	
NUMBER OF CHANNELS	7 FLEET SYSTEM (SEC)	30 FLEET SYSTEM (SEC)	8 FLEET SYSTEM SECURITY POLICE FLEET DIVIDED INTO 2 SUB-FLEETS (SECONDS)	8 FLEET SYSTEM FIRE/CRASH FLEET DIVIDED INTO 2 SUB-FLEETS (SECONDS)
1	80.7		78.7	79
2	29.7	9	23.7	29
3	26.7	4	22	26.7
4	27.3	3	22.7	26.3
5	27.7		24	
6	28.3			
7	27.3			
8			22.3	27.3
30		3		

XX(1) = 2 IN CONVENTIONAL MODEL XX(31) = 2 IN TRUNKED MODEL			CONVENTIONAL SYSTEM: 48.3 SEC	
NUMBER OF CHANNELS	7 FLEET SYSTEM (SEC)	30 FLEET SYSTEM (SEC)	8 FLEET SYSTEM SECURITY POLICE FLEET DIVIDED INTO 2 SUB-FLEETS (SECONDS)	8 FLEET SYSTEM FIRE/CRASH FLEET DIVIDED INTO 2 SUB-FLEETS (SECONDS)
1				
2	76.3	35	59.7	7[illegible]
3	58	15	41.3	61
4	58.7	12.3	39	61
5	56.3	12	39	59
6	59			
7	58.7			
8			39	57.3
30		12		

systems with XX(31) = 1 took 3 seconds (on average) for 98% of the callers to obtain a channel, so 30 fleet systems with 5-29 channels were not tested. Results of the original seven fleet system and the conventional system are also shown for comparison. These numbers are the overall wait times for all of the fleets in each system. Of course, in the two configurations where only one fleet was divided, all of the improvement took place in the divided fleet only.

Priority

The effect of prioritization on the overall wait time to begin a message in the trunked model was investigated by running the model with all fleet priorities set to the same value, and comparing results to results of runs with priorities set as in Table VIII. For both sets of runs, MD was set equal to 0.350 seconds, RU was set equal to 5 seconds, and other input parameters were set as in Table VIII. A 2 channel system was tested because, at XX(31) = 2 , measurable delay due to channel contention (when prioritization should be significant) occurs.

Results are presented in Table XI. Since they indicate no significant change in overall wait time between the two configurations, the results reported should be valid regardless of the prioritization scheme. Of course, although the overall wait time is unaffected by prioritization, the wait times for each individual fleet can be expected to be affected significantly, with high priority users obtaining channels quickly at the expense of lower priority users. (This is the reason for building prioritization into the trunked system.)

TABLE XI

Comparison Between a Prioritized Trunked System and a Similar System With Fleet Priorities Set to the Same Value

XX(31) = 1	PRIOR-ITIZED SYSTEM	EQUAL PRIORITY SYSTEM
% CALLS COMPLETED WITHIN 1 SECOND	76.7	76.7
TIME WHEN 80% CALLERS OBTAINED CHANNEL (SEC)	2	2
TIME WHEN 90% CALLERS OBTAINED CHANNEL (SEC)	11	10.7
TIME WHEN 98% CALLERS OBTAINED CHANNEL (SEC)	29.7	28.7
XX(31) = 2	PRIOR-ITIZED SYSTEM	EQUAL PRIORITY SYSTEM
% CALLS COMPLETED WITHIN 1 SECOND	43.5	42.6
TIME WHEN 80% CALLERS OBTAINED CHANNEL (SEC)	20.7	22
TIME WHEN 90% CALLERS OBTAINED CHANNEL (SEC)	37.7	39.7

Sensitivity

These series of runs were done to see how much error might result if inputs to the computer models, for one fleet or net, were off by a certain amount. Because results reported on earlier in the chapter indicate a 4 channel trunked system would be adequate for WPAFB, this model was tested, along with the conventional model. All inputs were the same as in Table VIII except for the one under test. MD was set equal to 0.350 seconds and RU was set equal to 5 seconds.

The Security Police Fleet was chosen for investigation because, as the busiest fleet in the models, it would probably tend to influence the overall wait time for a channel the most. Mean transmission length, mean messages per hour, mean transmissions per message, and tne standard deviation of transmissions per message, for the Security Police fleet, were all varied and results are shown in Tables XII-XV.

TABLE XII

Effects of a Change in Mean Transmission Length of the Security Police Fleet on the Conventional and 4 Channel Trunked Models (Time For 98% of Callers to Obtain a Channel)

TRANSMISSION LENGTH	% CHANGE FROM ORIGINAL VALUE	CONVENTIONAL MODEL MSG DELAY	TRUNKED MODEL MSG DELAY
2.332 SEC	-20 %	21.0 SEC	25.7 SEC
2.624	-10	22.3	25.7
2.915	0	24.0	27.3
3.207	+10	25.3	29.0
3.498	+20	25.7	30.7

TABLE XIII

Effects of a Change in Mean Messages/Hour of the Security Police Fleet on the Conventional and 4 Channel Trunked Models (Time For 98% of Callers to Obtain a Channel)

MESSAGES/HOUR	% CHANGE FROM ORIGINAL VALUE	CONVENTIONAL MODEL MSG DELAY	TRUNKED MODEL MSG DELAY
39	-20 %	21.7 SEC	24.3 SEC
44	-10	23.3	25.7
49	0	24.0	27.3
54	+10	25.0	29.3
59	+20	27.3	31.0

TABLE XIV

Effects of a Change in Mean Transmissions/Message of the Security Police Fleet on the Conventional and 4 Channel Trunked Models (Time For 98% of Callers to Obtain a Channel)

TRANSMISSIONS PER MESSAGE	% CHANGE FROM ORIGINAL VALUE	CONVENTIONAL MODEL MSG DELAY	TRUNKED MODEL MSG DELAY
3.152	-20 %	20.7 SEC	24.0 SEC
3.546	-10	21.7	25.7
3.940	0	24.0	27.3
4.334	+10	25.0	29.3
4.728	+20	26.0	31.0

TABLE XV

Effects of a Change in Standard Deviation of Transmissions/Message of the Security Police Fleet on the Conventional and 4 Channel Trunked Models (Time For 98% of Callers to Obtain a Channel)

STANDARD DEV OF TX/MSG	% CHANGE FROM ORIGINAL VALUE	CONVENTIONAL MODEL MSG DELAY	TRUNKED MODEL MSG DELAY
1.429	-20	23.7 SEC	26.3 SEC
1.607	-10	22.7	27.0
1.786	0	24.0	27.3
1.965	+10	24.0	26.7
2.143	+20	24.3	28.3

A comparison of the results indicates that changes in message delay are similar for the two models. Therefore, even if the inputs to the models were off for one fleet (if the Security Police parameters were measured during a busier week than normal, for example), relative comparisons between the models would still be valid. Change in the standard deviation of transmissions per message had very little effect on the wait time, confirming the statement made in Chapter V that the standard deviation is not as critical as the mean.

Optimum RU

In the proposed Air Force HTS, the amount of time a user remains in the recent user queue will be adjustable between 0 and 90 seconds (16). This is modelled as RU in the computer model and, in the series of runs reported on in this section, this parameter was adjusted in an attempt to find an optimum value.

The purpose of the recent user queue is to allow a message, once begun, to continue, as much as possible, without interruption by giving users who have initiated a message first priority in obtaining a channel for subsequent transmissions. As the value of RU is increased, there should be less delay in obtaining a channel for all transmissions except for the first one of each message, until a point is reached where little further improvement takes place. (Some delay in obtaining a channel will still exist, because users who have initiated a message must still contend with each other.) If RU were set too high, the first transmission of a message, coming from a fleet that just concluded a message, could be placed into the recent user queue. An optimum RU can, therefore, be found by increasing the parameter while looking at the wait time to obtain channels for transmissions other than the first one in each message, and picking the minimum RU that minimizes the wait time.

To do this, the trunked model was modified to record the wait time for a channel for transmissions other than the first one in each message (to the nearest tenth of a second). A significant delay due to channel contention was necessary to obtain results, so a 2 channel system with XX(31) = 2.25 was used. MD was set equal to 0.350 seconds and all other input parameters were set as in Table VIII. Results are shown in Figure 12. 5 seconds appears to be the optimum value for RU.

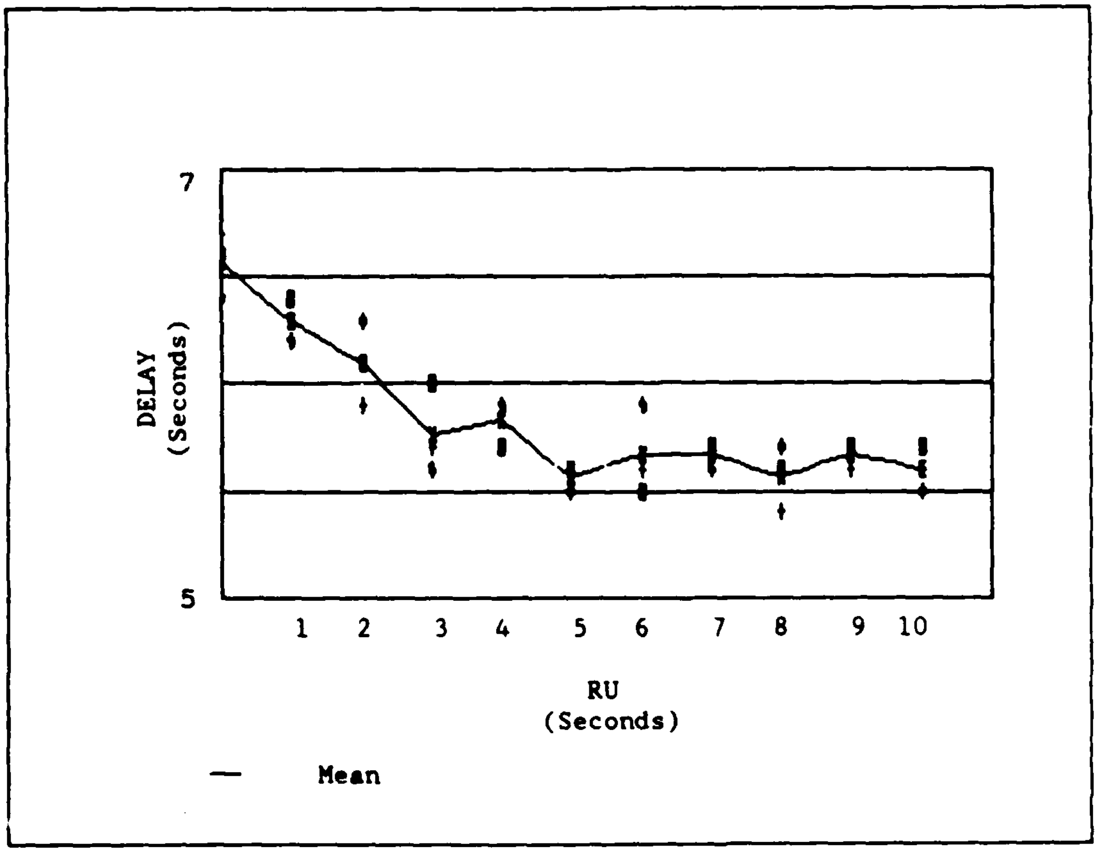

Figure 12. Delay in Obtaining a Channel For Transmissions Other Than the First One in a Message as a Function of Parameter RU

VII. Contingency Model Runs

Overview

This chapter reports on several runs made with the trunked model to simulate various contingencies. Since the number of possible contingency scenarios an Air Force base may become involved in is unlimited, the possible combinations of inputs for computer simulations are endless. Nevertheless, a relatively small number of runs tend to characterize the system well enough to generalize about the number of channels needed to handle a wide variety of possible contingency conditions. In this chapter two types of runs are made, one where the load on a single fleet, and two fleets, is increased disproportionate to the other fleets on the system, and one where one and two new sub-fleets are created and added to an existing system. [The baseline, "normally loaded" system, is one with inputs as shown in Table VIII (Chapter VI).]

Increase in Load; No Increase in Sub-fleets

This series of runs measured the delay in obtaining a channel, at the beginning of a message, for trunked systems with different numbers of channels. Two fleets, Security Police and Fire/Crash, were examined. Load was increased for each fleet individually and for both fleets together.

Those two fleets were picked primarily because a wide variety of contingency scenarios can cause their loads to increase. Security Police become involved in everything from civil demonstrations to wartime base attacks. Increased load on this fleet could be a result of increased activit: , or a result of more users, as personnel from other base services are incorporated as Security Police augmentees during a base contingency. The Fire/Crash fleet would show increased activity during several situations, such as an aircraft accident or building fire (actually whenever the building's alarm goes off, whether it turns out to be an actual fire or not). For a number of scenarios, both the Security Police and the Fire/Crash fleet users would be involved and both fleets would show increased activity. For example, Security Police might redirect traffic around a large fire, or cordon off, and guard, an area around an off-base aircraft crash.

Another reason for picking the Security Police and Fire/Crash fleets for examination is they represent extremes in loading. As shown in Table VIII, the Security Police fleet is the most loaded on WPAFB, while the Fire/Crash fleet is the lightest. Results common to tests of both fleets can, therefore, generally be assumed to apply for similar tests on other fleets.

For these runs all inputs to the model were as in Table VIII, except for the load of the fleet or fleets under examination. MD was set equal to 0.350 seconds and RU was set equal to 5 seconds.

Results of an increased load on the Security Police fleet are shown in Table XVI. The load of the fleet was picked to be 0.0217 messages/second because that value allowed about 50% of the users on the fleet to enter the channel queue immediately. (No other user from their fleet was already on the system.) This selection was, of course, somewhat arbitrary. At some loading, the LMR manager would have to divide the Security Police fleet into sub-fleets. The 0.0217 mes-

TABLE XVI

Results of an Increased Load on the Security Police Fleet

	SEC POLICE FLEET WITH 0.0217 MSGS/SEC		TOTAL MSG DELAY
CHANNELS IN SYSTEM	CALLERS PLACED IN QUEUE IMMEDIATELY (PERCENT)	90% CALLERS PLACED IN QUEUE (SECONDS)	90% CALLERS OBTAIN CHANNEL (SECONDS)
2	51.3	42	20.3
3	53.2	37.7	17.7
4	52.6	38.3	18
5	51.6	41.3	19
6	53.0	37	17.7
7	52.3	38.7	17.7

sages/second value was picked for these tests because a worst case loading on the fleet, before it would be broken into sub-fleets, was desired.

Results of an increased load on the Fire/Crash fleet are shown in Table XVII. The load of 0.0331 messages/second was picked for the same

TABLE XVII

Results of an Increased Load on the Fire/Crash Fleet

	FIRE/CRASH FLEET WITH 0.0331 MSGS/SEC		TOTAL MSG DELAY
CHANNELS IN SYSTEM	CALLERS PLACED IN QUEUE IMMEDIATELY (PERCENT)	90% CALLERS PLACED IN QUEUE (SECONDS)	90% CALLERS OBTAIN CHANNEL (SECONDS)
2	46.5	37	23.7
3	49.5	32.3	20.3
4	49.5	33	20.3
5	49.4	32.7	19.7
6	49.1	33	20.7
7	50.4	32.3	19.7

reasons 0.0217 messages/second was picked for the Security Police fleet.

Results of increased loads on both the Security Police and Fire/Crash fleets are shown in Table XVIII.

TABLE XVIII

Results of an Increased Load on the Security Police and Fire/Crash Fleets

	SEC POLICE FLEET WITH 0.0217 MSGS/SEC		FIRE/CRASH FLEET WITH 0.0331 MSGS/SEC		TOTAL MSG DELAY
CHANNELS IN SYSTEM	CALLERS PLACED IN QUEUE IMMEDIATELY (PERCENT)	90% CALLERS PLACED IN QUEUE (SECONDS)	CALLERS PLACED IN QUEUE IMMEDIATELY (PERCENT)	90% CALLERS PLACED IN QUEUE (SECONDS)	90% CALLERS OBTAIN CHANNEL (SECONDS)
2	50.1	44.3	46.0	39.3	29.7
3	52.8	38	49.5	32.3	24.3
4	53.4	38	50.3	31.3	23.7
5	52.6	39.3	50.0	32.3	24
6	52.9	38.7	49.7	32	24.3
7	52.5	39	50.2	30.3	24

In all three of these cases, as shown in the tables, no significant improvement in delay occurred in systems with more than three channels. Most of the delay occurred on the fleet or fleets with increased load, and the overall delay increased from a system with all inputs as in Table VIII. (For example, in a 4 channel trunked system with inputs as in Table VIII the average time for 90% of the callers to obtain a channel was found to be 9.3 seconds.) It should also be noted in all three tables that the values listed for the fleet or fleets under test are the percentage of callers who immediately entered the channel queue, and the time for 90% of the callers to enter the channel queue. Not included in those numbers is the amount of time the callers spent waiting for the channel.

Creation of New Sub-fleets

As discussed above, if the load on a certain fleet becomes too great, the LMR manager can break it into new sub-fleets. A logical division, in the case where a specific situation causes the increased load, would be to divide users dealing with the specific situation into one sub-fleet, while other users from the original fleet were put into another sub-fleet.

For these runs, the Security Police and Fire/Crash fleets are considered. In the first set of runs the Security Police fleet was divided into two sub-fleets, one with a load of 0.0136 messages/second (as in Table VIII) simulating the sub-fleet of the Security Police dealing with normal day-to-day activities, and the other with a load of 0.0217 messages/second (picked for reasons stated in the previous section) simulating the sub-fleet of Security Police dealing with the contingency. Similarly, in the second set of runs the Fire/Crash fleet was divided into two sub-fleets with loads of 0.0022 messages/second and 0.0331 messages/second, and, in the third set of runs, both the Security Police and Fire/Crash fleets were divided into sub-fleets. Results of these runs are shown in Tables XIX-XXI. The average delays in obtaining a channel for 7 fleet systems (with inputs as listed in Table VIII) are shown in Tables XIX-XXI for comparison.

The tables show, for all three cases, no significant improvement resulted by increasing the number of channels beyond three. Since, under normal conditions, the Security Police fleet is the most heavily loaded and the Fire/Crash fleet is the least heavily loaded, the similar results of these tests indicate results of breaking any fleet

TABLE XIX

Overall Message Delay on the Trunked System With an Extra Security Police Fleet Added, Compared With the Normal 7 Fleet System (Time For 90% of Callers to Obtain a Channel)

CHANNELS IN SYSTEM	OVERALL MSG DELAY (SECONDS)	7 FLEET SYSTEM (SECONDS)
2	22.3	11
3	18.7	9.7
4	18.7	9.3
5	18.7	10
6	17.3	9.7
7	18	9.3
8	19	

TABLE XX

Overall Message Delay on the Trunked System With an Extra Fire/Crash Fleet Added, Compared With the Normal 7 Fleet System (Time For 90% of Callers to Obtain a Channel)

CHANNELS IN SYSTEM	OVERALL MSG DELAY (SECONDS)	7 FLEET SYSTEM (SECONDS)
2	23	11
3	20	9.7
4	19.7	9.3
5	20	10
6	20	9.7
7	20	9.3
8	20	

into two sub-fleets would be similar. Furthermore, these results are probably similar to the results of a model in which a fleet, with loading too light to be measured in normal situations, suddenly increased its load in response to a contingency (for example: a situation where the Explosive Ordinance Disposal unit had to use its

TABLE XXI

Overall Message Delay on the Trunked System With Extra Security Police and Fire/Crash Fleets Added, Compared With the Normal 7 Fleet System (Time For 90% of Callers to Obtain a Channel)

CHANNELS IN SYSTEM	OVERALL MSG DELAY (SECONDS)	7 FLEET SYSTEM (SECONDS)
2	36.3	11
3	24.7	9.7
4	23.7	9.3
5	23.7	10
6	24	9.7
7	24.3	9.3
8	23	
9	24.3	

LMRs). Finally, these results are probably similar to the results of a model in which a new fleet is created out of users from several different fleets, a case which might occur when a situation required inter-communication among separate groups.

Failure of Parts of the Trunked System

Both the computer driven central controller and the repeaters could affect service throughout a trunked system if they failed. In a hybrid trunked system, a failure of the central controller would cause the rest of the system to revert to a conventional mode of operation. The number of channels required to operate the system in this mode, on WPAFB, will be discussed in Chapter VIII.

If a repeater failed, on a trunked system, a voice channel would be lost (the data channel would automatically switch if the repeater supporting that channel went down) and the performance would be identical to the performance of a fully functioning system with one less voice channel. (For example, users of a four voice channel system, with one broken repeater, would experience the same wait time to obtain a channel as users on a three channel system.) The results reported on in this document, comparing systems with different numbers of voice channels, will be valid for a system with lost voice channels, as long as the number of functioning voice channels is considered.

VIII. Conclusions and Recommendations

Summary

The results reported in this document indicate, for WPAFB under measured load conditions, a 3 voice channel trunked system would show only slight improvement over a 2 channel system; and no improvement over a 3 channel system would be seen in systems with more channels. Similar results were also seen with the selective increases in load reported in Chapter VII. However, in the case where the load of every LMR fleet on base were tripled, the 2 channel system would be totally inadequate, and the 3 channel system would not show as good results as 4, or more, channels.

Regardless of the number of channels available on the system, the trunked model indicated an improvement in access time could be achieved through a realignment of LMR users (dividing fleets into sub-fleets). With the proper use of sub-fleets, trunked systems with 2 or more channels showed better access time than the conventional system at WPAFB.

In Chapter VI, the optimum setting for the time in the recent user queue was examined and found to be 5 seconds for WPAFB.

Conclusions

A 4 voice channel trunked LMR system should be able to support WPAFB. 4 channels will be able to support the contingencies discussed and will be able to handle at least three times the measured load. If a repeater is lost, the 3 functioning voice channels will still adequately support the base.

A realignment of fleets in a trunked system is a relatively simple operation (compared to adding channels) and can probably best handle problems of channel access by individual fleets due to temporary increases in load (such as during contingencies). Of course, the ability of users to intercommunicate as desired will also be a factor in realignment.

A trunked system should be better able to support WPAFB, while using fewer channels, than the existing conventional system. With a good alignment of users into sub-fleets, a trunked system will have better access time than a corresponding conventional system. This will be more dramatic during high load conditions, such as contingencies, since access time delay in the conventional system, caused by users on the same net competing for the channel, is reduced in the trunked system when sub-fleets are used. (A trunked system can still function without excessive delay even when a single channel on a conventional system would be saturated.)

If a hybrid trunked system's central controller fails, the system reverts to conventional operation. Since traffic was only measured on nine nets at WPAFB (with two having such light traffic data could not be collected), no more than nine conventional channels should be necessary under normal load conditions. (Other LMR users could share channels with the busy users, for the duration of the central controller failure.) Since only one of those nine nets used a repeater, one possible configuration for a conventional mode of operation would be to take the 10 frequencies of a 4 voice channel system (two for each voice channel and two for the data channel), turn off all but one of the repeaters, and use the 9 resulting channels.

Recommendations For Further Work

Collection of data on LMR nets, via monitoring, at other Air Force bases, could be done to check whether the results obtained for WPAFB can be generalized. Collection of data during base exercises would also be valuable, since this data could then be used with the trunked model to more accurately simulate contingency conditions. Most United States Air Force bases in Europe, and many in the continental United States, regularly exercise realistic contingency scenarios.

As the first hybrid trunked systems are installed on bases, performance data should be collected and compared with the computer model's predicted results. Assuming the model is accurate, proposed configurations and changes in trunked systems can be simulated, and adjusted, before implementation.

```
;
;        Appendix A:  SLAM Code For the Conventional Simulation
;                                Model
;
;
;
GEN,T C FARRELL,CONVENTIONAL LMR,7/13/88;
LIMITS,60,4,100;
;
;     | NUM   |        | TX     | MEAN     | MEAN    | DEV    |
;     | RADIO |        | MEAN   | TIME     | TX/     | TX/    |
; NT  | ON NT | LOAD   | TIME   | BTWN TX  | MSG     | MSG    |
;-----|-------|--------|--------|----------|---------|--------|
;  1  | #1    | LOAD1  | TMT1   | MTBT1    | MTPM1   | SDTM1  |
;  2  | #2    | LOAD2  | TMT2   | MTBT2    | MTPM2   | SDTM2  |
;  3  | #3    | LOAD3  | TMT3   | MTBT3    | MTPM3   | SDTM3  |
;  4  | #4    | LOAD4  | TMT4   | MTBT4    | MTPM4   | SDTM4  |
;  5  | #5    | LOAD5  | TMT5   | MTBT5    | MTPM5   | SDTM5  |
;  6  | #6    | LOAD6  | TMT6   | MTBT6    | MTPM6   | SDTM6  |
;  7  | #7    | LOAD7  | TMT7   | MTBT7    | MTPM7   | SDTM7  |
;  8  | #8    | LOAD8  | TMT8   | MTBT8    | MTPM8   | SDTM8  |
;  9  | #9    | LOAD9  | TMT9   | MTBT9    | MTPM9   | SDTM9  |
; 10  | #10   | LOAD10 | TMT10  | MTBT10   | MTPM10  | SDTM10 |
; 11  | #11   | LOAD11 | TMT11  | MTBT11   | MTPM11  | SDTM11 |
; 12  | #12   | LOAD12 | TMT12  | MTBT12   | MTPM12  | SDTM12 |
; 13  | #13   | LOAD13 | TMT13  | MTBT13   | MTPM13  | SDTM13 |
; 14  | #14   | LOAD14 | TMT14  | MTBT14   | MTPM14  | SDTM14 |
; 15  | #15   | LOAD15 | TMT15  | MTBT15   | MTPM15  | SDTM15 |
; 16  | #16   | LOAD16 | TMT16  | MTBT16   | MTPM16  | SDTM16 |
; 17  | #17   | LOAD17 | TMT17  | MTBT17   | MTPM17  | SDTM17 |
; 18  | #18   | LOAD18 | TMT18  | MTBT18   | MTPM18  | SDTM18 |
; 19  | #19   | LOAD19 | TMT19  | MTBT19   | MTPM19  | SDTM19 |
; 20  | #20   | LOAD20 | TMT20  | MTBT20   | MTPM20  | SDTM20 |
; 21  | #21   | LOAD21 | TMT21  | MTBT21   | MTPM21  | SDTM21 |
; 22  | #22   | LOAD22 | TMT22  | MTBT22   | MTPM22  | SDTM22 |
; 23  | #23   | LOAD23 | TMT23  | MTBT23   | MTPM23  | SDTM23 |
; 24  | #24   | LOAD24 | TMT24  | MTBT24   | MTPM24  | SDTM24 |
; 25  | #25   | LOAD25 | TMT25  | MTBT25   | MTPM25  | SDTM25 |
; 26  | #26   | LOAD26 | TMT26  | MTBT26   | MTPM26  | SDTM26 |
; 27  | #27   | LOAD27 | TMT27  | MTBT27   | MTPM27  | SDTM27 |
; 28  | #28   | LOAD28 | TMT28  | MTBT28   | MTPM28  | SDTM28 |
; 29  | #29   | LOAD29 | TMT29  | MTBT29   | MTPM29  | SDTM29 |
; 30  | #30   | LOAD30 | TMT30  | MTBT30   | MTPM30  | SDTM30 |
;----------------------------------------------------------
;
; ATRIB(1)=NET NUMBER
; ATRIB(2)=TRANSMISSIONS LEFT IN MESSAGE
; ATRIB(3)=TRANSMISSIONS IN MESSAGE
; ATRIB(4)=TIME TRANSMISSION STARTED
;
; XX(1) IS THE LOAD FACTOR
```

```
;
INTLC,XX(1)=1;
;
NETWORK;
;
; EACH CHANNEL IS ASSIGNED A RESOURCE
;
        RESOURCE/CHAN1(1),1;
        RESOURCE/CHAN2(1),2;
        RESOURCE/CHAN3(1),3;
        RESOURCE/CHAN4(1),4;
        RESOURCE/CHAN5(1),5;
        RESOURCE/CHAN6(1),6;
        RESOURCE/CHAN7(1),7;
        RESOURCE/CHAN8(1),8;
        RESOURCE/CHAN9(1),9;
        RESOURCE/CHAN10(1),10;
        RESOURCE/CHAN11(1),11;
        RESOURCE/CHAN12(1),12;
        RESOURCE/CHAN13(1),13;
        RESOURCE/CHAN14(1),14;
        RESOURCE/CHAN15(1),15;
        RESOURCE/CHAN16(1),16;
        RESOURCE/CHAN17(1),17;
        RESOURCE/CHAN18(1),18;
        RESOURCE/CHAN19(1),19;
        RESOURCE/CHAN20(1),20;
        RESOURCE/CHAN21(1),21;
        RESOURCE/CHAN22(1),22;
        RESOURCE/CHAN23(1),23;
        RESOURCE/CHAN24(1),24;
        RESOURCE/CHAN25(1),25;
        RESOURCE/CHAN26(1),26;
        RESOURCE/CHAN27(1),27;
        RESOURCE/CHAN28(1),28;
        RESOURCE/CHAN29(1),29;
        RESOURCE/CHAN30(1),30;
;
; EACH RADIO IS A UNIT OF RESOURCE
;
        RESOURCE/NET1(#1),31;
        RESOURCE/NET2(#2),32;
        RESOURCE/NET3(#3),33;
        RESOURCE/NET4(#4),34;
        RESOURCE/NET5(#5),35;
        RESOURCE/NET6(#6),36;
        RESOURCE/NET7(#7),37;
        RESOURCE/NET8(#8),38;
        RESOURCE/NET9(#9),39;
        RESOURCE/NET10(#10),40;
        RESOURCE/NET11(#11),41;
        RESOURCE/NET12(#12),42;
```

```
     RESOURCE/NET13(#13),43;
     RESOURCE/NET14(#14),44;
     RESOURCE/NET15(#15),45;
     RESOURCE/NET16(#16),46;
     RESOURCE/NET17(#17),47;
     RESOURCE/NET18(#18),48;
     RESOURCE/NET19(#19),49;
     RESOURCE/NET20(#20),50;
     RESOURCE/NET21(#21),51;
     RESOURCE/NET22(#22),52;
     RESOURCE/NET23(#23),53;
     RESOURCE/NET24(#24),54;
     RESOURCE/NET25(#25),55;
     RESOURCE/NET26(#26),56;
     RESOURCE/NET27(#27),57;
     RESOURCE/NET28(#28),58;
     RESOURCE/NET29(#29),59;
     RESOURCE/NET30(#30),60;
;
; CREATE ENTITIES FOR THE NET AND ASSIGN NET # ATRIBUTE 1
;
     CREATE,EXPON(1/XX(1)/LOAD1),,4;
     ASSIGN,ATRIB(1)=1,1;
;
; KILL CALL IF RADIO IS NOT AVAILABLE
;
       ACT,,NNRSC(NET1).EQ.0,KILL;
       ACT;
;
; SEIZE A RADIO
;
     AWAIT(31),NET1/1;
;
; ASSIGN THE MESSAGE CHARACTERISTIC
;
     ASSIGN,ATRIB(3)=RNORM(MTPM1,SDTM1),
            ATRIB(2)=ATRIB(3);
;
; THIS NODE IS THE QUEUE OF ENTITIES WAITING TO FLOW
; THROUGH THE SYSTEM
;
     AWAIT(1),CHAN1/1;
;
; COLLECT THE TIME EACH ENTITY HAD TO WAIT
;
     COLCT,INT(4),WAIT TIME NET 1;
;
; THE ENTITY GOES TO THE MAIN COLLECTION NODE WHERE THE
; TOTAL WAIT TIME FOR ALL THE ENTITIES IN THE SYSTEM IS
; RECORDED
;
        ACT,,,MC;
```

```
;
M1      GOON;
;
; THE ENTITY IS DELAYED FOR A TRANSMISSION TIME
;
           ACT,EXPON(TMT1);
;
; THE TRANSMISSION/MESSAGE COUNTER IS DECREMENTED
;
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
;
; IF THERE ARE MORE TRANSMISSIONS IN THE MESSAGE THE
; ENTITY IS DELAYED BY A TIME BETWEEN TRANSMISSIONS
;
           ACT,EXPON(MTBT1),ATRIB(2).GT.0.0,M1;
;
; IF THE MESSAGE IS OVER THE ENTITY FREES THE CHANNEL
; AND RADIO AND RETURNS TO ITS POPULATION QUEUE
;
           ACT;
        FREE,CHAN1/1;
        FREE,NET1/1;
        TERM;
;
; THE PROCESS IS REPEATED FOR THE OTHER CHANNELS
;
        CREATE,EXPON(1/XX(1)/LOAD2),,4;
        ASSIGN,ATRIB(1)=2,1;
           ACT,,NNRSC(NET2).EQ.0,KILL;
           ACT;
        AWAIT(32),NET2/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM2,SDTM2),
               ATRIB(2)=ATRIB(3);
        AWAIT(2),CHAN2/1;
        COLCT,INT(4),WAIT TIME NET 2;
           ACT,,,MC;
;
M2      GOON;
           ACT,EXPON(TMT2);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT2),ATRIB(2).GT.0.0,M2;
           ACT;
        FREE,CHAN2/1;
        FREE,NET2/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD3),,4;
        ASSIGN,ATRIB(1)=3,1;
           ACT,,NNRSC(NET3).EQ.0,KILL;
           ACT;
        AWAIT(33),NET3/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM3,SDTM3),
```

```
              ATRIB(2)=ATRIB(3);
       AWAIT(3),CHAN3/1;
       COLCT,INT(4),WAIT TIME NET 3;
          ACT,,,MC;
;
M3     GOON;
          ACT,EXPON(TMT3);
       ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
          ACT,EXPON(MTBT3),ATRIB(2).GT.0.0,M3;
          ACT;
       FREE,CHAN3/1;
       FREE,NET3/1;
       TERM;
;
       CREATE,EXPON(1/XX(1)/LOAD4),,4;
       ASSIGN,ATRIB(1)=4,1;
          ACT,,NNRSC(NET4).EQ.0,KILL;
          ACT;
       AWAIT(34),NET4/1;
       ASSIGN,ATRIB(3)=RNORM(MTPM4,SDTM4),
              ATRIB(2)=ATRIB(3);
       AWAIT(4),CHAN4/1;
       COLCT,INT(4),WAIT TIME NET 4;
          ACT,,,MC;
;
M4     GOON;
          ACT,EXPON(TMT4);
       ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
          ACT,EXPON(MTBT4),ATRIB(2).GT.0.0,M4;
          ACT;
       FREE,CHAN4/1;
       FREE,NET4/1;
       TERM;
;
       CREATE,EXPON(1/XX(1)/LOAD5),,4;
       ASSIGN,ATRIB(1)=5,1;
          ACT,,NNRSC(NET5).EQ.0,KILL;
          ACT;
       AWAIT(35),NET5/1;
       ASSIGN,ATRIB(3)=RNORM(MTPM5,SDTM5),
              ATRIB(2)=ATRIB(3);
       AWAIT(5),CHAN5/1;
       COLCT,INT(4),WAIT TIME NET 5;
          ACT,,,MC;
;
M5     GOON;
          ACT,EXPON(TMT5);
       ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
          ACT,EXPON(MTBT5),ATRIB(2).GT.0.0,M5;
          ACT;
       FREE,CHAN5/1;
       FREE,NET5/1;
```

```
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD6),,4;
        ASSIGN,ATRIB(1)=6,1;
           ACT,,NNRSC(NET6).EQ.0,KILL;
           ACT;
        AWAIT(36),NET6/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM6,SDTM6),
                ATRIB(2)=ATRIB(3);
        AWAIT(6),CHAN6/1;
        COLCT,INT(4),WAIT TIME NET 6;
           ACT,,,MC;
;
M6      GOON;
           ACT,EXPON(TMT6);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT6),ATRIB(2).GT.0.0,M6;
           ACT;
        FREE,CHAN6/1;
        FREE,NET6/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD7),,4;
        ASSIGN,ATRIB(1)=7,1;
           ACT,,NNRSC(NET7).EQ.0,KILL;
           ACT;
        AWAIT(37),NET7/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM7,SDTM7),
                ATRIB(2)=ATRIB(3);
        AWAIT(7),CHAN7/1;
        COLCT,INT(4),WAIT TIME NET 7;
           ACT,,,MC;
;
M7      GOON;
           ACT,EXPON(TMT7);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT7),ATRIB(2).GT.0.0,M7;
           ACT;
        FREE,CHAN7/1;
        FREE,NET7/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD8),,4;
        ASSIGN,ATRIB(1)=8,1;
           ACT,,NNRSC(NET8).EQ.0,KILL;
           ACT;
        AWAIT(38),NET8/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM8,SDTM8),
                ATRIB(2)=ATRIB(3);
        AWAIT(8),CHAN8/1;
        COLCT,INT(4),WAIT TIME NET 8;
           ACT,,,MC;
```

```
;
M8      GOON;
           ACT,EXPON(TMT8);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT8),ATRIB(2).GT.0.0,M8;
           ACT;
        FREE,CHAN8/1;
        FREE,NET8/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD9),,4;
        ASSIGN,ATRIB(1)=9,1;
           ACT,,NNRSC(NET9).EQ.0,KILL;
           ACT;
        AWAIT(39),NET9/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM9,SDTM9),
              ATRIB(2)=ATRIB(3);
        AWAIT(9),CHAN9/1;
        COLCT,INT(4),WAIT TIME NET 9;
           ACT,,,MC;
;
M9      GOON;
           ACT,EXPON(TMT9);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT9),ATRIB(2).GT.0.0,M9;
           ACT;
        FREE,CHAN9/1;
        FREE,NET9/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD10),,4;
        ASSIGN,ATRIB(1)=10,1;
           ACT,,NNRSC(NET10).EQ.0,KILL;
           ACT;
        AWAIT(40),NET10/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM10,SDTM10),
              ATRIB(2)=ATRIB(3);
        AWAIT(10),CHAN10/1;
        COLCT,INT(4),WAIT TIME NET 10;
           ACT,,,MC;
;
M10     GOON;
           ACT,EXPON(TMT10);
        ASSIGN.ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT10),ATRIB(2).GT.0.0,M10;
           ACT;
        FREE,CHAN10/1;
        FREE,NET10/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD11),,4;
        ASSIGN,ATRIB(1)=11,1;
```

```
         ACT,,NNRSC(NET11).EQ.0,KILL;
         ACT;
      AWAIT(41),NET11/1;
      ASSIGN,ATRIB(3)=RNORM(MTPM11,SDTM11),
             ATRIB(2)=ATRIB(3);
      AWAIT(11),CHAN11/1;
      COLCT,INT(4),WAIT TIME NET 11;
         ACT,,,MC;
;
M11   GOON;
         ACT,EXPON(TMT11);
      ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
         ACT,EXPON(MTBT11),ATRIB(2).GT.0.0,M11;
         ACT;
      FREE,CHAN11/1;
      FREE,NET11/1;
      TERM;
;
      CREATE,EXPON(1/XX(1)/LOAD12),,4;
      ASSIGN,ATRIB(1)=12,1;
         ACT,,NNRSC(NET12).EQ.0,KILL;
         ACT;
      AWAIT(42),NET12/1;
      ASSIGN,ATRIB(3)=RNORM(MTPM12,SDTM12),
             ATRIB(2)=ATRIB(3);
      AWAIT(12),CHAN12/1;
      COLCT,INT(4),WAIT TIME NET 12;
         ACT,,,MC;
;
M12   GOON;
         ACT,EXPON(TMT12);
      ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
         ACT,EXPON(MTBT12),ATRIB(2).GT.0.0,M12;
         ACT;
      FREE,CHAN12/1;
      FREE,NET12/1;
      TERM;
;
      CREATE,EXPON(1/XX(1)/LOAD13),,4;
      ASSIGN,ATRIB(1)=13,1;
         ACT,,NNRSC(NET13).EQ.0,KILL;
         ACT;
      AWAIT(43),NET13/1;
      ASSIGN,ATRIB(3)=RNORM(MTPM13,SDTM13),
             ATRIB(2)=ATRIB(3);
      AWAIT(13),CHAN13/1;
      COLCT,INT(4),WAIT TIME NET 13;
         ACT,,,MC;
;
M13   GOON;
         ACT,EXPON(TMT13);
      ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
```

```
            ACT,EXPON(MTBT13),ATRIB(2).GT.0.0,M13;
            ACT;
        FREE,CHAN13/1;
        FREE,NET13/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD14),,4;
        ASSIGN,ATRIB(1)=14,1;
            ACT,,NNRSC(NET14).EQ.0,KILL;
            ACT;
        AWAIT(44),NET14/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM14,SDTM14),
               ATRIB(2)=ATRIB(3);
        AWAIT(14),CHAN14/1;
        COLCT,INT(4),WAIT TIME NET 14;
            ACT,,,MC;
;
M14     GOON;
            ACT,EXPON(TMT14);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
            ACT,EXPON(MTBT14),ATRIB(2).GT.0.0,M14;
            ACT;
        FREE,CHAN14/1;
        FREE,NET14/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD15),,4;
        ASSIGN,ATRIB(1)=15,1;
            ACT,,NNRSC(NET15).EQ.0,KILL;
            ACT;
        AWAIT(45),NET15/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM15,SDTM15),
               ATRIB(2)=ATRIB(3);
        AWAIT(15),CHAN15/1;
        COLCT,INT(4),WAIT TIME NET 15;
            ACT,,,MC;
;
M15     GOON;
            ACT.EXPON(TMT15);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
            ACT,EXPON(MTBT15),ATRIB(2).GT.0.0,M15;
            ACT;
        FREE,CHAN15/1;
        FREE,NET15/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD16),,4;
        ASSIGN,ATRIB(1)=16,1;
            ACT,,NNRSC(NET16).EQ.0,KILL;
            ACT;
        AWAIT(46),NET16/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM16,SDTM16),
```

```
         ATRIB(2)=ATRIB(3);
      AWAIT(16),CHAN16/1;
      COLCT,INT(4),WAIT TIME NET 16;
         ACT,,,MC;
;
M16   GOON;
         ACT,EXPON(TMT16);
      ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
         ACT,EXPON(MTBT16),ATRIB(2).GT.0.0,M16;
         ACT;
      FREE,CHAN16/1;
      FREE,NET16;
      TERM;
;
      CREATE,EXPON(1/XX(1)/LOAD17),,4;
      ASSIGN,ATRIB(1)=17,1;
         ACT,,NNRSC(NET17).EQ.0,KILL;
         ACT;
      AWAIT(47),NET17/1;
      ASSIGN,ATRIB(3)=RNORM(MTPM17,SDTM17),
            ATRIB(2)=ATRIB(3);
      AWAIT(17),CHAN17/1;
      COLCT,INT(4),WAIT TIME NET 17;
         ACT,,,MC;
;
M17   GOON;
         ACT,EXPON(TMT17);
      ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
         ACT,EXPON(MTBT17),ATRIB(2).GT.0.0,M17;
         ACT;
      FREE,CHAN17/1;
      FREE,NET17/1;
      TERM;
;
      CREATE,EXPON(1/XX(1)/LOAD18),,4;
      ASSIGN,ATRIB(1)=18,1;
         ACT,,NNRSC(NET18).EQ.0,KILL;
         ACT;
      AWAIT(48),NET18/1;
      ASSIGN,ATRIB(3)=RNORM(MTPM18,SDTM18),
            ATRIB(2)=ATRIB(3);
      AWAIT(18),CHAN18/1;
      COLCT,INT(4),WAIT TIME NET 18;
         ACT,,,MC;
;
M18   GOON;
         ACT,EXPON(TMT18);
      ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
         ACT,EXPON(MTBT18),ATRIB(2).GT.0.0,M18;
         ACT;
      FREE,CHAN18/1;
      FREE,NET18/1;
```

```
        TERM;

        CREATE,EXPON(1/XX(1)/LOAD19),,4;
        ASSIGN,ATRIB(1)=19,1;
           ACT,,NNRSC(NET19).EQ.0,KILL;
           ACT;
        AWAIT(49),NET19/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM19,SDTM19),
               ATRIB(2)=ATRIB(3);
        AWAIT(19),CHAN19/1;
        COLCT,INT(4),WAIT TIME NET 19;
           ACT,,,MC;
;
M19     GOON;
           ACT,EXPON(TMT19);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT19),ATRIB(2).GT.0.0,M19;
           ACT;
        FREE,CHAN19/1;
        FREE,NET19/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD20),,4;
        ASSIGN,ATRIB(1)=20,1;
           ACT,,NNRSC(NET20).EQ.0,KILL;
           ACT;
        AWAIT(50),NET20/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM20,SDTM20),
               ATRIB(2)=ATRIB(3);
        AWAIT(20),CHAN20/1;
        COLCT,INT(4),WAIT TIME NET 20;
           ACT,,,MC;
;
M20     GOON;
           ACT,EXPON(TMT20);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT20),ATRIB(2).GT.0.0,M20;
           ACT;
        FREE,CHAN20/1;
        FREE,NET20/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD21),,4;
        ASSIGN,ATRIB(1)=21,1;
           ACT,,NNRSC(NET21).EQ.0,KILL;
           ACT;
        AWAIT(51),NET21/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM21,SDTM21),
               ATRIB(2)=ATRIB(3);
        AWAIT(21),CHAN21/1;
        COLCT,INT(4),WAIT TIME NET 21;
           ACT,,,MC;
```

```
;
M21     GOON;
           ACT,EXPON(TMT21);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT21),ATRIB(2).GT.0.0,M21;
           ACT;
        FREE,CHAN21/1;
        FREE,NET21/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD22),,4;
        ASSIGN,ATRIB(1)=22,1;
           ACT,,NNRSC(NET22).EQ.0,KILL;
           ACT;
        AWAIT(52),NET22/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM22,SDTM22).
               ATRIB(2)=ATRIB(3);
        AWAIT(22),CHAN22/1;
        COLCT,INT(4),WAIT TIME NET 22;
           ACT,,,MC;
;
M22     GOON;
           ACT,EXPON(TMT22);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT22),ATRIB(2).GT.0.0,M22;
           ACT;
        FREE,CHAN22/1;
        FREE,NET22/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD23),,4;
        ASSIGN,ATRIB(1)=23,1;
           ACT,,NNRSC(NET23).EQ.0,KILL;
           ACT;
        AWAIT(53),NET23/1;
        ASSIGN,ATRIB(3)=RNORM(MTPM23,SDTM23),
               ATRIB(2)=ATRIB(3);
        AWAIT(23),CHAN23/1;
        COLCT,INT(4),WAIT TIME NET 23;
           ACT,,,MC;
;
M23     GOON;
           ACT,EXPON(TMT23);
        ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
           ACT,EXPON(MTBT23),ATRIB(2).GT.0.0,M23;
           ACT;
        FREE,CHAN23/1;
        FREE,NET23/1;
        TERM;
;
        CREATE,EXPON(1/XX(1)/LOAD24),,4;
        ASSIGN,ATRIB(1)=24,1;
```

```
       ACT,,NNRSC(NET24).EQ.0,KILL;
       ACT;
    AWAIT(54),NET24/1;
    ASSIGN,ATRIB(3)=RNORM(MTPM24,SDTM24),
           ATRIB(2)=ATRIB(3);
    AWAIT(24),CHAN24/1;
    COLCT,INT(4),WAIT TIME NET 24;
       ACT,,,MC;
;
M24 GOON;
       ACT,EXPON(TMT24);
    ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
       ACT,EXPON(MTBT24),ATRIB(2).GT.0.0,M24;
       ACT;
    FREE,CHAN24/1;
    FREE,NET24/1;
    TERM;
;
    CREATE,EXPON(1/XX(1)/LOAD25),,4;
    ASSIGN,ATRIB(1)=25,1;
       ACT,,NNRSC(NET25).EQ.0,KILL;
       ACT;
    AWAIT(55),NET25/1;
    ASSIGN,ATRIB(3)=RNORM(MTPM25,SDTM25),
           ATRIB(2)=ATRIB(3);
    AWAIT(25),CHAN25/1;
    COLCT,INT(4),WAIT TIME NET 25;
       ACT,,,MC;
;
M25 GOON;
       ACT,EXPON(TMT25);
    ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
       ACT,EXPON(MTBT25),ATRIB(2).GT.0.0,M25;
       ACT;
    FREE,CHAN25/1;
    FREE,NET25/1;
    TERM;
;
    CREATE,EXPON(1/XX(1)/LOAD26),,4;
    ASSIGN,ATRIB(1)=26,1;
       ACT,,NNRSC(NET26).EQ.0,KILL;
       ACT;
    AWAIT(56),NET26/1;
    ASSIGN,ATRIB(3)=RNORM(MTPM26,SDTM26),
           ATRIB(2)=ATRIB(3);
    AWAIT(26),CHAN26/1;
    COLCT,INT(4),WAIT TIME NET 26;
       ACT,,,MC;
;
M26 GOON;
       ACT,EXPON(TMT26);
    ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
```

```
        ACT,EXPON(MTBT26),ATRIB(2).GT.0.0,M26;
        ACT;
     FREE,CHAN26/1;
     FREE,NET26/1;
     TERM;
;
     CREATE,EXPON(1/XX(1)/LOAD27),,4;
     ASSIGN,ATRIB(1)=27,1;
        ACT,,NNRSC(NET27).EQ.0,KILL;
        ACT;
     AWAIT(57),NET27/1;
     ASSIGN,ATRIB(3)=RNORM(MTPM27,SDTM27),
            ATRIB(2)=ATRIB(3);
     AWAIT(27),CHAN27/1;
     COLCT,INT(4),WAIT TIME NET 27;
        ACT,,,MC;
;
M27  GOON;
        ACT,EXPON(TMT27);
     ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
        ACT,EXPON(MTBT27),ATRIB(2).GT.0.0,M27;
        ACT;
     FREE,CHAN27/1;
     FREE,NET27/1;
     TERM;
;
     CREATE,EXPON(1/XX(1)/LOAD28),,4;
     ASSIGN,ATRIB(1)=28,1;
        ACT,,NNRSC(NET28).EQ.0,KILL;
        ACT;
     AWAIT(58),NET28/1;
     ASSIGN,ATRIB(3)=RNORM(MTPM28,SDTM28),
            ATRIB(2)=ATRIB(3);
     AWAIT(28),CHAN28/1;
     COLCT,INT(4),WAIT TIME NET 28;
        ACT,,,MC;
;
M28  GOON;
        ACT,EXPON(TMT28);
     ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
        ACT,EXPON(MTBT28),ATRIB(2).GT.0.0,M28;
        ACT;
     FREE,CHAN28/1;
     FREE,NET28/1;
     TERM;
;
     CREATE,EXPON(1/XX(1)/LOAD29),,4;
     ASSIGN,ATRIB(1)=29,1;
        ACT,,NNRSC(NET29).EQ.0,KILL;
        ACT;
     AWAIT(59),NET29/1;
     ASSIGN,ATRIB(3)=RNORM(MTPM29,SDTM29),
```

```
              ATRIB(2)=ATRIB(3);
       AWAIT(29),CHAN29/1;
       COLCT,INT(4),WAIT TIME NET 29;
          ACT,,,MC;
;
M29    GOON;
          ACT,EXPON(TMT29);
       ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
          ACT,EXPON(MTBT29),ATRIB(2).GT.0.0,M29;
          ACT;
       FREE,CHAN29/1;
       FREE,NET29/1;
       TERM
;
       CREATE,EXPON(1/XX(1)/LOAD30),,4;
       ASSIGN,ATRIB(1)=30,1;
          ACT,,NNRSC(NET30).EQ.0,KILL;
          ACT;
       AWAIT(60),NET30/1;
       ASSIGN,ATRIB(3)=RNORM(MTPM30,SDTM30),
              ATRIB(2)=ATRIB(3);
       AWAIT(30),CHAN30/1;
       COLCT,INT(4),WAIT TIME NET 30;
          ACT,,,MC;
;
M30    GOON;
          ACT,EXPON(TMT30);
       ASSIGN,ATRIB(2)=ATRIB(2)-1.0,1;
          ACT,EXPON(MTBT30),ATRIB(2).GT.0.0,M30;
          ACT;
       FREE,CHAN30/1;
       FREE,NET30/1;
       TERM;
;
;
; THE MAIN COLLECTION NODE COLLECTS THE WAIT TIMES FOR
; ALL THE ENTITIES IN THE SYSTEM
;
MC     COLCT,INT(4),TOTAL WAIT TIME;
;
; THE ENTITIES RETURN TO THEIR PARTS OF THE SYSTEM
;
          ACT,,ATRIB(1).EQ.1,M1;
          ACT,,ATRIB(1).EQ.2,M2;
          ACT,,ATRIB(1).EQ.3,M3;
          ACT,,ATRIB(1).EQ.4,M4;
          ACT,,ATRIB(1).EQ.5,M5;
          ACT,,ATRIB(1).EQ.6,M6;
          ACT,,ATRIB(1).EQ.7,M7;
          ACT,,ATRIB(1).EQ.8,M8;
          ACT,,ATRIB(1).EQ.9,M9;
          ACT,,ATRIB(1).EQ.10,M10;
```

```
            ACT,,ATRIB(1).EQ.11,M11;
            ACT,,ATRIB(1).EQ.12,M12;
            ACT,,ATRIB(1).EQ.13,M13;
            ACT,,ATRIB(1).EQ.14,M14;
            ACT,,ATRIB(1).EQ.15,M15;
            ACT,,ATRIB(1).EQ.16,M16;
            ACT,,ATRIB(1).EQ.17,M17;
            ACT,,ATRIB(1).EQ.18,M18;
            ACT,,ATRIB(1).EQ.19,M19;
            ACT,,ATRIB(1).EQ.20,M20;
            ACT,,ATRIB(1).EQ.21,M21;
            ACT,,ATRIB(1).EQ.22,M22;
            ACT,,ATRIB(1).EQ.23,M23;
            ACT,,ATRIB(1).EQ.24,M24;
            ACT,,ATRIB(1).EQ.25,M25;
            ACT,,ATRIB(1).EQ.26,M26;
            ACT,,ATRIB(1).EQ.27,M27;
            ACT,,ATRIB(1).EQ.28,M28;
            ACT,,ATRIB(1).EQ.29,M29;
            ACT,,ATRIB(1).EQ.30,M30;
KILL    TERM;
        ENDNETWORK;
INIT,0,177800;        RUN FOR 48 HOURS
MONT,CLEAR,5000;
SIMULATE;
MONT,CLEAR,5000;
SEEDS,90700,99505,58629,16379,54613,
       42880,12952,32307,56941,64952;
SIMULATE;
MONT,CLEAR,5000;
SEEDS,91291,39615,63348,97758,01263,
       44394,10634,42508,05585,18593;
FIN;
```

```
;
;           Appendix B:  SLAM Code For the Trunked Simulation
;                                  Model
;
;
;
GEN,T C FARRELL,HTS,7/14/88,3,N,N;
LIMITS,62,10,100;
;
;     ¦ NUM    ¦         ¦ TX     ¦ MEAN    ¦ MEAN    ¦ DEV     ¦     ¦
;     ¦ RADIO  ¦         ¦ MEAN   ¦ TIME    ¦ TX/     ¦ TX/     ¦     ¦
; FL  ¦ ON FL  ¦ LOAD    ¦ TIME   ¦ BTWN TX ¦ MSG     ¦ MSG     ¦ PR  ¦
;-----¦--------¦---------¦--------¦---------¦---------¦---------¦-----¦
;  1  ¦ #1     ¦ LOAD1   ¦ TMT1   ¦ MTBT1   ¦ MTPM1   ¦ SDTM1   ¦ P1  ¦
;  2  ¦ #2     ¦ LOAD2   ¦ TMT2   ¦ MTBT2   ¦ MTPM2   ¦ SDTM2   ¦ P2  ¦
;  3  ¦ #3     ¦ LOAD3   ¦ TMT3   ¦ MTBT3   ¦ MTPM3   ¦ SDTM3   ¦ P3  ¦
;  4  ¦ #4     ¦ LOAD4   ¦ TMT4   ¦ MTBT4   ¦ MTPM4   ¦ SDTM4   ¦ P4  ¦
;  5  ¦ #5     ¦ LOAD5   ¦ TMT5   ¦ MTBT5   ¦ MTPM5   ¦ SDTM5   ¦ P5  ¦
;  6  ¦ #6     ¦ LOAD6   ¦ TMT6   ¦ MTBT6   ¦ MTPM6   ¦ SDTM6   ¦ P6  ¦
;  7  ¦ #7     ¦ LOAD7   ¦ TMT7   ¦ MTBT7   ¦ MTPM7   ¦ SDTM7   ¦ P7  ¦
;  8  ¦ #8     ¦ LOAD8   ¦ TMT8   ¦ MTBT8   ¦ MTPM8   ¦ SDTM8   ¦ P8  ¦
;  9  ¦ #9     ¦ LOAD9   ¦ TMT9   ¦ MTBT9   ¦ MTPM9   ¦ SDTM9   ¦ P9  ¦
; 10  ¦ #10    ¦ LOAD10  ¦ TMT10  ¦ MTBT10  ¦ MTPM10  ¦ SDTM10  ¦ P10 ¦
; 11  ¦ #11    ¦ LOAD11  ¦ TMT11  ¦ MTBT11  ¦ MTPM11  ¦ SDTM11  ¦ P11 ¦
; 12  ¦ #12    ¦ LOAD12  ¦ TMT12  ¦ MTBT12  ¦ MTPM12  ¦ SDTM12  ¦ P12 ¦
; 13  ¦ #13    ¦ LOAD13  ¦ TMT13  ¦ MTBT13  ¦ MTPM13  ¦ SDTM13  ¦ P13 ¦
; 14  ¦ #14    ¦ LOAD14  ¦ TMT14  ¦ MTBT14  ¦ MTPM14  ¦ SDTM14  ¦ P14 ¦
; 15  ¦ #15    ¦ LOAD15  ¦ TMT15  ¦ MTBT15  ¦ MTPM15  ¦ SDTM15  ¦ P15 ¦
; 16  ¦ #16    ¦ LOAD16  ¦ TMT16  ¦ MTBT16  ¦ MTPM16  ¦ SDTM16  ¦ P16 ¦
; 17  ¦ #17    ¦ LOAD17  ¦ TMT17  ¦ MTBT17  ¦ MTPM17  ¦ SDTM17  ¦ P17 ¦
; 18  ¦ #18    ¦ LOAD18  ¦ TMT18  ¦ MTBT18  ¦ MTPM18  ¦ SDTM18  ¦ P18 ¦
; 19  ¦ #19    ¦ LOAD19  ¦ TMT19  ¦ MTBT19  ¦ MTPM19  ¦ SDTM19  ¦ P19 ¦
; 20  ¦ #20    ¦ LOAD20  ¦ TMT20  ¦ MTBT20  ¦ MTPM20  ¦ SDTM20  ¦ P20 ¦
; 21  ¦ #21    ¦ LOAD21  ¦ TMT21  ¦ MTBT21  ¦ MTPM21  ¦ SDTM21  ¦ P21 ¦
; 22  ¦ #22    ¦ LOAD22  ¦ TMT22  ¦ MTBT22  ¦ MTPM22  ¦ SDTM22  ¦ P22 ¦
; 23  ¦ #23    ¦ LOAD23  ¦ TMT23  ¦ MTBT23  ¦ MTPM23  ¦ SDTM23  ¦ P23 ¦
; 24  ¦ #24    ¦ LOAD24  ¦ TMT24  ¦ MTBT24  ¦ MTPM24  ¦ SDTM24  ¦ P24 ¦
; 25  ¦ #25    ¦ LOAD25  ¦ TMT25  ¦ MTBT25  ¦ MTPM25  ¦ SDTM25  ¦ P25 ¦
; 26  ¦ #26    ¦ LOAD26  ¦ TMT26  ¦ MTBT26  ¦ MTPM26  ¦ SDTM26  ¦ P26 ¦
; 27  ¦ #27    ¦ LOAD27  ¦ TMT27  ¦ MTBT27  ¦ MTPM27  ¦ SDTM27  ¦ P27 ¦
; 28  ¦ #28    ¦ LOAD28  ¦ TMT28  ¦ MTBT28  ¦ MTPM28  ¦ SDTM28  ¦ P28 ¦
; 29  ¦ #29    ¦ LOAD29  ¦ TMT29  ¦ MTBT29  ¦ MTPM29  ¦ SDTM29  ¦ P29 ¦
; 30  ¦ #30    ¦ LOAD30  ¦ TMT30  ¦ MTBT30  ¦ MTPM30  ¦ SDTM30  ¦ P30 ¦
;----------------------------------------------------------------------
;
; CH = NUMBER OF CHANNELS
; RU = TIME IN RECENT USER QUEUE
; MD = MECHANICAL DELAY
;
; ATRIB(1)=FLEET NUMBER
; ATRIB(2)=TRANSMISSIONS LEFT IN MESSAGE
; ATRIB(3)=TRANSMISSIONS IN MESSAGE
```

```
; ATRIB(4)-TIME MESSAGE STARTED
; ATRIB(5)-TIME TRANSMISSION STARTED/ENDED
; ATRIB(6)-PRIORITY
; ATRIB(7)-TRANSMISSION MEAN TIME
; ATRIB(8)-MEAN TIME BETWEEN TRANSMISSIONS
; ATRIB(9)-MEAN TRANSMISSIONS/MESSAGE
; ATRIB(10)-STANDARD DEVIATION OF TRANSMISSIONS/MESSAGE
;
; ASSIGN THE RECENT USER QUEUE AND THE QUEUE OF
; TRANSMISSIONS WAITING FOR A CHANNEL THEIR PROPER
; PRIORITIES
;
PRIORITY/61,LIFO/62,LVF(6);
;
; XX(31) IS THE LOAD FACTOR
;
INTLC,XX(31)=1;
;
; XX(1) THRU XX(30) ARE THE ENDING TIMES OF THE LAST
; TRANSMISSION OF A FLEET
;
INTLC,XX(1)=0;
INTLC,XX(2)=0;
INTLC,XX(3)=0;
INTLC,XX(4)=0;
INTLC,XX(5)=0;
INTLC,XX(6)=0;
INTLC,XX(7)=0;
INTLC,XX(8)=0;
INTLC,XX(9)=0;
INTLC,XX(10)=0;
INTLC,XX(11)=0;
INTLC,XX(12)=0;
INTLC,XX(13)=0;
INTLC,XX(14)=0;
INTLC,XX(15)=0;
INTLC,XX(16)=0;
INTLC,XX(17)=0;
INTLC,XX(18)=0;
INTLC,XX(19)=0;
INTLC,XX(20)=0;
INTLC,XX(21)=0;
INTLC,XX(22)=0;
INTLC,XX(23)=0;
INTLC,XX(24)=0;
INTLC,XX(25)=0;
INTLC,XX(26)=0;
INTLC,XX(27)=0;
INTLC,XX(28)=0;
INTLC,XX(29)=0;
INTLC,XX(30)=0;
;
```

```
NETWORK;
;
; EACH FLEET IS ASSIGNED A RESOURCE
;
       RESOURCE/1,FLT1,1/2,FLT2,2/3,FLT3,3/4,FLT4,4;
       RESOURCE/5,FLT5,5/6,FLT6,6/7,FLT7,7/8,FLT8,8;
       RESOURCE/9,FLT9,9/10,FLT10,10/11,FLT11,11/12,FLT12,12;
       RESOURCE/13,FLT13,13/14,FLT14,14/15,FLT15,15;
       RESOURCE/16,FLT16,16/17,FLT17,17/18,FLT18,18;
       RESOURCE/19,FLT19,19/20,FLT20,20/21,FLT21,21;
       RESOURCE/22,FLT22,22/23,FLT23,23/24,FLT24,24;
       RESOURCE/25,FLT25,25/26,FLT26,26/27,FLT27,27;
       RESOURCE/28,FLT28,28/29,FLT29,29/30,FLT30,30;
;
; EACH RADIO IS ASSIGNED A RESOURCE
;
       RESOURCE/31,RAD1(#1),31;
       RESOURCE/32,RAD2(#2),32;
       RESOURCE/33,RAD3(#3),33;
       RESOURCE/34,RAD4(#4),34;
       RESOURCE/35,RAD5(#5),35;
       RESOURCE/36,RAD6(#6),36;
       RESOURCE/37,RAD7(#7),37;
       RESOURCE/38,RAD8(#8),38;
       RESOURCE/39,RAD9(#9),39;
       RESOURCE/40,RAD10(#10),40;
       RESOURCE/41,RAD11(#11),41;
       RESOURCE/42,RAD12(#12),42;
       RESOURCE/43,RAD13(#13),43;
       RESOURCE/44,RAD14(#14),44;
       RESOURCE/45,RAD15(#15),45;
       RESOURCE/46,RAD16(#16),46;
       RESOURCE/47,RAD17(#17),47;
       RESOURCE/48,RAD18(#18),48;
       RESOURCE/49,RAD19(#19),49;
       RESOURCE/50,RAD20(#20),50;
       RESOURCE/51,RAD21(#21),51;
       RESOURCE/52,RAD22(#22),52;
       RESOURCE/53,RAD23(#23),53;
       RESOURCE/54,RAD24(#24),54;
       RESOURCE/55,RAD25(#25),55;
       RESOURCE/56,RAD26(#26),56;
       RESOURCE/57,RAD27(#27),57;
       RESOURCE/58,RAD28(#28),58;
       RESOURCE/59,RAD29(#29),59;
       RESOURCE/60,RAD30(#30),60;
;
; EACH VOICE CHANNEL IS ASSIGNED A RESOURCE
;
       RESOURCE/CHAN(CH),61,62;
;
; CREATE ENTITIES FOR THE FLEET AND ASSIGN ITS ATRIBUTES
```

```
;
      CREATE,EXPON(1/XX(31)/LOAD1),,4;
      ASSIGN,ATRIB(1)=1,ATRIB(6)=P1,
             ATRIB(7)=TMT1,ATRIB(8)=MTBT1,
             ATRIB(9)=MTPM1,ATRIB(10)=SDTM1,1;
;
; KILL THE ENTITY IF NO RADIOS ARE AVAILABLE
;
         ACT,,NNRSC(RAD1).EQ.0,KILL;
         ACT;
;
; ENTITY SEIZES A RADIO
;
      AWAIT(31),RAD1/1;
;
; THIS AWAIT NODE ONLY ALLOWS ONE ENTITY IN THE FLEET
; TO BE IN THE SYSTEM AT A TIME
;
      AWAIT(1),FLT1/1;
;
; COLLECT THE TIME AN ENTITY WAITS FROM THE TIME IT WANTS
; TO MAKE CALL TO THE TIME ITS FLEET IS CLEAR
;
      COLCT,INT(4),INT DELAY FLT 1;
;
; ASSIGN THE ENDING TIME OF THE LAST TRANSMISSION FROM THE
; FLEET TO ATRIB(5)
;
      ASSIGN,ATRIB(5)=XX(1);
         ACT,,,MSGC;
;
; CODE REPEATS FOR EACH FLEET
;
      CREATE,EXPON(1/XX(31)/LOAD2),,4;
      ASSIGN,ATRIB(1)=2,ATRIB(6)=P2.
             ATRIB(7)=TMT2,ATRIB(8)=MTBT2,
             ATRIB(9)=MTPM2,ATRIB(10)=SDTM2,1;
         ACT,,NNRSC(RAD2).EQ.0,KILL;
         ACT;
      AWAIT(32),RAD2/1;
      AWAIT(2),FLT2/1;
      COLCT,INT(4),INT DELAY FLT 2;
      ASSIGN,ATRIB(5)=XX(2);
         ACT,,,MSGC;
;
      CREATE,EXPON(1/XX(31)/LOAD3),,4;
      ASSIGN,ATRIB(1)=3,ATRIB(6)=P3,
             ATRIB(7)=TMT3,ATRIB(8)=MTBT3,
             ATRIB(9)=MTPM3,ATRIB(10)=SDTM3,1;
         ACT,,NNRSC(RAD3).EQ.0,KILL;
         ACT;
      AWAIT(33),RAD3/1;
```

```
        AWAIT(3),FLT3/1;
        COLCT,INT(4),INT DELAY FLT 3;
        ASSIGN,ATRIB(5)=XX(3);
          ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD4),,4;
        ASSIGN,ATRIB(1)=4,ATRIB(6)=P4,
              ATRIB(7)=TMT4,ATRIB(8)=MTBT4,
              ATRIB(9)=MTPM4,ATRIB(10)=SDTM4,1;
          ACT,,NNRSC(RAD4).EQ.0,KILL;
          ACT;
        AWAIT(34),RAD4/1;
        AWAIT(4),FLT4/1;
        COLCT,INT(4),INT DELAY FLT 4;
        ASSIGN,ATRIB(5)=XX(4);
          ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD5),,4;
        ASSIGN,ATRIB(1)=5,ATRIB(6)=P5,
              ATRIB(7)=TMT5,ATRIB(8)=MTBT5,
              ATRIB(9)=MTPM5,ATRIB(10)=SDTM5,1;
          ACT,,NNRSC(RAD5).EQ.0,KILL;
          ACT;
        AWAIT(35),RAD5/1;
        AWAIT(5),FLT5/1;
        COLCT,INT(4),INT DELAY FLT 5;
        ASSIGN,ATRIB(5)=XX(5);
          ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD6),,4;
        ASSIGN,ATRIB(1)=6,ATRIB(6)=P6,
              ATRIB(7)=TMT6,ATRIB(8)=MTBT6,
              ATRIB(9)=MTPM6,ATRIB(10)=SDTM6,1;
          ACT,,NNRSC(RAD6).EQ.0,KILL;
          ACT;
        AWAIT(36),RAD6/1;
        AWAIT(6),FLT6/1;
        COLCT,INT(4),INT DELAY FLT 6;
        ASSIGN,ATRIB(5)=XX(6);
          ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD7),,4;
        ASSIGN,ATRIB(1)=7,ATRIB(6)=P7,
              ATRIB(7)=TMT7,ATRIB(8)=MTBT7,
              ATRIB(9)=MTPM7,ATRIB(10)=SDTM7,1;
          ACT,,NNRSC(RAD7).EQ.0,KILL;
          ACT;
        AWAIT(37),RAD7/1;
        AWAIT(7),FLT7/1;
        COLCT,INT(4),INT DELAY FLT 7;
        ASSIGN,ATRIB(5)=XX(7);
          ACT,,,MSGC;
```

```
;
        CREATE,EXPON(1/XX(31)/LOAD8),,4;
        ASSIGN,ATRIB(1)=8,ATRIB(6)=P8,
               ATRIB(7)=TMT8,ATRIB(8)=MTBT8,
               ATRIB(9)=MTPM8,ATRIB(10)=SDTM8,1;
           ACT,,NNRSC(RAD8).EQ.0,KILL;
           ACT;
        AWAIT(38),RAD8/1;
        AWAIT(8),FLT8/1;
        COLCT,INT(4),INT DELAY FLT 8;
        ASSIGN,ATRIB(5)=XX(8);
           ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD9),,4;
        ASSIGN,ATRIB(1)=9,ATRIB(6)=P9,
               ATRIB(7)=TMT9,ATRIB(8)=MTBT9,
               ATRIB(9)=MTPM9,ATRIB(10)=SDTM9,1;
           ACT,,NNRSC(RAD9).EQ.0,KILL;
           ACT;
        AWAIT(39),RAD9/1;
        AWAIT(9),FLT9/1;
        COLCT,INT(4),INT DELAY FLT 9;
        ASSIGN,ATRIB(5)=XX(9);
           ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD10),,4;
        ASSIGN,ATRIB(1)=10,ATRIB(6)=P10,
               ATRIB(7)=TMT10,ATRIB(8)=MTBT10,
               ATRIB(9)=MTPM10,ATRIB(10)=SDTM10,1;
           ACT,,NNRSC(RAD10).EQ.0,KILL;
           ACT;
        AWAIT(40),RAD10/1;
        AWAIT(10),FLT10/1;
        COLCT,INT(4),INT DELAY FLT 10;
        ASSIGN,ATRIB(5)=XX(10);
           ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD11),,4;
        ASSIGN,ATRIB(1)=11,ATRIB(6)=P11,
               ATRIB(7)=TMT11,ATRIB(8)=MTBT11,
               ATRIB(9)=MTPM11,ATRIB(10)=SDTM11,1;
           ACT,,NNRSC(RAD11).EQ.0,KILL;
           ACT;
        AWAIT(41),RAD11/1;
        AWAIT(11),FLT11/1;
        COLCT,INT(4),INT DELAY FLT 11;
        ASSIGN,ATRIB(5)=XX(11);
           ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD12),,4;
        ASSIGN,ATRIB(1)=12,ATRIB(6)=P12,
               ATRIB(7)=TMT12,ATRIB(8)=MTBT12,
```

```
        ATRIB(9)=MTPM12,ATRIB(10)=SDTM12,1;
     ACT,,NNRSC(RAD12).EQ.0,KILL;
     ACT;
  AWAIT(42),RAD12/1;
  AWAIT(12),FLT12/1;
  COLCT,INT(4),INT DELAY FLT 12;
  ASSIGN,ATRIB(5)=XX(12);
     ACT,,,MSGC;
;
  CREATE,EXPON(1/XX(31)/LOAD13),,4;
  ASSIGN,ATRIB(1)=13,ATRIB(6)=P13,
        ATRIB(7)=TMT13,ATRIB(8)=MTBT13,
        ATRIB(9)=MTPM13,ATRIB(10)=SDTM13,1;
     ACT,,NNRSC(RAD13).EQ.0,KILL;
     ACT;
  AWAIT(43),RAD13/1;
  AWAIT(13),FLT13/1;
  COLCT,INT(4),INT DELAY FLT 13;
  ASSIGN,ATRIB(5)=XX(13);
     ACT,,,MSGC;
;
  CREATE,EXPON(1/XX(31)/LOAD14),,4;
  ASSIGN,ATRIB(1)=14,ATRIB(6)=P14,
        ATRIB(7)=TMT14,ATRIB(8)=MTBT14,
        ATRIB(9)=MTPM14,ATRIB(10)=SDTM14,1;
     ACT,,NNRSC(RAD14).EQ.0,KILL;
     ACT;
  AWAIT(44),RAD14/1;
  AWAIT(14),FLT14/1;
  COLCT,INT(4),INT DELAY FLT 14;
  ASSIGN,ATRIB(5)=XX(14);
     ACT,,,MSGC;
;
  CREATE,EXPON(1/XX(31)/LOAD15),,4;
  ASSIGN,ATRIB(1)=15,ATRIB(6)=P15,
        ATRIB(7)=TMT15,ATRIB(8)=MTBT15,
        ATRIB(9)=MTPM15,ATRIB(10)=SDTM15,1;
     ACT,,NNRSC(RAD15).EQ.0,KILL;
     ACT;
  AWAIT(45),RAD15/1;
  AWAIT(15),FLT15/1;
  COLCT,INT(4),INT DELAY FLT 15;
  ASSIGN,ATRIB(5)=XX(15);
     ACT,,,MSGC;
;
  CREATE,EXPON(1/XX(31)/LOAD16),,4;
  ASSIGN,ATRIB(1)=16,ATRIB(6)=P16,
        ATRIB(7)=TMT16,ATRIB(8)=MTBT16,
        ATRIB(9)=MTPM16,ATRIB(10)=SDTM16,1;
     ACT,,NNRSC(RAD16).EQ.0,KILL;
     ACT;
  AWAIT(46),RAD16/1;
```

```
AWAIT(16),FLT16/1;
COLCT,INT(4),INT DELAY FLT 16;
ASSIGN,ATRIB(5)=XX(16);
   ACT,,,MSGC;
;
CREATE,EXPON(1/XX(31)/LOAD17),,4;
ASSIGN,ATRIB(1)=17,ATRIB(6)=P17,
       ATRIB(7)=TMT17,ATRIB(8)=MTBT17,
       ATRIB(9)=MTPM17,ATRIB(10)=SDTM17,1;
   ACT,,NNRSC(RAD17).EQ.0,KILL;
   ACT;
AWAIT(47),RAD17/1;
AWAIT(17),FLT17/1;
COLCT,INT(4),INT DELAY FLT 17;
ASSIGN,ATRIB(5)=XX(17);
   ACT,,,MSGC;
;
CREATE,EXPON(1/XX(31)/LOAD18),,4;
ASSIGN,ATRIB(1)=18,ATRIB(6)=P18,
       ATRIB(7)=TMT18,ATRIB(8)=MTBT18,
       ATRIB(9)=MTPM18,ATRIB(10)=SDTM18,1;
   ACT,,NNRSC(RAD18).EQ.0,KILL;
   ACT;
AWAIT(48),RAD18/1;
AWAIT(18),FLT18/1;
COLCT,INT(4),INT DELAY FLT 18;
ASSIGN,ATRIB(5)=XX(18);
   ACT,,,MSGC;
;
CREATE,EXPON(1/XX(31)/LOAD19),,4;
ASSIGN,ATRIB(1)=19,ATRIB(6)=P19,
       ATRIB(7)=TMT19,ATRIB(8)=MTBT19,
       ATRIB(9)=MTPM19,ATRIB(10)=SDTM19,1;
   ACT,,NNRSC(RAD19).EQ.0,KILL;
   ACT;
AWAIT(49),RAD19/1;
AWAIT(19),FLT19/1;
COLCT,INT(4),INT DELAY FLT 19;
ASSIGN,ATRIB(5)=XX(19);
   ACT,,,MSGC;
;
CREATE,EXPON(1/XX(31)/LOAD20),,4;
ASSIGN,ATRIB(1)=20,ATRIB(6)=P20,
       ATRIB(7)=TMT20,ATRIB(8)=MTBT20,
       ATRIB(9)=MTPM20,ATRIB(10)=SDTM20,1;
   ACT,,NNRSC(RAD20).EQ.0,KILL;
   ACT;
AWAIT(50),RAD20/1;
AWAIT(20),FLT20/1;
COLCT,INT(4),INT DELAY FLT 20;
ASSIGN,ATRIB(5)=XX(20);
   ACT,,,MSGC;
```

```
;
          CREATE,EXPON(1/XX(31)/LOAD21),,4;
          ASSIGN,ATRIB(1)=21,ATRIB(6)=P21,
                 ATRIB(7)=TMT21,ATRIB(8)=MTBT21,
                 ATRIB(9)=MTPM21,ATRIB(10)=SDTM21,1;
             ACT,,NNRSC(RAD21).EQ.0,KILL;
             ACT;
          AWAIT(51),RAD21/1;
          AWAIT(21),FLT21/1;
          COLCT,INT(4),INT DELAY FLT 21;
          ASSIGN,ATRIB(5)=XX(21);
             ACT,,,MSGC;
;
          CREATE,EXPON(1/XX(31)/LOAD22),,4;
          ASSIGN,ATRIB(1)=22,ATRIB(6)=P22,
                 ATRIB(7)=TMT22,ATRIB(8)=MTBT22,
                 ATRIB(9)=MTPM22,ATRIB(10)=SDTM22,1;
             ACT,,NNRSC(RAD22).EQ.0,KILL;
             ACT;
          AWAIT(52),RAD22/1;
          AWAIT(22),FLT22/1;
          COLCT,INT(4),INT DELAY FLT 22;
          ASSIGN,ATRIB(5)=XX(22);
             ACT,,,MSGC;
;
          CREATE,EXPON(1/XX(31)/LOAD23),,4;
          ASSIGN,ATRIB(1)=23,ATRIB(6)=P23,
                 ATRIB(7)=TMT23,ATRIB(8)=MTBT23,
                 ATRIB(9)=MTPM23,ATRIB(10)=SDTM23,1;
             ACT,,NNRSC(RAD23).EQ.0,KILL;
             ACT;
          AWAIT(53),RAD23/1;
          AWAIT(23),FLT23/1;
          COLCT,INT(4),INT DELAY FLT 23;
          ASSIGN,ATRIB(5)=XX(23);
             ACT,,,MSGC;
;
          CREATE,EXPON(1/XX(31)/LOAD24),,4;
          ASSIGN,ATRIB(1)=24,ATRIB(6)=P24,
                 ATRIB(7)=TMT24,ATRIB(8)=MTBT24,
                 ATRIB(9)=MTPM24,ATRIB(10)=SDTM24,1;
             ACT,,NNRSC(RAD24).EQ.0,KILL;
             ACT;
          AWAIT(54),RAD24/1;
          AWAIT(24),FLT24/1;
          COLCT,INT(4),INT DELAY FLT 24;
          ASSIGN,ATRIB(5)=XX(24);
             ACT,,,MSGC;
;
          CREATE,EXPON(1/XX(31)/LOAD25),,4;
          ASSIGN,ATRIB(1)=25,ATRIB(6)=P25,
                 ATRIB(7)=TMT25,ATRIB(8)=MTBT25,
```

```
          ATRIB(9)-MTPM25,ATRIB(10)-SDTM25,1;
     ACT,,NNRSC(RAD25).EQ.0,KILL;
     ACT;
AWAIT(55),RAD25/1;
AWAIT(25),FLT25/1;
COLCT,INT(4),INT DELAY FLT 25;
ASSIGN,ATRIB(5)-XX(25);
     ACT,,,MSGC;
;
CREATE,EXPON(1/XX(31)/LOAD26),,4;
ASSIGN,ATRIB(1)-26,ATRIB(6)-P26,
          ATRIB(7)-TMT26,ATRIB(8)-MTBT26,
          ATRIB(9)-MTPM26,ATRIB(10)-SDTM26,1;
     ACT,,NNRSC(RAD26).EQ.0,KILL;
     ACT;
AWAIT(56),RAD26/1;
AWAIT(26),FLT26/1;
COLCT,INT(4),INT DELAY FLT 26;
ASSIGN,ATRIB(5)-XX(26);
     ACT,,,MSGC;
;
CREATE,EXPON(1/XX(31)/LOAD27),,4;
ASSIGN,ATRIB(1)-27,ATRIB(6)-P27,
          ATRIB(7)-TMT27,ATRIB(8)-MTBT27,
          ATRIB(9)-MTPM27,ATRIB(10)-SDTM27,1;
     ACT,,NNRSC(RAD27).EQ.0,KILL;
     ACT;
AWAIT(57),RAD27/1;
AWAIT(27),FLT27/1;
COLCT,INT(4),INT DELAY FLT 27;
ASSIGN,ATRIB(5)-XX(27);
     ACT,,,MSGC;
;
CREATE,EXPON(1/XX(31)/LOAD28),,4;
ASSIGN,ATRIB(1)-28,ATRIB(6)-P28,
          ATRIB(7)-TMT28,ATRIB(8)-MTBT28,
          ATRIB(9)-MTPM28,ATRIB(10)-SDTM28,1;
     ACT,,NNRSC(RAD28).EQ.0,KILL;
     ACT;
AWAIT(58),RAD28/1;
AWAIT(28),FLT28/1;
COLCT,INT(4),INT DELAY FLT 28;
ASSIGN,ATRIB(5)-XX(28);
     ACT,,,MSGC;
;
CREATE,EXPON(1/XX(31)/LOAD29),,4;
ASSIGN,ATRIB(1)-29,ATRIB(6)-P29,
          ATRIB(7)-TMT29,ATRIB(8)-MTBT29,
          ATRIB(9)-MTPM29,ATRIB(10)-SDTM29,1;
     ACT,,NNRSC(RAD29).EQ.0,KILL;
     ACT;
AWAIT(59),RAD29/1;
```

```
        AWAIT(29),FLT29/1;
        COLCT,INT(4),INT DELAY FLT 29;
        ASSIGN,ATRIB(5)=XX(29);
           ACT,,,MSGC;
;
        CREATE,EXPON(1/XX(31)/LOAD30),,4;
        ASSIGN,ATRIB(1)=30,ATRIB(6)=P30,
               ATRIB(7)=TMT30,ATRIB(8)=MTBT30,
               ATRIB(9)=MTPM30,ATRIB(10)=SDTM30,1;
           ACT,,NNRSC(RAD30).EQ.0,KILL;
           ACT;
        AWAIT(60),RAD30/1;
        AWAIT(30),FLT30/1;
        COLCT,INT(4),INT DELAY FLT 30;
        ASSIGN,ATRIB(5)=XX(30);
           ACT,,,MSGC;
;
;
; DETERMINE TRANSMISSIONS/MESSAGE
;
MSGC    ASSIGN,ATRIB(3)=RNORM(ATRIB(9),ATRIB(10)),
               ATRIB(2)=ATRIB(3);
;
; DETERMINE WHETHER THE CALL IS SENT TO THE RECENT USER
; QUEUE
;
TRAN    GOON,1;
           ACTIVITY,,TNOW.LE.ATRIB(5)+RU,B1;
           ACT,,,B2;
;
; FILE 61 IS THE RECENT USER QUEUE AND IS SERVED LIFO
;
B1      ASSIGN,ATRIB(5)=TNOW;
RUQ     AWAIT(61),CHAN/1;
           ACT,,,B3;
;
; FILE 62 IS THE QUEUE OF TRANSMISSIONS WAITING FOR A
; CHANNEL.  IT IS A PRIORITY (LOW NUMBER SERVED FIRST)
; QUEUE.  TIES IN PRIORITY ARE SERVED FIFO
;
B2      ASSIGN,ATRIB(5)=TNOW;
CHQ     AWAIT(62),CHAN/1;
           ACT,,,B3
;
B3      GOON,1;
;
; MD SIMULATES THE WORST CASE MECHANICAL DELAY FOR CHANNEL
; ASSIGNMENT
;
; COLLECT STATISTICS ON DELAY DUE TO THE CHANNELS BEING
; UNAVAILABLE
;
```

```
          ACTIVITY,MD,ATRIB(1).EQ.1,CD1;
          ACTIVITY,MD,ATRIB(1).EQ.2,CD2;
          ACTIVITY,MD,ATRIB(1).EQ.3,CD3;
          ACTIVITY,MD,ATRIB(1).EQ.4,CD4;
          ACTIVITY,MD,ATRIB(1).EQ.5,CD5;
;
          ACTIVITY,MD,ATRIB(1).EQ.6,CD6;
          ACTIVITY,MD,ATRIB(1).EQ.7,CD7;
          ACTIVITY,MD,ATRIB(1).EQ.8,CD8;
          ACTIVITY,MD,ATRIB(1).EQ.9,CD9;
          ACTIVITY,MD,ATRIB(1).EQ.10,CD10;
;
          ACTIVITY,MD,ATRIB(1).EQ.11,CD11;
          ACTIVITY,MD,ATRIB(1).EQ.12,CD12;
          ACTIVITY,MD,ATRIB(1).EQ.13,CD13;
          ACTIVITY,MD,ATRIB(1).EQ.14,CD14;
          ACTIVITY,MD,ATRIB(1).EQ.15,CD15;
;
          ACTIVITY,MD,ATRIB(1).EQ.16,CD16;
          ACTIVITY,MD,ATRIB(1).EQ.17,CD17;
          ACTIVITY,MD,ATRIB(1).EQ.18,CD18;
          ACTIVITY,MD,ATRIB(1).EQ.19,CD19;
          ACTIVITY,MD,ATRIB(1).EQ.20,CD20;
;
          ACTIVITY,MD,ATRIB(1).EQ.21,CD21;
          ACTIVITY,MD,ATRIB(1).EQ.22,CD22;
          ACTIVITY,MD,ATRIB(1).EQ.23,CD23;
          ACTIVITY,MD,ATRIB(1).EQ.24,CD24;
          ACTIVITY,MD,ATRIB(1).EQ.25,CD25;
;
          ACTIVITY,MD,ATRIB(1).EQ.26,CD26;
          ACTIVITY,MD,ATRIB(1).EQ.27,CD27;
          ACTIVITY,MD,ATRIB(1).EQ.28,CD28;
          ACTIVITY,MD,ATRIB(1).EQ.29,CD29;
          ACTIVITY,MD,ATRIB(1).EQ.30,CD30;
;
CD1     COLCT,INT(5),FLT 1 CH DELAY;
          ACT,,,TCD;
CD2     COLCT,INT(5),FLT 2 CH DELAY;
          ACT,,,TCD;
CD3     COLCT,INT(5),FLT 3 CH DELAY;
          ACT,,,TCD;
CD4     COLCT,INT(5),FLT 4 CH DELAY;
          ACT,,,TCD;
CD5     COLCT,INT(5),FLT 5 CH DELAY;
          ACT,,,TCD;
;
CD6     COLCT,INT(5),FLT 6 CH DELAY;
          ACT,,,TCD;
CD7     COLCT,INT(5),FLT 7 CH DELAY;
          ACT,,,TCD;
CD8     COLCT,INT(5),FLT 8 CH DELAY;
```

```
          ACT,,,TCD;
CD9    COLCT,INT(5),FLT 9 CH DELAY;
          ACT,,,TCD;
CD10   COLCT,INT(5),FLT 10 CH DELAY;
          ACT,,,TCD;
;
CD11   COLCT,INT(5),FLT 11 CH DELAY;
          ACT,,,TCD;
CD12   COLCT,INT(5),FLT 12 CH DELAY;
          ACT,,,TCD;
CD13   COLCT,INT(5),FLT 13 CH DELAY;
          ACT,,,TCD;
CD14   COLCT,INT(5),FLT 14 CH DELAY;
          ACT,,,TCD;
CD15   COLCT,INT(5),FLT 15 CH DELAY;
          ACT,,,TCD;
;
CD16   COLCT,INT(5),FLT 16 CH DELAY;
          ACT,,,TCD;
CD17   COLCT,INT(5),FLT 17 CH DELAY;
          ACT,,,TCD;
CD18   COLCT,INT(5),FLT 18 CH DELAY;
          ACT,,,TCD;
CD19   COLCT,INT(5),FLT 19 CH DELAY;
          ACT,,,TCD;
CD20   COLCT,INT(5),FLT 20 CH DELAY;
          ACT,,,TCD;
;
CD21   COLCT,INT(5),FLT 21 CH DELAY;
          ACT,,,TCD;
CD22   COLCT,INT(5),FLT 22 CH DELAY;
          ACT,,,TCD;
CD23   COLCT,INT(5),FLT 23 CH DELAY;
          ACT,,,TCD;
CD24   COLCT,INT(5),FLT 24 CH DELAY;
          ACT,,,TCD;
CD25   COLCT,INT(5),FLT 25 CH DELAY;
          ACT,,,TCD;
;
CD26   COLCT,INT(5),FLT 26 CH DELAY;
          ACT,,,TCD;
CD27   COLCT,INT(5),FLT 27 CH DELAY;
          ACT,,,TCD;
CD28   COLCT,INT(5),FLT 28 CH DELAY;
          ACT,,,TCD;
CD29   COLCT,INT(5),FLT 29 CH DELAY;
          ACT,,,TCD;
CD30   COLCT,INT(5),FLT 30 CH DELAY;
          ACT,,,TCD;
;
TCD    COLCT,INT(5),TOTAL CH DELAY,,1;
;
```

```
; COLLECT STATISTICS ON TOTAL DELAY--THIS IS DELAY DUE
; TO WAIT TIME WITHIN A FLEET PLUS DELAY WAITING FOR A
; CHANNEL FOR THE FIRST TRANSMISSION IN A MESSAGE
;
            ACTIVITY,,ATRIB(3).NE.ATRIB(2),B4;
            ACT;
         COLCT,INT(4),MSG DELAY;
B4       GOON;
;
; TRANSMISSION TIME
;
         ACTIVITY,EXPON(ATRIB(7));
;
; ASSIGN TIME TRANSMISSION ENDS
;
         ASSIGN,ATRIB(2)=ATRIB(2)-1.0,ATRIB(5)=TNOW;
;
; FREE CHANNEL AT END OF TRANSMISSION AND, IF THERE ARE
; MORE TRANSMISSIONS IN THE MESSAGE, WAIT THE TIME
; BETWEEN TRANSMISSIONS AND REENTER THE QUEUE
;
         FREE,CHAN/1,1;
            ACTIVITY,EXPON(ATRIB(8)),ATRIB(2).GT.0.0,TRAN;
            ACT;
;
; SET THE GLOBAL VARIABLE EQUAL TO THE ENDING TRANSMISSION
; TIME
;
         ASSIGN,II=ATRIB(1),
                XX(II)=ATRIB(5);
;
; AT THE END OF MESSAGE RELEASE THE FLEET RESOURCE
;
         FREE,ATRIB(1)/1,1;
;
; FREE THE RADIO
;
         ASSIGN,ATRIB(1)=ATRIB(1)+30;
         FREE,ATRIB(1)/1;
;
KILL     TERM;
         ENDNETWORK;
INIT,0,177800;      RUN FOR 48 HRS
MONTR,CLEAR,5000;
SIMULATE;
MONTR,CLEAR,5000;
SEEDS,90700,99505,58629,16379,54613,
      42880,12952,32307,56941,64952;
```

```
SIMULATE;
MONTR,CLEAR,5000;
SEEDS,91291,39615,63348,97758,01263,
      44394,10634,42508,05585,18593;
FIN;
```

Appendix C: Frequencies of Number of Transmissions Per Message For Each Channel Monitored

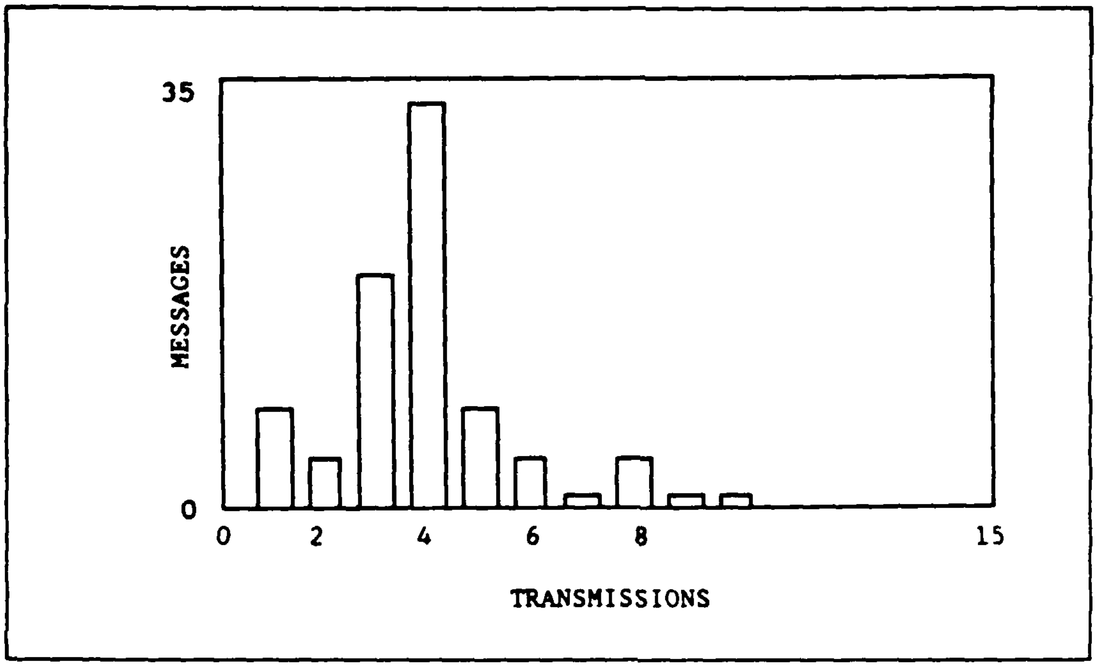

Figure 13. Frequency of Messages By Number of Transmissions For the Security Police Net

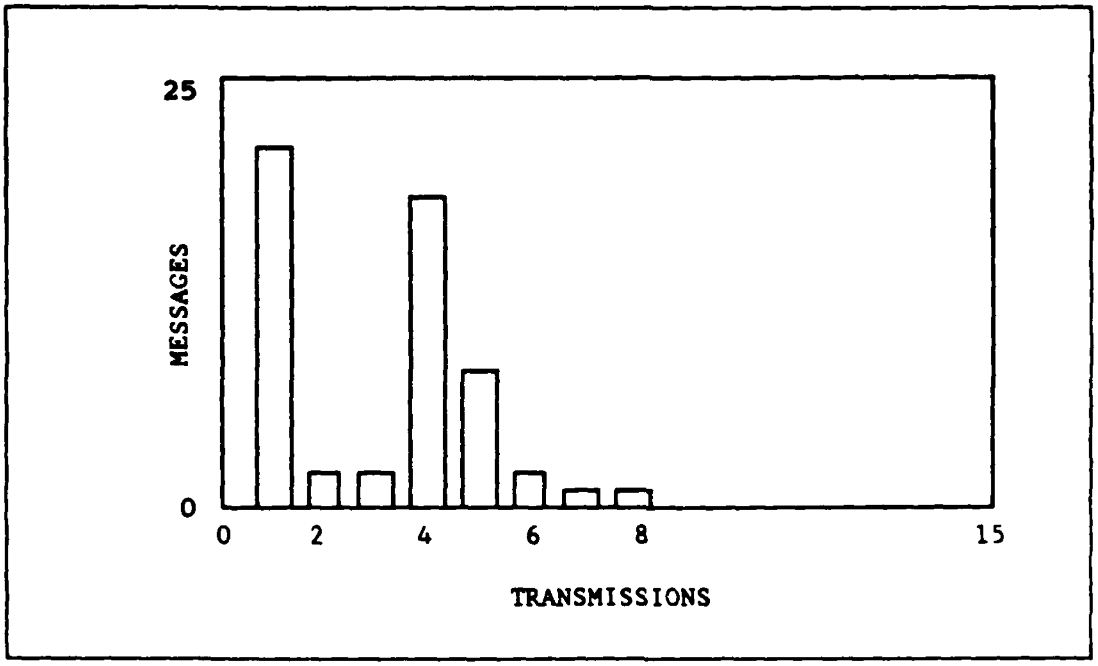

Figure 14. Frequency of Messages By Number of Transmissions For the Motorpool Net

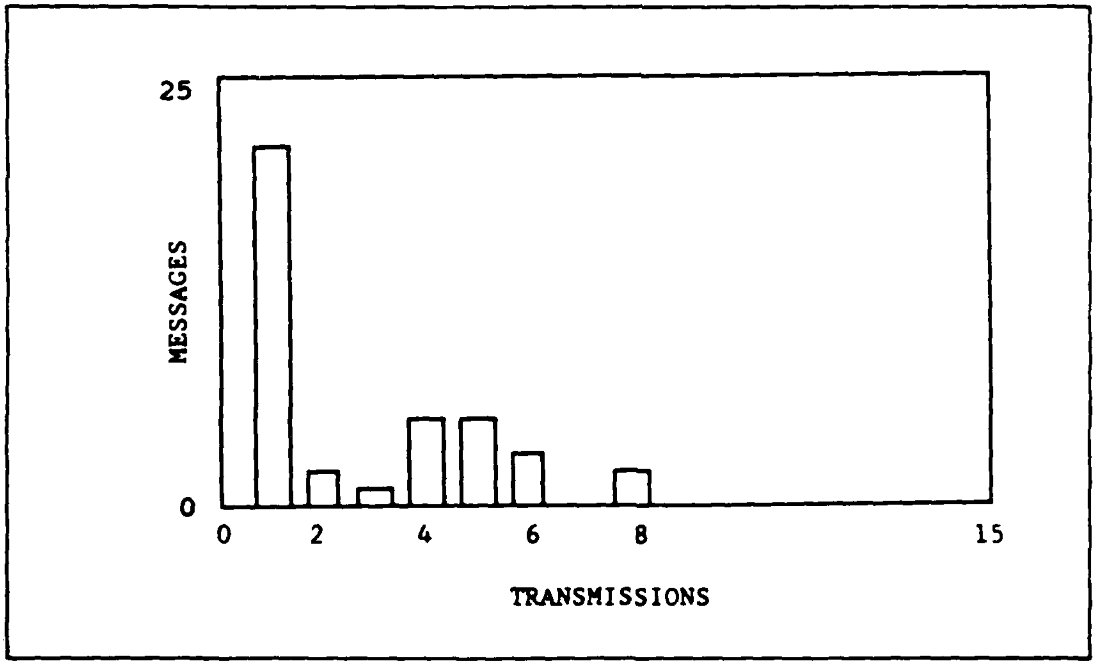

Figure 15. Frequency of Messages By Number of Transmissions For the Base Supply & Distribution C Net

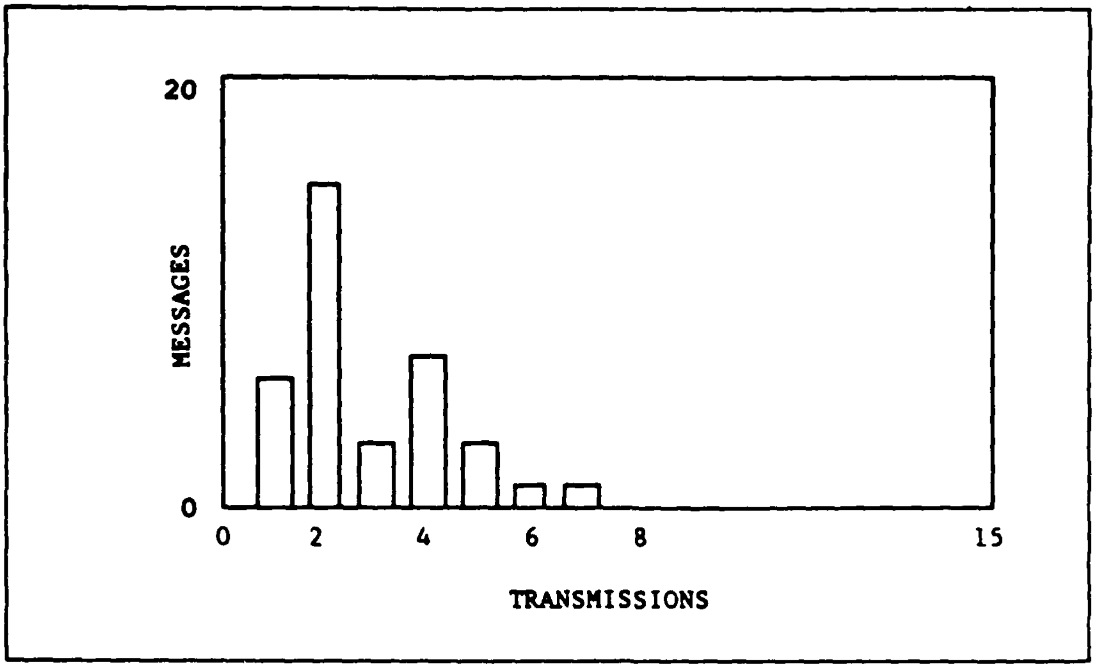

Figure 16. Frequency of Messages By Number of Transmissions For the Fire/Crash Net

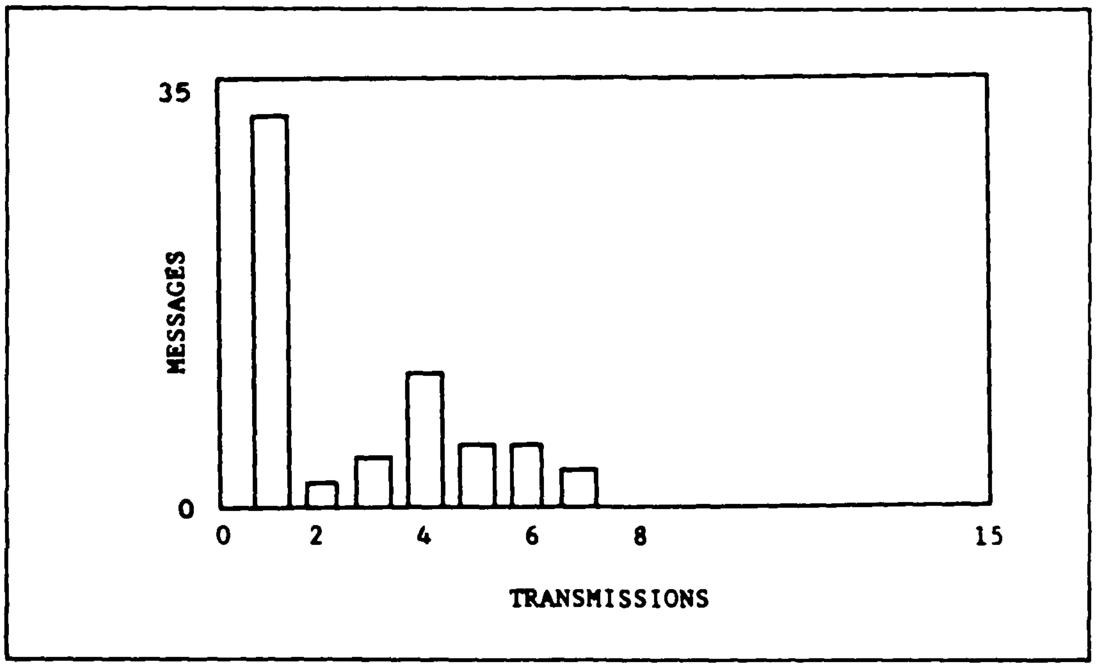

Figure 17. Frequency of Messages By Number of Transmissions For the Civil Engineers Channel 1 Net

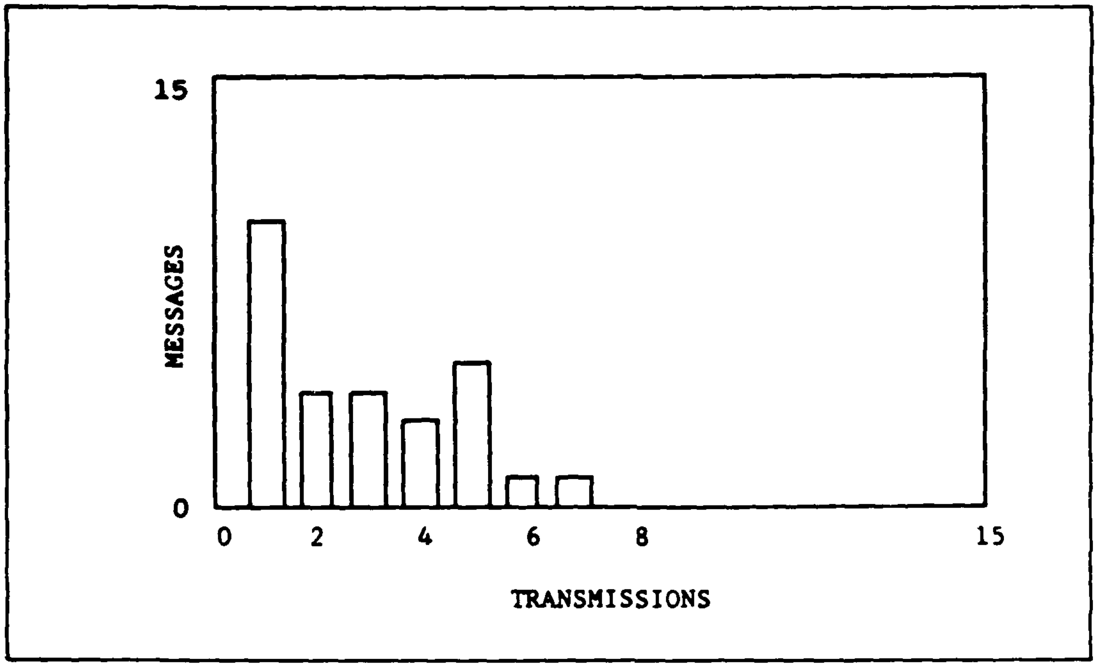

Figure 18. Frequency of Messages By Number of Transmissions For the Civil Engineers Channel 2 Net

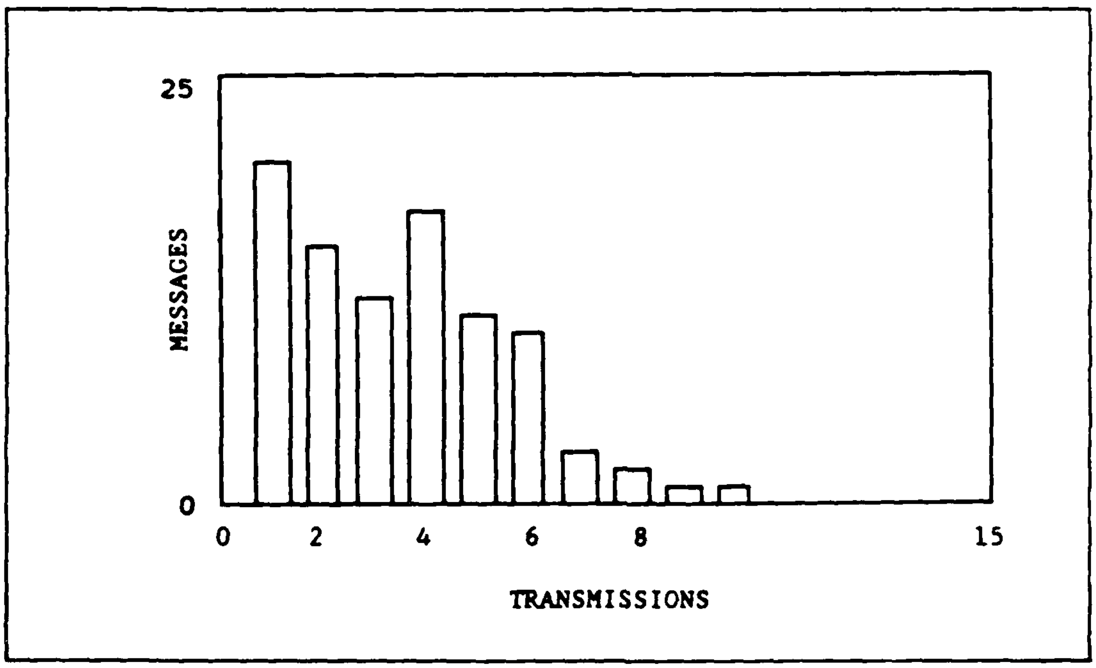

Figure 19. Frequency of Messages By Number of Transmissions For the Specialist Dispatch/POL/Base Operations Net

Appendix D: SLAM Output From the Conventional Model

This output was produced using the conventional LMR model with 7 nets with inputs as shown in Table VIII.

```
***********************************************************************
*                                                                     *
*                                                                     *
*                                                                     *
*                                                                     *
*                    * * * * * * * * * * * * * * *                    *
*                    *                           *                    *
*                    *     SLAM II VERSION 4.0   *                    *
*                    *                           *                    *
*                    * * * * * * * * * * * * * * *                    *
*                                                                     *
*                                                                     *
*                                                                     *
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*                                                                     *
*                                                                     *
```

*   *
****
1
1 **INTERMEDIATE RESULTS**

1

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT CONVENTIONAL LMR   BY T C FARRELL

DATE 8/25/1988   RUN NUMBER 1 OF 3

CURRENT TIME 0.1778E+06
STATISTICAL ARRAYS CLEARED AT TIME 0.5000E+04

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
WAIT TIME NET 1	0.472E+01	0.108E+02	0.228E+01	0.000E+00	0.902E+02	2314
WAIT TIME NET 2	0.974E+00	0.361E+01	0.370E+01	0.000E+00	0.364E+02	2098
WAIT TIME NET 3	0.392E+00	0.258E+01	0.659E+01	0.000E+00	0.332E+02	668
WAIT TIME NET 4	0.178E+00	0.140E+01	0.786E+01	0.000E+00	0.205E+02	384
WAIT TIME NET 5	0.600E+00	0.289E+01	0.482E+01	0.000E+00	0.242E+02	1042
WAIT TIME NET 6	0.294E+01	0.794E+01	0.270E+01	0.000E+00	0.750E+02	2375
WAIT TIME NET 7	0.204E+01	0.582E+01	0.286E+01	0.000E+00	0.522E+02	2257
TOTAL WAIT TIME	0.229E+01	0.709E+01	0.310E+01	0.000E+00	0.902E+02	****

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	AWAIT	0.063	0.284	4	0	4.717
2	AWAIT	0.012	0.115	3	0	0.974
3	AWAIT	0.002	0.039	2	0	0.392
4	AWAIT	0.000	0.021	2	0	0.178
5	AWAIT	0.004	0.061	2	0	0.600
6	AWAIT	0.040	0.227	4	0	2.943
7	AWAIT	0.027	0.181	3	0	2.039
8		0.000	0.000	0	0	0.000
9		0.000	0.000	0	0	0.000
10		0.000	0.000	0	0	0.000

11		0.000	0.000	0	0	0.000
12		0.000	0.000	0	0	0.000
13		0.000	0.000	0	0	0.000
14		0.000	0.000	0	0	0.000
15		0.000	0.000	0	0	0.000
16		0.000	0.000	0	0	0.000
17		0.000	0.000	0	0	0.000
18		0.000	0.000	0	0	0.000
19		0.000	0.000	0	0	0.000
20		0.000	0.000	0	0	0.000
21		0.000	0.000	0	0	0.000
22		0.000	0.000	0	0	0.000
23		0.000	0.000	0	0	0.000
24		0.000	0.000	0	0	0.000
25		0.000	0.000	0	0	0.000
26		0.000	0.000	0	0	0.000
27		0.000	0.000	0	0	0.000
28		0.000	0.000	0	0	0.000
29		0.000	0.000	0	0	0.000
30		0.000	0.000	0	0	0.000
31	AWAIT	0.000	0.000	1	0	0.000
32	AWAIT	0.000	0.000	1	0	0.000
33	AWAIT	0.000	0.000	1	0	0.000
34	AWAIT	0.000	0.000	1	0	0.000
35	AWAIT	0.000	0.000	1	0	0.000
36	AWAIT	0.000	0.000	1	0	0.000
37	AWAIT	0.000	0.000	1	0	0.000
38		0.000	0.000	0	0	0.000
39		0.000	0.000	0	0	0.000
40		0.000	0.000	0	0	0.000
41		0.000	0.000	0	0	0.000
42		0.000	0.000	0	0	0.000
43		0.000	0.000	0	0	0.000
44		0.000	0.000	0	0	0.000
45		0.000	0.000	0	0	0.000
46		0.000	0.000	0	0	0.000
47		0.000	0.000	0	0	0.000
48		0.000	0.000	0	0	0.000
49		0.000	0.000	0	0	0.000
50		0.000	0.000	0	0	0.000
51		0.000	0.000	0	0	0.000
52		0.000	0.000	0	0	0.000
53		0.000	0.000	0	0	0.000
54		0.000	0.000	0	0	0.000
55		0.000	0.000	0	0	0.000
56		0.000	0.000	0	0	0.000
57		0.000	0.000	0	0	0.000
58		0.000	0.000	0	0	0.000
59		0.000	0.000	0	0	0.000
60		0.000	0.000	0	0	0.000
61	CALENDAR	7.910	0.864	13	7	7.844

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	CHAN1	1	0.27	0.443	1	0
2	CHAN2	1	0.12	0.323	1	0
3	CHAN3	1	0.04	0.204	1	0
4	CHAN4	1	0.03	0.174	1	0
5	CHAN5	1	0.07	0.257	1	0
6	CHAN6	1	0.21	0.405	1	0
7	CHAN7	1	0.17	0.376	1	0
8	NET1	100	0.33	0.608	5	0
9	NET2	100	0.13	0.372	4	0
10	NET3	100	0.04	0.214	3	0
11	NET4	100	0.03	0.178	3	0
12	NET5	100	0.07	0.276	3	0
13	NET6	100	0.25	0.529	5	0
14	NET7	100	0.20	0.467	4	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	CHAN1	1	0.7312	0	1
2	CHAN2	1	0.8817	0	1
3	CHAN3	1	0.9567	0	1
4	CHAN4	1	0.9686	0	1
5	CHAN5	1	0.9292	0	1
6	CHAN6	1	0.7930	0	1
7	CHAN7	1	0.8298	0	1
8	NET1	100	99.6680	95	100
9	NET2	100	99.8700	96	100
10	NET3	100	99.9552	97	100
11	NET4	100	99.9682	97	100
12	NET5	100	99.9256	97	100
13	NET6	100	99.7526	95	100
14	NET7	100	99.8030	96	100

1 **HISTOGRAM NUMBER 8**

TOTAL WAIT TIME

```
OBS   RELA    UPPER
FREQ  FREQ   CELL LIM 0         20        40        60        80        100
                      +    +    +    +    +    +    +    +    +    +    +
*** 0.835 0.000E+00 +******************************************          +
 98 0.009 0.100E+01 +                                          C         +
 84 0.008 0.200E+01 +                                           C        +
 99 0.009 0.300E+01 +                                           C        +
 87 0.008 0.400E+01 +                                           C        +
```

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94 0.008 0.500E+01 +                                           C     +
90 0.008 0.600E+01 +                                           C     +
86 0.008 0.700E+01 +                                            C    +
72 0.006 0.800E+01 +                                            C    +
72 0.006 0.900E+01 +                                            C    +
95 0.009 0.100E+02 +                                             C   +
59 0.005 0.110E+02 +                                             C   +
65 0.006 0.120E+02 +                                             C   +
61 0.005 0.130E+02 +                                              C  +
46 0.004 0.140E+02 +                                              C  +
56 0.005 0.150E+02 +                                              C  +
60 0.005 0.160E+02 +                                              C  +
50 0.004 0.170E+02 +                                              C  +
43 0.004 0.180E+02 +                                               C +
51 0.005 0.190E+02 +                                               C +
42 0.004 0.200E+02 +                                               C +
44 0.004 0.210E+02 +                                               C +
38 0.003 0.220E+02 +                                               C +
18 0.002 0.230E+02 +                                                C+
23 0.002 0.240E+02 +                                                C+
25 0.002 0.250E+02 +                                                C+
20 0.002 0.260E+02 +                                                C+
20 0.002 0.270E+02 +                                                C+
20 0.002 0.280E+02 +                                                C+
15 0.001 0.290E+02 +                                                C+
16 0.001 0.300E+02 +                                                C+
13 0.001 0.310E+02 +                                                C+
12 0.001 0.320E+02 +                                                C+
15 0.001 0.330E+02 +                                                C+
19 0.002 0.340E+02 +                                                C+
10 0.001 0.350E+02 +                                                C+
 3 0.000 0.360E+02 +                                                C+
17 0.002 0.370E+02 +                                                 C
10 0.001 0.380E+02 +                                                 C
 7 0.001 0.390E+02 +                                                 C
 6 0.001 0.400E+02 +                                                 C
 9 0.001 0.410E+02 +                                                 C
 5 0.000 0.420E+02 +                                                 C
 7 0.001 0.430E+02 +                                                 C
 7 0.001 0.440E+02 +                                                 C
 5 0.000 0.450E+02 +                                                 C
 5 0.000 0.460E+02 +                                                 C
 3 0.000 0.470E+02 +                                                 C
 2 0.000 0.480E+02 +                                                 C
 2 0.000 0.490E+02 +                                                 C
 2 0.000 0.500E+02 +                                                 C
29 0.003     INF   +                                                 C
---                +    +    +    +    +    +    +    +    +    +    +
***                0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TOTAL WAIT TIME	0.229E+01	0.709E+01	0.310E+01	0.000E+00	0.902E+02	****

1

1 **INTERMEDIATE RESULTS**

1

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT CONVENTIONAL LMR BY T C FARRELL

DATE 8/25/1988 RUN NUMBER 2 OF 3

CURRENT TIME 0.1778E+06
STATISTICAL ARRAYS CLEARED AT TIME 0.5000E+04

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
WAIT TIME NET 1	0.524E+01	0.119E+02	0.227E+01	0.000E+00	0.844E+02	2371
WAIT TIME NET 2	0.866E+00	0.310E+01	0.358E+01	0.000E+00	0.309E+02	2097
WAIT TIME NET 3	0.337E+00	0.216E+01	0.641E+01	0.000E+00	0.232E+02	690
WAIT TIME NET 4	0.151E+00	0.126E+01	0.837E+01	0.000E+00	0.146E+02	334
WAIT TIME NET 5	0.510E+00	0.277E+01	0.544E+01	0.000E+00	0.351E+02	1033
WAIT TIME NET 6	0.323E+01	0.862E+01	0.267E+01	0.000E+00	0.788E+02	2495
WAIT TIME NET 7	0.208E+01	0.604E+01	0.291E+01	0.000E+00	0.557E+02	2189
TOTAL WAIT TIME	0.247E+01	0.771E+01	0.313E+01	0.000E+00	0.844E+02	****

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	AWAIT	0.072	0.318	4	0	5.236
2	AWAIT	0.011	0.107	2	0	0.866
3	AWAIT	0.001	0.037	1	0	0.337
4	AWAIT	0.000	0.017	1	0	0.151
5	AWAIT	0.003	0.059	3	0	0.510
6	AWAIT	0.047	0.249	4	0	3.235

7	AWAIT	0.026	0.183	3	0	2.078
8		0.000	0.000	0	0	0.000
9		0.000	0.000	0	0	0.000
10		0.000	0.000	0	0	0.000
11		0.000	0.000	0	0	0.000
12		0.000	0.000	0	0	0.000
13		0.000	0.000	0	0	0.000
14		0.000	0.000	0	0	0.000
15		0.000	0.000	0	0	0.000
16		0.000	0.000	0	0	0.000
17		0.000	0.000	0	0	0.000
18		0.000	0.000	0	0	0.000
19		0.000	0.000	0	0	0.000
20		0.000	0.000	0	0	0.000
21		0.000	0.000	0	0	0.000
22		0.000	0.000	0	0	0.000
23		0.000	0.000	0	0	0.000
24		0.000	0.000	0	0	0.000
25		0.000	0.000	0	0	0.000
26		0.000	0.000	0	0	0.000
27		0.000	0.000	0	0	0.000
28		0.000	0.000	0	0	0.000
29		0.000	0.000	0	0	0.000
30		0.000	0.000	0	0	0.000
31	AWAIT	0.000	0.000	1	0	0.000
32	AWAIT	0.000	0.000	1	0	0.000
33	AWAIT	0.000	0.000	1	0	0.000
34	AWAIT	0.000	0.000	1	0	0.000
35	AWAIT	0.000	0.000	1	0	0.000
36	AWAIT	0.000	0.000	1	0	0.000
37	AWAIT	0.000	0.000	1	0	0.000
38		0.000	0.000	0	0	0.000
39		0.000	0.000	0	0	0.000
40		0.000	0.000	0	0	0.000
41		0.000	0.000	0	0	0.000
42		0.000	0.000	0	0	0.000
43		0.000	0.000	0	0	0.000
44		0.000	0.000	0	0	0.000
45		0.000	0.000	0	0	0.000
46		0.000	0.000	0	0	0.000
47		0.000	0.000	0	0	0.000
48		0.000	0.000	0	0	0.000
49		0.000	0.000	0	0	0.000
50		0.000	0.000	0	0	0.000
51		0.000	0.000	0	0	0.000
52		0.000	0.000	0	0	0.000
53		0.000	0.000	0	0	0.000
54		0.000	0.000	0	0	0.000
55		0.000	0.000	0	0	0.000
56		0.000	0.000	0	0	0.000
57		0.000	0.000	0	0	0.000
58		0.000	0.000	0	0	0.000

59		0.000	0.000	0	0	0.000
60		0.000	0.000	0	0	0.000
61	CALENDAR	7.911	0.862	13	8	7.833

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	CHAN1	1	0.27	0.446	1	0
2	CHAN2	1	0.11	0.318	1	0
3	CHAN3	1	0.04	0.205	1	0
4	CHAN4	1	0.03	0.158	1	0
5	CHAN5	1	0.07	0.259	1	0
6	CHAN6	1	0.22	0.412	1	0
7	CHAN7	1	0.16	0.370	1	1
8	NET1	100	0.35	0.636	5	0
9	NET2	100	0.13	0.363	3	0
10	NET3	100	0.05	0.214	2	0
11	NET4	100	0.03	0.161	2	0
12	NET5	100	0.08	0.276	4	0
13	NET6	100	0.26	0.552	5	0
14	NET7	100	0.19	0.463	4	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	CHAN1	1	0.7264	0	1
2	CHAN2	1	0.8855	0	1
3	CHAN3	1	0.9560	0	1
4	CHAN4	1	0.9743	0	1
5	CHAN5	1	0.9275	0	1
6	CHAN6	1	0.7828	0	1
7	CHAN7	0	0.8368	0	1
8	NET1	100	99.6546	95	100
9	NET2	100	99.8750	97	100
10	NET3	100	99.9546	98	100
11	NET4	100	99.9740	98	100
12	NET5	100	99.9245	96	100
13	NET6	100	99.7363	95	100
14	NET7	99	99.8104	96	100

```
1                            **HISTOGRAM NUMBER 8**
                                TOTAL WAIT TIME

OBS   RELA    UPPER
FREQ  FREQ   CELL LIM  0         20        40        60        80        100
                       +    +    +    +    +    +    +    +    +    +    +
*** 0.829 0.000E+00 +******************************************          +
```

```
109 0.010 0.100E+01 +                                         C       +
104 0.009 0.200E+01 +                                         C       +
 85 0.008 0.300E+01 +                                          C      +
102 0.009 0.400E+01 +                                          C      +
 90 0.008 0.500E+01 +                                           C     +
 95 0.008 0.600E+01 +                                           C     +
 76 0.007 0.700E+01 +                                           C     +
 97 0.009 0.800E+01 +                                            C    +
 74 0.007 0.900E+01 +                                            C    +
 69 0.006 0.100E+02 +                                            C    +
 74 0.007 0.110E+02 +                                             C   +
 83 0.007 0.120E+02 +                                             C   +
 72 0.006 0.130E+02 +                                             C   +
 49 0.004 0.140E+02 +                                              C  +
 58 0.005 0.150E+02 +                                              C  +
 60 0.005 0.160E+02 +                                              C  +
 44 0.004 0.170E+02 +                                              C  +
 52 0.005 0.180E+02 +                                               C +
 36 0.003 0.190E+02 +                                               C +
 30 0.003 0.200E+02 +                                               C +
 38 0.003 0.210E+02 +                                               C +
 38 0.003 0.220E+02 +                                               C +
 19 0.002 0.230E+02 +                                               C +
 20 0.002 0.240E+02 +                                               C +
 26 0.002 0.250E+02 +                                                C+
 22 0.002 0.260E+02 +                                                C+
 25 0.002 0.270E+02 +                                                C+
 10 0.001 0.280E+02 +                                                C+
 14 0.001 0.290E+02 +                                                C+
 19 0.002 0.300E+02 +                                                C+
 11 0.001 0.310E+02 +                                                C+
 15 0.001 0.320E+02 +                                                C+
 13 0.001 0.330E+02 +                                                C+
 12 0.001 0.340E+02 +                                                C+
 15 0.001 0.350E+02 +                                                C+
  9 0.001 0.360E+02 +                                                C+
 15 0.001 0.370E+02 +                                                C+
 14 0.001 0.380E+02 +                                                C+
  6 0.001 0.390E+02 +                                                C+
  7 0.001 0.400E+02 +                                                C+
  7 0.001 0.410E+02 +                                                 C
  9 0.001 0.420E+02 +                                                 C
  9 0.001 0.430E+02 +                                                 C
  9 0.001 0.440E+02 +                                                 C
  7 0.001 0.450E+02 +                                                 C
  6 0.001 0.460E+02 +                                                 C
  4 0.000 0.470E+02 +                                                 C
  1 0.000 0.480E+02 +                                                 C
  5 0.000 0.490E+02 +                                                 C
  4 0.000 0.500E+02 +                                                 C
 53 0.005    INF    +                                                 C
---                 +    +    +    +    +    +    +    +    +    +    +
```

***	0	20	40	60	80	100

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TOTAL WAIT TIME	0.247E+01	0.771E+01	0.313E+01	0.000E+00	0.844E+02	****

1

1 **INTERMEDIATE RESULTS**

1

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT CONVENTIONAL LMR BY T C FARRELL

DATE 8/25/1988 RUN NUMBER 3 OF 3

CURRENT TIME 0.1778E+06
STATISTICAL ARRAYS CLEARED AT TIME 0.5000E+04

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
WAIT TIME NET 1	0.492E+01	0.110E+02	0.223E+01	0.000E+00	0.836E+02	2342
WAIT TIME NET 2	0.101E+01	0.355E+01	0.350E+01	0.000E+00	0.417E+02	1979
WAIT TIME NET 3	0.472E+00	0.256E+01	0.542E+01	0.000E+00	0.308E+02	698
WAIT TIME NET 4	0.366E+00	0.242E+01	0.660E+01	0.000E+00	0.247E+02	389
WAIT TIME NET 5	0.559E+00	0.303E+01	0.543E+01	0.000E+00	0.425E+02	1007
WAIT TIME NET 6	0.325E+01	0.901E+01	0.277E+01	0.000E+00	0.882E+02	2328
WAIT TIME NET 7	0.213E+01	0.607E+01	0.285E+01	0.000E+00	0.598E+02	2309
TOTAL WAIT TIME	0.245E+01	0.753E+01	0.307E+01	0.000E+00	0.882E+02	****

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	AWAIT	0.067	0.294	4	0	4.923
2	AWAIT	0.012	0.117	3	0	1.015

3	AWAIT	0.002	0.046	2	0	0.472
4	AWAIT	0.001	0.029	1	0	0.366
5	AWAIT	0.003	0.061	3	0	0.559
6	AWAIT	0.044	0.245	4	0	3.252
7	AWAIT	0.028	0.184	3	0	2.126
8		0.000	0.000	0	0	0.000
9		0.000	0.000	0	0	0.000
10		0.000	0.000	0	0	0.000
11		0.000	0.000	0	0	0.000
12		0.000	0.000	0	0	0.000
13		0.000	0.000	0	0	0.000
14		0.000	0.000	0	0	0.000
15		0.000	0.000	0	0	0.000
16		0.000	0.000	0	0	0.000
17		0.000	0.000	0	0	0.000
18		0.000	0.000	0	0	0.000
19		0.000	0.000	0	0	0.000
20		0.000	0.000	0	0	0.000
21		0.000	0.000	0	0	0.000
22		0.000	0.000	0	0	0.000
23		0.000	0.000	0	0	0.000
24		0.000	0.000	0	0	0.000
25		0.000	0.000	0	0	0.000
26		0.000	0.000	0	0	0.000
27		0.000	0.000	0	0	0.000
28		0.000	0.000	0	0	0.000
29		0.000	0.000	0	0	0.000
30		0.000	0.000	0	0	0.000
31	AWAIT	0.000	0.000	1	0	0.000
32	AWAIT	0.000	0.000	1	0	0.000
33	AWAIT	0.000	0.000	1	0	0.000
34	AWAIT	0.000	0.000	1	0	0.000
35	AWAIT	0.000	0.000	1	0	0.000
36	AWAIT	0.000	0.000	1	0	0.000
37	AWAIT	0.000	0.000	1	0	0.000
38		0.000	0.000	0	0	0.000
39		0.000	0.000	0	0	0.000
40		0.000	0.000	0	0	0.000
41		0.000	0.000	0	0	0.000
42		0.000	0.000	0	0	0.000
43		0.000	0.000	0	0	0.000
44		0.000	0.000	0	0	0.000
45		0.000	0.000	0	0	0.000
46		0.000	0.000	0	0	0.000
47		0.000	0.000	0	0	0.000
48		0.000	0.000	0	0	0.000
49		0.000	0.000	0	0	0.000
50		0.000	0.000	0	0	0.000
51		0.000	0.000	0	0	0.000
52		0.000	0.000	0	0	0.000
53		0.000	0.000	0	0	0.000
54		0.000	0.000	0	0	0.000

55		0.000	0.000	0	0	0.000
56		0.000	0.000	0	0	0.000
57		0.000	0.000	0	0	0.000
58		0.000	0.000	0	0	0.000
59		0.000	0.000	0	0	0.000
60		0.000	0.000	0	0	0.000
61	CALENDAR	7.905	0.862	13	8	7.903

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	CHAN1	1	0.28	0.447	1	0
2	CHAN2	1	0.11	0.312	1	0
3	CHAN3	1	0.04	0.206	1	0
4	CHAN4	1	0.03	0.177	1	0
5	CHAN5	1	0.07	0.256	1	1
6	CHAN6	1	0.20	0.400	1	0
7	CHAN7	1	0.17	0.378	1	0
8	NET1	100	0.34	0.619	5	0
9	NET2	100	0.12	0.363	4	0
10	NET3	100	0.05	0.220	3	0
11	NET4	100	0.03	0.184	2	0
12	NET5	100	0.07	0.274	4	1
13	NET6	100	0.24	0.539	5	0
14	NET7	100	0.20	0.473	4	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	CHAN1	1	0.7231	0	1
2	CHAN2	1	0.8908	0	1
3	CHAN3	1	0.9556	0	1
4	CHAN4	1	0.9675	0	1
5	CHAN5	0	0.9297	0	1
6	CHAN6	1	0.8004	0	1
7	CHAN7	1	0.8276	0	1
8	NET1	100	99.6563	95	100
9	NET2	100	99.8792	96	100
10	NET3	100	99.9538	97	100
11	NET4	100	99.9666	98	100
12	NET5	99	99.9264	96	100
13	NET6	100	99.7566	95	100
14	NET7	100	99.7993	96	100

1 **HISTOGRAM NUMBER 8**

TOTAL WAIT TIME

```
OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80       100
                    +    +    +    +    +    +    +    +    +    +    +
*** 0.825 0.000E+00 +*****************************************        +
103 0.009 0.100E+01 +                                         C       +
103 0.009 0.200E+01 +                                         C       +
 96 0.009 0.300E+01 +                                          C      +
 94 0.009 0.400E+01 +                                          C      +
106 0.010 0.500E+01 +                                           C     +
 97 0.009 0.600E+01 +                                           C     +
 86 0.008 0.700E+01 +                                           C     +
 84 0.008 0.800E+01 +                                            C    +
 82 0.007 0.900E+01 +                                            C    +
 72 0.007 0.100E+02 +                                            C    +
 79 0.007 0.110E+02 +                                             C   +
 73 0.007 0.120E+02 +                                             C   +
 56 0.005 0.130E+02 +                                             C   +
 61 0.006 0.140E+02 +                                              C  +
 58 0.005 0.150E+02 +                                              C  +
 53 0.005 0.160E+02 +                                              C  +
 50 0.005 0.170E+02 +                                              C  +
 43 0.004 0.180E+02 +                                               C +
 49 0.004 0.190E+02 +                                               C +
 39 0.004 0.200E+02 +                                               C +
 37 0.003 0.210E+02 +                                               C +
 32 0.003 0.220E+02 +                                               C +
 28 0.003 0.230E+02 +                                               C +
 27 0.002 0.240E+02 +                                                C+
 33 0.003 0.250E+02 +                                                C+
 18 0.002 0.260E+02 +                                                C+
 18 0.002 0.270E+02 +                                                C+
 21 0.002 0.280E+02 +                                                C+
 17 0.002 0.290E+02 +                                                C+
 18 0.002 0.300E+02 +                                                C+
 16 0.001 0.310E+02 +                                                C+
 17 0.002 0.320E+02 +                                                C+
 15 0.001 0.330E+02 +                                                C+
 14 0.001 0.340E+02 +                                                C+
 17 0.002 0.350E+02 +                                                C+
  6 0.001 0.360E+02 +                                                C+
  8 0.001 0.370E+02 +                                                 C
  9 0.001 0.380E+02 +                                                 C
  5 0.000 0.390E+02 +                                                 C
  6 0.001 0.400E+02 +                                                 C
  8 0.001 0.410E+02 +                                                 C
  8 0.001 0.420E+02 +                                                 C
  6 0.001 0.430E+02 +                                                 C
  3 0.000 0.440E+02 +                                                 C
  7 0.001 0.450E+02 +                                                 C
  2 0.000 0.460E+02 +                                                 C
  1 0.000 0.470E+02 +                                                 C
  2 0.000 0.480E+02 +                                                 C
```

```
  2 0.000 0.490E+02 +                                                C
  4 0.000 0.500E+02 +                                                C
 45 0.004     INF   +                                                C
---                 +    +    +    +    +    +    +    +    +    +   +
***                 0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TOTAL WAIT TIME	0.245E+01	0.753E+01	0.307E+01	0.000E+00	0.882E+02	****

Appendix E: SLAM Output From the Trunked Model

This output was produced using the trunked model with 7 fleets with inputs as shown in Table VIII. MD was set equal to 0.350 seconds, RU was set equal to 5 seconds, and CH was set equal to 7.

*   *
*   *
*   *
****
1
1 **INTERMEDIATE RESULTS**

1

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT HTS   BY T C FARRELL

DATE 8/29/1988   RUN NUMBER 1 OF 3

CURRENT TIME 0.1778E+06
STATISTICAL ARRAYS CLEARED AT TIME 0.5000E+04

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
INT DELAY FLT 1	0.629E+01	0.132E+02	0.209E+01	0.000E+00	0.112E+03	2290
INT DELAY FLT 2	0.105E+01	0.353E+01	0.335E+01	0.000E+00	0.301E+02	2078
INT DELAY FLT 3	0.322E+00	0.213E+01	0.663E+01	0.000E+00	0.274E+02	655
INT DELAY FLT 4	0.438E+00	0.244E+01	0.559E+01	0.000E+00	0.238E+02	386
INT DELAY FLT 5	0.802E+00	0.343E+01	0.427E+01	0.000E+00	0.298E+02	1039
INT DELAY FLT 6	0.336E+01	0.823E+01	0.245E+01	0.000E+00	0.642E+02	2334
INT DELAY FLT 7	0.209E+01	0.601E+01	0.287E+01	0.000E+00	0.535E+02	2228
FLT 1 CH DELAY	0.349E+00	0.335E-02	0.960E-02	0.344E+00	0.352E+00	****
FLT 2 CH DELAY	0.349E+00	0.336E-02	0.962E-02	0.344E+00	0.352E+00	7582
FLT 3 CH DELAY	0.349E+00	0.324E-02	0.928E-02	0.344E+00	0.352E+00	2192
FLT 4 CH DELAY	0.349E+00	0.355E-02	0.102E-01	0.344E+00	0.352E+00	1312
FLT 5 CH DELAY	0.349E+00	0.330E-02	0.944E-02	0.344E+00	0.352E+00	3721
FLT 6 CH DELAY	0.349E+00	0.336E-02	0.962E-02	0.344E+00	0.352E+00	7771
FLT 7 CH DELAY	0.349E+00	0.330E-02	0.946E-02	0.344E+00	0.352E+00	9177
TOTAL CH DELAY	0.349E+00	0.334E-02	0.956E-02	0.344E+00	0.352E+00	****
MSG DELAY	0.310E+01	0.811E+01	0.261E+01	0.344E+00	0.112E+03	****

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME

1	AWAIT	0.083	0.346	5	0	6.295
2	AWAIT	0.013	0.117	2	0	1.052
3	AWAIT	0.001	0.037	2	0	0.322
4	AWAIT	0.001	0.031	1	0	0.438
5	AWAIT	0.005	0.072	2	0	0.802
6	AWAIT	0.045	0.231	3	0	3.362
7	AWAIT	0.027	0.178	3	0	2.094
8		0.000	0.000	0	0	0.000
9		0.000	0.000	0	0	0.000
10		0.000	0.000	0	0	0.000
11		0.000	0.000	0	0	0.000
12		0.000	0.000	0	0	0.000
13		0.000	0.000	0	0	0.000
14		0.000	0.000	0	0	0.000
15		0.000	0.000	0	0	0.000
16		0.000	0.000	0	0	0.000
17		0.000	0.000	0	0	0.000
18		0.000	0.000	0	0	0.000
19		0.000	0.000	0	0	0.000
20		0.000	0.000	0	0	0.000
21		0.000	0.000	0	0	0.000
22		0.000	0.000	0	0	0.000
23		0.000	0.000	0	0	0.000
24		0.000	0.000	0	0	0.000
25		0.000	0.000	0	0	0.000
26		0.000	0.000	0	0	0.000
27		0.000	0.000	0	0	0.000
28		0.000	0.000	0	0	0.000
29		0.000	0.000	0	0	0.000
30		0.000	0.000	0	0	0.000
31	AWAIT	0.000	0.000	1	0	0.000
32	AWAIT	0.000	0.000	1	0	0.000
33	AWAIT	0.000	0.000	1	0	0.000
34	AWAIT	0.000	0.000	1	0	0.000
35	AWAIT	0.000	0.000	1	0	0.000
36	AWAIT	0.000	0.000	1	0	0.000
37	AWAIT	0.000	0.000	1	0	0.000
38		0.000	0.000	0	0	0.000
39		0.000	0.000	0	0	0.000
40		0.000	0.000	0	0	0.000
41		0.000	0.000	0	0	0.000
42		0.000	0.000	0	0	0.000
43		0.000	0.000	0	0	0.000
44		0.000	0.000	0	0	0.000
45		0.000	0.000	0	0	0.000
46		0.000	0.000	0	0	0.000
47		0.000	0.000	0	0	0.000
48		0.000	0.000	0	0	0.000
49		0.000	0.000	0	0	0.000
50		0.000	0.000	0	0	0.000
51		0.000	0.000	0	0	0.000
52		0.000	0.000	0	0	0.000

53			0.000	0.000	0	0	0.000
54			0.000	0.000	0	0	0.000
55			0.000	0.000	0	0	0.000
56			0.000	0.000	0	0	0.000
57			0.000	0.000	0	0	0.000
58			0.000	0.000	0	0	0.000
59			0.000	0.000	0	0	0.000
60			0.000	0.000	0	0	0.000
61	RUQ	AWAIT	0.000	0.000	1	0	0.000
62	CHQ	AWAIT	0.000	0.000	1	0	0.000
63		CALENDAR	7.984	0.881	13	8	2.771

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	FLT1	1	0.29	0.454	1	0
2	FLT2	1	0.13	0.336	1	0
3	FLT3	1	0.05	0.208	1	0
4	FLT4	1	0.03	0.183	1	0
5	FLT5	1	0.08	0.276	1	0
6	FLT6	1	0.22	0.412	1	1
7	FLT7	1	0.19	0.389	1	0
31	RAD1	100	0.37	0.666	6	0
32	RAD2	100	0.14	0.386	3	0
33	RAD3	100	0.05	0.217	3	0
34	RAD4	100	0.04	0.190	2	0
35	RAD5	100	0.09	0.300	3	0
36	RAD6	100	0.26	0.542	4	1
37	RAD7	100	0.21	0.477	4	0
38	CHAN	7	0.65	0.748	5	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	FLT1	1	0.7100	0	1
2	FLT2	1	0.8703	0	1
3	FLT3	1	0.9547	0	1
4	FLT4	1	0.9655	0	1
5	FLT5	1	0.9172	0	1
6	FLT6	0	0.7839	0	1
7	FLT7	1	0.8136	0	1
31	RAD1	100	99.6267	94	100
32	RAD2	100	99.8576	97	100
33	RAD3	100	99.9535	97	100
34	RAD4	100	99.9644	98	100
35	RAD5	100	99.9123	97	100

```
        36      RAD6          99       99.7385        96          100
        37      RAD7         100       99.7866        96          100
        38      CHAN           7        6.3471         2            7
1                             **HISTOGRAM NUMBER16**
                                   MSG DELAY

 OBS   RELA    UPPER
 FREQ  FREQ   CELL LIM 0        20        40        60        80        100
                       +    +    +    +    +    +    +    +    +    +    +
   0 0.000 0.000E+00 +                                                   +
 *** 0.824 0.100E+01 +*****************************************          +
 100 0.009 0.200E+01 +                                         C         +
  83 0.008 0.300E+01 +                                         C         +
  93 0.008 0.400E+01 +                                         C         +
  85 0.008 0.500E+01 +                                          C        +
 100 0.009 0.600E+01 +                                          C        +
  88 0.008 0.700E+01 +                                           C       +
  87 0.008 0.800E+01 +                                           C       +
  80 0.007 0.900E+01 +                                           C       +
  73 0.007 0.100E+02 +                                            C      +
  70 0.006 0.110E+02 +                                            C      +
  69 0.006 0.120E+02 +                                            C      +
  72 0.007 0.130E+02 +                                             C     +
  77 0.007 0.140E+02 +                                             C     +
  65 0.006 0.150E+02 +                                             C     +
  53 0.005 0.160E+02 +                                              C    +
  61 0.006 0.170E+02 +                                              C    +
  48 0.004 0.180E+02 +                                              C    +
  39 0.004 0.190E+02 +                                              C    +
  50 0.005 0.200E+02 +                                               C   +
  40 0.004 0.210E+02 +                                               C   +
  27 0.002 0.220E+02 +                                               C   +
  35 0.003 0.230E+02 +                                               C   +
  36 0.003 0.240E+02 +                                               C   +
  33 0.003 0.250E+02 +                                               C   +
  22 0.002 0.260E+02 +                                               C   +
  19 0.002 0.270E+02 +                                               C   +
  28 0.003 0.280E+02 +                                                 C+
  23 0.002 0.290E+02 +                                                 C+
  20 0.002 0.300E+02 +                                                 C+
  23 0.002 0.310E+02 +                                                 C+
  25 0.002 0.320E+02 +                                                 C+
  17 0.002 0.330E+02 +                                                 C+
  20 0.002 0.340E+02 +                                                 C+
  13 0.001 0.350E+02 +                                                 C+
  17 0.002 0.360E+02 +                                                 C+
  18 0.002 0.370E+02 +                                                 C+
  13 0.001 0.380E+02 +                                                 C+
   8 0.001 0.390E+02 +                                                 C+
   7 0.001 0.400E+02 +                                                  C
   5 0.000 0.410E+02 +                                                  C
   6 0.001 0.420E+02 +                                                  C
```

```
 4 0.000 0.430E+02 +                                                  C
 7 0.001 0.440E+02 +                                                  C
 9 0.001 0.450E+02 +                                                  C
 7 0.001 0.460E+02 +                                                  C
 4 0.000 0.470E+02 +                                                  C
 5 0.000 0.480E+02 +                                                  C
 5 0.000 0.490E+02 +                                                  C
 1 0.000 0.500E+02 +                                                  C
53 0.005    INF    +                                                  C
---                +    +    +    +    +    +    +    +    +    +    +
***                0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
MSG DELAY	0.310E+01	0.811E+01	0.261E+01	0.344E+00	0.112E+03	****

1
1 **INTERMEDIATE RESULTS**

1

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT HTS BY T C FARRELL

DATE 8/29/1988 RUN NUMBER 2 OF 3

CURRENT TIME 0.1778E+06
STATISTICAL ARRAYS CLEARED AT TIME 0.5000E+04

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
INT DELAY FLT 1	0.628E+01	0.138E+02	0.220E+01	0.000E+00	0.116E+03	2345
INT DELAY FLT 2	0.107E+01	0.371E+01	0.347E+01	0.000E+00	0.444E+02	2166
INT DELAY FLT 3	0.349E+00	0.207E+01	0.594E+01	0.000E+00	0.248E+02	712
INT DELAY FLT 4	0.229E+00	0.177E+01	0.770E+01	0.000E+00	0.240E+02	355
INT DELAY FLT 5	0.825E+00	0.368E+01	0.446E+01	0.000E+00	0.354E+02	1032
INT DELAY FLT 6	0.301E+01	0.822E+01	0.273E+01	0.000E+00	0.796E+02	2361
INT DELAY FLT 7	0.241E+01	0.673E+01	0.279E+01	0.000E+00	0.586E+02	2258
FLT 1 CH DELAY	0.349E+00	0.336E-02	0.963E-02	0.344E+00	0.352E+00	****

FLT 2 CH DELAY	0.349E+00	0.333E-02	0.954E-02	0.344E+00	0.352E+00	7803
FLT 3 CH DELAY	0.349E+00	0.336E-02	0.961E-02	0.344E+00	0.352E+00	2362
FLT 4 CH DELAY	0.349E+00	0.331E-02	0.948E-02	0.344E+00	0.352E+00	1177
FLT 5 CH DELAY	0.349E+00	0.341E-02	0.977E-02	0.344E+00	0.352E+00	3650
FLT 6 CH DELAY	0.349E+00	0.340E-02	0.974E-02	0.344E+00	0.352E+00	7750
FLT 7 CH DELAY	0.349E+00	0.338E-02	0.968E-02	0.344E+00	0.352E+00	9451
TOTAL CH DELAY	0.349E+00	0.337E-02	0.964E-02	0.344E+00	0.352E+00	****
MSG DELAY	0.309E+01	0.846E+01	0.274E+01	0.344E+00	0.116E+03	****

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	AWAIT	0.085	0.353	5	0	6.280
2	AWAIT	0.013	0.122	3	0	1.070
3	AWAIT	0.001	0.042	3	0	0.349
4	AWAIT	0.000	0.022	1	0	0.229
5	AWAIT	0.005	0.074	2	0	0.825
6	AWAIT	0.041	0.230	4	0	3.014
7	AWAIT	0.031	0.198	4	0	2.410
8		0.000	0.000	0	0	0.000
9		0.000	0.000	0	0	0.000
10		0.000	0.000	0	0	0.000
11		0.000	0.000	0	0	0.000
12		0.000	0.000	0	0	0.000
13		0.000	0.000	0	0	0.000
14		0.000	0.000	0	0	0.000
15		0.000	0.000	0	0	0.000
16		0.000	0.000	0	0	0.000
17		0.000	0.000	0	0	0.000
18		0.000	0.000	0	0	0.000
19		0.000	0.000	0	0	0.000
20		0.000	0.000	0	0	0.000
21		0.000	0.000	0	0	0.000
22		0.000	0.000	0	0	0.000
23		0.000	0.000	0	0	0.000
24		0.000	0.000	0	0	0.000
25		0.000	0.000	0	0	0.000
26		0.000	0.000	0	0	0.000
27		0.000	0.000	0	0	0.000
28		0.000	0.000	0	0	0.000
29		0.000	0.000	0	0	0.000
30		0.000	0.000	0	0	0.000
31	AWAIT	0.000	0.000	1	0	0.000
32	AWAIT	0.000	0.000	1	0	0.000
33	AWAIT	0.000	0.000	1	0	0.000
34	AWAIT	0.000	0.000	1	0	0.000
35	AWAIT	0.000	0.000	1	0	0.000
36	AWAIT	0.000	0.000	1	0	0.000

37		AWAIT	0.000	0.000	1	0	0.000
38			0.000	0.000	0	0	0.000
39			0.000	0.000	0	0	0.000
40			0.000	0.000	0	0	0.000
41			0.000	0.000	0	0	0.000
42			0.000	0.000	0	0	0.000
43			0.000	0.000	0	0	0.000
44			0.000	0.000	0	0	0.000
45			0.000	0.000	0	0	0.000
46			0.000	0.000	0	0	0.000
47			0.000	0.000	0	0	0.000
48			0.000	0.000	0	0	0.000
49			0.000	0.000	0	0	0.000
50			0.000	0.000	0	0	0.000
51			0.000	0.000	0	0	0.000
52			0.000	0.000	0	0	0.000
53			0.000	0.000	0	0	0.000
54			0.000	0.000	0	0	0.000
55			0.000	0.000	0	0	0.000
56			0.000	0.000	0	0	0.000
57			0.000	0.000	0	0	0.000
58			0.000	0.000	0	0	0.000
59			0.000	0.000	0	0	0.000
60			0.000	0.000	0	0	0.000
61	RUQ	AWAIT	0.000	0.000	1	0	0.000
62	CHQ	AWAIT	0.000	0.000	1	0	0.000
63		CALENDAR	7.998	0.895	13	8	2.736

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	FLT1	1	0.30	0.457	1	0
2	FLT2	1	0.13	0.341	1	0
3	FLT3	1	0.05	0.218	1	0
4	FLT4	1	0.03	0.173	1	1
5	FLT5	1	0.08	0.271	1	0
6	FLT6	1	0.21	0.410	1	0
7	FLT7	1	0.19	0.396	1	0
31	RAD1	100	0.38	0.673	6	0
32	RAD2	100	0.15	0.393	4	0
33	RAD3	100	0.05	0.228	4	0
34	RAD4	100	0.03	0.177	2	1
35	RAD5	100	0.08	0.296	3	0
36	RAD6	100	0.25	0.534	5	0
37	RAD7	100	0.23	0.496	5	0
38	CHAN	7	0.66	0.757	5	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	FLT1	1	0.7039	0	1
2	FLT2	1	0.8659	0	1
3	FLT3	1	0.9499	0	1
4	FLT4	0	0.9690	0	1
5	FLT5	1	0.9202	0	1
6	FLT6	1	0.7868	0	1
7	FLT7	1	0.8059	0	1
31	RAD1	100	99.6186	94	100
32	RAD2	100	99.8526	96	100
33	RAD3	100	99.9484	96	100
34	RAD4	99	99.9686	98	100
35	RAD5	100	99.9154	97	100
36	RAD6	100	99.7455	95	100
37	RAD7	100	99.7744	95	100
38	CHAN	7	6.3398	2	7

```
1                                  **HISTOGRAM NUMBER16**
                                         MSG DELAY

OBS   RELA   UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80      100
                    +    +    +    +    +    +    +    +    +    +    +
  0 0.000 0.000E+00 +                                                 +
*** 0.826 0.100E+01 +*****************************************        +
110 0.010 0.200E+01 +                                         C       +
 99 0.009 0.300E+01 +                                         C       +
 90 0.008 0.400E+01 +                                          C      +
 77 0.007 0.500E+01 +                                          C      +
100 0.009 0.600E+01 +                                          C      +
 99 0.009 0.700E+01 +                                           C     +
 81 0.007 0.800E+01 +                                           C     +
 77 0.007 0.900E+01 +                                            C    +
 93 0.008 0.100E+02 +                                            C    +
 85 0.008 0.110E+02 +                                            C    +
 78 0.007 0.120E+02 +                                             C   +
 48 0.004 0.130E+02 +                                             C   +
 71 0.006 0.140E+02 +                                             C   +
 59 0.005 0.150E+02 +                                              C  +
 47 0.004 0.160E+02 +                                              C  +
 47 0.004 0.170E+02 +                                              C  +
 48 0.004 0.180E+02 +                                              C  +
 32 0.003 0.190E+02 +                                              C  +
 43 0.004 0.200E+02 +                                              C  +
 51 0.005 0.210E+02 +                                               C +
 46 0.004 0.220E+02 +                                               C +
 36 0.003 0.230E+02 +                                               C +
 32 0.003 0.240E+02 +                                               C +
 29 0.003 0.250E+02 +                                               C +
 19 0.002 0.260E+02 +                                               C +
```

```
 36 0.003 0.270E+02 +                                                          C+
 21 0.002 0.280E+02 +                                                          C+
 24 0.002 0.290E+02 +                                                          C+
 20 0.002 0.300E+02 +                                                          C+
 19 0.002 0.310E+02 +                                                          C+
 17 0.002 0.320E+02 +                                                          C+
 19 0.002 0.330E+02 +                                                          C+
 13 0.001 0.340E+02 +                                                          C+
 12 0.001 0.350E+02 +                                                          C+
 13 0.001 0.360E+02 +                                                          C+
  8 0.001 0.370E+02 +                                                          C+
  9 0.001 0.380E+02 +                                                          C+
 10 0.001 0.390E+02 +                                                          C+
  8 0.001 0.400E+02 +                                                          C+
  7 0.001 0.410E+02 +                                                          C+
  4 0.000 0.420E+02 +                                                          C+
  6 0.001 0.430E+02 +                                                           C
  3 0.000 0.440E+02 +                                                           C
  5 0.000 0.450E+02 +                                                           C
  9 0.001 0.460E+02 +                                                           C
  2 0.000 0.470E+02 +                                                           C
  4 0.000 0.480E+02 +                                                           C
  2 0.000 0.490E+02 +                                                           C
  7 0.001 0.500E+02 +                                                           C
 76 0.007    INF    +                                                           C
---                 +    +    +    +    +    +    +    +    +    +    +
***                 0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
MSG DELAY	0.309E+01	0.846E+01	0.274E+01	0.344E+00	0.116E+03	****

1

1 **INTERMEDIATE RESULTS**

1

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT HTS   BY T C FARRELL

DATE 8/29/1988   RUN NUMBER 3 OF 3

CURRENT TIME 0.1778E+06

STATISTICAL ARRAYS CLEARED AT TIME 0.5000E+04

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
INT DELAY FLT 1	0.575E+01	0.123E+02	0.213E+01	0.000E+00	0.104E+03	2336
INT DELAY FLT 2	0.112E+01	0.391E+01	0.349E+01	0.000E+00	0.343E+02	2084
INT DELAY FLT 3	0.309E+00	0.224E+01	0.725E+01	0.000E+00	0.333E+02	680
INT DELAY FLT 4	0.374E+00	0.219E+01	0.586E+01	0.000E+00	0.240E+02	387
INT DELAY FLT 5	0.985E+00	0.441E+01	0.448E+01	0.000E+00	0.450E+02	1081
INT DELAY FLT 6	0.287E+01	0.764E+01	0.267E+01	0.000E+00	0.583E+02	2333
INT DELAY FLT 7	0.241E+01	0.652E+01	0.270E+01	0.000E+00	0.618E+02	2237
FLT 1 CH DELAY	0.349E+00	0.341E-02	0.976E-02	0.344E+00	0.352E+00	****
FLT 2 CH DELAY	0.349E+00	0.338E-02	0.970E-02	0.344E+00	0.352E+00	7575
FLT 3 CH DELAY	0.349E+00	0.337E-02	0.964E-02	0.344E+00	0.352E+00	2229
FLT 4 CH DELAY	0.349E+00	0.324E-02	0.926E-02	0.344E+00	0.352E+00	1229
FLT 5 CH DELAY	0.349E+00	0.323E-02	0.925E-02	0.344E+00	0.352E+00	3659
FLT 6 CH DELAY	0.349E+00	0.336E-02	0.963E-02	0.344E+00	0.352E+00	7755
FLT 7 CH DELAY	0.349E+00	0.328E-02	0.939E-02	0.344E+00	0.352E+00	9116
TOTAL CH DELAY	0.349E+00	0.335E-02	0.960E-02	0.344E+00	0.352E+00	****
MSG DELAY	0.298E+01	0.779E+01	0.262E+01	0.344E+00	0.104E+03	****

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	AWAIT	0.078	0.315	4	0	5.748
2	AWAIT	0.014	0.125	3	0	1.120
3	AWAIT	0.001	0.035	1	0	0.309
4	AWAIT	0.001	0.029	1	0	0.374
5	AWAIT	0.006	0.092	4	0	0.985
6	AWAIT	0.039	0.215	3	0	2.866
7	AWAIT	0.031	0.194	3	0	2.411
8		0.000	0.000	0	0	0.000
9		0.000	0.000	0	0	0.000
10		0.000	0.000	0	0	0.000
11		0.000	0.000	0	0	0.000
12		0.000	0.000	0	0	0.000
13		0.000	0.000	0	0	0.000
14		0.000	0.000	0	0	0.000
15		0.000	0.000	0	0	0.000
16		0.000	0.000	0	0	0.000
17		0.000	0.000	0	0	0.000
18		0.000	0.000	0	0	0.000
19		0.000	0.000	0	0	0.000
20		0.000	0.000	0	0	0.000

21			0.000	0.000	0	0	0.000
22			0.000	0.000	0	0	0.000
23			0.000	0.000	0	0	0.000
24			0.000	0.000	0	0	0.000
25			0.000	0.000	0	0	0.000
26			0.000	0.000	0	0	0.000
27			0.000	0.000	0	0	0.000
28			0.000	0.000	0	0	0.000
29			0.000	0.000	0	0	0.000
30			0.000	0.000	0	0	0.000
31		AWAIT	0.000	0.000	1	0	0.000
32		AWAIT	0.000	0.000	1	0	0.000
33		AWAIT	0.000	0.000	1	0	0.000
34		AWAIT	0.000	0.000	1	0	0.000
35		AWAIT	0.000	0.000	1	0	0.000
36		AWAIT	0.000	0.000	1	0	0.000
37		AWAIT	0.000	0.000	1	0	0.000
38			0.000	0.000	0	0	0.000
39			0.000	0.000	0	0	0.000
40			0.000	0.000	0	0	0.000
41			0.000	0.000	0	0	0.000
42			0.000	0.000	0	0	0.000
43			0.000	0.000	0	0	0.000
44			0.000	0.000	0	0	0.000
45			0.000	0.000	0	0	0.000
46			0.000	0.000	0	0	0.000
47			0.000	0.000	0	0	0.000
48			0.000	0.000	0	0	0.000
49			0.000	0.000	0	0	0.000
50			0.000	0.000	0	0	0.000
51			0.000	0.000	0	0	0.000
52			0.000	0.000	0	0	0.000
53			0.000	0.000	0	0	0.000
54			0.000	0.000	0	0	0.000
55			0.000	0.000	0	0	0.000
56			0.000	0.000	0	0	0.000
57			0.000	0.000	0	0	0.000
58			0.000	0.000	0	0	0.000
59			0.000	0.000	0	0	0.000
60			0.000	0.000	0	0	0.000
61	RUQ	AWAIT	0.000	0.000	1	0	0.000
62	CHQ	AWAIT	0.000	0.000	1	0	0.000
63		CALENDAR	7.980	0.880	14	8	2.771

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	FLT1	1	0.29	0.455	1	0

2	FLT2	1	0.13	0.335	1	0
3	FLT3	1	0.05	0.210	1	0
4	FLT4	1	0.03	0.177	1	0
5	FLT5	1	0.08	0.271	1	0
6	FLT6	1	0.22	0.413	1	0
7	FLT7	1	0.18	0.387	1	1
31	RAD1	100	0.37	0.645	5	0
32	RAD2	100	0.14	0.389	4	0
33	RAD3	100	0.05	0.218	2	0
34	RAD4	100	0.03	0.184	2	0
35	RAD5	100	0.09	0.306	5	0
36	RAD6	100	0.26	0.526	4	0
37	RAD7	100	0.22	0.488	4	1
38	CHAN	7	0.65	0.749	6	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	FLT1	1	0.7073	0	1
2	FLT2	1	0.8715	0	1
3	FLT3	1	0.9540	0	1
4	FLT4	1	0.9677	0	1
5	FLT5	1	0.9199	0	1
6	FLT6	1	0.7824	0	1
7	FLT7	0	0.8162	0	1
31	RAD1	100	99.6295	95	100
32	RAD2	100	99.8579	96	100
33	RAD3	100	99.9527	98	100
34	RAD4	100	99.9668	98	100
35	RAD5	100	99.9138	95	100
36	RAD6	100	99.7437	96	100
37	RAD7	99	99.7851	96	100
38	CHAN	7	6.3480	1	7

1 **HISTOGRAM NUMBER16**

MSG DELAY

```
OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80        100
                    +    +    +    +    +    +    +    +    +    +    +
  0 0.000 0.000E+00 +                                                 +
*** 0.825 0.100E+01 +*****************************************        +
112 0.010 0.200E+01 +*                                        C       +
103 0.009 0.300E+01 +                                         C       +
 94 0.008 0.400E+01 +                                          C      +
101 0.009 0.500E+01 +                                          C      +
 84 0.008 0.600E+01 +                                          C      +
 81 0.007 0.700E+01 +                                           C     +
 70 0.006 0.800E+01 +                                           C     +
 98 0.009 0.900E+01 +                                            C    +
 74 0.007 0.100E+02 +                                            C    +
```

```
65 0.006 0.110E+02 +                                            C    +
84 0.008 0.120E+02 +                                             C   +
65 0.006 0.130E+02 +                                             C   +
64 0.006 0.140E+02 +                                             C   +
62 0.006 0.150E+02 +                                             C   +
57 0.005 0.160E+02 +                                              C  +
53 0.005 0.170E+02 +                                              C  +
45 0.004 0.180E+02 +                                              C  +
42 0.004 0.190E+02 +                                              C  +
56 0.005 0.200E+02 +                                               C +
37 0.003 0.210E+02 +                                               C +
44 0.004 0.220E+02 +                                               C +
33 0.003 0.230E+02 +                                               C +
34 0.003 0.240E+02 +                                               C +
38 0.003 0.250E+02 +                                               C +
30 0.003 0.260E+02 +                                                C+
26 0.002 0.270E+02 +                                                C+
24 0.002 0.280E+02 +                                                C+
17 0.002 0.290E+02 +                                                C+
19 0.002 0.300E+02 +                                                C+
23 0.002 0.310E+02 +                                                C+
12 0.001 0.320E+02 +                                                C+
16 0.001 0.330E+02 +                                                C+
14 0.001 0.340E+02 +                                                C+
15 0.001 0.350E+02 +                                                C+
14 0.001 0.360E+02 +                                                C+
17 0.002 0.370E+02 +                                                C+
10 0.001 0.380E+02 +                                                C+
15 0.001 0.390E+02 +                                                 C
 7 0.001 0.400E+02 +                                                 C
 7 0.001 0.410E+02 +                                                 C
 5 0.000 0.420E+02 +                                                 C
 7 0.001 0.430E+02 +                                                 C
 4 0.000 0.440E+02 +                                                 C
 4 0.000 0.450E+02 +                                                 C
 5 0.000 0.460E+02 +                                                 C
 3 0.000 0.470E+02 +                                                 C
 7 0.001 0.480E+02 +                                                 C
 5 0.000 0.490E+02 +                                                 C
 5 0.000 0.500E+02 +                                                 C
39 0.004    INF    +                                                 C
---                +    +    +    +    +    +    +    +    +    +    +
***                0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
MSG DELAY	0.298E+01	0.779E+01	0.262E+01	0.344E+00	0.104E+03	****

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Vita

Capt Farrell was born at a very young age [redacted] He first became involved in communications at the age of 5, when he attempted to build a long-haul circuit (several hundred feet) with two paper cups and a length of string. Although the project was abandoned due to technical difficulties (a small hillock on the line-of-site path caused the string to become "grounded") his interest never waned. He attended Lehigh University, in Bethlehem, Pennsylvania, where he learned to survive on nothing but pizza and beer, and graduated with a Bachelor of Science in Electrical Engineering in June 1984. Somehow, he managed to receive a commission in the USAF through the ROTC program, and was assigned to RAF Croughton in the United Kingdom. At Croughton, he gained valuable experience with HF, satellite, wideband, and LMR communications systems, particularly when the technicians actually let him touch the equipment. Upon his departure from Croughton, he received his Murphy's Law degree and was made an honorary Tech-Controller (not necessarily in that order). Much to his surprise, he was accepted to AFIT, and entered the School of Engineering in June 1987.

[redacted]

REPORT DOCUMENTATION PAGE

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12. PERSONAL AUTHOR(S)
Thomas C Farrell, Capt, USAF

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

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19. Abstract

Trunked land mobile radio systems, currently being developed by several companies, allow many groups of land mobile radio (LMR) users to share a set of channels dynamically, reducing the total number of channels needed to support these groups. These systems also support "dynamic regrouping", reassigning individual users to different groups through software in the controlling computer. Hybrid trunked systems (HTSs) have the added advantage of being able, in the event of controlling system failure, to default to certain channels, adding a degree of robustness to the system. HTSs seem to be an answer to many of the Air Force's intra-base communications needs. These needs include the ability to support an ever increasing number of users with a minimal increase in allocated channels, a very high level of system reliability under extremely adverse conditions, and an ability to manage users under a variety of contingencies (base attack, aircraft crash, etc.) In order to determine the number of channels a HTS will require for a specific facility, information about traffic loading, and how the system reacts to it, is needed.

This paper discusses a computer model of existing LMR networks on Wright Patterson Air Force Base (WPAFB), and a model of a possible trunked system for the base. Data was collected from off the air monitoring of LMR nets, and was used to determine numerical values for various parameters. These values were input to the computer models to determine the time required for a user to obtain a channel while traffic load and (for the trunked model) user grouping were varied to simulate various conditions.

A 5 (1 data, 4 voice) channel HTS was found to adequately support WPAFB, even with a loss of one repeater and an increase in LMR traffic. With proper user grouping, trunked system performance is shown to be superior to the existing conventional system while using fewer channels.