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ANALYSIS OF THE ARMY MEDICAL EVACUATION

SUPPORT SYSTEM IN FORWARD COMBAT AREAS

THESIS

AFIT/GST/OS/84M-6 VIRGIL W. COOK, JR.
Captain US Army

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Abstract

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Using Simulation for Alternative Modeling (SLAM), a combined network-discrete event computer simulation model was developed and used to study the evacuation system. The model was used to estimate vehicle requirements for the battalion aid station and brigade clearing station evacuation sections. The model was also used to test currently proposed and alternative operating concepts. A statistical analysis of the model output was performed. A complete description of the model and the results of the analysis are presented.

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Analysis of the Army Medical Evacuation Support System in Forward Combat Areas

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

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Captain US Army

Graduate Strategic and Tactical Sciences

March, 1984

Preface

The purpose of this study was to analyze the medical evacuation system using the newly developed High Mobility Multipurpose Wheeled Vehicle (HMMWV) in a light infantry brigade area of a combat zone. A systems simulation approach was used to study the evacuation system. The simulation model of the system was developed using Simulation Language for Alternative Modeling (SLAM). Anyone who is interested in studying the ground evacuation capability in an infantry brigade area should find the model and computer program in this report useful.

I wish to gratefully acknowledge the following people for their assistance with this study: Lieutenant Colonel (P) George Hausler, Major Glenn Flint, Captain Joe Makarsky and others of the Academy of Health Sciences, Fort Sam Houston, Texas, for their interest and support; Mr. Dennis Collins at Fort Benning, Georgia for his ideas and counsel; and to my thesis committee of Lieutenant Colonel Thomas D. Clark, Jr., thesis advisor, and Major James Coakley, reader, for providing many insights and the ideal learning environment.

Finally, I wish to thank my wife, Doreen Cook, for her patience and understanding throughout the long hours spent on this project and course of study.

Virgil W. Cook, Jr.

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Abstract

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Chapter I.

Introduction

This introductory chapter presents an overview of the health service support system of the US Army and focuses on the problem of patient evacuation from company aid posts to the medical clearing station within an infantry brigade's area of operation. This overview is followed by a concise statement of the problem, the research question, the objectives, and the scope of this research effort. Also, existing models related to this topic are described. The remainder of this chapter presents the methodology and the order of presentation for the following chapters.

Overview

Department of the Army doctrine for health service support specifies concepts and organizational structures for supporting the Army forces in a theater of operations (Ref 12). Typically, a theater of operations is divided into two zones, the combat zone under the command of the corps headquarters and the communications zone under the command of the theater army headquarters. The health service support system in the combat zone is the focus of this study.

Health service support includes the required care and treatment in the shortest possible time for sick, injured, and wounded soldiers. This support system includes medical treatment and hospitalization; patient evacuation and medical regulating; medical supply, maintenance, and material management; and dental, optical, laboratory, blood bank, veterinary, preventive medicine, medical intelligence, and food services (Ref 14). Patient evacuation from a forward combat zone is the part of this complex system addressed in this study. Specifically, the new High Mobility Multipurpose Wheeled Vehicle (HMMWV) used as an ambulance will be evaluated. The purpose of the evaluation will be addressed after the general nature of the system is discussed.

A combat zone (CZ) is the forward area of a theater of operations. The CZ is usually the area designated to combat forces to conduct military operations. The size of the CZ depends on such things as the number of forces involved, the type of operations to be conducted, the terrain, and the enemy's capabilities. Normally, the CZ is subdivided into corps areas. Each corps area is then subdivided into division areas. Each division may have several combat brigades operating in its area. Figure 1 illustrates how a corps area might be subdivided. Each of the brigade areas illustrated in Figure 1 would be further subdivided into battalion areas.

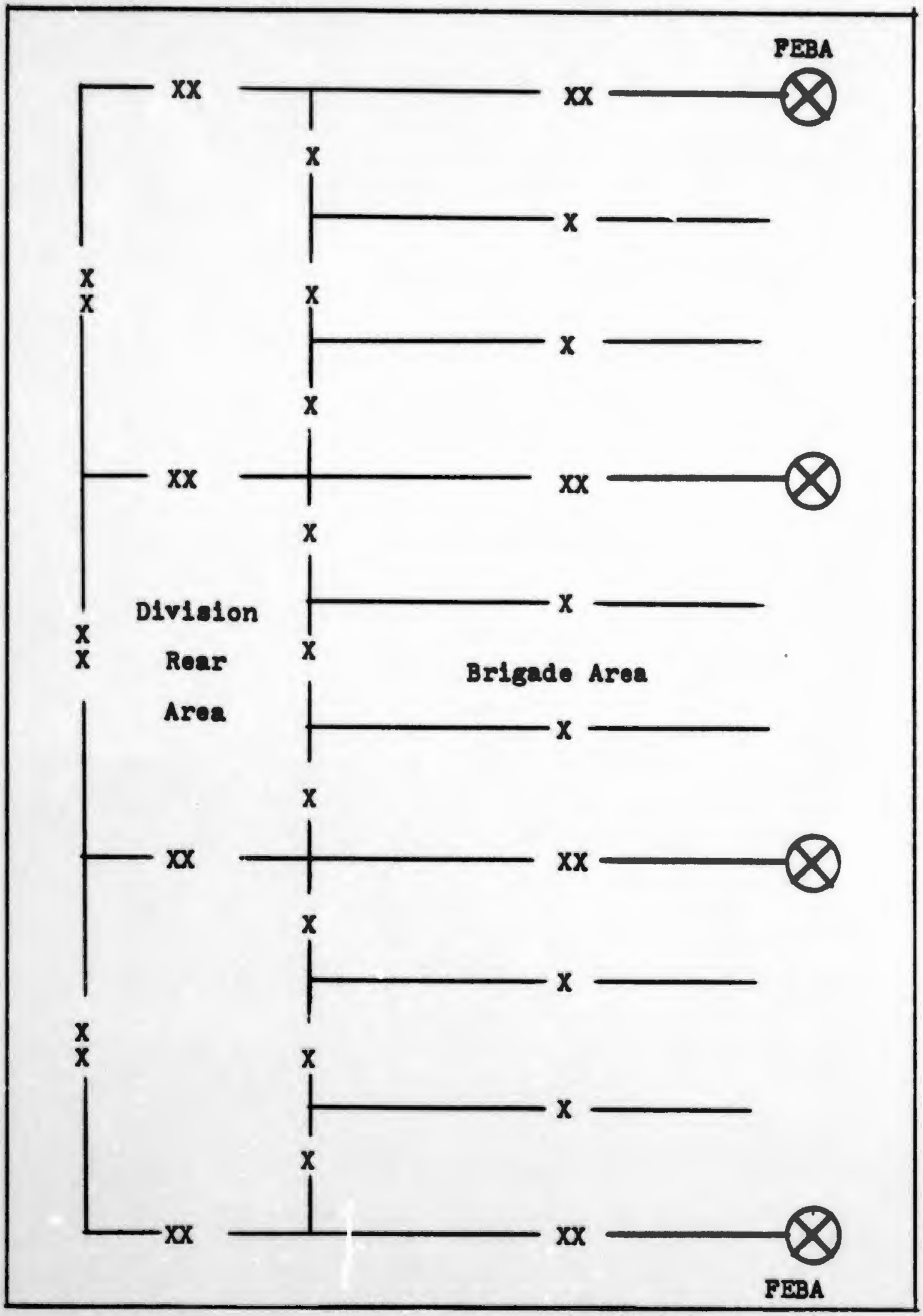


Figure 1. Typical Subdivision of Corps Area

Typically, there are three maneuver battalions assigned to each brigade headquarters. An infantry battalion normally has three rifle companies. Figure 2 illustrates how a brigade area of operation might be partitioned. This concept provides the framework and foundation for understanding the evacuation process of the health service support system. Patient evacuation within an infantry brigade area is the focus of this research. The research is concerned with the movement of sick, injured, wounded, and pyschologically disabled personnel from the battlefield to the appropriate medical treatment facility within the health service system. These personnel may include soldiers, government civilians, local non-combatants, and enemy soldiers. Nonmilitary personnel who accompany combat forces such as DA civilian employees, press, contractors, and Red Cross personnel are authorized treatment in the military medical facilities and evacuation as specified in Army Regulation 40-3 (Ref 14:1-3). The patient evacuation process within the brigade area is described next.

Normally, the evacuation process begins at the forward companies near the forward edge of the battle area (FEBA). Each company has a designated aid post. The aid post serves as a collection point for patients where the patients receive first aid and are prepared for further evacuation if required. Each patient's condition must be stable before evacuation.

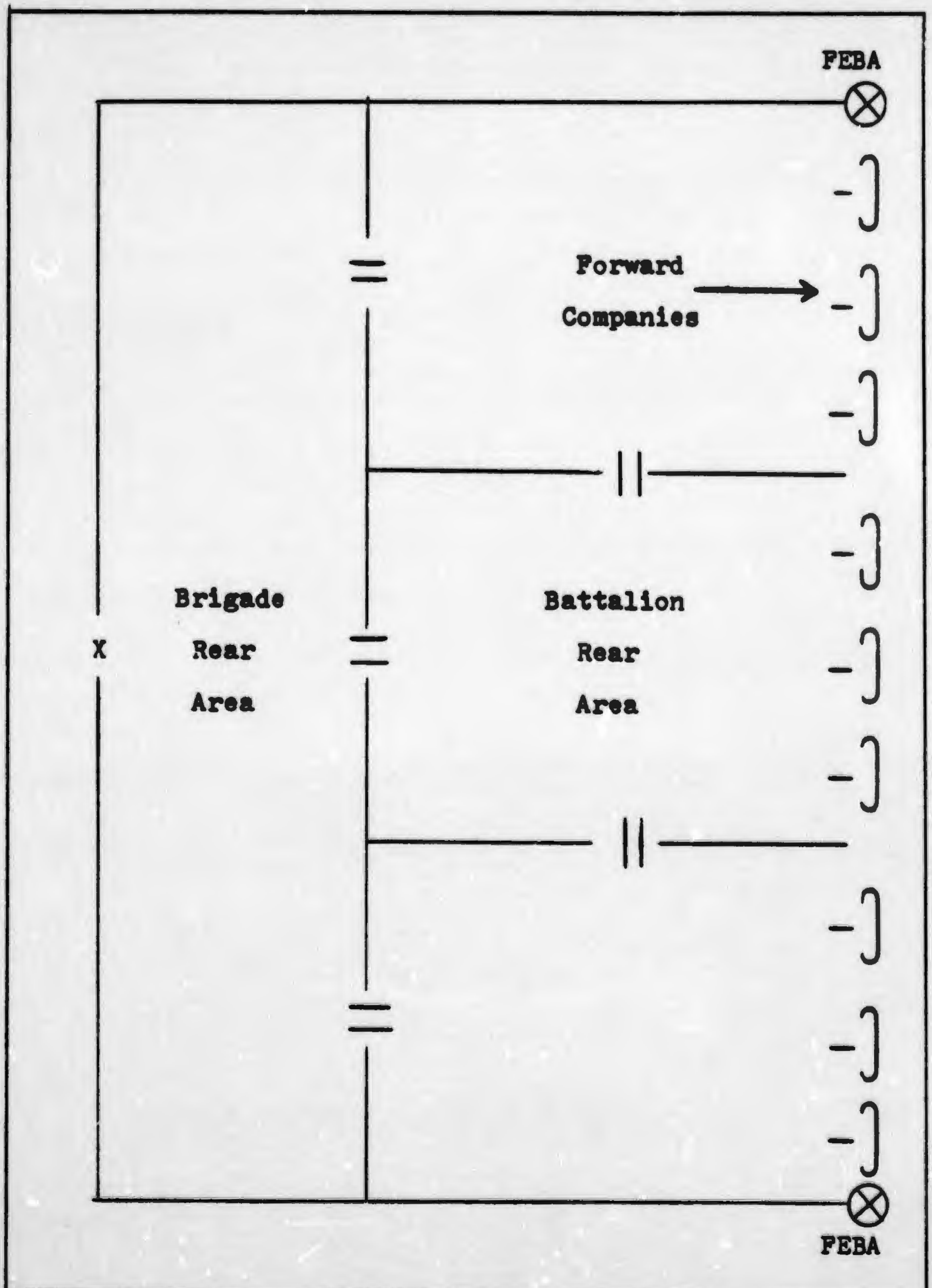


Figure 2. Typical Subdivision of Brigade Area

Evacuation support is from the rear to the front except within the companies. Within the companies, designated litter teams carry patients to the company aid post. Able patients walk to the aid post in order to conserve the size of the fighting force. But, the primary means of evacuation to the battalion aid station (BAS) is the tactical field ambulance.

The evacuation support of the forward companies is provided by the evacuation section of the battalion's medical platoon. The medical platoon headquarters is responsible for establishing the battalion aid station (BAS). Normally, the BAS is located five to eight kilometers behind the companies. Patients that require further evacuation are moved by the ambulance platoon of the medical company. There is one medical company in support of an infantry brigade and this medical company is responsible for establishing the clearing station located 10 to 16 kilometers from the battalions' aid stations. Also, this ambulance platoon will be equipped with the HMMWV as the tactical field ambulance.

Air evacuation may be possible at this level but it is not considered here for several reasons. First, air evacuation by helicopter is prevented by adverse weather conditions. Also, air evacuation may not be feasible due to enemy air defenses in the main battle area. In a chemical warfare environment, helicopters are much more difficult to decontaminate than tactical vehicles;

therefore, air evacuation may not be used. For planning purposes, the tactical field ambulance is the primary means of evacuation not only from the company aid posts to the battalion aid stations but also from the BAS to the medical company clearing station (Ref 9). The evacuation system at the brigade level is illustrated in Figure 3.

The evacuation as depicted in Figure 3 is the critical link in the system. There are no treatment facilities in this area with the capability of holding patients for extensive treatment. The company aid posts and battalion aid stations do not hold patients for treatment. They either treat minor wounds and return soldiers to duty or prepare them for further evacuation. The clearing station is the first facility in the system that has the capability of providing more than merely first aid. Therefore, the evacuation capability is essential for the care of the critically wounded. As technology increases the lethality of modern weapons, the number of casualties expected in a high intensity conflict is likely to increase resulting in a tremendous demand on the evacuation system. It is for this reason that the evacuation system needs to be analysed. Under such circumstances, how will the evacuation system perform?

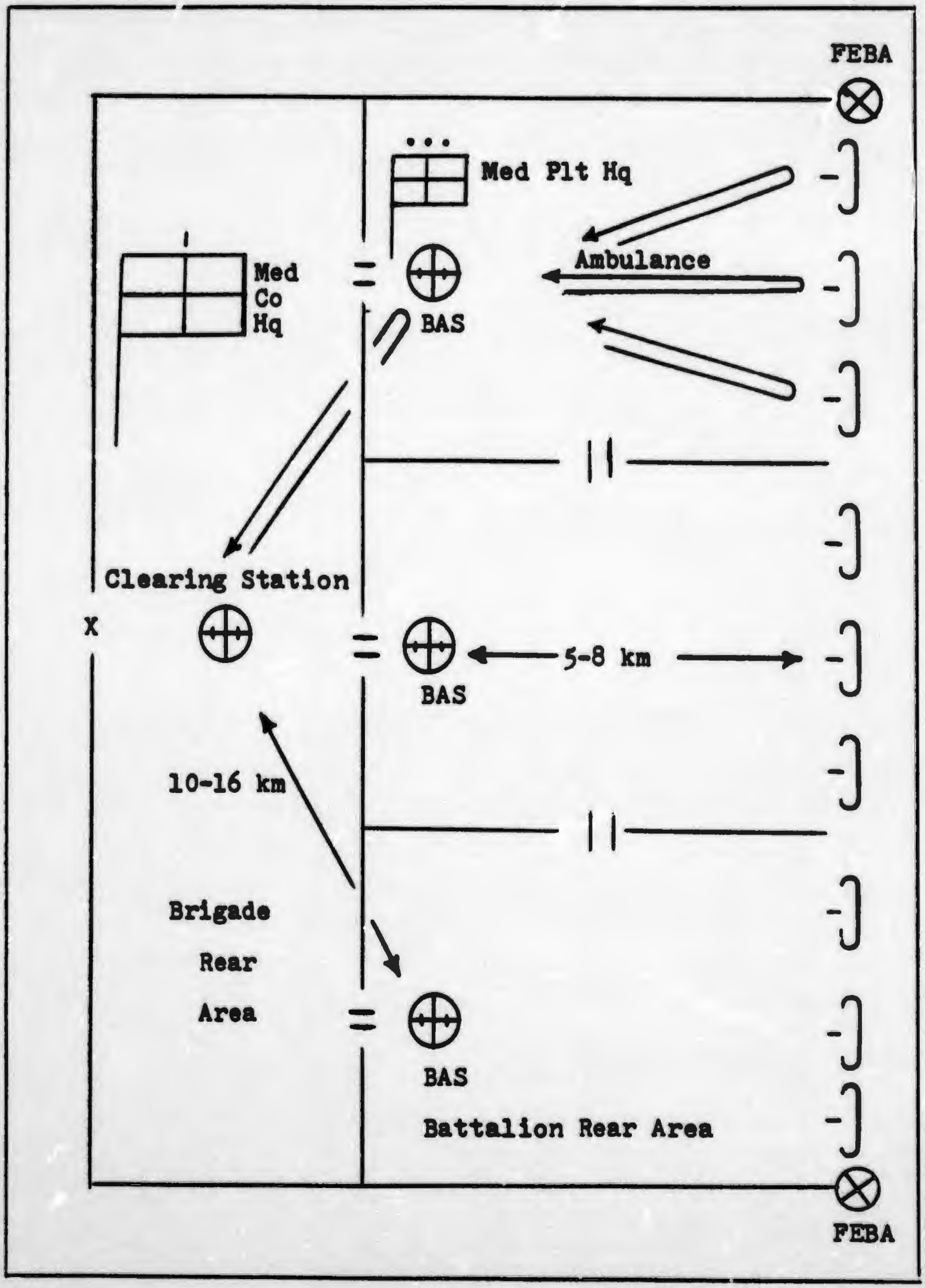


Figure 3. Evacuation in a Brigade Area

Problem

An analysis of the ground evacuation capability using the highly mobile multi-purpose wheeled vehicle (HMMWV) as the tactical field ambulance is required to predict the number of vehicles required for the evacuation sections to provide support in a high intensity conventional conflict.

Research Questions

How will the proposed ground evacuation system in an infantry brigade area of operation perform in a high intensity conventional conflict? Specifically:

a. What will be the expected time for patient evacuation from the company aid posts to the medical company clearing station?

b. What will be the expected ambulance utilization?

c. How long will patients have to wait at the battalion aid station for evacuation to the clearing station?

d. How many ambulances are required to provide evacuation support in accordance with the existing doctrine and tactics?

Objectives

The primary objective of this research is to evaluate the ground evacuation system using the highly mobile multi-purpose wheeled vehicle (HMMWV) configured as a tactical field ambulance. Inherent in this evaluation is an investigation of the system to provide answers to the research questions. Analysis of the evacuation system can provide insight to such things as the number of field ambulances required for support in accordance with Army evacuation guidelines, the capabilities of the proposed system, and possibly validate existing concepts or identify questionable concepts in the tactics and doctrine governing the evacuation system.

Scope

This research is directed to evaluating the ground evacuation system in an infantry brigade area of operation. The newly developed highly mobile multi-purpose wheeled vehicle (HMMWV) is considered as the tactical field ambulance used to provide evacuation support at both the battalion aid station and the medical company clearing station. No other means of evacuation is considered in the analysis. The tactical field ambulance is the primary means of evacuation and it could possibly be the only means of evacuation in the brigade area.

A combined network-discrete event simulation model has been chosen as the method for analyzing the evacuation system. The reasons for selecting a SLAM combined network-discrete event simulation model are presented in Chapter 3.

Existing models related to this topic are described next. Then, the following section presents the rationale not only for using simulation in systems study but also for selecting SLAM (Simulation Language for Alternative Modeling) as the simulation language.

Existing Models

There are seven existing simulation models that are in some way related to the topic of patient evacuation. The models are the Patient Flow Model, the Combat Zone Assessments & Requirements Model (CZAR), the Patient Workload Model (PWM), the Facilities Model formerly named the Hospital Model, the Patient Generator model, the World Wide Military Medical Support System model, and the Patient Evacuation and Treatment System (PETS) model. The proponent agency for these models is the Directorate of Combat Developments, Academy of Health Sciences, Fort Sam Houston, Texas. Brief descriptions of these models are provided below.

Patient Flow Model. The Patient Flow Model (PFM) is a discrete event simulation model written in FORTRAN. This model simulates the flow of hospitalized patients in a theater and the sustaining base. The model is used to forecast hospital bed requirements at appropriate echelons and to forecast the impact upon the CONUS hospitalization system. The model can be used to perform sensitivity analysis on evacuation policies. This model is designed primarily for theater-level land forces in which the division is the lowest echelon analyzed. The output of this model includes an admission summary by echelon, bed requirements, and the number of evacuees, deaths, discharges, and skipped evacuees.

<u>Combat Zone Assessments & Requirements Model</u>. The Combat Zone Assessments & Requirements Model (CZAR) is actually a combination of two models, CZAR I and CZAR II. CZAR I was developed to evaluate manpower requirements for initial entry care in a combat scenario. CZAR I was then enhanced to assess ward care and hospital bed requirements. CZAR II is a further enhancement of CZAR I. CZAR II enhancements provide evaluation of medical personnel, bed, and evacuation requirements at each echelon in both the Combat Zone and the Communication Zone. Both models are discrete event simulations coded in FORTRAN.

<u>Patient Workload Model</u>. The Patient Workload Model was developed at the US Army Logistics Center as an analytical logistics model to assess the resource requirements for health care for Army units in the field. This model generates the expected number and types of patients from specified combat situations and determines the resources required to process the generated patient workload through a division medical support system. In this model patients are processed from the battalion aid station to the supporting combat hospitals. The model consists of two submodels, the Patient General Submodel which generates the patient stream and the Division Processor Submodel which simulates patient processing in the division medical support system. The patient stream

generated may be used in the Hospital Model. Both FORTRAN and SIMSCRIPT programming languages are used in this model.

Facilities Model (Hospital Model). Initially named the Hospital Model, this model is now called the Facilities Model. This is a discrete event simulation model written in FORTRAN. It is used to simulate a hospital or a chain of hospitals for the purpose of determining capabilities and hospital requirements. This model can also be used for scheduling staff personnel and assessing staff utilization. It also provides an estimate of bed requirements for assumed evacuation policies.

Patient Generator. The Patient Generator is a stochastic simulation model that may be used to generate a patient stream for use in the Facilities Model and the CZAR Model. This model is coded in the FORTRAN language. The patient stream generated simulates the expected workload for the Combat Zone medical support system. As input, this model requires user specified probabilities for the occurrences and types of patients as well as casualty rates and troop strengths.

World Wide Military Medical Support System. The World Wide Military Medical Support System (WWMMSS) is a computer program coded in SIMSCRIPT II.5 that simulates the operation of multi-echelon medical treatment and evacuation systems. WWMMSS is an enhanced version of the Patient Workload Model. During the Medical Planning Factors (MEDPLN) Study, this model was improved by the Naval

Research Laboratory for the Office of the Assistant Secretary of Defense for Health Affairs and renamed the Navy Amphibious Medical Evacuation Simulation (NAMES) and subsequently named the World Wide Military Medical Support System (Ref 1). This model will be upgraded to enhance its usefulness for Army medical planners and the planned upgraded model has been named the Patient Evacuation and Treatment System (PETS).

Although all of the above models are in some way related to patient evacuation in a Combat Zone and useful for their designed purposes, none are specifically designed for analyzing the system for ground evacuation of patients from forward companies to the battalion aid stations and then to the medical company clearing station using the Highly Mobile Multi Purpose Wheeled Vehicle configured as a tactical field ambulance. Either a standard model must fit the situation reasonably well or a tailor-made model must be developed to a level of detail required for the situation. Chapter 3 presents a SLAM simulation model tailor-made for the analysis of the evacuation capability in a brigade area using the new HMMWV. Next, a general discussion of the rationale for using simulation for studying systems is presented and it is followed by a short discussion of the advantages and capabilities of SLAM.

Methodology

The models described above illustrate applications of simulation modeling for the analysis of various medical support activities within the health care system. Simulation is a powerful methodology for the analyst to experiment with real or proposed systems where it might otherwise be impractical or impossible. Clearly, the ground evacuation system in a brigade area of a Combat Zone is an example of a system for which it would be politically and economically infeasible to experiment. Although it may be necessary to modify this system during combat, a simulation study of the process may provide the awareness so that contingency plans correctly anticipate required changes.

> Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system (Ref 38:2).

Although there are various definitions given by other authors (Ref 20,23,37), the above definition is appropriate here with one exception; the system to be studied by simulation may be a proposed system as well as a real system. Simulation modeling is applicable to hypothetical systems also.

The existing models described above are all computer simulation models. Computers make large scale simulations feasible but not all simulation models need to be computer models. In a broad sense, simulation modeling is:

> ... an experimental and applied methodology which seeks to describe the behavior of systems, to construct theories or hypotheses that account for the observed behavior, and to use these theories to predict future behavior, that is, the effects that will be produced by changes in the system or in its method of operation (Ref 38:2).

Simulation modeling may be one of several methodologies available for studying a given problem. It is desirable to fit the methodology to the problem rather than to fit the problem to the methodology. And when simulation modeling is appropriate, its use should not be over looked. There are many advantages of simulation modeling. These advantages and the reasons for using simulation are presented next.

Simulation Rationale. It was stated that simulation may be useful when experimentation with a system may be infeasible. Simulation modeling enables the analyst to overcome otherwise impossible experimental difficulties and duplication of the experimental environment. But there are certainly other reasons for using simulation modeling. It may be difficult or impossible to create a mathematical formulation of the problem. Furthermore, once the problem is formulated, there may be no analytical solution technique. This is often the case in stochastic complex queueing models. Shannon (Ref 38:11) suggests that the analyst consider the use of simulation when one or more of the following conditions exist:

1. A complete mathematical formulation of the

problem does not exist or analytical methods of solving the mathematical model have not yet been developed.

2. Analytical methods are available, but the mathematical procedures are so complex and arduous that simulation provides a simpler method of solution.

3. Analytical solutions exist and are possible but are beyond the mathematical ability of available personnel.

4. It is desired to observe a simulated history of the process over a period of time in addition to estimating certain parameters.

5. Simulation may be the only possibility because of the difficulty in conducting experiments and observing phenomena in their actual environment-e.g., studies of space vehicles in interplanetary flight.

6. Time compression may be required for systems or processes with long time frames. Simulation affords complete control over time, since a phenomenon may be speeded up or slowed down at will.

The fact is that simulation is one of the most widely used operations reseach techniques. Table 1 (Ref 38) shows the results of a survey conducted by Biles and Shannon (Ref 39) and reflects the value of simulation to a sample of operations research practitioners.

Table 1. Utility of O.R. Techniques to Practitioners

Topic	Frequency	%
Simulation studies	60	29
Linear programming	43	21
Network analysis (including PERT and CPM)	28	14
Inventory theory	24	12
Nonlinear programming	16	8
Dynamic programming	8	4
Integer programming	7	3
Queueing theory	7	3
Other	12	6
	205	100

The results of another survey reinforce the earlier results about the frequent use of simulation. This survey of the 1000 largest US firms according to "Fortune" magizine indicated that simulation study is the most frequently used technique in corporate planning. The results of this survey are illustrated in Table 2 (Ref 38).

Table 2. Quantitative Tools Most Frequently Employed in Corporate Planning

Topic	Value
Probability theory (and statistical inference)	0.182
Economic analysis (cost effectiveness)	0.150
Simulation	0.143
Linear programming	0.120
Inventory	0.097
Waiting line (queueing)	0.085
Network analysis (sequencing)	0.072
Replacement analysis	0.042
Gaming theory	0.040
Dynamic programming	0.031
Search techniques	0.020
Nonlinear programming	0.018
	1.000

Additionally, Morgenthaler (Ref 27:372) states at least 16 reasons to use simulation. Six of the reasons pertinent to this reaseach are restated here.

1. The task of laying out and operating a simulation of a process is a good way to systematically gather the pertinent data about the process. It makes necessary a broad education in the process or operation being simulated, on the part of all who participate seriously in the simulation.

2. Simulation of a complex operation may provide an indication of which variables are important and how they relate.

3. Simulations are sometimes valuable in that they afford a convenient way of breaking down a complicated system into subsystems, each of which may then be modeled by an analyst or team which is expert in that area.

4. Simulation is cheaper than many other forms of experiment or test facility.

5. Simulation may be used to develop enthusiasm and gain acceptance for a proposed change.

6. When new equipment or weapons are introduced unforseen bottlenecks and problems in the operation may arise. Simulation can help to forsee these difficulties. It forces attention on problems which might otherwise be ignored.

These reasons may be considered as rationale for simulation in general, but they are also the rationale and motivation for using simulation modeling in this research. The rationale for selecting SLAM as the simulation programming language is discussed next.

<u>SLAM for Simulation Modeling</u>. Simulation Language for Alternative Modeling (SLAM) is an advanced FORTRAN based language that allows simulation models to be built based on three different world views. It provides network symbols for building graphical models that are easily translated into input statements for direct computer processing. It contains subprograms that support both discrete event and continuous model developments, and specifies the organizational structure for building such models (Ref 32).

> In 1979, the state-of-the-art in simulation languages was extended with the introduction of SLAM, the first language that provided three different modeling viewpoints in a single

integrated framework. SLAM permits discrete event, continuous, and network modeling perspectives and/or any combination of the three to be implemented in a single model. SLAM represented a significant breakthrough in simulation methods development, as it provided the flexibility to use the most appropriate world view for the system being studied (Ref 40:197).

By the end of 1980, SLAM had been installed in more than 100 industrial, academic and governmental organizations (Ref 40:197). SLAM affords the analyst the capability for rapid model development using network modeling concepts and makes it possible to model a wider variety of systems using the most effective modeling perspective without restricting the modeling perspective as the model evolves. For these reasons, SLAM was chosen as the simulation language for the ground evacuation model in this research. This model is decribed in detail in Chapter 3. A discussion of the applied simulation methodology is presented next.

Applied Methodology. The system simulation process adopted for this study includes the 11 stages described by Shannon (Ref 38:23):

1. System Definition
2. Model Formulation
3. Data Formulation
4. Model Translation
5. Validation (Verification)
6. Strategic Planning
7. Tactical Planning
8. Experimentation
9. Interpretation
10. Implementation
11. Documentation

A brief discusion of these stages as they relate to this research is presented here while a more detailed description of the model, validation and verification, and experimentation is presented in later chapters.

The flow diagram presented in Figure 4 illustrates these 11 stages and their relationship in the simulation process. Although the stages are distinctly identified, the steps of the process may in fact overlap. Moreover, strategic planning of how to design an experiment that will yield the desired information should be considered early in the process, desirably during the model formulation. Also, this simulation process is iterative. It is possible to have feedback loops at each stage as more information and more knowledge about the system is acquired.

The system in this research has already been described in the overview. The evacuation system in the brigade area is based on current military doctrine (Ref 11,13,15). The conceptual model, restrictions and the measure of effectiveness as well as a logic flow diagram of the process and the data preparation of system parameters for this system will be discussed in Chapter II. Model translation -- a description of the evacuation network illustrsted in SLAM graphic symbols is presented in Chapter III. Methods of model verification and validation are presented in Chapter IV. Strategic planning is included in Chapter II while tactical planning is discussed in

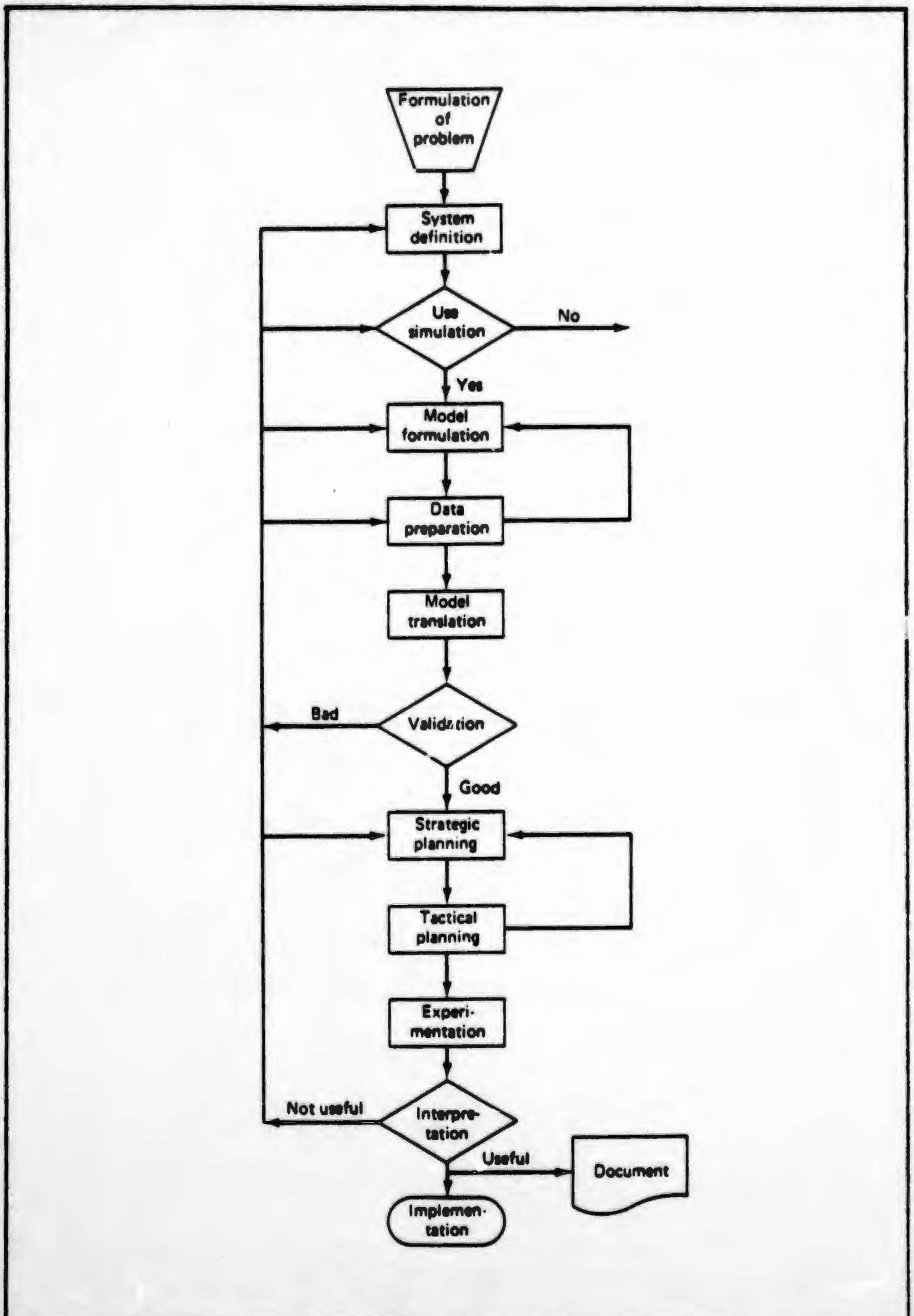


Figure 4. Flow Diagram of Simulation Process

Chapter IV along with experimentation and interpretation. Implemntation and documentation are discussed in the final chapter, Chapter V.

Order of Presentation

The remainder of this report discusses the implementation of the simulation methodology described above.

Chapter II, Simulation Design, discusses the conceptual model, the experimental design, the method of analysis, the factor levels of the experment, and the patient incident rate used for this study.

In Chapter III, The SLAM Model, the SLAM graphics used in the evacuation network and the combined network-discrete event perspective are discussed. Also, the significant assumptions of the model are described.

Chapter IV, Experimentation and Analysis, presents a discussion of verification and validation techniques with the application of appropriate techniques to this model. The experimental procedure and the analysis of the model output are discussed, and the results of sensitivity analysis performed by varying the patient incident rate is included in this chapter.

Finally, Chapter V outlines the conclusions drawn from this research and contains the recommendations for further study.

Chapter Summary

Chapter I has presented an overview of the medical support system, the problem statement, research questions, objectives, scope, existing models, and the methodology applied in this research. The next chapter, Chapter II, presents the simulation design.

Chapter II

Simulation Design

In order to perform an experiment efficiently, a scientific approach to planning the experiment is necessary. The statistical design of experiments refers to the process of planning the experiment so that the collected data may be analysed by statistical methods resulting in valid and objective conclusions (Ref 26:2). In order to follow the statistical approach, Montgomery recommends the procedure outline as follows:

1. Recognition and statement of the problem.
2. Choice of factors and levels.
3. Selection of response variable.
4. Choice of experimental design.
5. Performing the experiment.
6. Data analysis.
7. Conclusions and recommendations.

The statement of the problem and the objectives were presented in Chapter I. The choice of factors and the selection of response variables will be presented with a description of the conceptual model. An approach for the experimental design and the method of analysis as well as the factor levels will also be described in this chapter.

Conceptual Model

The purpose of the conceptual model is to identify the significant system components and their relationships. Almost every model consists of some combination of the following ingredients:

1. components
2. variables
3. parameters
4. functional relationships
5. constraints
6. criterion functions

These ingredients are defined and described by Shannon (Ref 38:14). A causal diagram of the system to be studied can be useful to the analyst to conceptualize a model of the system and to identify the parameters of interest. Figure 5 illustrates the causal diagram for the evacuation model.

Figure 5 depicts the interactions of the evacuation system. Causal diagrams are used in system analysis as tools to graphically represent and to aid in visualization of the system structure and key relationships. Relationships are depicted as solid lines with an arrow-tipped end that either has a positive or a negative sign. A positive sign indicates that an increase in one variable will result in an increase of the connected variable; whereas, a minus sign denotes that increasing one variable will decrease the other. These connections illustrate causal loops in the system. The effect of the loop is determined by summing the signs of the arrowheads. A positive number of arrowheads indicates a positive loop that, if uncontrolled by some external influence, can cause explosive destabilization. On the other hand, a negative sum of the signs indicates a goal oriented and stability producing loop. The development of the causal diagram,

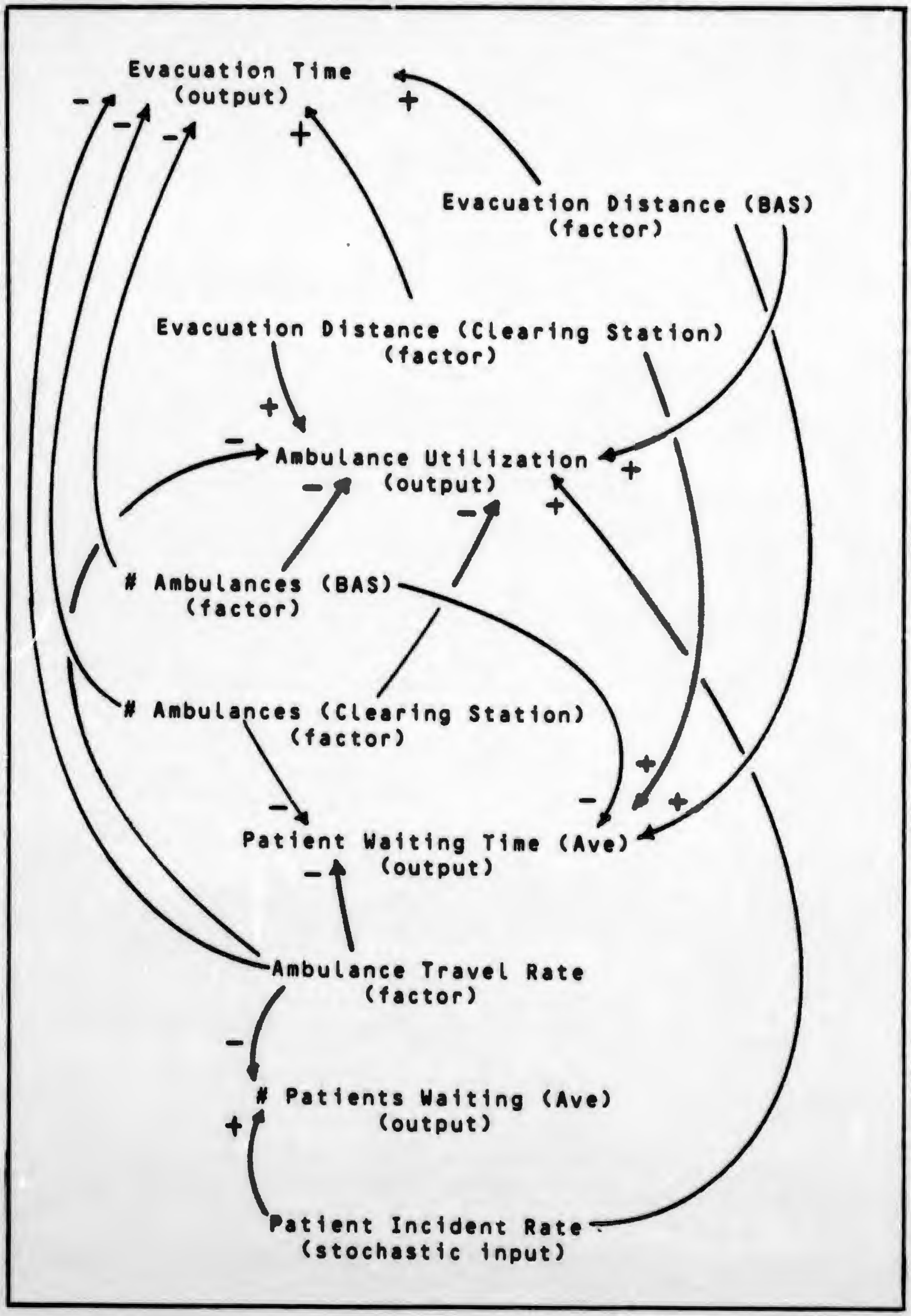


Figure 5. Causal Diagram for Evacuation Model

therefore, aids in the conceptualization phase of of key relationships in the model. Using this technique, the model output parameters of interest were identified.

For this study, the model was developed to provide the evacuation time, the ambulance utilization, the patient waiting time and the average number of patients waiting for evacuation as output. These are the response variables of interest and are the output of the model. There are five input variables that influence these response variables. The input variables are the number of available ambulances at the battalion aid stations, the number of ambulances available at the medical company clearing station, the evacuation distance to the battalion aid stations, the evacuation distance to the clearing station, and the ambulance travel rate (kilometers/hour). These input variables are controlled. In reality, these variables are controlled by changing the operating policy specified by tactics and doctrine. But, the number of patients to be evacuated (patient incident rate expressed as # patients per hour) is a stochastic parameter. In other words, the patient incident rate cannot be directly controlled. An analogy can be made to the weather. The weather cannot be controlled, but measures can be taken to minimize the effects of the weather. Similarly, measures can be taken to minimize the patient incident rate but it cannot be controlled. However, this parameter may be changed in order to perform sensitivity analysis for the response variables. (The results of this sensitivity analysis are discussed in Chapter IV.) The patient incident rate and the selection of a representative distribution is addressed later. These five input variables are the five factors to be considered in the experimental design. All of the input and response variables are measurable on a ratio scale. However, the input variables are discrete; whereas, the response variables are continuous. The measurement scale must be considered for the experimental design and analysis.

Experimental Design

To perform a general factorial design, an investigator selects a fixed number of "levels" (or "versions") for each of a number of variables (factors) and then runs experiments with all possible combinations. A two-level factorial design is of importance because it requires relatively few runs per factor studied; and although it is unable to explore fully a wide region in the factor space, it can indicate major linear trends and so determine a promising direction for further experimentation (Ref 3:306). Since there are five factors, a full five factor design set at two specified levels is a possible choice for the initial design to identify the significant factors. With two fixed levels for each factor, this fixed model requires 32 experiments to be complete. In other words, there are 32 experimental conditions for a full factorial design with five factors each set to two levels. (Figure 12 in Chapter IV illustrates the 32 cells for this design.)

The simulation used in this study is of the terminating type rather than a steady-state type. The simulation type is important with regard to the analysis of the output data. A terminating simulation is one for which the desired measures of system performance are defined relative to the interval of simulated time (Ref 23:280). The interval of simulated time is specified before the simulation begins. For this evacuation study, the interval of time is 10 days. This 10 day period is used in conjunction with the patient incident rate to simulate 10 days of high intensity conflict. This time interval represents a transient period in the evacuation process when there is peak demand on the medical support system. The transient period is considered for this analysis because, intuitively, the steady state analysis would result in a low estimate.

The accuracy of an estimator is usually bounded by a confidence interval. For terminating simulations, there are two procedures that can be used to determine confidence intervals; one procedure is for a fixed number of replicates per cell and the other procedure is for a specified precision of the estimator. The fixed sample size procedure is the usual approach for constructing a confidence interval. But, the disadvantage of this approach is that the simulator has no control over the confidence interval half-length. That is to say for a fixed number of replications, the half-length depends on the population variance, so a relatively large variance can render the half-length meaningless. This problem can be reduced by applying a variance reduction technique. (The variance reduction techniques applied to this model are discussed later.) The procedure for obtaining a confidence interval with a specified precision is generally to increase the number of replications until the desired precision is achieved. These procedures are described in detail by Law and Kelton (Ref 23:288-294). The application of these procedures is discussed in Chapter IV. (Analysis of variance (ANOVA) is the methodology used to test the significance of the factors in this experiment. It is discussed in the next section.)

In addition to constructing confidence intervals, it is also important to consider the number of replications per cell when using the ANOVA methodology. For a full factorial design when estimating all main effects and all possible interaction effects, more than one replication is required in order to obtain an estimate of the error term in the design. Experience indicates that from three to ten replications per cell are sufficient for simulation experiments where variance reduction techniques are applied. More than 10 replications provides marginal return for the additional effort (Ref 4). Additionally, Shannon states that an experiment on one factor would seldom be considered as adequately replicated unless it had about eight samples at each level (Ref 38:163). Therefore, 256 replications would be required for this complete design. Similarly, 10 replications in the full factorial design yields 320 runs.

In general, when changing two or more factors, the most efficient method is to use a factorial design. Shannon summarizes the advantages of factorial design over the classical "one factor at a time" approach as follows (Ref 38:165):

> 1. Maximum efficiency in the estimation of the effects of the variables.
>
> 2. Correct identification and interpretation of factor interactions if they exist.
>
> 3. The effect of a factor is estimated at several levels of the other factors, and thus the conclusions reached hold over a wide range of conditions.
>
> 4. Ease of use and interpretation.

The method of analysis for the 5 factor fixed model design is presented next.

Method of Analysis

Analysis of variance (ANOVA) can be used to investigate the simultaneous effects of factors in an experimental design. When there are n factors, the analysis is referred to as an n-way ANOVA. For this design, a 5-way ANOVA is used to determine the effects of the factors. The full factorial design of this research is analysed using the Statistical Package for the Social Sciences (SPSS) subprogram called ANOVA.

The response variable (independent variable) selected as the criterion for the analysis is the average time to evacuate patients from the company aid posts to the medical company clearing station. The other response variables (vehicle utilization, average patient waiting time, and average number of patients waiting at the battalion aid stations) are used to rank order the 32 operating policies of the experimental design. When the levels of the factors (independent variables) are fixed as opposed to being random, the analysis is a fixed-effect or linear hypothesis model. The ordinary output (F ratios) provided by subprogram ANOVA assumes the fixed-effect model. This assumption of the model is applicable to the design described above. Additionally, there are three basic assumptions for ANOVA (Ref 3:182). The first assumption is that the random samples are from normal populations having the same variance but possibly different means. Also, the errors are assumed to be independent and normally distributed with zero mean and a fixed variance. And finally, the effects are assumed to be additive. In practice, these assumptions are only approximately fulfilled. Experience suggests that in the majority of experiments, these disturbances are not sufficiently great to invalidate the technique (Ref 5:91). However, the implication is that the significance levels and confidence limits must be considered as approximate rather than exact.

The factor levels are fixed in this design and they are discussed next. More will be said about the analysis and the experimentation in Chapter V.

Factor Levels

The objective as presented earlier, is to evaluate the evacuation system. To do this, one level of each factor is chosen so that it represents the proposed operating policy. For example, suppose that the number of ambulances available at the battalion aid station is called factor 2. Then one level of factor 2 would be set to 6 ambulances because the proposed operating policy allocates 6 ambulances to the evacuation section of the battalion aid station. It may be optimistic to assume that each evacuation section will have 6 vehicles so this could be designated as the high level. In fact, each evacuation section may only have 4 ambulances authorized or operational. Therefore, the low level would be set to 4 ambulances. In like manner, the high and low levels for the number of ambulances available at the clearing station are set to 10 and 8 ambulances, respectively. The levels for the remaining factors are similarly established based on the proposed operating policy and a likely alternate level corresponding to each factor so that each factor is set to two levels. The levels for the five factors of interest in this problem are illustrated in Table 3.

The ambulance travel rates are based on the results of a ride and shock test, and mobility assessment of the HMMWV conducted at the Geotechnical Laboratory, US Army Engineer Waterways Experiment Station (Ref 10). "Effective speed would be an important factor in determining the type and number of ambulances required (TOE assignment), based upon projected casualties, number of sorties and evacuation distances (mission profile)" (Ref 10). The 20 km/hr rate is the expected rate of the HMMWV in cross-country terrain characteristic of the Middle East. The 35 km/hr rate is the expected rate of the HMMWV in generic cross-country terrain and trails as used in the mobility study.

Table 3. Factor Levels

Factor	Low Level	High Level
1	20 km/hr	35 km/hr
2	4 ambls	6 ambls
3	5 km	10 km
4	8 ambls	10 ambls
5	10 km	20 km

Factors:

1 Ambulance travel rate

2 Available ambulances at BAS

3 Evacuation distance to BAS

4 Available ambulances at Clearing Station

5 Evacuation distance to Clearing Station

By setting the factors to these levels, the observed responses will indicate whether or not the system performs in accordance with the Army guidelines for evacuation. In other words, these responses are the measures of merit. These measures of merit are used to evaluate the criterion function. Shannon defines a criterion function as an explicit statement of the objectives or goals of the system and how they are to be evaluated (Ref 38:16). The criteria used to evaluate the system are described next.

The ultimate criterion used to evaluate the performance of the system is the time to evacuate the patient to the clearing station. According to staff officers at the US Army Academy of Health Sciences, the critical time for evacuation in general must be less than 2 hours to the medical company clearing station (Ref 18). This is the first echelon of the unit level medical support system at which a patient can receive medical care and treatment which are more than mere first aid and life saving measures.

There are three secondary criteria used in this evaluation as well. They are an ambulance utilization rate less than 50%, a patient waiting time of less than 30 minutes, and an average number of patients at the BAS of less than four. The 50% utilization rate criterion for the ambulances is imposed because time must be allotted for crew rest and vehicle maintenance. Unlike the Air Force where there may be several crews per aircraft, the Army assigns only one crew per vehicle. Estimates indicate that a soldier requires at least 50% of the time to devote to rest, personal hygiene, and maintenance of individual weapons and equipment (Ref 18). Ideally, the patient waiting time and the average number of patients waiting at the BAS should be zero. The BAS is not designed and therefore not equipped to hold and care for patients. The BAS exists to treat soldiers with minor wounds and return them immediately to duty, or to stabilize patients and request further immediate evacuation. Failing to meet these two criteria may be cause to question the organization and equipment of the battalion aid station (BAS). Fundamental and essential to the evaluation and application of these criteria to the model is the patient incident rate used in the model. The patient incident rate selected for the simulation study is described next.

<u>Patient Incident Rate</u>

Forecasting casualty rates is not a simple task. The Army has recognized a need for an accepted methodology for the computation of casualties. Therefore, the Deputy Chief of Staff for Operations and Plans (DCSOPS), Department of the Army (DA), directed that a comprehensive study be conducted to develop a reliable, analytically rigorous methodology for estimating Army wartime casualties (Ref 30). The US Army Concepts Analysis Agency (CAA) was designated as the lead agency for the study. CAA was directed to review the current methodology and identify improvements for the casualty estimation process applicable to conventional scenarios. This included an analysis of the casualty estimation process in the main battle area (MBA) including the new diseased and nonbattle injury rates. The findings of this study were to be incorporated into the Army Model Improvement Program (AMIP) which was developed to oversee the design, development, and implementation of Army combat and support models. The results of this study by CAA were submitted to DCSOPS, DA in a final report prepared by the Force Analysis Directorate, CAA dated December, 1981. This report is used as a source for estimating the patient incident rate in this simulation study. Definitions and data relevant to the patient incident rate for this simulation study are presented next.

Generally, casualties are described as losses that require personnel replacements. Not all of these casualties place a demand on the evacuation support system. Table 4 illustrates the general categories of casualties as used in force related analyses conducted for the Army.

Obviously, administrative losses do not place a demand on the evacuation system. Also, CMIA and KIA battle casualties do not place a demand on the evacuation system. Transportation of KIA casualties is the responsibility of the graves and registration section which is a Quartermaster Corps function. Medical care and evacuation are the responsibility of the Medical Service Corps. Evacuation of patients and transportation of the dead are two distinctly separate responsibilities. Therefore, the term patient incident rate has been adopted for this simulation study to indicate the demand placed on the evacuation system. The patient incident rate includes the casualty categories wounded in action and all diseased nonbattle injuries.

Table 4. Casualty Categories

* Battle

  Killed in action (KIA)
  Captured/missing in action (CMIA)
  Wounded in action (WIA)
  - Hospitalized and evacuated
  - Hospitalized and returned to duty (RTD)
  - Died of wounds
  - Treated and released (not hospitalized)

* Nonbattle

  Diseased, injured (DNBI)
  - Hospitalized and evacuated
  - Hospitalized and RTD
  - Died of injuries/disease (DIH)
  - Treated and released (not hospitalized)

* Administrative losses

  AWOL
  Desertion
  Confinement
  Missing (not MIA)

The Casualty Estimation Study conducted by CAA indicated that the current methodology for estimating casualties in the main battle area consists of using historical rates for nonbattle casualties and a new attrition algorithm for calculating battle casualties. The study reported shortcomings for both methods. A sub-study conducted at the Academy of Health Sciences concluded that the historical DNBI rates are of limited value. The study recommended that the rates projected by the Army Medical Department (AMEDD) Treatment/Evacuation Model be adopted for the Central European scenario (Ref 22:34). For other scenarios, the rates now listed in the Army Force Planning Data and Assumptions FY 1981-1990 (U) are to be used until new scenario-specific rates are generated using the AMEDD model.

For this simulation, the Central Europe rate of 30.1/1000 active duty soldiers per day is adopted. This rate does not include government civilian personnel, representatives of the press, enemy or noncombatants and is lower than the rate (35.22/1000) reported in a study conducted during the annual Reforger Exercise in 1979. From the exercise, this rate was determined from patients seen at the clearing station of the 1st Medical Battalion of the 1st Infantry Division (Ref 22:20). The assumed rate can be changed in order to perform sensitivity analysis after the initial simulation experiment has been conducted.

The new attrition algorithm for battle casualties is proposed for use in the theater level simulation model, Force Evaluation Model (FORCEM). The rate for this study is an estimate of battle casualties (WIA) combined with the nonbattle casualty estimate to yield an incident rate of 130/1000 soldiers per day. This is approximately a 3:1 ratio of WIA to nonbattle casualties. This 3:1 ratio is selected based on the "FORECAST Casualty-Loss Methodology Study Report", a study prepared by ASM Programming Services, Inc. under contract and supervision of the FORECAST Project Office, Department of the Army (Ref 35:2-16). This rate is used to determine an estimate of the parameter for an exponential distribution to model the interarrival times of patients at the company aid post. The exponential distribution is used for the reasons discussed next.

Interarrival time is a term frequently used in queueing theory. It is defined as the time between consecutive arrivals to the system. The common assumption is that the arrivals occur in a statistical pattern known as a Poisson process. That is, the number of arrivals generated until any specific time has a Poisson distribution (Ref 20:402). In the case where the arrivals to the system occur randomly but at a certain average rate, an equivalent assumption is that the probability distribution of the time between consecutive arrivals is an exponential distribution (Ref 20:402). For the real system, the distribution could take on almost any form. But in order to formulate the model of the real system, it is necessary to assume a distribution.

> To be useful, the assumed form should be sufficiently realistic, so that the model provides reasonable predictions while, at the same time, be sufficiently simple, so that the model is mathematically tractable. On these bases, the most important probability distribution in queueing theory is the exponential distribution(Ref 20:408).

The parameter for the distribution is determined as follows. Each battalion is assumed to have a total strength of 1000 soldiers. Therefore, the average number of incidents per day per battalion would be 130. In hour time units, the average is approximately 5.4 incidents per hour. This rate then yields a 1.8 incidents per hour rate for each of the three forward companies. Early experimentation with various parameters for the exponential distribution resulted in selecting 0.54 as the test parameter for the interarrival distribution. This parameter yielded approximately 134 incidents per day per battalion. Another reason for selecting the exponential distribution is that it has a single parameter. This facilitates the sensitivity analysis in that only one parameter has to be changed. A brief discussion of variance reduction techniques for this simulation study is presented next.

Variance Reduction

Some mention of sample size was presented in the discussion of the number of replications desired for each experimental condition. Another technique for determining sample size is presented here.

> In the most straightforward case, where we can invoke the central limit theorem and assume no auto correlation, we can take a confidence limit approach to determining the sample size required for estimating parameters to a specified level of precision (Ref 38:187).

The relationship between sample size, reliability, and variance is illustrated in the following equation that Shannon suggests for determining sample size:

$$n = t^2 * Var/d^2$$

where t is the tabulated t value for the desired confidence level and the degrees of freedom of the initial sample, d is the half-with of the desired confidence interval, and Var is the estimate of the variance obtained in a sample or pilot run.

Variance reduction techniques are sample-estimating procedures that either increase precision of estimates for a fixed sample size or decrease the sample size required to obtain a fixed degree of precision. Table 5 lists three classifications and 16 variance reduction techniques as classified by E. J. McGrath et al (Ref 25).

The two techniques that are most frequently used in practice are correlated sampling (common random numbers) and antithetic variates (Ref 40). These two correlation methods for variance reduction will be incorporated into the design. The technique of common random number streams will be utilized in the design for all combinations of the factors. Using this technique insures that the experimental environment is the same for each cell in the design. The antithetic variate technique is used within each cell of the experimental design. Of the 10 replications for each cell, 5 replications are made each with a unique positive seed and then 5 more replications made with the corresponding seed negative to produce the antithetic number stream. This combination will yield 5 paired observations with a reduced variance. It is anticipated that using both techniques will increase the efficiency of the simulation. The rationale for these two correlation methods is presented next.

Antithetic variates and common random numbers are two variance reduction techniques that take advantage of correlation among simulation output responses to achieve improved efficiency. These two techniques are used to induce negative or positive correlation, respectively, among blocks of simulation runs by manipulating the random number input.

The antithetic technique is useful to estimate the response from a single system. This technique is also sometimes referred to as using complimentary random numbers. The idea is to use a mean response that is computed from two complimentary responses. That is to say, one response is generated from a random number and the other is generated from the compliment of the first random number. This causes the first response to be a high estimate and the other response to be a low estimate or vice versa, so that the responses are negatively correlated. The average of the two responses is then used as a single estimate of the system response. The variance of this average will then be reduced by the negative covariance of the two responses. The amount of variance reduction depends on the amount of negative correlation induced by the complimentary random numbers. SLAM has the capability of generating antithetic variates (Ref 32:150).

Table 5. Classification of Variance Reduction Techniques

MODIFICATION OF THE SAMPLING TECHNIQUE

* Importance Sampling
* Russian Roulette and Splitting
* Systematic Sampling
* Stratified Sampling

USE OF ANALYTICAL EQUIVALENCE

* Expected Values
* Statistical Estimation
* Correlated Sampling
* History Reanalysis
* Control Variates
* Antithetic Variates
* Regression

SPECIALIZED TECHNIQUES

* Sequential Sampling
* Adjoint Formulation
* Transformations
* Orthonormal Functions
* Conditional Monte Carlo

On the other hand, common random number technique is useful when comparing two systems or for controlling the experimental environment. In contrast to antithetic variates, common random numbers are used to induce a positive correlation among the responses in order to estimate the difference between two means. The variance of this difference is equal to the variance of the first response plus the variance of the second response minus two times the covariance of the first and second responses. When the correlation induced is positive, the variance of the difference is reduced because the covariance term is subtracted. In both techniques the experimenter must insure that the output responses respond in a similar way to changes in the random number input. In addition to making sample tests on the variance reduction, the analyst can appeal to the physical properties of the system. For example, in a queueing system, by increasing the service time it is reasonable to expect a longer time in the system. On the other hand, by decreasing the service time, it is reasonable to expect a shorter time in the system. If these two service times are complimentary, the variance of the average of the two will be reduced because of the negative correlation induced as explained above.

Chapter Summary

This chapter has presented a simulation design for the patient evacuation analysis in a combat zone. The plan specifically addresses the conceptual model and the experimental design. The plan also addresses techniques for selecting distributions, determining sample size and reliability, and reducing variance. It should be noted that this plan is flexible and dynamic. The plan is improved and modified as needed as the study progresses. The following chapter describes the combined network and discrete event model developed for this study.

Chapter III

The SLAM Model

Introduction

The combined network-discrete event evacuation model development using SLAM is discussed in this chapter. The graphic symbols of SLAM are explained and illustrated as they are used in the model to represent the patient incidents, unit identification, the battalion aid stations, and the clearing station. Also, the concept of modeling the ambulances as resources is discussed. Additionally, the interaction of the network with the discrete events using FORTRAN subroutines is described.

The System and SLAM Structure

The evacuation process described in Chapter 1 and illustrated in Figure 3 is translated into the SLAM simulation model using graphic symbols to represent the components and activities of the evacuation process. This structural model is computerized with SLAM input statements for the network symbols and FORTRAN code for the user-written discrete events. The complete network illustrated in SLAM graphics is provided in Appendix A. The SLAM input statements and FORTRAN code are provided in Appendix B.

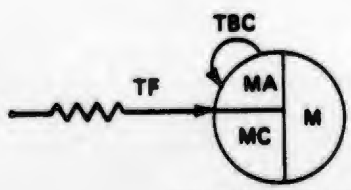
A SLAM network model consists of a set of interconnected symbols that depict the operation under study.

The nodes and branches of the SLAM network symbol set provide for commonly used routing and processing functions which are assembled by the modeler into a representative model (Ref 32). Here, the description of the evacuation model begins with a description of the nodes used in the structural model. Then, the user-written discrete events are described. This description includes an overview of the SLAM processor that controls the combined network-discrete event model.

Patient Generation

The determination of the patient incident rate was discussed in Chapter II. How that rate is implemented into the model is described in this section.

In SLAM, entities are inserted into the network by CREATE nodes. The symbol for the create node is shown below



CREATE Node Symbol

where:

TF is the time at which the first entity is to be created and sent into the network;

TBC is the time between creations of entities;

MA is the attribute number in which the creation or mark time is to be maintained;

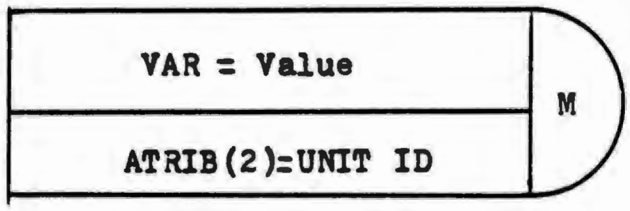
MC is the maximum number of entities that can be created at this node; and

M is the maximum number of branches along which a created entity can be routed from this node.

In the evacuation model, the entities are the patients to be evacuated. There are nine CREATE nodes in the model which represent nine infantry companies in the brigade area. The model is designed so that the three battalion, in the brigade each have three companies. This balanced force was selected as being the most representative organization because it reflects the current organization even though the force may be tailored differently as deemed necessary by the commander. It is assumed that if force tailoring occurs, the support is tailored accordingly. Changes to the organization proposed by force modernization can easily be accommodated by adjusting the number of CREATE nodes.

In the model, the time of the first entity creation at each of the CREATE nodes is selected arbitrarily from approximately 0.5 to 5 minutes after the beginning of time in order to provide a staggered start. Thereafter, the time between each incident is a variate from the exponential distribution selected as explained in Chapter II. The creation time is stored as attribute 1 of the entity so that the time of evacuation can later be determined.

The entities (patients) are routed from the node along a single branch (activity) to an ASSIGN node where the unit identification is assigned to attribute 2 of the entity. The graphic symbol for the branch is a line with an arrowhead pointing in the direction of travel. The ASSIGN node used for each unit is as shown here



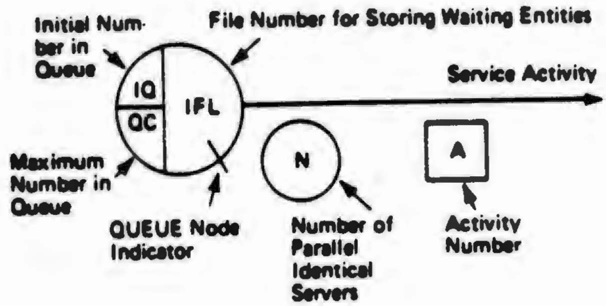
The ASSIGN node functions like a FORTRAN replacement statement. The variable VAR on the left side of the equal sign is assigned the value of the right side which can be a SLAM variable or an arithmetic operation.

In the real system, each patient is tagged by the field medic before being evacuated. The assign node represents this action and attribute 2 is later used to track patients throughout the system.

Company Aid Post

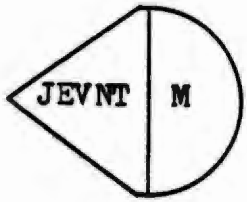
There are two nodes following each of the assign nodes. The first node described is a QUEUE node and the other is an EVENT node.

A QUEUE node is a location in the network where entities (patients) wait for service. The QUEUE node associated with each CREATE node represents the company aid post where the patients wait for the evacuation ambulance. The basic symbol for a QUEUE node is shown below.



In the model, each of these QUEUE nodes has a unique file number, an infinite capacity, and zero patients initially in the QUEUE. Patients waiting at the QUEUE nodes are ranked on a first-in, first-out (FIFO) priority; however, other ranking priorities are possible. In the real system, the senior medic would determine the evacuation priority for the patients and it might not be FIFO. However, for the model, FIFO is appropriate since the difference in evacuation times would average out over time because the evacuation time is computed based on the mark time at the CREATE node. Furthermore, the medic will ensure that the most critical patient is evacuated first. The HMMWV can carry four litter patients. If there are more than four patients to be evacuated, the senior aidman faces a real dilemma. In the model, when there are more than four patients waiting to be evacuated, another request is made. The evacuation request is generated at the EVENT nodes associated with each CREATE node.

The EVENT node is included in the network model to interface with a discrete event. The EVENT node is shown below.



The EVENT node causes the FORTRAN subroutine EVENT to be called every time an entity arrives at the node. The logic associated with the EVENT node is coded by the modeler as a discrete event; therefore, the modeler has complete modeling flexibility. So, when the modeler is faced with an operation for which there is no network node, the EVENT node can be used to model the specialized operation. The value of JEVENT in the node specifies the discrete event to be executed in the user-written subroutine. In the evacuation model these events are numbered 1 through 11. In the node, M specifies the maximum number of emanating activities to be taken by entities after the processing of the EVENT node.

The EVENT subroutine logic for the ambulance request is discussed later in this chapter. Also, the other discrete events are described. Following the return from the discrete event, the SLAM processor returns to the network model.

Highly Mobile Multi-purpose Wheeled Vehicle

As stated earlier, the HMMWV ("hum-vee") is the vehicle modeled as the tactical field ambulance. In this combined network-discrete event model, the ambulances available to each of the three battalion evacuation sections and to the clearing station evacuation section are modeled as resources. SLAM provides the capability to model the situation in which an entity requires a resource during a set of activities. This is done in the model by defining the resource type and the number of resources available. Entities that require resources wait at an AWAIT node. The RESOURCE block is used to identify the resource name, the initial number of resources available, and the order in which files associated with AWAIT nodes are to be checked to allocate freed units of the resource to the entities.

The RESOURCE block is unlike the nodes. It has no inputs or outputs because entities do not flow through it. The RESOURCE blocks can be placed together on the network diagram to form a legend. The RESOURCE block symbol is shown below.

RLBL(IRC)	IFL1	IFL2

In the RESOURCE block, RLBL(IRC) identifies the resource (label) and IRC specifies the initial resource capacity. The IFL# specifies the file to be checked for entities awaiting resources. In the model, the resources (ambulances) are labeled AMBL# corresponding to the appropriate unit; there are four RESOURCE blocks, one for each of the three battalion evacuation sections and one for the brigade clearing station evacuation section (Appendix A).

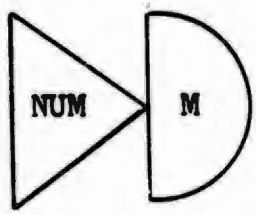
AWAIT nodes are used to store entities waiting for a specified resource. When an entity arrives at an AWAIT node, it passes directly through the node and is routed according to the branches if the required resource is available. If the entity has to wait at the node for a resource to become available, it is placed in a file associated with the node (IFL). As soon as the required resource becomes available, the entity passes through the node. The symbol for the AWAIT node is shown below.

The evacuation model has a total of four AWAIT nodes; one node is for each of the three battalion aid stations and one node is for the clearing station. Again, RLBL is the resource label and UR specifies the number of resources required by each entity. In the evacuation model, UR is set to 4 and 6 at the battalion aid stations and to 8 and 10 at the clearing station, depending on the factor level combination desired. The AWAIT nodes provide the control mechanism for the allocation of ambulances to the company aid posts and to the battalion aid stations.

<u>The Evacuation Process</u>

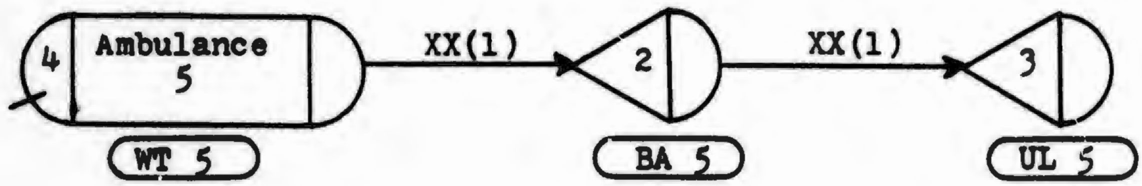
The evacuation process modeled in the network between the company aid posts and the battalion aid stations is essentially the same as between the battalion aid stations and the clearing station. This process is described below.

In the evacuation process, an entity arrives to the AWAIT node from an ENTER node. The ENTER node is another interface between the network and the discrete portion of a combined model. The symbol for the ENTER node is shown below.



The ENTER node allows the modeler to insert selectively an entity into the network from the user-written discrete event subroutine. Each ENTER node has a unique user-assigned integer code NUM and a M value which specifies the maximum number of activities to be taken at the release of the node. In the model, each ENTER node is released from within the corresponding user-written discrete event by a call to subroutine ENTER (NUM,A) where NUM corresponds to the node and A is the name of the array specified by the user which contains the attributes of the entity to be inserted into the network. This technique is used in conjunction with making an evacuation request from the company aid posts and the battalion aid stations.

One iteration of the evacuation process is described here and is illustrated in the following graphic representation.

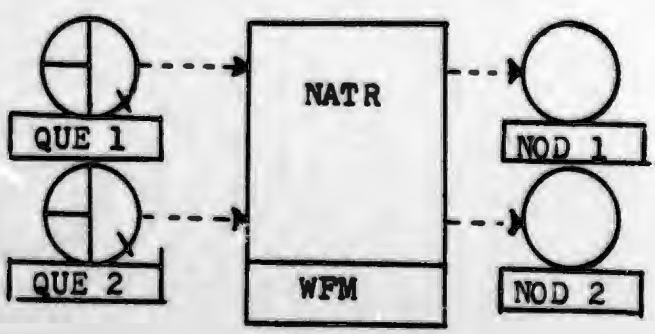


The activity exiting from the AWAIT node labeled WT5 has a specified travel time associated with it that represents the ambulance travel rate and evacuation distance. A SLAM global variable XX(1) is assigned the value of the travel time for this regular activity which routes the entity to EVENT node labeled BA5. Arriving to the EVENT node (BA5) represents the arrival of the ambulance to evacuate the patients. EVENT node (BA5) makes another call to the EVENT (2) subroutine at which time the patients are loaded into the ambulance. At the return of the subroutine, the SLAM processor returns to the network and the entity is routed over the next regular activity which also has the associated travel time for the return trip to the battalion aid station. The arrival of the entity at the next EVENT node labeled UL5 represents the arrival at the battalion aid station. At this EVENT node (UL5), a call is made to the EVENT (3) subroutine where the resource (ambulance) is freed and another evacuation request is made, if necessary. This completes one iteration of the evacuation process. The logic used in this process is also used for the other two battalions as well as for the clearing station segment of the network.

The Battalion Aid Station

The battalion aid station and the company aid posts are similarly represented graphically. Again, a QUEUE node is used to hold the entities waiting for evacuation ambulances. Each battalion QUEUE node is preceded by an ENTER node into which entities are placed from the user-written EVENT subroutine. A modeling "trick" is used in conjunction with the QUEUE nodes. The trick is that a MATCH node is used for an unusual purpose.

The MATCH nodes are used to match entities residing in specified QUEUE nodes that have equal values of a specified attribute. When each QUEUE node preceding a MATCH node has an entity with the specified common attribute value (NATR), the MATCH node removes each entity from the corresponding QUEUE node and routes it to a node associated with the QUEUE node and each entity is routed individually. The symbol for the MATCH node is shown here.



The trick in the model regarding the MATCH node is that the entities residing in the QUEUE nodes preceding the MATCH node never have a common attribute value because the specified match attribute is the unit identification number which is different at every QUEUE node. Therefore, there can never be a match and no entities can be routed through the MATCH node. But, this is exactly what is desired in the model network. The QUEUE nodes are used to hold the patients waiting for evacuation. The patients are removed from the files associated with the QUEUE nodes from within the user-written EVENT subroutine.

Data Collection in the Model

Data collection in the network model is accomplished by using the COLCT node. The COLCT node provides an estimate of the mean and the standard deviation of the specified variable of interest. The symbol for the COLCT node is shown below. In the node, TYPE specifies the type of variable for which statistics are to be collected. ID is the identification for the statistic specified by the user. H can be used to request a histogram in addition to the statistics.

Seven COLCT nodes are used in the network model. At each battalion, two COLCT nodes are used. One node collects statistics on the time interval for evacuation to the battalion aid station. The other node collects statistics for the time interval between ambulance arrivals at the battalion aid station. The final COLCT node is used at the end of the network to collect statistics on the total evacuation time from the company aid posts to the clearing station.

Other data automatically collected from the network include statistics for resource utilization, file statistics, regular activity statistics, and node statistics. These data used in the experimental design are explained in Chapter IV.

Fortran Coded Discrete Events

The network approach described so far in this chapter is useful in the model development because it provides the framework for the flow of entities (patients). The advantage of the network orientation is that this framework can be developed with relative ease. When the system can be represented by the network world view, the time and effort required to develop the simulation model normally will be less than that required by the discrete event world view (Ref 32:315). Here the network model is the representation of the evacuation process in whch the nodes and resources are used to model the combat units and the ambulances. A resource (ambulance) is busy when it is processing an entity (patient), otherwise it is idle. However, the network model by itself lacks the elements necessary to model the more complex processes in the evacuation system. The discrete event orientation provides the capability required for modeling the complex processes in the system. Using both the network orientation and the discrete event orientation is called combined network-discrete event modeling with SLAM. This orientation enhances modeling flexibility and reduces modeling effort relative to a pure discrete event orientation. The remainder of this chapter describes the discrete event modeling included in this model. A complete listing of the FORTRAN code for this portion of the model is provided in Appendix B.

The EVENT and ENTER nodes described earlier are the key interface points between the network portion and discrete event portion of the combined model. In addition to these nodes, SLAM provides many subroutines and functions which allow the modeler to alter the status of the network elements. Also, the modeler has the capability to model any level of complexity of a system with user-written subroutines and functions. Before the discussion of the discrete events modeled in this system is presented, a brief description of the SLAM processing logic for combined network-discrete event models is provided. The next event processing logic employed by SLAM for simulating combined network-discrete event models is depicted in Figure 6 (Ref 32:327).

A call to the SLAM processor is made from the user-written main program. The processor begins by interpreting the SLAM input statements (Appendix B). This is followed by an initialization process and a call to the user-written subroutine INTLC where the initial conditions for the simulation as specified by the modeler are established. In this model, the SLAM global variables XX(2) and XX(4) to XX(16) are initialized at zero. Also during this initialization process, the processor schedules the first entity arrival at each of the nine create nodes at the specified time for the first release of each of the nodes. The SLAM processor maintains the event calendar.

Next, the execution phase of the simulation begins by selecting the first event on the event calendar which may be either a user-coded event of the discrete portion of the model or a node arrival event of the network portion of the model. In either case, the processor advances the simulated time, TNOW, to the event time of the event. As illustrated in Figure 6, a decision is made to determine if the event is associated with the discrete or network portion of the model. After the processing of either the discrete or network event, a test is made for the end of simulation condition specified by the modeler. If the end of simulation condition is not satisfied, the processor selects the next event on the event calendar and

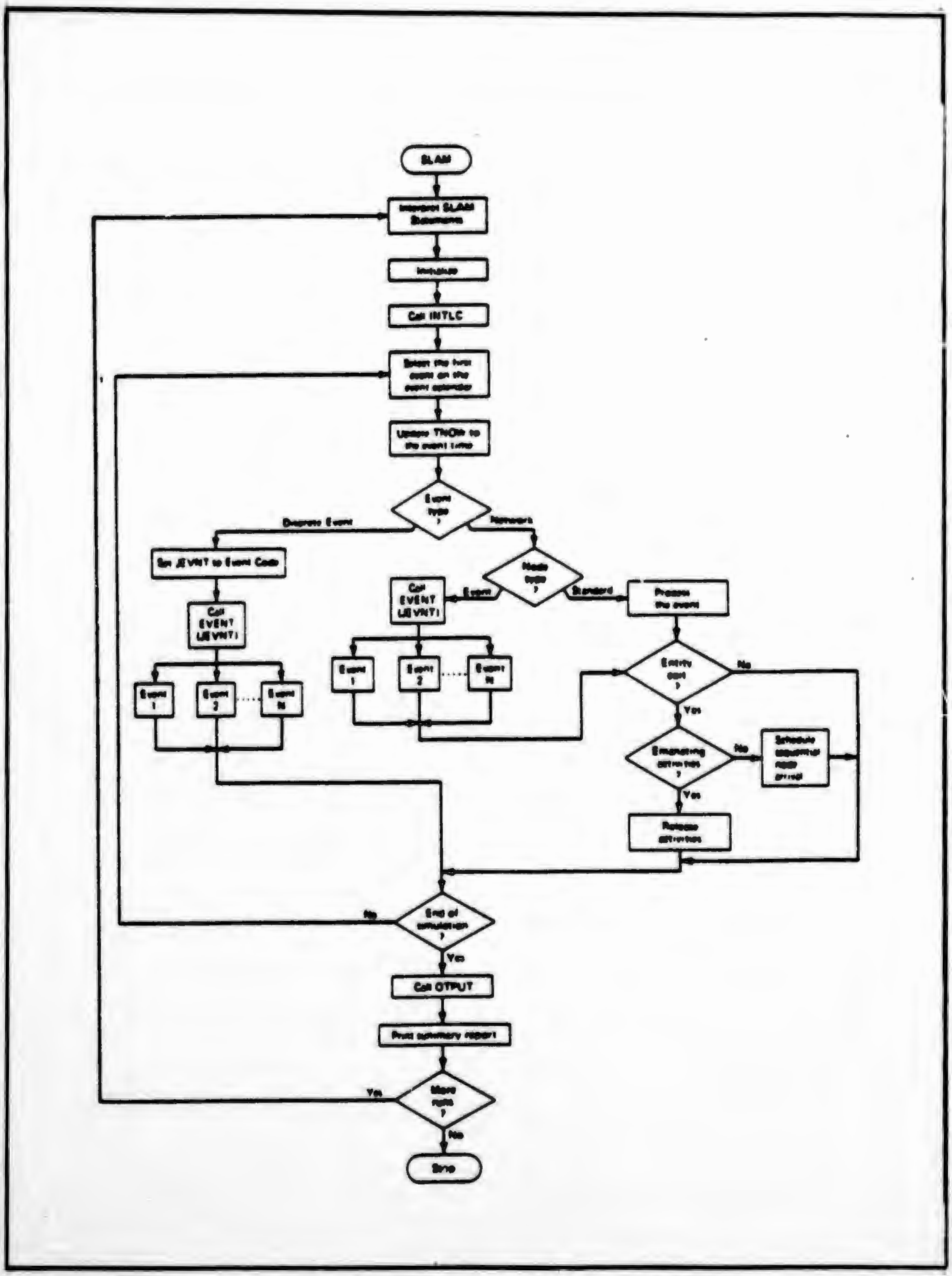


Figure 6. SLAM Processing Logic for Combined Network-Discrete Event Models

the procedure continues. When the end of simulation condition is satisfied, the simulation run is ended, statistics are calculated, a call to subroutine OTPUT is made, and the SLAM Summary Report is printed. A final test is then made to determine if additional simulation runs are to be executed. If there are more runs to be executed, the next simulation begins. When all simulation runs have been completed, SLAM returns control to the user-written main program.

In this model, 5 of the 11 coded discrete events in Subroutine Event are unique. The remaining six events are modifications of the others for the associated combat units. Therefore, only the five unique events are described here.

EVENT 1 models the process of requesting an ambulance for evacuation. The logic diagram for this process is presented in Figure 7.

First, the unit identification is recorded and then a decision is made based on the unit identification. The sum of the patients at the unit is incremented by one and then a check is made to determine if an ambulance request must be made. An ambularce is requested for the first patient and thereafter whenever the number of patients waiting at the unit exceeds the carrying capacity of the ambulance(s) already requested. After this, control returns to the SLAM processor. Event 1, EVENT 4, and EVENT 7 are associated with the units and resources of the battalions designated

5, 19, and 27, respectively.

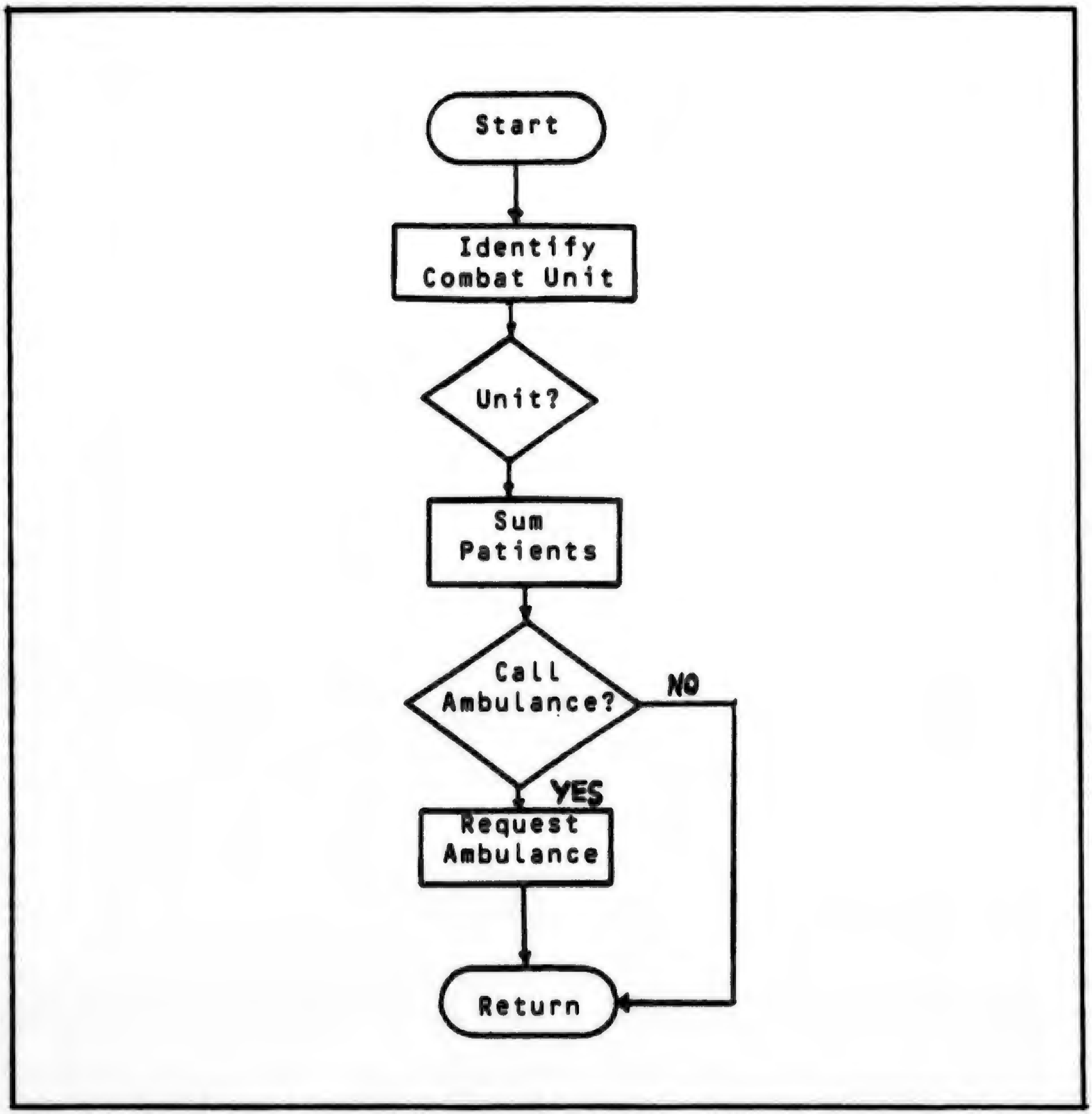


Figure 7. Logic Diagram for BAS Ambulance Request

EVENT 2 illustrates the second unique event. It models the ambulance loading process when the ambulance arrives at the unit to pickup patients. Figure 8 presents the logic diagram for this process.

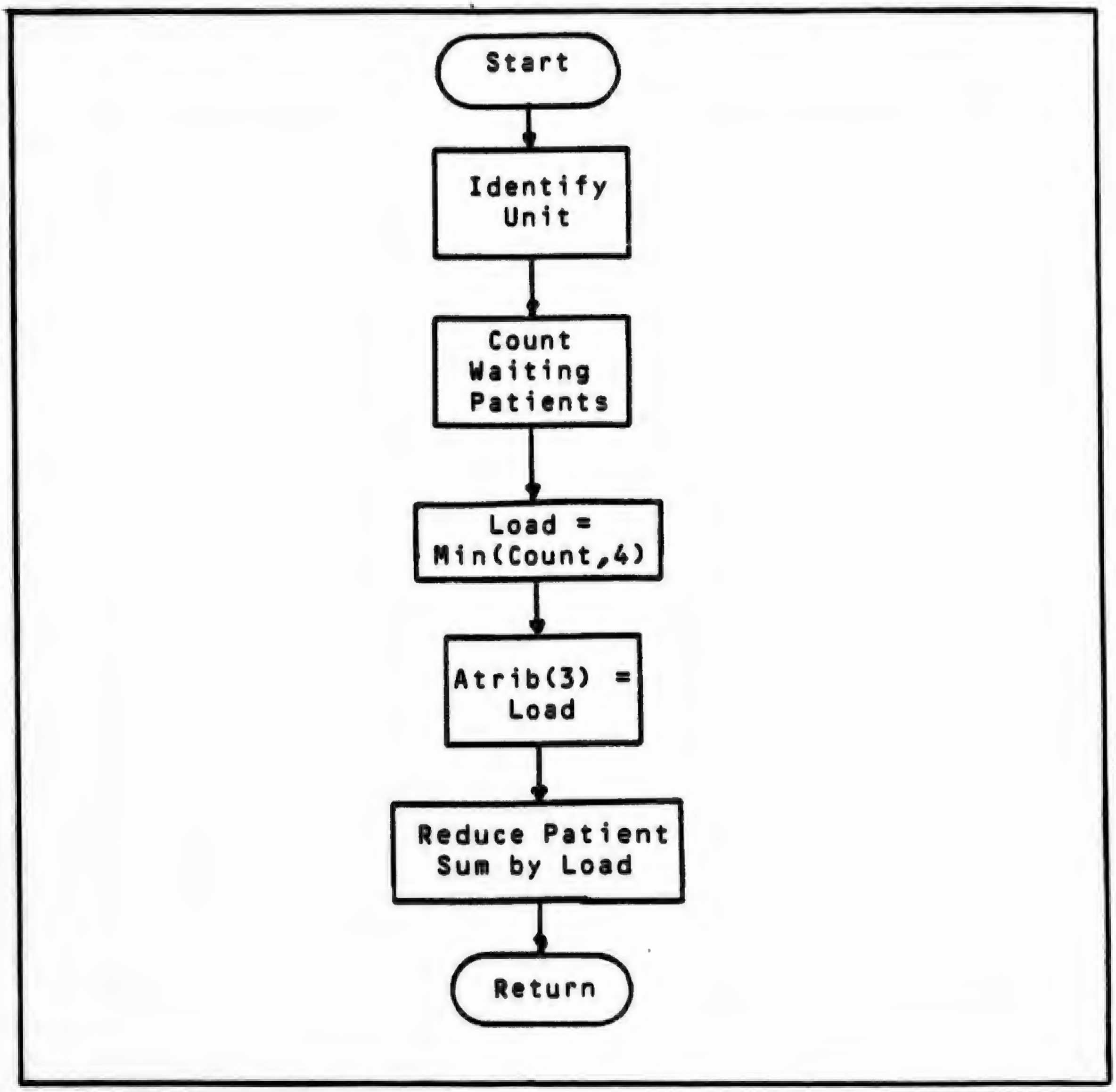


Figure 8. Logic Diagram for Loading Ambulance

In EVENT 2, the unit is identified and then the process continues according to the associated unit. The number of patients waiting at the unit is counted and the load is determined as the minimum of either the count or the maximum capacity of the ambulance which is four litter patients. The load is recorded as attribute 3 and then the sum of the patients waiting at the unit is reduced by the load size. When this process is completed, control is returned to the SLAM processor.

EVENT 2 is associated with the units of battalion 5; EVENT 5 and EVENT 8 perform the same functions for the battalions designated 19 and 27, respectively.

EVENT 3 illustrates the third unique event in the discrete event portion of the model. The logic diagram is illustrated in Figure 9.

In EVENT 3 (FIGURE 9), the resource (ambulance) is freed because the ambulance has returned to the battalion aid station and it is available for another trip forward to a company aid post. The patients are unloaded, counted, and tagged as patients from the battalion designated 5. A request for further evacuation is made for the first patient to be counted and thereafter whenever the number of patients at the BAS exceeds the capacity of the ambulance(s) already requested. Following these actions, control is returned to the SLAM processor. EVENT 6 and EVENT 9 perform the same functions for the battalions designated 19 and 27, respectively. EVENT 10 is similar to EVENT 2, EVENT 5, and EVENT 8 and only differs in that it functions at the next higher echelon in the system. Figure 10 illustrates the logic diagram for this event.

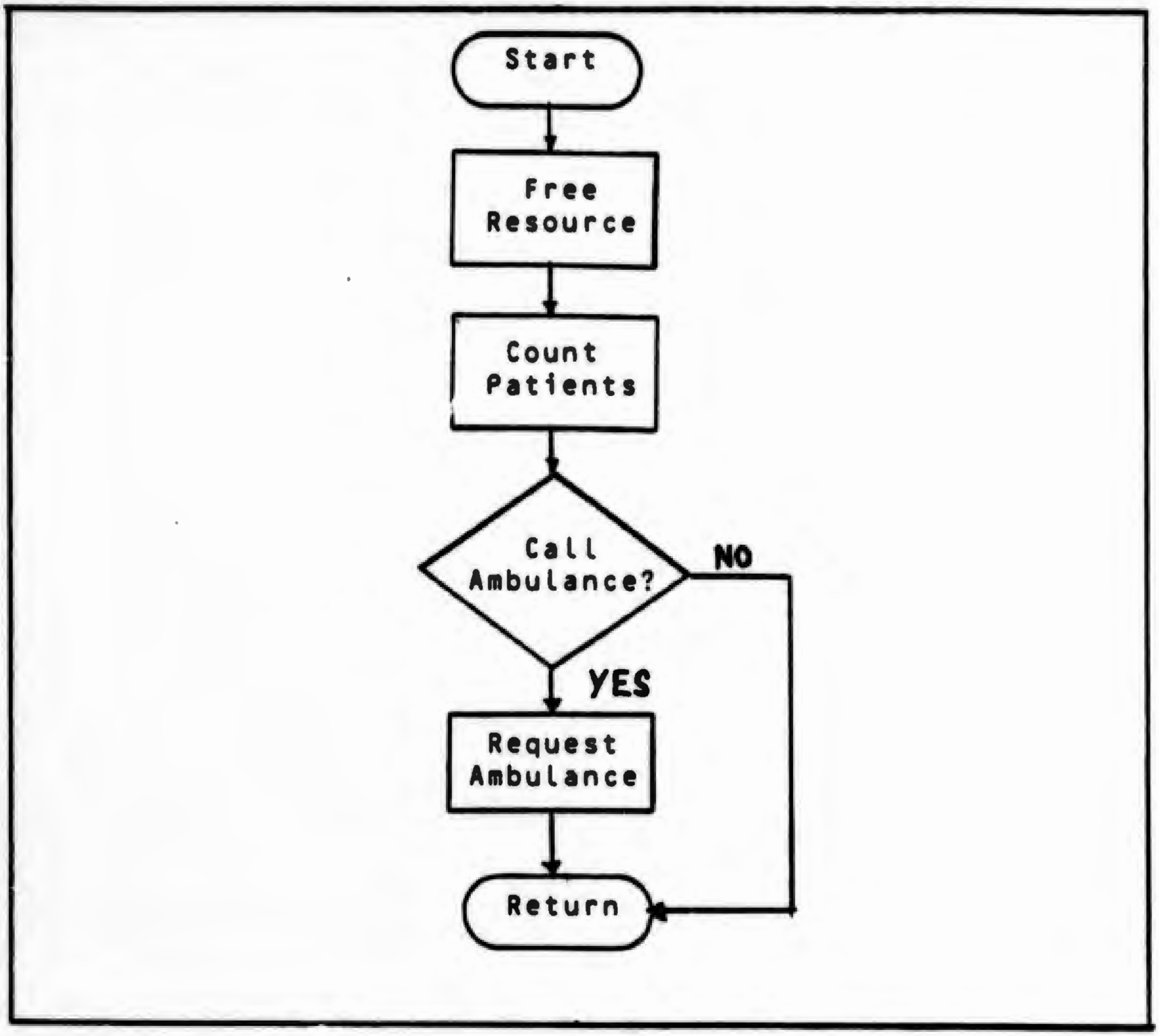


Figure 9. Logic Diagram for Ambulance Request to Clearing Station

Finally, EVENT 11 counts the total number of patients evacuated to the clearing station and releases the resource for the next evacuation request. This is the last discrete event in this portion of the model. EVENT 11 is shown in Figure 11.

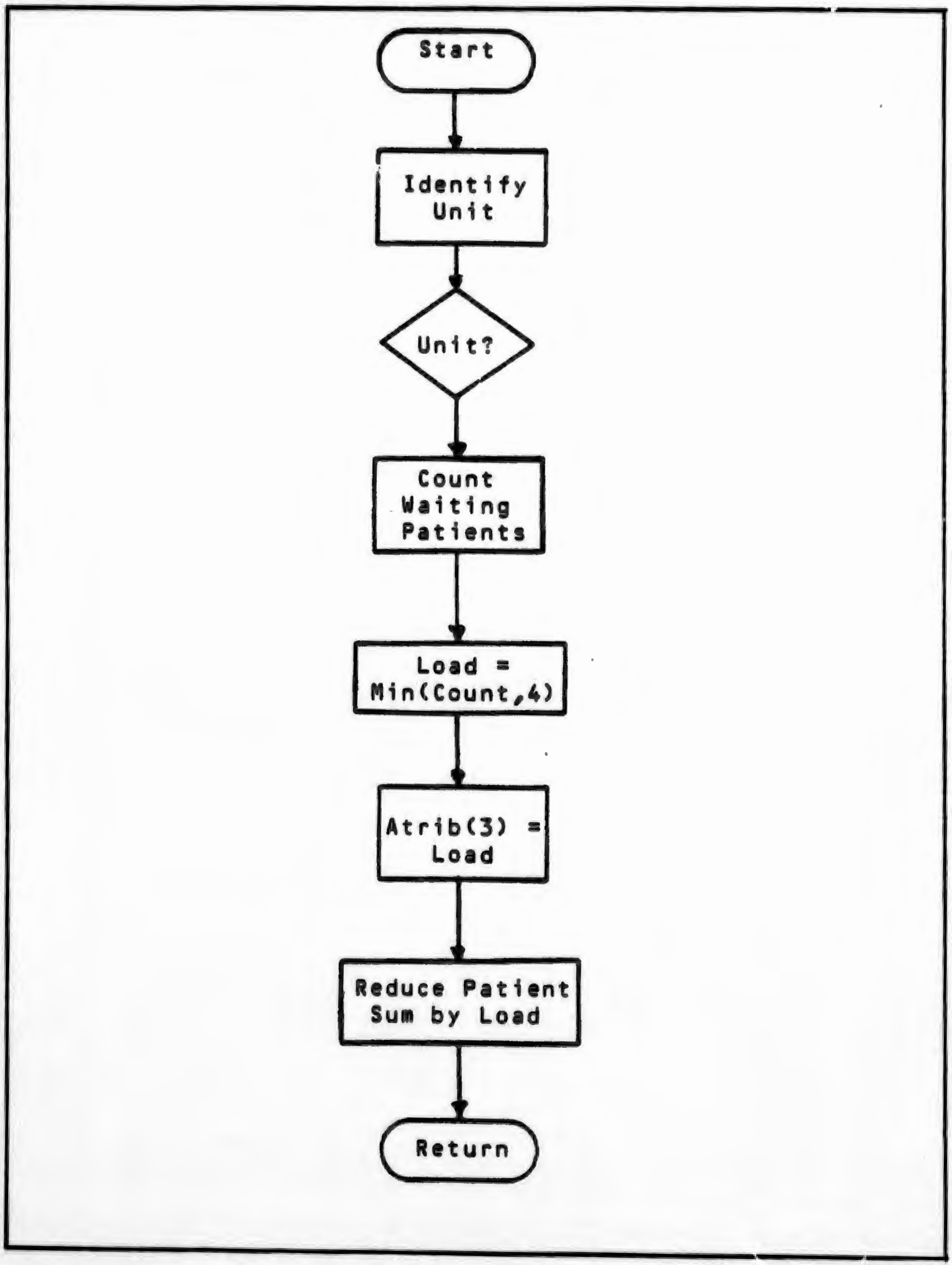


Figure 10. Logic Diagram for Loading Patients at BAS

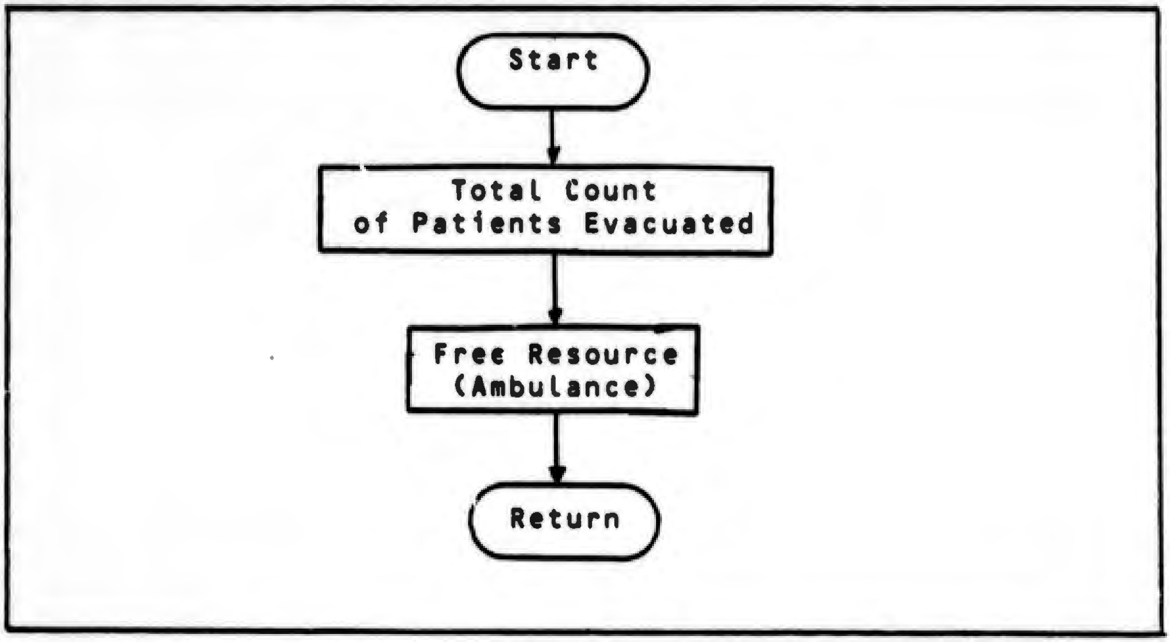


Figure 11. Logic Diagram for Clearing Station Final Event

Chapter Summary

This completes the description of the combined network-discrete event model of the evacuation system. In the next chapter, a discussion of the experimentation and analysis of the data collected from the model is presented. The chapter begins with a discussion of the methods used for model verification and validation.

Chapter IV

Experimentation and Analysis

Introduction

This chapter contains a report of the experimental procedure, the data collection process, and the data analysis performed in this study. It also includes a ranking of alternatives--a priority list of feasible factor combinations for the evacuation model. Additionally, the results of a sensitivity analysis performed on the alternatives are presented. This chapter begins with a discussion of model verification and validation.

Verification and Validation

An important and difficult task for the simulation analyst is that of trying to determine whether the simulation model is an accurate representation of the real world system that is being studied. Understanding the distinction of the two terms verification and validation is essential for everyone involved with the study. Since there appears to be some confusion about these terms in the literature, the following definitions are provided.

> Verification is determining whether a simulation model performs as intended, i.e., debugging the computer program. Although verification is simple in concept, debugging a large-scale simulation model can be quite an arduous task.

Validation is determining whether a simulation model (as opposed to the computer program) is an accurate representation of the real-world system under study (Ref 23:334).

In this study, model verification means a test of the model to insure that it behaves as the modeler intends. Towards the goal of verification, the following techniques were used. The first technique was to test and debug the model as it was being built. This was done by building the model in modules that were easily managed. The first module of the model to be built and tested was the company aid post portion of the network. In review, it consists of a CREATE node, an ASSIGN node, an EVENT node, and a QUEUE node. Of significant importance to the model and study is the number of patients generated at the CREATE nodes. At this stage, the model was checked to insure that the distribution and its associated parameter behaved as expected. The number of patients generated was checked by recording the number of entities placed into the system. The ASSIGN node recorded the unit identification number as the value of attribute number two. This procedure was checked by inspecting the number reported as attribute number two on the SLAM Trace Report. The TRACE option causes a report summarizing each entity arrival event to be printed during execution of the simulation. The Trace Report generates a detailed account of the progress of a simulation by printing for each entity arrival event, the event time, the node label and type to which the entity is arriving, and the attributes of the arriving entity (Ref 32:156). As can be seen by its description, the trace is a very useful method for model verification. This option was used throughout the model development.

After the company portion of the network was tested, three company modules were combined to form one battalion. The battalion portion of the network was designed and added to the three company modules. The complete battalion network portion of the model was then tested in a similar manner. The second and third battalions were then designed in the same fashion as the initial battalion network.

The remaining portion of the model, the evacuation process from the battalions to the clearing station, was similar in design to the evacuation process already developed for the evacuation from the companies to the battalion aid station. After this module was added to the network, the completed model was verified using the Trace Report. Building the model in this modular fashion facilitated verification at each step of the model development. It is easier to add to the model to make it more complex as needed than to start at the complex level with more detail than might be required.

Validation as defined above is determining whether a simulation model is an accurate representation of the real-world system. It is a test of the agreement between the behavior of the model and that of the real system (Ref 38:210). A three-step approach to model validation suggested by Law and Kelton (Ref 23:338) was implemented in this study.

Validation should address theoretical validity, data validity, and operational validity. Theoretical validity is concerned with the theories used in the conceptualization of the model and the associated assumptions. Data validity is concerned with the accuracy and completeness of the input data. And operational validity is concerned with the ability of the model to predict the real world behavior of the system.

The first step was to develop the model with high face validity. A model with high face validity is a model which on the surface seems reasonable to people who are knowledgeable about the system under study (Ref 23:338). This can be done by consulting with the "experts", applying existing theory, observing the real system, applying relevant results from similar models, and using intuition to hypothesize how certain components of the system operate.

This was accomplished by a combination of the following techniques. This simulation has been developed with the assistance of the evacuation "experts" at the Academy of Health Sciences. The model was not developed in isolation but rather in close cooperation with people that are very familiar with the system. Also, the simulator's general knowledge and intuition have been used to hypothesize how certain components of the system operate.

The modeler's military experience was useful in this regard.

The next step was to test the assumptions of the model. Probably the most useful technique was to perform sensitivity analysis to determine how much the output will vary with a change in the input. This technique was accomplished by changing the patient incident rate and noting any changes in the responses. These results are reported later in this chapter.

The final step was to determine how representative the simulation output data are. This is also perhaps the most difficult step in any simulation study where the system can not actually be physically tested. An actual combat operation would be needed to test the real evacuation system -- a dreadful alternative. The test in this case must be whether the output makes sense. But, because there is a one-to-one relationship between the model and the evacuation system, there is also a correspondence between the operational characteristics of the model and the system. This is the importance of the isomorphic mappings between the model and the actual system (Ref 37:32). In any case, the final test should be whether the simulation has provided either new insight or confirmed existing beliefs about the system. To this end, the results of the study are reported later in this chapter. In the next section, the procedure used to collect the data and experiment with the system is described.

Data Collection and Experimentation

After verifying the model, the next task in the study was to collect the data for the analysis of the system. As described earlier, the analyst must determine how many observations to collect for each cell in the design.

Again, this experimental design is a 2^5 factorial. That is, that are five factors and two levels for each factor. The factor combinations at these levels represent the existing doctrine and proposed alternatives. A factorial experiment is one in which all levels of a given factor are combined with all levels of every other factor in the experiment (Ref 38:164). Also, this is a symmetrical design, that is, each factor has an equal number of levels. The design matrix for this experiment is illustrated in Figure 12. The cells in the matrix are numbered from 1 to 32 and are referenced by the number. Table 6 shows the 32 combinations of the design matrix. The combinations are numbered according to the corresponding cell and the factors are numbered 1 to 5 as in Figure 3.

In order to determine the number of observations required for each cell, several pilot runs were made for selected cells of the matrix. Cell 1 was used for the first pilot run. The simulation was replicated 10 times for cell 1 to collect 10 independent observations. Each observation was a measure of effectiveness of the system,

		AMBULANCE TRAVEL RATE							
		Low Level (20 km/hr)				High Level (35 km/hr)			
		AMBULANCES AVAILABLE AT BAS							
		4		6		4		6	
		EVACUATION DISTANCE (BAS)							
		5	10	5	10	5	10	5	10
8	10	1	5	9	13	17	21	25	29
	20	2	6	10	14	18	22	26	30
10	10	3	7	11	15	19	23	27	31
	20	4	8	12	16	20	24	28	32

EVACUATION DISTANCE (CLEARING STATION)

AMBULANCES AVAILABLE AT CLEARING STATION

Figure 12. Cells in the 2^5 Factorial Design

Table 6. 32 Factor Combinations for the Design Matrix

FACTOR COMBINATION

CELL	FACTOR 1	2	3	4	5
1	L	L	L	L	L
2	L	L	L	L	H
3	L	L	L	H	L
4	L	L	L	H	H
5	L	L	H	L	L
6	L	L	H	L	H
7	L	L	H	H	L
8	L	L	H	H	H
9	L	H	L	L	L
10	L	H	L	L	H
11	L	H	L	H	L
12	L	H	L	H	H
13	L	H	H	L	L
14	L	H	H	L	H
15	L	H	H	H	L
16	L	H	H	H	H
17	H	L	L	L	L
18	H	L	L	L	H
19	H	L	L	H	L
20	H	L	L	H	H
21	H	L	H	L	L
22	H	L	H	L	H
23	H	L	H	H	L
24	H	L	H	H	H
25	H	H	L	L	L
26	H	H	L	L	H
27	H	H	L	H	L
28	H	H	L	H	H
29	H	H	H	L	L
30	H	H	H	L	H
31	H	H	H	H	L
32	H	H	H	H	H

L = FACTOR AT LOW LEVEL

H = FACTOR AT HIGH LEVEL

that is, the evacuation time required to move a patient from the company aid post to the clearing station. For cell 1, the evacuation time (1.5 hours) was the same for each replication. This meant that there was no variation in the system response for the factor combination represented by cell 1. This was not totally surprising for the following reasons. First, cell 1 represents each factor set at its low level. And, secondly, similar results were obtained in a preliminary study of the battalion's evacuation capability (Ref 6). This preliminary study was a QGERT Network Analysis (Ref 31) of the battalion evacuation network only. The QGERT analysis was the precursor to the SLAM analysis. In the initial study, the battalion evacuation capability was adequate except for extreme conditions. That is, when the evacuation distance was increased and the number of available ambulances was decreased, the evacuation time increased beyond acceptable limits. Therefore, in this study of the evacuation system of the entire brigade, the next logical step was to experiment with the system with the factors set at the extreme levels.

Intuitively, cell 6 would be the worst cell because it represented the situation where the evacuation distances were the longest, the travel rate was the slowest, and the number of available ambulances was the fewest. Therefore, the simulation was replicated 10 times for cell 6 to produce 10 independent responses. This pilot run used a different seed for each run. The results are presented in Table 7. The variance for cell 6 for this pilot run was 2.31 hours. A confidence interval for this response was then determined.

Table 7. Results of Pilot Run for Cell 6

SEED	EVACUATION TIME (Hours)
37895	10.60
942895	8.08
895432	6.36
4195432	11.30
112566	7.13
5114566	9.40
183573	10.30
-183573	8.48
79416	7.56
-79416	9.23

MEAN = 8.84 hours

VARIANCE = 2.31 hours

Each of the 10 responses were assumed to be independent, identically distributed normal random variables. Then, a 100(1-alpha) percent confidence interval using the sample mean was determined using the formula given by Law and Kelton (Ref 23:288). This is the same formula used in classical statistics to construct a confidence interval for the mean of a population. For this pilot run, an approximate 90 percent confidence level was 8.84 hours plus or minus 0.88 hours. Next, a variance reduction technique was applied to cell 6 to improve the confidence interval. By applying the antithetic variate reduction technique, the variance was reduced. The seeds used to produce the antithetic sequence in the SLAM model and the resulting responses are shown in Table 8. Table 8 shows that 10 replications were made.

Table 8. Cell 6 Pilot Run Using Antithetic Sequence

REPLICATION	SEED	EVACUATION TIME (hrs)
1	42895	8.63
2	-42895	7.69
3	195432	6.86
4	-195432	11.30
5	114566	10.40
6	-114566	9.16
7	183573	10.30
8	-183573	8.48
9	79416	7.56
10	-79416	9.23

MEAN = 8.96

VARIANCE = 1.98

Each odd replication was paired with the following even replication, its antithetic mate. Then the mean response of the pair was determined. The results using the antithetic pairs are shown in Table 9. This mean response was used to construct a 90 percent confidence interval. Note that the mean response of 8.96 (Table 9) is close to the sample mean of 8.84 (Table 7) calculated in the previous pilot run. However, the variance for this pilot run is only 0.45 as compared to 2.31 for the other run.

Table 9. Results Using Antithetic Pairs in Cell 6

PAIR	MEAN RESPONSE
1,2	8.16
3,4	9.08
5,6	9.78
7,8	9.39
9,10	8.39

MEAN = 8.96

VARIANCE = 0.45

For these five paired observations, the 90 percent confidence interval was 8.96 plus or minus 0.55 hours. It was obvious from this experiment that the variance reduction technique provided a better confidence interval for the estimate of the evacuation time. The 90 percent confidence interval without using the variance reduction technique was 8.14 to 9.77 hours; whereas, the interval using variance reduction was only 8.41 to 9.51 hours. By applying the variance reduction technique, the variance was improved by approximately 77 percent.

Further investigation was conducted to determine the number of replications required for a specified confidence interval half-length. The technique to construct a confidence interval for a specified half-length is described by Law and Kelton (Ref 23:291). In order to reduce the half-length to 0.275 hours, 20 replications of each cell were required. In other words, to reduce the half-length by approximately one-half required more than three times the effort. For this 2^5 factorial design, a 0.275 hour half-length at the 90 percent confidence level would require 640 simulation runs. The tradeoff was obvious. The cost of further reducing the variance, the twofold increase of work and computer time, was considered prohibitively large for the initial data collection phase of the study. Therefore, the 0.55 hour half-length was accepted.

Furthermore, it was speculated from the pilot runs that many of the cells would provide estimates without any variance. Therefore, based on these considerations, the data were collected for all 32 cells using 10 replications to produce five paired observations per cell. This required a total of 320 simulation runs.

The responses for the 10 replications per cell are shown in Table 10. Again, some cells had no variance. Cells with no variance represented configurations in which the evacuation time only was a function of the ambulance travel rate and the evacuation distance. In other words, the evacuation capability exceeded the patient incident rate. The variance for each cell was computed using a program coded in Fortran. The input for this program is a file containing the 10 observations for a cell of the design matrix. Using this raw data file, the program computes the mean and standard variance as well as the mean and the reduced variance. This program is provided in Appendix D with an example of the raw data input file and the corresponding results illustrating the effect of applying variance reduction.

By using the mean of the paired observations, the number of data points was reduced to five for each of the 32 cells in the design. The total number of observations used in the data analysis, therefore, was 160 as illustrated in Table 11.

Table 10. Cell Responses for 10 Replications Per Cell

CELL	REPLICATION 1	2	3	4	5	6	7	8	9	10	M	V
1	1.5	----------------------------------									1.5	0.0
2	6.7	8.7	9.8	5.6	8.4	8.7	9.1	4.0	6.7	7.1	7.5	3.2
3	1.5	----------------------------------									1.5	0.0
4	2.6	2.5	2.6	2.5	2.6	2.5	2.6	2.5	2.5	2.5	2.5	0.0
5	2.0	----------------------------------									2.0	0.0
6	7.4	9.3	10.3	6.1	9.0	9.3	9.8	4.7	7.2	7.6	8.0	3.1
7	2.0	----------------------------------									2.0	0.0
8	3.1	----------------------------------									3.1	0.0
9	1.5	----------------------------------									1.5	0.0
10	6.7	8.7	9.8	5.6	8.4	8.7	9.1	4.0	6.7	7.1	7.5	3.2
11	1.5	----------------------------------									1.5	0.0
12	2.6	2.5	2.6	2.5	2.6	2.5	2.6	2.5	2.5	2.5	2.5	0.0
13	2.0	----------------------------------									2.0	0.0
14	7.3	9.3	10.3	6.2	9.0	9.3	9.8	4.7	7.2	7.6	8.0	3.1
15	2.0	----------------------------------									2.0	0.0
16	3.1	----------------------------------									3.1	0.0
17	0.8	----------------------------------									0.8	0.0
18	1.4	----------------------------------									1.4	0.0
19	0.8	----------------------------------									0.8	0.0
20	1.4	----------------------------------									1.4	0.0
21	1.1	----------------------------------									1.1	0.0
22	1.7	----------------------------------									1.7	0.0
23	1.1	----------------------------------									1.1	0.0
24	1.7	----------------------------------									1.7	0.0
25	0.8	----------------------------------									0.8	0.0
26	1.4	----------------------------------									1.4	0.0
27	0.8	----------------------------------									0.8	0.0
28	1.4	----------------------------------									1.4	0.0
29	1.1	----------------------------------									1.1	0.0
30	1.7	----------------------------------									1.7	0.0
31	1.1	----------------------------------									1.1	0.0
32	1.7	----------------------------------									1.7	0.0

M = CELL MEAN

V = CELL VARIANCE

Table 11. Observations used in Data Analysis

CELL	OBSERVATIONS 1	2	3	4	5	M	V
1	1.5	-----	-----	-----	1.5	1.5	0.00
2	7.7	7.7	8.5	6.5	6.9	7.5	0.61
3	1.5	-----	-----	-----	1.5	1.5	0.00
4	2.5	-----	-----	-----	2.5	2.5	0.00
5	2.0	-----	-----	-----	2.0	2.0	0.00
6	8.3	8.1	9.1	7.2	7.4	8.0	0.60
7	2.0	-----	-----	-----	2.0	2.0	0.00
8	3.1	-----	-----	-----	3.1	3.1	0.00
9	1.5	-----	-----	-----	1.5	1.5	0.00
10	7.7	7.7	8.5	6.5	6.9	7.5	0.61
11	1.5	-----	-----	-----	1.5	1.5	0.00
12	2.5	-----	-----	-----	2.5	2.5	0.00
13	2.0	-----	-----	-----	2.0	2.0	0.00
14	8.3	8.2	9.1	7.2	7.4	8.0	0.59
15	2.0	-----	-----	-----	2.0	2.0	0.00
16	3.0	-----	-----	-----	3.0	3.0	0.00
17	0.8	-----	-----	-----	0.8	0.8	0.00
18	1.4	-----	-----	-----	1.4	1.4	0.00
19	0.8	-----	-----	-----	0.8	0.8	0.00
20	1.4	-----	-----	-----	1.4	1.4	0.00
21	1.1	-----	-----	-----	1.1	1.1	0.00
22	1.7	-----	-----	-----	1.7	1.7	0.00
23	1.1	-----	-----	-----	1.1	1.1	0.00
24	1.7	-----	-----	-----	1.7	1.7	0.00
25	0.8	-----	-----	-----	0.8	0.8	0.00
26	1.4	-----	-----	-----	1.4	1.4	0.00
27	0.8	-----	-----	-----	0.8	0.8	0.00
28	1.4	-----	-----	-----	1.4	1.4	0.00
29	1.1	-----	-----	-----	1.1	1.1	0.00
30	1.7	-----	-----	-----	1.1	1.1	0.00
31	1.1	-----	-----	-----	1.1	1.1	0.00
32	1.7	-----	-----	-----	1.7	1.7	0.00

M = CELL MEAN

V = CELL VARIANCE

Data Analysis

The next step in the study of the evacuation system was to analyze the the data collected from the 320 simulation runs of the SLAM model. As stated in Chapter II, analysis of variance (ANOVA) was selected as the method of analysis to investigate the simultaneous effects of factors in this experimental design. Two subprograms of the Statistical Package for the Social Sciences (SPSS), ANOVA and MANOVA, were used to analyze the data collected from the model. In turn, how each of these subprograms was used is described. The raw data input file, the various procedure statements for each of the subprograms, and the resulting ANOVA tables are provided in Appendix E and Appendix F, respectively.

The SPSS subprogram ANOVA allows the user to obtain analysis of variance for factorial designs, allowing up to five factors in the design. ANOVA uses the general linear hypothesis approach to analysis of variance. That is, it is basically a multiple regression. A complete description of subprogram ANOVA can be found in SPSS: Statistical Package for the Social Sciences (Ref 29:398). The first step in this analysis procedure was to run a 5-Way ANOVA.

5-WAY ANOVA. The first task of the analysis of variance with a factorial design was to evaluate the overall effect and the interaction effects. As stated before, a factorial experiment is one in which all levels of a given factor are combined with all levels of every other factor in the experiment. When a change in one factor produces a different change in the response variable at one level of another factor than at other levels of this factor, it is said that there is an interaction between the two factors. The number of possible interactions is determined from the number of factor combinations. For this 2^5 factorial design, there are five main effects, ten first order, ten second order, five third order, and one fourth order interaction that can be recovered if the full factorial is run. Some of these high-order interactions may be used as error, as those above second order (three way) would be difficult to explain if found significant (Ref 19:303). The steps for testing the significance of the various effects are summarized here.

First, significance testing was used to determine whether the five factors as a whole had a statistically significant effect. The main objective was to determine whether all the observed sums of squares due to the five factors were likely to have come from a population where no such effects exist. If in fact the null hypothesis that the response variance is equal to the error variance is true, the ratio between the sum of squares of the factors plus the sum of squares of the interactions divided by the associated degrees of freedom and the error sum of squares divided by its associated degrees of freedom is known to have an F distribution. The numerator and denominator of this ratio are known as mean squares, due to the total joint effects of the five factors and due to the error variance, respectively. Using SPSS notation, the F ratio may be written as

$$F = MS_{factors,interactions} / MS_{error}$$

When the F ratio is significant at the specified level, the model as a whole is said to have some effect on the response. The SPSS subprogram ANOVA routinely produces all the relevant statistics and the probability associated with a given F value.

Next, the task was to examine whether the interaction effects were significant. If the population variance of the interactions is zero, then the ratio between the $MS_{interactions}$ and the MS_{error} also follows the F distribution.

The results of the 5-Way ANOVA in Appendix E are summarized here. The tests show that one of the five main effects (number of ambulances available at the BAS) was not significant. None of the four way interactions or the five way interactions were significant. Only one three way interaction (ambulance rate by number of ambulances available at the clearing station by evacuation distance to the clearing station) was significant, and four of the two way interactions were significant. The main effects and the significant interactions are presented graphically in Appendix E.

Four of the five main effects were determined to be significant. As illustrated in Appendix E, the effect of increasing Factor 1 (Ambulance travel rate) was a significantly reduced evacuation time. However, Factor 5 (Evacuation distance to the clearing station) had an approximately equal but opposite effect for evacuation time. The steep slope of the line connecting the change in the response for the change in the factor level illustrates the significance of the factor level change. Note that the slope of the line for Factor 2 (Available ambulances at the BAS) is zero which indicates that the change in levels has no effect. This implies that there is no difference in the support capability of the BAS evacuation section when equipped with either four or six ambulances. However, the grahical presentation also illustrates that there was a statistically significant increase in the evacuation time when the evacuation distance to the BAS was increased from 5 to 10 kilometers. On the other hand, there was a statistically significant decrease in the evacuation time when the number of ambulances available at the clearing station was increased from eight to ten.

When two factors interact, the question arises whether the factor level means, which are averages of specific factor means, are meaningful measures. The graphical presentations of Appendix E effectively illustrate the interacting effects of the significant two way interactions identified by the analysis of variance and F tests. Perfectly parallel curves indicate there are no interactions; whereas, lines that are not parallel indicate there are interactions. Thus, the amount of deviation indicates the degree and importance of the interaction. The advantage of unimportant or no interactions is that one is then able to analyze the factor effects separately. Here, the results indicate that the interaction of ambulance travel rate and the evacuation distance to the BAS is relatively unimportant; the lines of the graph are almost parallel. Whereas, the interaction of the ambualnce travel rate and the distance to the clearing station is important; the lines of the graph clearly are not parallel. Similarly, the interaction of ambulance travel rate and the number of ambulances at the clearig station is important, relatively. Additionally, the interaction of the number of ambualces at the clearing station and the distance to the clearing station is important.

Another bit of descriptive information obtained from this ANOVA is the multiple regression R^2. R^2 also is known as the coefficient of determination (Ref 36:261). Basically, R^2 provides a measure of the goodness of fit of the model, that is, how well the observations fit the linear regression model. An R^2 equal to one would indicate a "perfect" fit; whereas, R^2 equal to zero would indicate a total lack of fit. In practice, R^2 is not likely to be zero or one, but rather somewhere in between these limits (Ref 28:90). The R^2 equaled 0.612 for this 5-Way ANOVA which indicates the relative goodness of fit by this standard.

Also worth noting in this 5-Way ANOVA is the value reported for the unexplained error. On the ANOVA table this value is indicated as the RESIDUAL. The RESIDUAL is the value of the error sum of squares, also known as the unexplained error in the model. Ideally, the RESIDUAL value should be zero. That would indicate that there is no unexplained error in the model in which case R^2 would equal one. Therefore, the task in the analysis is to search for the model with the lowest RESIDUAL value. For this 5-Way ANOVA the value of the RESIDUAL was 0.074 which is obviously close to zero. Subprogram ANOVA has options that allow the user to specify a wide variety of analyses of variance. One option is to eliminate higher-order interaction effects from the analysis. When it is reasonable to expect that higher-order interactions are negligible, they may be pooled into the error term in order to increase the explanatory power of the test. This means that any negligible effect of the higher-order interactions is treated as error in the basic ANOVA model. Using this technique, other analyses can be made to search for the model that produces the least RESIDUAL value.

By using option 5, the four-way and higher interactions were eliminated so that only the two-way and the three-way interactions would be assessed in addition to the five factor main effects. This is known as pooling the higher-order interactions with the error term in the model.

This reduced the RESIDUAL value to 0.071 from 0.074 and the R^2 value remained 0.612. Since this 5-Way ANOVA showed that one factor (Number of Ambulances Available at BAS) was not significant, a 4-WAY ANOVA was used next.

4-WAY ANOVA. The four-way ANOVA was made by eliminating the insignificant factor from the ANOVA procedure card of the SPSS subprogram. Again, the test was made to determine the significance of the overall model, and then to determine the significance of the interaction effects. The resulting ANOVA table and graphic presentations of the factor effects are provided in Appendix E.

As expected, all four main effects were significant. The same two-way interactions were significant, also; but, the significance of the interaction of the ambulance rate by the distance to the clearing station increased slightly from 0.009 to 0.005. And, the one significant three-way interaction remained as before. However, the RESIDUAL value was reduced from 0.074 to 0.066. This meant that the unexplained error had been reduced by pooling the higher-order interactions when the insignificant main effect was excluded from the analysis. The R^2 value remained at 0.612. A reasonble conclusion is that the four factor model is an improvement from the five factor model. This analysis supports the findings and conclusions drawn from the five factor model; however, the four factor model has more explanatory power as evidenced by the reduced

RESIDUAL value. In addition to using subprogram ANOVA, subprogram MANOVA was used.

MANOVA. SPSS MANOVA is a multivariate analysis of variance and covariance program which will perform univariate and multivariate linear estimation and tests of hypotheses for any crossed and/or nested design with or without covariates (Ref 21:1). MANOVA was used for a univariate analysis of variance. Used in this fashion, it provided the same basic results as ANOVA. But, MANOVA has some options not available in ANOVA; therefore, it was used to supplement the analysis already performed using ANOVA.

MANOVA has tests for the assumption of homogeneity of variance and plotting options useful for graphical analysis of the basic ANOVA model. Graphical analysis is an important part of data analysis. Box and others (Ref 3:182-183) suggest that graphical analysis be a routine procedure for diagnostic checking of the basic model. Many plots useful for assessing the validity of the ANOVA model's assumptions can be obtained by using the PLOT subcommand available in subprogram MANOVA. The plots obtained from the MANOVA subroutine are described next.

The MANOVA procedure cards used to generate the plots are provided in Appendix F. By specifying the keyword CELLPLOTS with the PLOT subcommand, the MANOVA program provides plots of cell statistics, including a plot of cell means versus cell variances, a plot of cell means versus cell standard deviations, and a histogram of cell means for the response variable defined on the MANOVA specification card. The first two plots can be used to check for homogeneity of variance. Recall that the analysis of variance model assumes each probability distribution has the same variance. A basically horizontal line indicates that homogeneity of variance exists. These two plots are shown in Figures 13 and 14, respectively. In each plot, the line is horizontal except for the four outliers. The third plot provides a frequency distribution for the cell means. This frequency distribution can be used as an indication of normality. Recall that the analysis of variance model assumes that the probability distributions are normal, also. This frequency distribution is shown in Figure 15. In Figure 15, each "*" indicates two obsevations. The total number of observations shown is 32.

These three figures were very useful for analyzing this model. Each of the figures illustrated that the model had four outliers (extreme observations). These four outliers are identified in Figures 13 and 14 by the difference in their variances and standard deviations, respectively. Also, this indicated that some heteroscedasticity existed in the ANOVA model for this data. However, this finding does not invalidate the model. Neter and Wasserman state:

> If the error variances are unequal, the F test for the equality of means is only slightly affected if all factor level sample sizes are equal. Specifically, unequal error variances then raise the actual level of significance only

slightly higher than the specified level. Thus, the F test and related analyses are robust against unequal variances if the sample sizes are equal. The use of equal sample sizes for all factor levels not only tends to minimize the effects of unequal variances on inferences with the F distribution but also simplifies calculational procedures. Thus here at least, simplicity and robustness go hand in hand (Ref 28:514).

By specifying the keyword NORMAL, MANOVA produces a normal probability plot and a detrended normal probability plot for the response variable. For the normal probability plot, the points of the plot tending to form a straight line indicate that the response variable is normally distributed. This is shown in Figure 16. The detrended normal plot is shown in Figure 17. The points of this plot clustered about zero indicate that the response variable is normally distributed. Although these plots indicate that there may be a slight departure from normality, it has little affect on the analysis of the data. On the subject of nonnormality, Neter and Wasserman state:

> For the fixed effects model, lack of normality is not an important matter, provided the departure from normality is not of extreme form. The point estimators and contrasts are unbiased whether or not the populations are normal. The F test for the equality of factor level means is but little affected by lack of normality, either in terms of the level of significance or power of the test. Hence, the F test is a robust test against departures from normality (Ref 28:513).

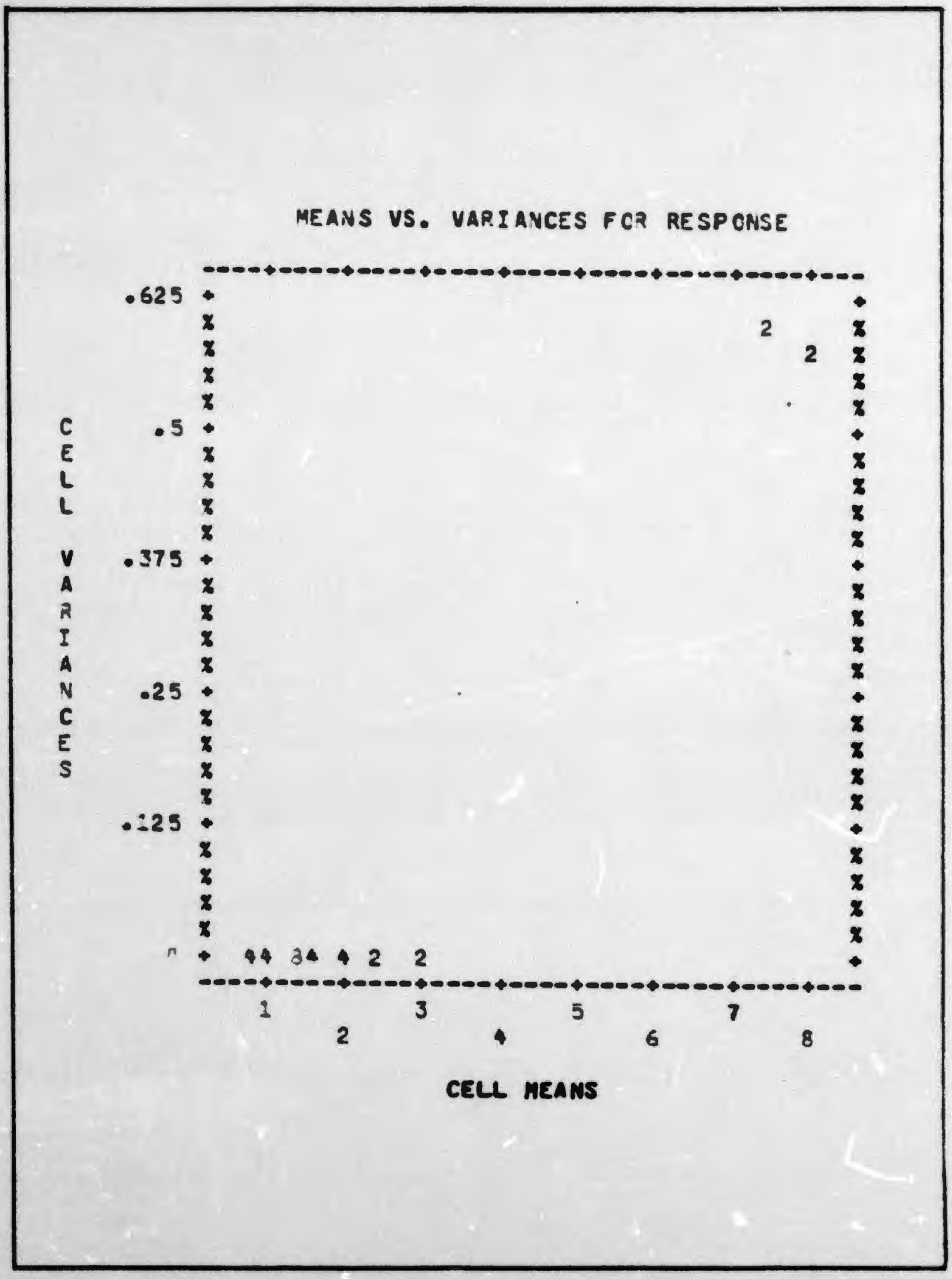


Figure 13. CELLPLOT: Cell Variance versus Cell Means

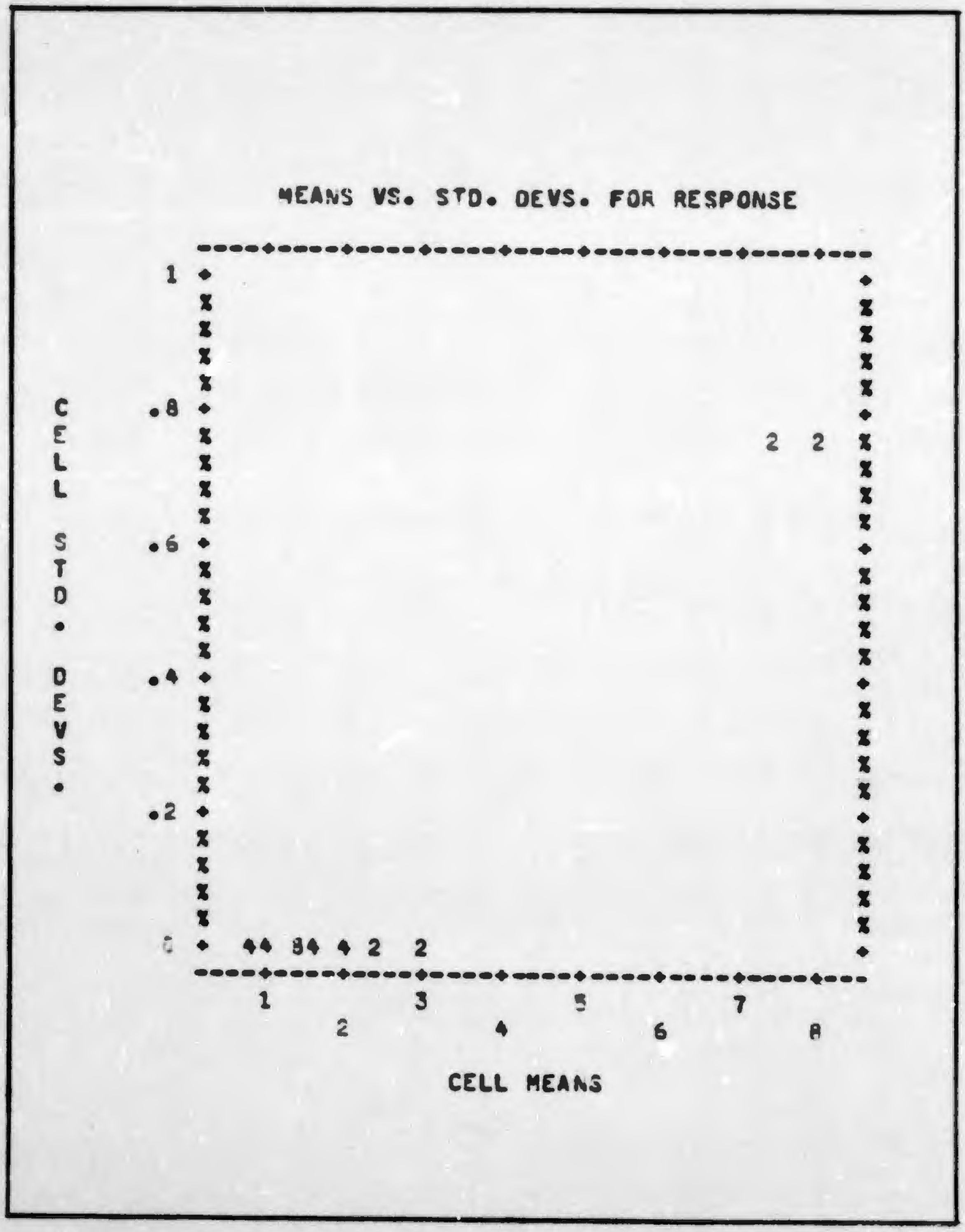


Figure 14. CELLPLOT: Cell Standard Deviation versus Cell Means

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            DISTRIBUTION OF CELL MEANS FOR RESPONSE

3WAY MANOVA FOR EVACUATION MODEL

* * * * * * * * * A N A L Y S I S   O F   V A R I A N C E *

FREQUENCY       4   20    3    1    0    0    0    2    2
-----------------------------------------------------------
EACH * EQUALS    2 POINTS

      20             *
      18             *
      16             *
      14             *
      12             *
      10             *
       8             *
       6             *
       4        *    *
       2        *    *    *                        *    *
----------------*----*----*----*----*----*----*----*----*---
INTERVAL  %     .500      2.500     4.500     6.500     8.500
MID-POINTS%          1.500     3.500     5.500     7.500

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 15. CELLPLOT: Cell Mean Frequency Distribution

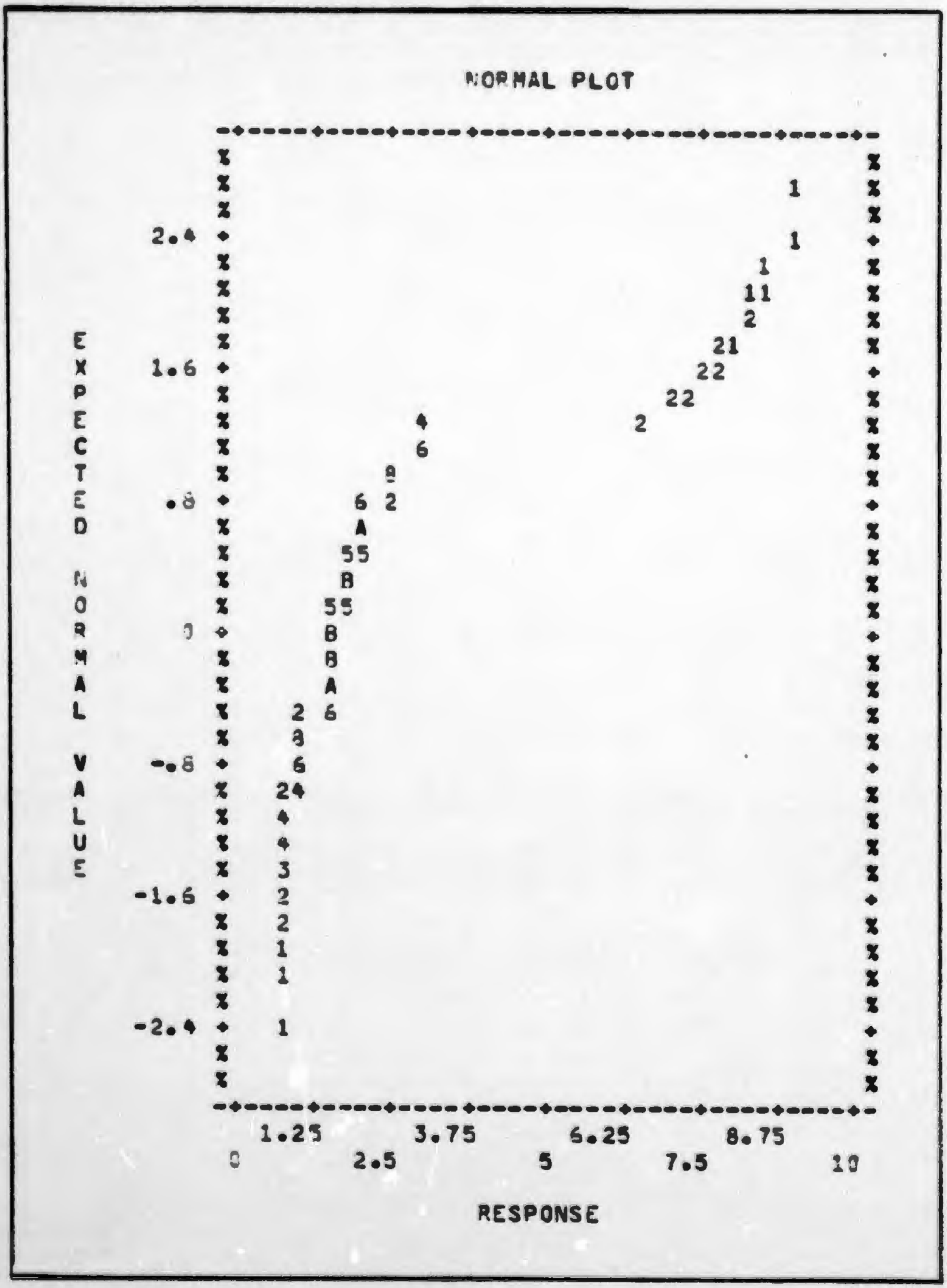

Figure 16. Normal Probability Plot

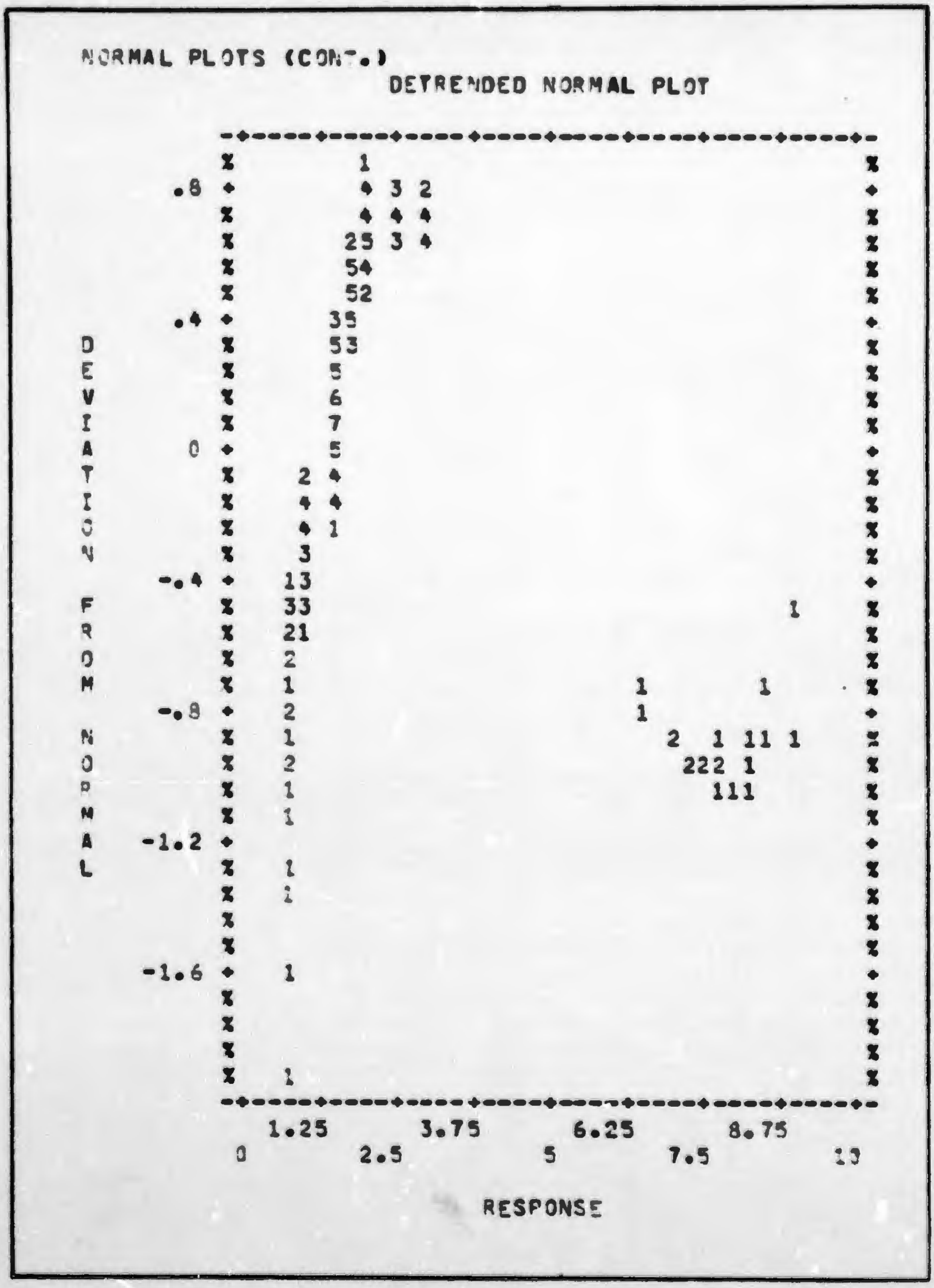

Figure 17. Detrended Normal Probability Plot

By specifying the keyword POBS (POBS stands for predicted observations), MANOVA provides six plots, all but one of which are residual plots. The first plot provides a check of the model's goodness of fit. This is a plot of the observed versus the predicted values. A generally straight line indicates a good fit. This plot is shown in Figure 18. The plot of Figure 18 is straight with a positive slope from observed values of approximately 1.0 to 3.75. Then there is a break in the line and the plot resumes at observed values of approximately 7.0 to 8.75. This apparent discontinuity prompted further investigation. A plot of the cell means readily showed that the means of cells 2, 6, 10, and 14 were the outliers (extreme observations). In order to explain this phenomenon, the simulation model was run again for these cells using the SLAM plotting capability for further graphical analysis.

The RECORD input statement was used to produce a plot of the evacuation time as it changed over the 10 day conflict. This plot revealed that the average evacuation time was approximately 3 hours for the first 24 hours, but it increased steadily to approximately eight hours at the end of the 10 day conflict. For these four cells, the patient arrival rate exceeded the evacuation rate so that there was a significant and continuous buildup of patients waiting to be evacuated. This caused the increase in the average evacuation time. After determining the cause of the outliers, they were excluded from further analysis

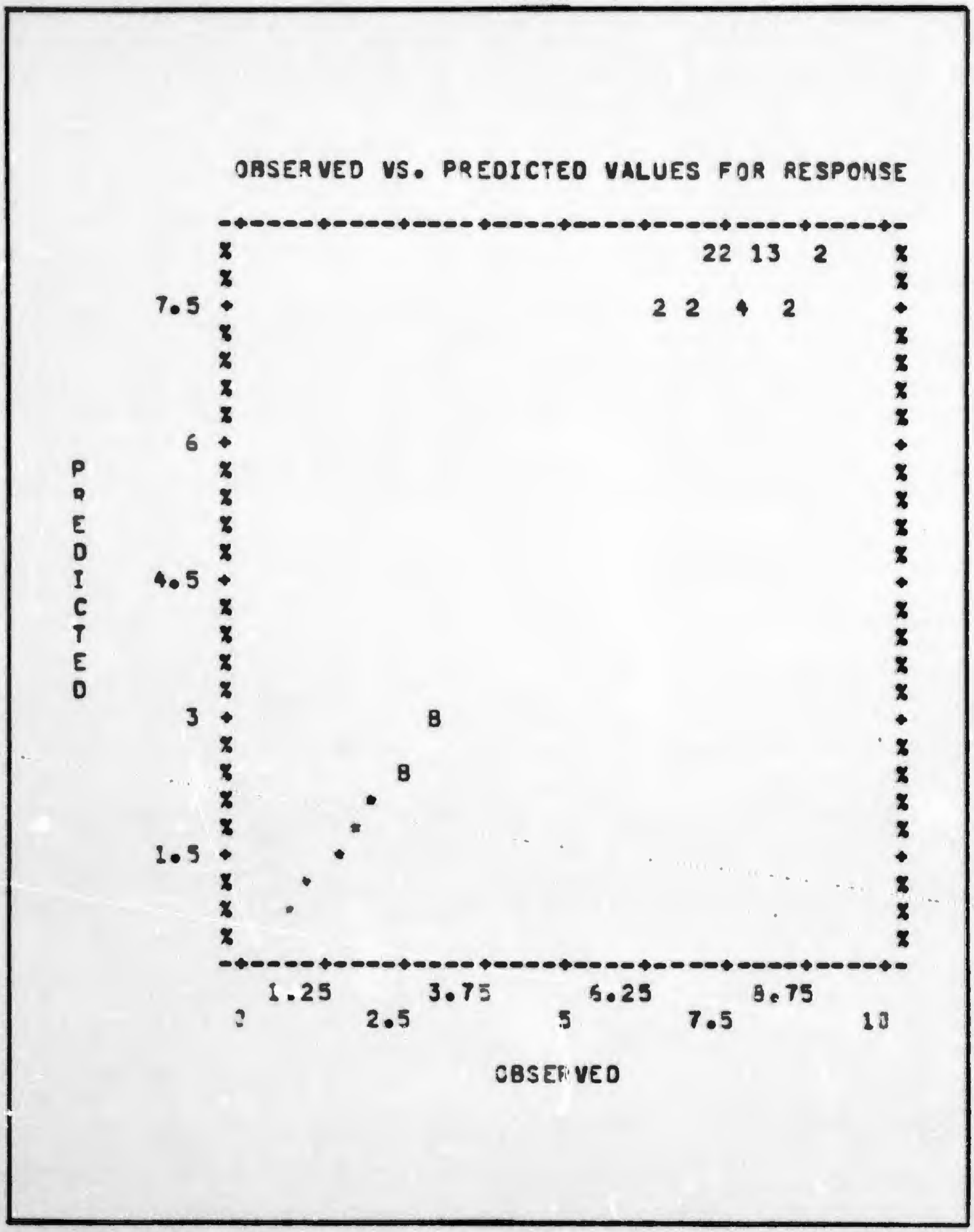

Figure 18. POBS: Plot of Observed versus Predicted Values

because they were not feasible alternatives in the sense that eight hours for evacuation to the clearing station is not acceptable by Army evacuation requirements. The remaining cells represented possible operating policies for the evacuation system. The analysis of these responses indicated that the system response was deterministic over the conditions represented by the remaining cells. That is, the system was not sensitive to the stochastic input of patient incidents. Rather, the evacuation time was a function of the ambulance travel rate and the evacuation distance. Therefore, the next reasonable task was to rank order the remaining alternatives based on the vehicle utilization for each feasible configuration of the evacuation system.

Ranking of Alternatives

Each of the cells represents an operating policy. That is, each combination of the factors at the different levels is a different way in which the evacuation system might be configured. In addition to using the evacuation time as a measure of effectiveness, the vehicle utilization for each cell was used to rank order the alternatives. Tables 12 through 17 provide many of the answers to the stated research objectives.

The battalion aid station resource (ambulance) statistics collected from the simulation runs for each cell are shown in Table 12. In table 12, the number of available ambulances, the average ambulance utilization, the standard deviation, the minimum and maximum number of available ambulances, and the ambulance utilization percentage are shown for each cell. The ambulance utilization percentage is the average ambulance utilization divided by the number of available ambulances and then multiplied by 100. All of the cells resulted in a utilization percentage of less than or equal to 70 percent. This indicates that for all cases, at least 30 percent of the time the ambulances would be idle. The average utilization statistic is a time weighted average.

This result indicates that it would be possible to schedule the ambulances for maintenance during this idle period. The ANOVA showed that the number of ambulances available at the BAS was not significant. The utilization percentage also indicated that the number of available ambulances at the BAS was not significant with regard to time available for required maintenance. This time is not only important for vehicle maintenace but also for crew rest. Table 12 illustrates that there would be time for the crews to rest and maintain individual equipment.

Similarly, in Table 13, the brigade clearing station resource (ambulance) statistics are shown. Tables 14 and 15 show the statistics of interest regarding holding capability of the company aid posts and the battalion aid stations, respectively. In each table, the AVE LENGTH indicates the average number of patients waiting for evacuation and STD DEV is the standard deviation. MAX LENGTH is the maximum number of patients waiting for evacuation during the simulated 10 day battle. The last column, AVERAGE WAITING TIME, is the average time that patients waited for evacuation. It is evident that the waiting time at both locations does not pose a problem for the remaining alternatives.

Table 16 illustrates the cell rankings based on the utilization percentages of the brigade clearing station resources (ambulances). Based on this analysis, the cells ranked from 1 to 4 are the remaining feasible alternatives. The other cells were eliminated because the utilization exceeded 50 percent. In every case where the evacuation distance to the clearing station (Factor 5) at the high level (20 km) and the ambulance travel rate (Factor 1) at the low level (16 km/hr) occurred, the cell was not feasible. All other cases seemed to be feasible operating policies.

In Table 17, the number of patients evacuated to the battalion aid stations and to the clearing station are shown. The difference in the totals in each cell is due to the shutdown transients in the simulation model. In other words, the difference is due to the number of patients still waiting to be evacuated and those that are in route to the clearing station at the end of the 10 day simulation. The average number of patients evacuated to the battalion aid stations was 4015 for the 10 day period

Table 12. BAS Resource (Ambulance) Statistics

CELL	No. AMBLS	AVE UTIL	STD DEV	MIN AVAIL	MAX AVAIL	UTIL(%)
1	4	1.8	0.9	0	4	45.0
2	4	1.8	0.9	0	4	45.0
3	4	1.8	0.9	0	4	45.0
4	4	1.8	0.9	0	4	45.0
5	4	2.8	0.9	0	4	70.0
6	4	2.8	0.9	0	4	70.0
7	4	2.8	0.9	0	4	70.0
8	4	2.8	0.9	0	4	70.0
9	6	1.8	0.9	1	6	30.0
10	6	1.8	0.9	1	6	30.0
11	6	1.8	0.9	1	6	30.0
12	6	1.8	0.9	1	6	30.0
13	6	2.8	1.0	0	6	46.6
14	6	2.8	1.0	0	6	46.6
15	6	2.8	1.0	0	6	46.6
16	6	2.8	1.0	0	6	46.6
17	4	1.1	0.8	0	4	27.5
18	4	1.1	0.8	0	4	27.5
19	4	1.1	0.8	0	4	27.5
20	4	1.1	0.8	0	4	27.5
21	4	1.9	0.9	0	4	47.5
22	4	1.9	0.9	0	4	47.5
23	4	1.9	0.9	0	4	47.5
24	4	1.9	0.9	0	4	47.5
25	6	1.1	0.8	0	6	18.3
26	6	1.1	0.8	0	6	18.3
27	6	1.1	0.8	0	6	18.3
28	6	1.1	0.8	0	6	18.3
29	6	1.9	0.9	1	6	31.6
30	6	1.9	0.9	1	6	31.6
31	6	1.9	0.9	1	6	31.6
32	6	1.9	0.9	1	6	31.6

Table 13. BDE Resource (Ambulance) Statistics

CELL	No. AMBLS	AVE UTIL	STD DEV	MIN AVAIL	MAX AVAIL	UTIL(%)
1	8	5.1	1.1	0	8	63.7
2	8	7.9	0.4	0	8	98.7
3	10	5.2	1.2	0	10	52.0
4	10	8.5	1.3	0	10	85.0
5	8	5.2	1.2	0	8	65.0
6	8	7.9	0.5	0	8	98.7
7	10	5.4	1.3	0	10	53.0
8	10	8.5	1.4	0	10	85.0
9	8	5.1	1.2	0	8	63.7
10	8	7.9	0.4	0	8	98.7
11	10	5.2	1.2	0	10	52.0
12	10	8.5	1.3	0	10	85.0
13	8	5.2	1.3	0	8	65.0
14	8	7.9	0.5	0	8	98.7
15	10	5.2	1.3	0	10	52.0
16	10	8.5	1.4	0	10	85.0
17	8	3.7	1.1	0	8	46.2
18	8	5.5	1.2	0	8	68.7
19	10	3.7	1.1	2	10	37.0
20	10	5.6	1.2	0	10	56.0
21	8	3.6	1.1	0	8	45.0
22	8	5.6	1.2	0	8	70.0
23	10	3.9	1.1	2	10	36.0
24	10	5.6	1.2	0	10	56.0
25	8	3.7	1.1	0	8	46.2
26	8	5.5	1.2	0	8	68.7
27	10	3.7	1.1	1	10	37.0
28	10	5.6	1.2	0	10	56.0
29	8	3.6	1.1	0	8	45.0
30	8	5.6	1.2	0	8	70.0
31	10	3.6	1.1	2	10	36.0
32	10	5.6	1.2	0	10	56.0

Table 14. Comapny Aid Post File Statistics

CELL	AVE LENGTH	STD DEV	MAX LENGTH	AVERAGE WAITING TIME
1	0.4	0.6	5	0.2
2	0.4	0.6	5	0.2
3	0.4	0.6	5	0.2
4	0.4	0.6	5	0.2
5	0.7	0.9	7	0.4
6	0.7	0.9	7	0.4
7	0.7	0.9	7	0.4
8	0.7	0.9	7	0.4
9	0.4	0.6	5	0.2
10	0.4	0.6	5	0.2
11	0.4	0.6	5	0.2
12	0.4	0.6	5	0.2
13	0.7	0.9	7	0.4
14	0.7	0.9	7	0.4
15	0.7	0.9	7	0.4
16	0.7	0.9	7	0.4
17	0.3	0.5	4	0.1
18	0.3	0.5	4	0.1
19	0.3	0.5	4	0.1
20	0.3	0.5	4	0.1
21	0.4	0.7	7	0.2
22	0.4	0.7	7	0.2
23	0.4	0.7	7	0.2
24	0.4	0.7	7	0.2
25	0.3	0.5	4	0.1
26	0.3	0.5	4	0.2
27	0.3	0.5	4	0.2
28	0.3	0.5	4	0.2
29	0.4	0.7	7	0.2
30	0.4	0.7	7	0.2
31	0.4	0.7	7	0.2
32	0.4	0.7	7	0.2

Table 15. BAS File Statistics

CELL	AVE LENGTH	STD DEV	MAX LENGTH	AVERAGE WAITING TIME
1	2.1	1.8	11	0.3
2	29.8	21.4	84	5.1
3	2.1	1.8	11	0.3
4	4.6	2.7	16	0.8
5	2.3	2.1	12	0.4
6	30.7	21.4	86	5.3
7	2.2	2.1	12	0.3
8	4.8	2.8	17	0.8
9	2.1	1.9	11	0.3
10	29.8	21.4	84	5.1
11	2.1	1.9	11	0.3
12	4.6	2.7	16	0.8
13	2.3	2.1	12	0.4
14	30.2	21.4	84	5.2
15	2.3	2.1	12	0.4
16	4.8	2.9	18	0.8
17	1.2	1.3	9	0.2
18	2.3	1.9	11	0.4
19	1.2	1.3	9	0.2
20	2.3	1.9	11	0.4
21	1.3	1.5	11	0.2
22	2.4	2.0	11	0.4
23	1.3	1.5	11	0.2
24	2.4	2.0	11	0.4
25	1.2	1.3	9	0.2
26	2.3	1.9	11	0.4
27	1.2	1.3	9	0.2
28	2.3	1.9	11	0.4
29	1.3	1.5	11	0.2
30	2.4	2.0	11	0.4
31	1.3	1.5	11	0.2
32	2.4	2.0	11	0.4

Table 16. CELL Rankings by Utilization

RANK	UTILIZATION (%)	CELLS
1	36.0	23, 31
2	37.0	19, 27
3	45.0	21, 29
4	46.2	17, 25
5	52.0	3, 15
6	53.0	7
7	56.0	20, 24, 28, 32
8	63.7	1, 9
9	65.0	5, 13
10	68.7	18, 26
11	70.0	11, 22, 30
12	85.0	4, 8, 12, 16
13	98.7	2, 6, 10, 14

Table 17. Total Number of Patients Evacuated (10 Days)

CELL	TO BAS	TO CLEARING STATION
1	4018	4002
2	4018	3805
3	4018	4002
4	4018	3989
5	4007	3993
6	4007	3798
7	4007	3993
8	4007	3978
9	4018	4002
10	4018	3805
11	4018	4002
12	4018	3989
13	4007	3993
14	4007	3800
15	4007	3993
16	4007	3978
17	4020	4011
18	4020	4003
19	4020	4011
20	4020	4003
21	4018	4006
22	4018	4000
23	4018	4006
24	4018	4000
25	4020	4011
26	4020	4003
27	4020	4011
28	4020	4003
29	4018	4006
30	4018	4000
31	4018	4006
32	4018	4000

or 401.5 per day. Dividing this by the number of battalions (3) yields approximately 133 patient incidents per day per battalion. This result is very close to the assumed patient incident rate of 130 incidents per day per battalion.

Overall, these results tend to validate the existng concepts for the evacuation system in the brigade area. That is, for the proposed operating distances, number of ambulances, and assumed travel rate of 35 km/hr, the system performance meets all criteria. The evacuation times were less than 2 hours, the ambulance utilization was less than 50 percent, and the number of patients and average waiting time for evacuation were insignificant. But, the system failed to meet the criteria when the evacuation distances were extended. This implies that in order to provide the desired evacuation support at extended distances, the ambulance travel rate must be improved. Some improvement can be made by increasing the number of available ambulances, but as will be explained in the next section, additional ambulances does not alleviate the problem totally.

Sensitivity Analysis

Sensitivity analysis should always be performed to determine how the model output will vary with changes in the input parameters. The purpose is to determine the range of the input parameters over which the model output remains constant. Sensitivity analysis is essential because the simulation analysis only provides insight to the system for decision makers. Simulation analysis alone does not provide the answers per se. Quade states:

> Making plans and decisions in the face of uncertainty, even if aided by the best possible systems analysis, can be also be very expensive. In the end it comes down to a matter of judgement and successive iterations. We supplement the data we have by sensitivity testing; that is, we systematically but arbitrarily vary various parameters, working out how these changed values affect the results (Ref 33 :57).

The method used for this sensitivity analysis was to increase the patient incident rate. This was done by changing the parameter of the exponential distribution used to generate the patients at each of the CREATE nodes in the network portion of the model. This analysis revealed that the evacuation time remained constant for 10 and 20 percent increases in the patient incident rate. But, at a 30 percent increase, the evacuation time rapidly began to increase. This was due to the build-up of patients waiting for evacuation. Similar to cells 2, 6, 10, and 14 in the initial analysis, a 30 percent increase in the incident rate exceeded the evacuation capability of the system. As time increased, the evacuation time increased. This means that the range of the estimated patient incident rate could be extended up to approximately 169 patients per day per battalion without affecting the evacuation time estimated by the model.

Since the analysis indicated that Factor 5 (Number of ambulances available at the BAS--four or six) was not significant, it seemed reasonable to perform another experiment in which the number of ambulances was fixed at four and the remaining vehicles were allocated to the clearing station in order to determine whether this would reduce the evacuation time for cells 2, 6, 10, and 14.

It was found that by allocating additional ambulances to the clearing station, the evacuation time for cells 2, 6, 10, and 14 could be reduced to the point at which the evacuation time was a function of the distance and ambulance travel rate. For example, for the worst cell case (cell 6), the evacuation time was reduced from a mean time of 8.0 hours to 3.0 hours. The 3.0 hour evacuation time was deterministic for this configuration. That is, the configuration was not sensitive to the stochastic input of patient incidents. In other words, having 14 ambulances available at the clearing station enabled the clearing station to evacuate all patients in 3 hours. Examining the combination of Factors 1, 3, and 5 for cell 6 illustrates this point. Factor 1 (Ambulance travel rate) was 20 km/hr. Factor 3 (Evacuation distance to BAS) was 10 km and Factor 5 (Evacuation distance to clearing station) was 20 km. Therefore, the round trip travel time for the battalion aid station ambulance was 1 hour; and, the round trip travel time for the clearing station ambulance was 2 hours. Therefore, the total travel time to move the patient was 3 hours.

This indicates that the average waiting time for the patients waiting for evacuation should have been less than or equal to the the one-way travel time from the BAS and the clearing station. Indeed, the average waiting time was less than the one-way travel time as reported in the file statistics on the SLAM Summary Report. The average waiting time at the company aid posts was approximately 0.42 hours and at the BAS the time was approximately 0.76 hours. This result implies that the waiting time is not a problem. That is, since the aid posts and the aid stations are not designed and therefore not equipped to hold patients, the waiting times indicated that was no problem of patient buildup created at these locations.

Chapter Summary

In this chapter, a discussion of model verification and validation has been presented. Also, the experimentation and data collection processes have been described. The use of the SPSS programs ANOVA and MANOVA were used to analyze the data collected from the model. One of the five factors, the number of ambulances available at the battalion aid stations was found to be insignificant. Then, the remaining alternatives were rank ordered according to the vehicle utilization. Finally, sensitivity analysis indicated that the results remain constant as the patient incident rate was increased up to a

30 percent increase; and, re-allocating ambulances from the BAS to the clearing station reduced the evacuation time to the deterministic range.

Additionally, Appendix D and Appendix F contain information to supplement the data analysis described in this chapter. Appendix D contains the 5-WAY and 4-WAY ANOVA tables and a graphic presentation of the factor effects. Appendix F contains the MANOVA procedure statements used to generate the plots described in this chapter. Next, the summary, conclusions, and recommendations for further research resulting from this study are presented in the final chapter, Chapter V.

Chapter V

Summary, Conclusions, and Recommendations

This chapter summarizes the research effort discussing the accomplishment of each research objective, how the research objectives answered the research questions, general conclusions drawn from this research, and recommendations for further research.

Summary of Research Accomplishments

The hypothesized problem was that the ground evacuation system in a brigade area of a combat zone was not adequate. Therefore, the primary objective of this research was to analyze the Army medical evacuation support system equipped with the newly developed High Mobility Multipurpose Wheeled Vehicle (HMMWV) in a forward combat area of a light infantry brigade. The answers to the four specific research queations are summarized here.

The first question asked what will be the expected time for patient evacuation from the company aid posts to the medical company clearing station. Table 10 and Figure 15 answer this question. Generally, patients are evacuated within two hours. But, when evacuation distances are increased to the high level, the time exceeded the two hour criterion.

The second question asked what will be the expected ambulance utilization. Tables 12, 13, and 16 answer this question. Basically, ambulance utilization exceeded the established 50 percent criterion for all but eight cells. These eight cells represented the eight possible combinations of the 35 km/hr ambulance travel rate and the 10 km evacuation distance to the clearing station. Therefore, utilization was a problem except when the system operated at the reduced distances.

The third question asked what will be the patient waiting time for evacuation from the BAS to the clearing station. Table 15 answers this question. Essentially, the average waiting time was less than 25 minutes. Therefore, patient buildup was not a problem.

The final question asked how many ambulances are required to provide evacuation support in the brigade system. The analysis indicated that there was no statisical difference in the support for either four or six ambulances at the BAS. Either the proposed ten ambulances or eight ambulances at the clearing station is sufficient to provide support with a utilization rate of less than 50 percent. Since either ten or eight ambulances is adequate with regard to the utilization criterion, eight ambulances is preferred due to the reduced cost incurred. The remainder of this section presents a recap of the study.

The causal diagram (Figure 5) of the conceptual system was used to explain component relationships and to develop measures of effectiveness of the evacuation system.

Systems simulation techniques were implemented as the study methodology. The rationale for using simulation was presented in Chapter I.

A SLAM combined network-discrete event simulation model of this system was developed using systems simulation principles in order to study the evacuation system. The model was developed specifically for this study. The research design used in this simulation analysis was a 2^5 factorial design. The five factors and levels used in the study were presented in Table 3. Model parameters were selected based on existing doctrine and tactics, and possible alternatives.

The model produced data that was analyzed using analysis of variance to test for the statistical significance of the five factors to system output. These results were described in Chapter IV with supplemental information concerning the data analysis provided in Appendix D and Appendix E.

Stages 1 through 9 of the system simulation process have been completed. This study may be used as input for the infantry close combat mission area analysis and considered by Army analysts as insight for the HMMWV distribution plan. Any implementation (Stage 11) of this study will follow the documentation and presentation of the results (Stage 12). Using this model, the analysis tended to validate the existing concepts using the assumed vehicle characteristics of the HMMWV and the other model parameters.

Conclusions

Four of the 5 main factor effects were determined to be significant. As illustrated in Appendix E, the effect of Factor 1 (Ambulance travel rate) was a significantly reduced evacuation time. However, Factor 5 (Evacuation distance to the clearing station) had an approximately equal but opposite effect for evacuation time. But, the analysis identified four 2-way interactions and one 3-way interaction. The graphic presentations of these interactions (Appendix D) indicated that they were important interactions; therefore, one should not discuss the effects of each factor separately in terms of factor level means. However, the 2-way interaction of Factor 1 (Ambulance travel rate) and Factor 3 (Evacuation distance to the BAS) is relatively unimportant as evidenced by the slopes of the lines in the graphic presentation. In the 3-way interaction, the evacuation time increase was fourfold, approximately. This implied that there was a synergetic effect. That is, the evacuation time increase was more than expected when these factors changed levels.

The primary measure of effectiveness (MOE) used in the analysis was the time required to move patients from company aid posts tu the brigade clearing station. Based on the analysis, the expected time to evacuate patients from the company aid posts to the brigade clearing stations generally was less than 2 hours for the current doctrinal and tactical considerations. Furthermore, ambulance utilization rates would allow time for required maintenance and crew rest. Also, patient waiting time was insignificant; therefore, no holding capability would be required in the brigade area.

The most important finding of the study was that there was no difference in system performance when the BAS was equipped with either four or six ambulances. For the assumed patient incident rate (plus 30%), the battalion aid stations could be equipped with four ambulances instead of the six that are planned. This reduction could amount to a considerable cost savings. For example, considering the purchase price of the HMMWV at $35,000 per vehicle and 60 Army infantry battalions to be equipped with the HMMWV over the next 5 years, the reduction from six to four vehicles per battalion would result in a savings of approximately $4,200,000. This simple estimate neglects the resulting reduction of operating and maintenance costs that would likely occur, also.

The HMMWV, as modeled in this analysis, will provide the evacuation capability required in the brigade area for the existing operating concepts. However, if evacuation distances were increased as modeled, a greater travel rate would be required for the ambulance.

For the employment concepts described by the current doctrine, system performance met the established criterion which was to have the evacuation time less than or equal to two hours. However, the system failed the evacuation time criterion for alternative conceptual configurations of the evacuation system. The ambulance utilization rate was used as a secondary measure of effectiveness (MOE) of system performance. Again, the analysis tended to validate existing concepts with regard to the criterion established for utilization. But, for the alternative concepts that required extended operating distances, the average utilization rates exceeded 50 percent. The analysis illustrated that for the existing operational concepts, the average evacuation time was a function of the ambulance travel rate and the evacuation distance, only. Furthermore, the average time that patients had to wait for evacuation was less than the one-way ambulance travel time. Therefore, no requirement for additional holding capability was identified. The most important finding from this analysis was that for the assumed system parameters, there was no difference in system performance when the number of available ambulances at the battalion aid station was reduced from six to four. But, a limitation of the analysis is that neither the probability of downtime nor the probibility of damage or kill for the ambualnces was considered.

Recommendations for Further Research.

There are several recommendations for follow-on research. First, the model developed for this study assumed that the assigned ambulances were always available during the 10 day conflict. But, there is some uncertainty about this assumption. Additional analysis could focus on the expected downtime and the probability of kill for the ambulances while operating in the hostile environment. Intuitively, a decrease in ambulance availability would cause an increase in the average evacuation time. Due to the scope of this analysis, the probability of damage or kill for the vehicles was not considered.

Also, this model assumed that the ambulances supported three point sources of equal distance. Therefore, another possible area for further research would be to enhance the model to support other organizational configurations for various missions other than an area defense as in this study.

Another possible area for further research with this model is in the research design. This study used a fixed effects model at two levels for each of the five factors. But, another analysis using the same model could be performed using a random effects model or a fixed model with more than two levels per factor.

These are but a few of the further possibilities for additional study. In conclusion, this study has accomplished the stated research objectives. As stated before, validattion of the model is at best difficult. However, validation of the model used in this study was enhanced becuase of the common structural relationships of the model and the real system. Good models correspond point for point with the object modeled (Ref 37:31). Where a one-to-one correspondence exists of the elements of one system with those of another, the systems are said to be isomorphic. Of importance in isomorphic mappings is that there is also a correspondence not only of structure but also of operational characteristics (Ref 37:32). It is this feature that allows researchers to investigate and to predict properties of other systems.

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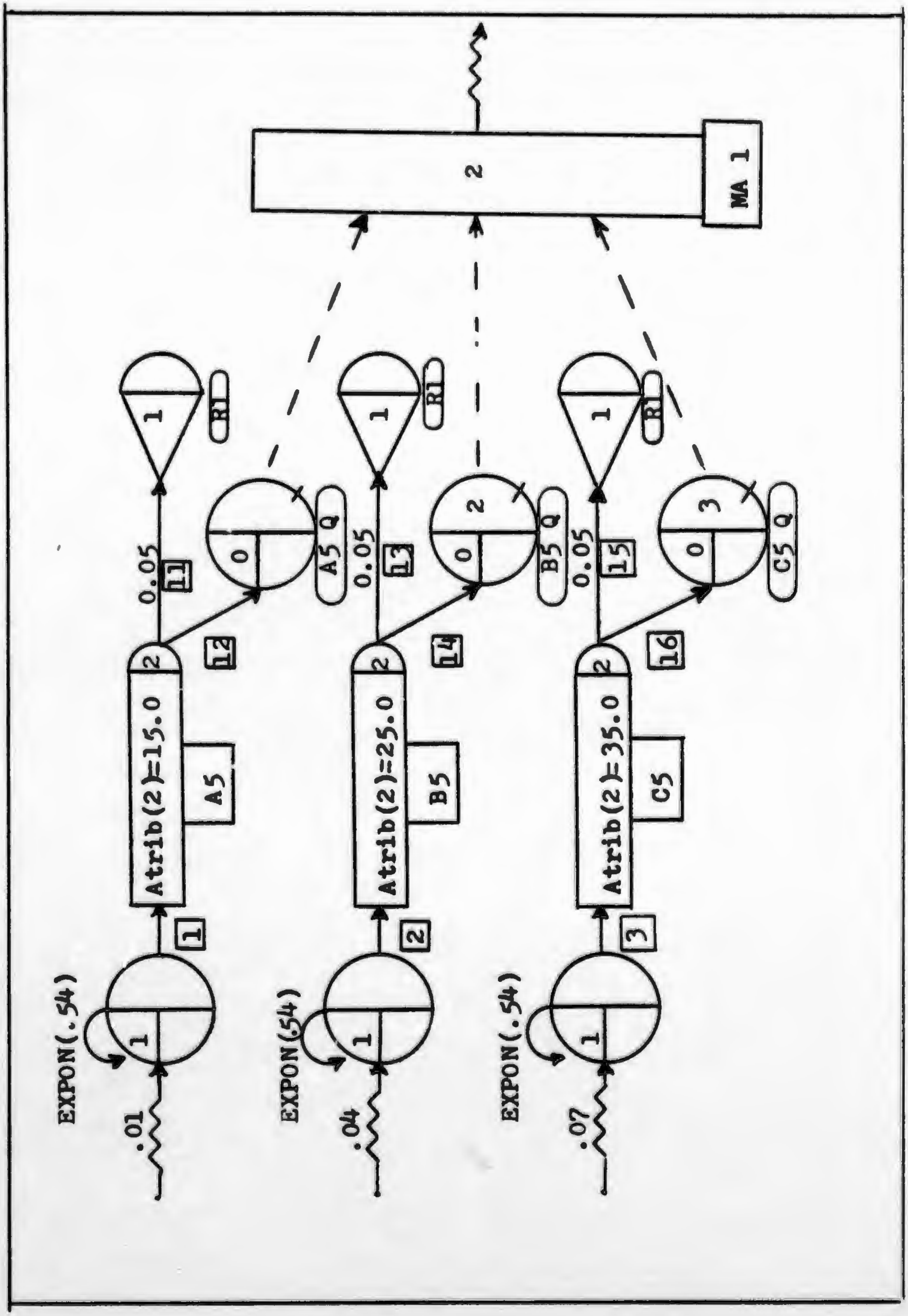
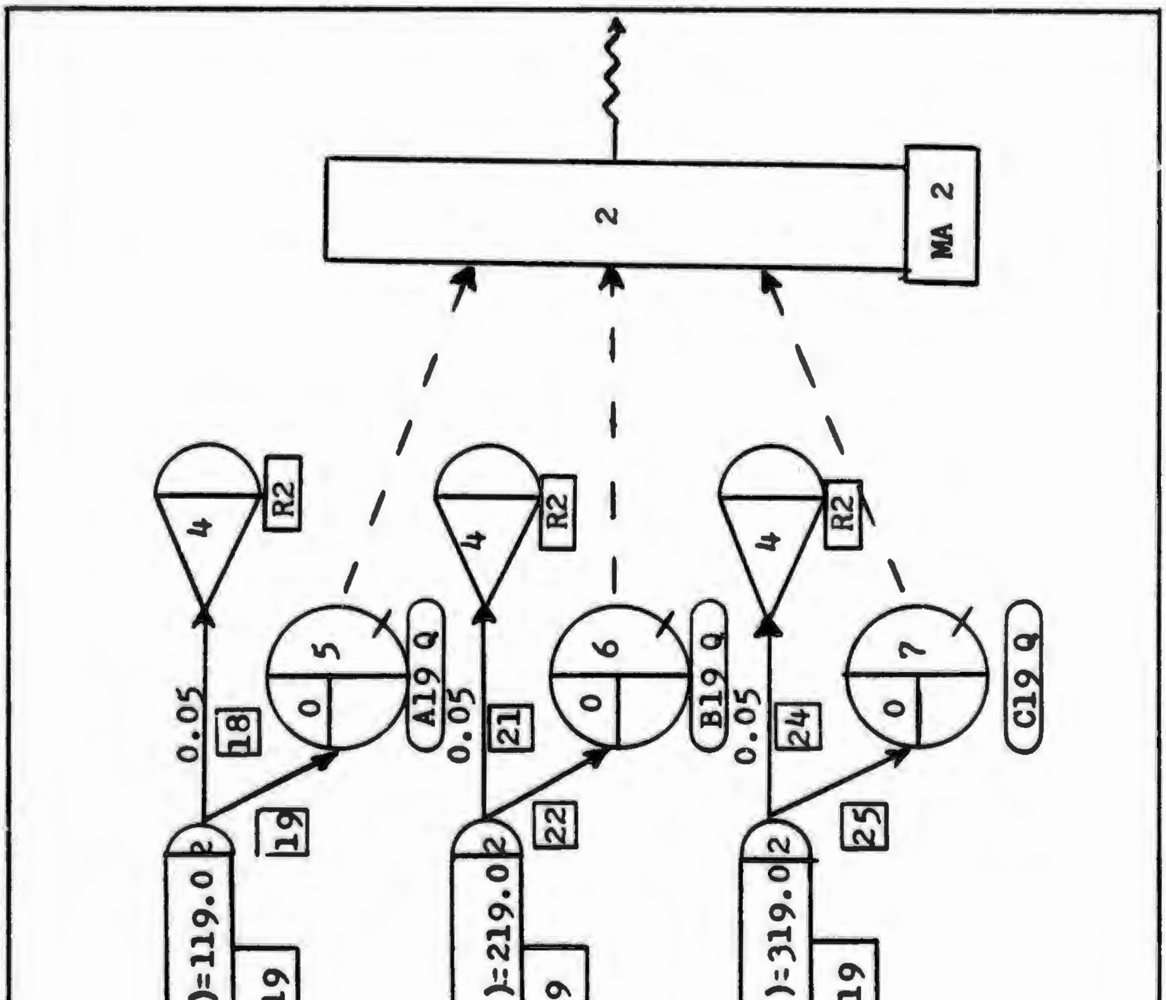
Appendix A

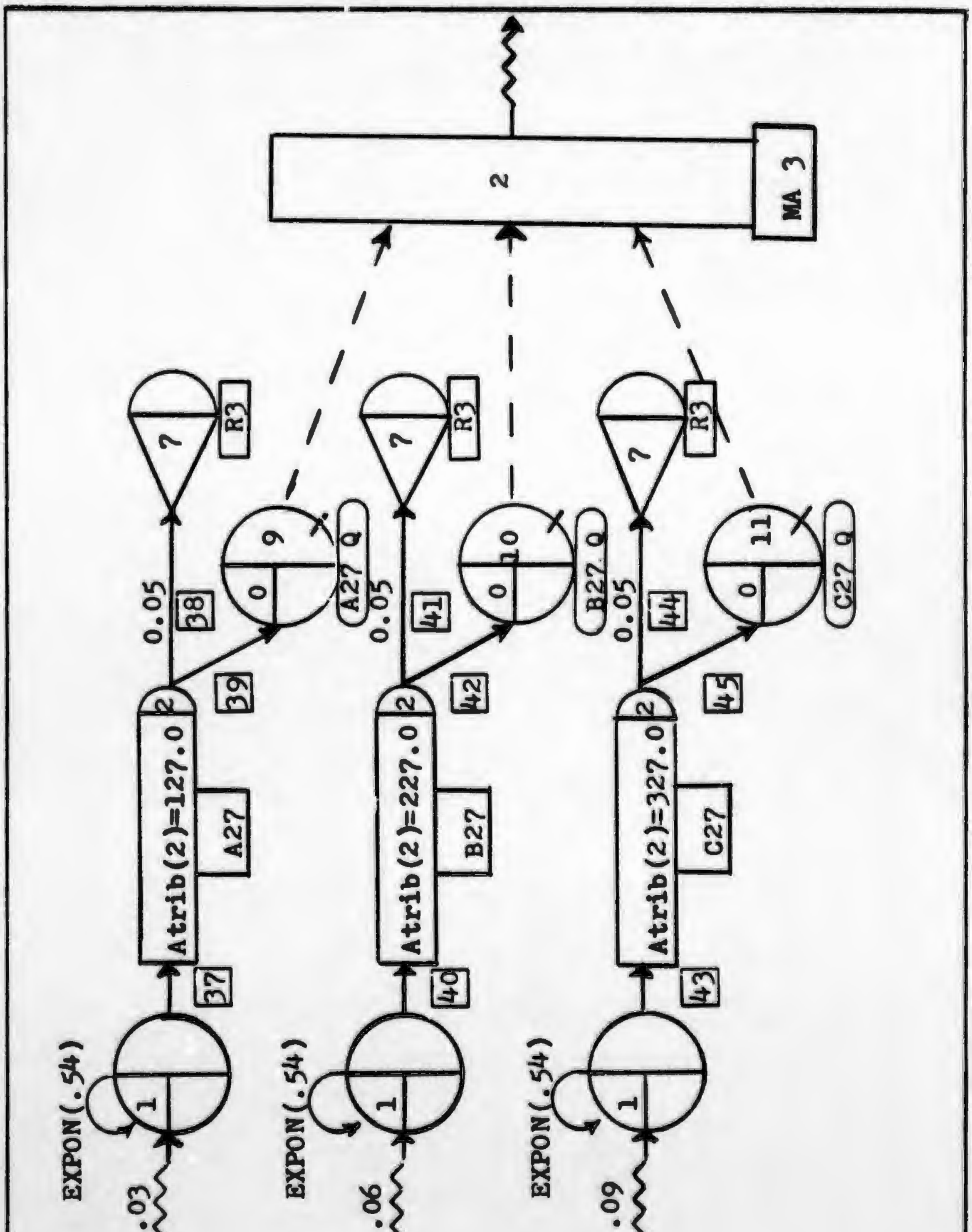
SLAM Network Diagrams

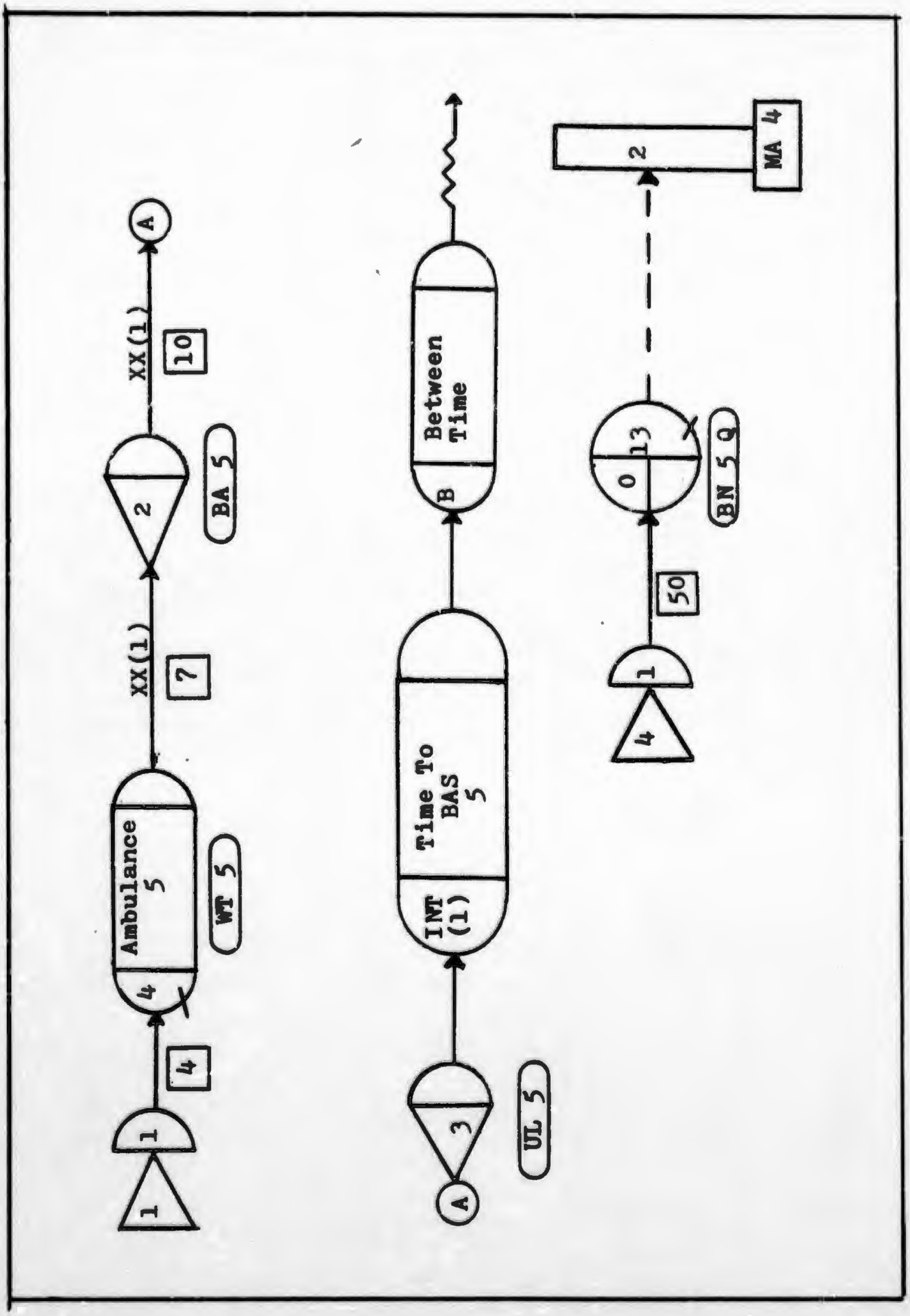
In this appendix, Appendix A, there are seven diagrams each on a separate page. On the first three pages, the diagrams that represent the nine companies in the brigade area are presented. Each of these pages illutrates the network for the three companies of one of the three battalions. On the following three pages, the diagrams for the battalion aid stations are illustrated; the diagram on each page represents a different battalion. The final page illustrates the network used to transport the patients from the battalion aid stations to the clearing station.


EXPON(.54)
.01
.04
.07
1
2
3
Atrib(2)=15.0
Atrib(2)=25.0
Atrib(2)=35.0
A5
B5
C5
0.05
11
12
13
14
15
16
0
A5 Q
B5 Q
C5 Q
R1
MA 1

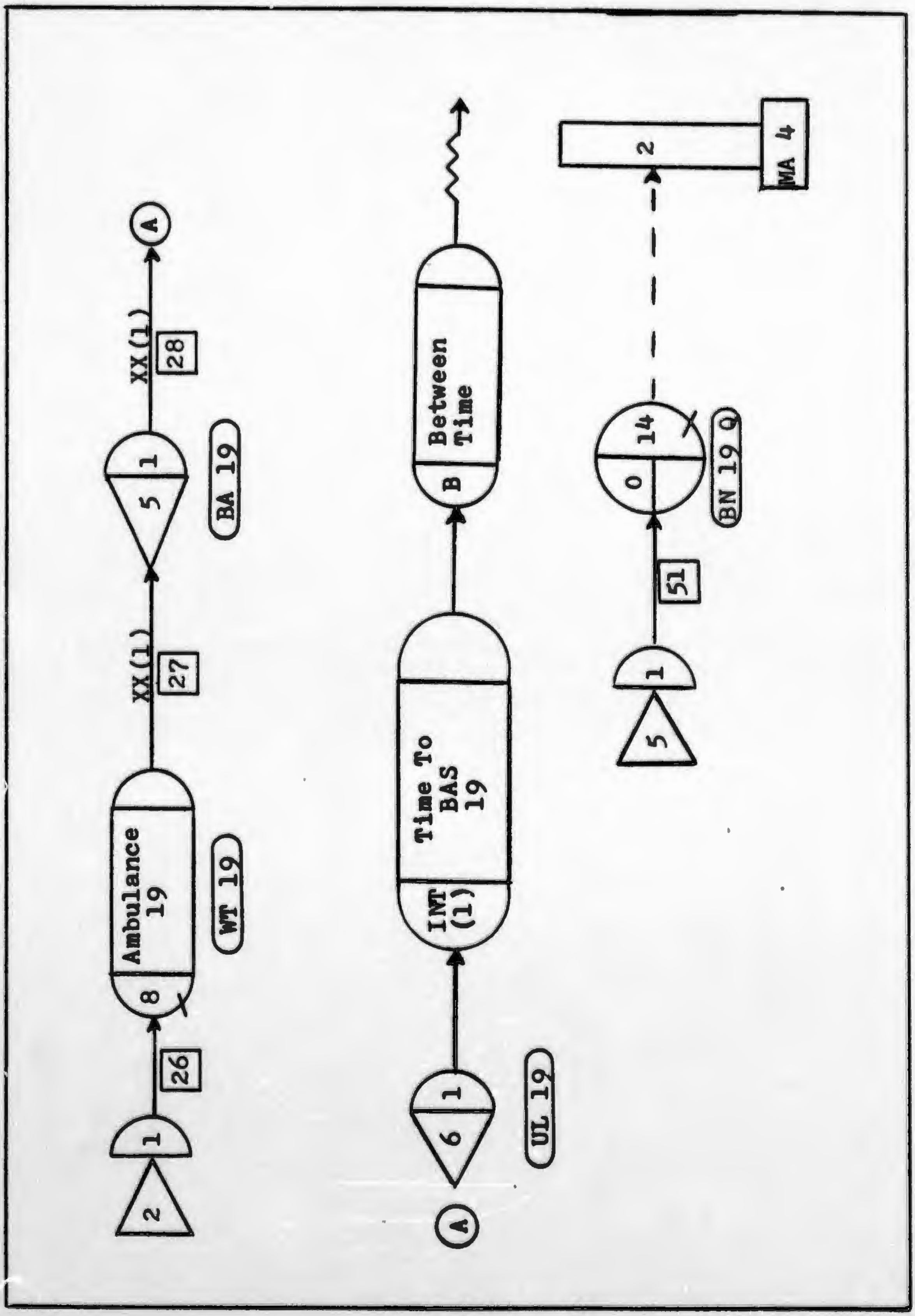


EXPON(.54)
.02
.05
.08
Atrib(2)=119.0
Atrib(2)=219.0
Atrib(2)=319.0
A19
B19
C19
0.05
A19 Q
B19 Q
C19 Q
R2
MA 2

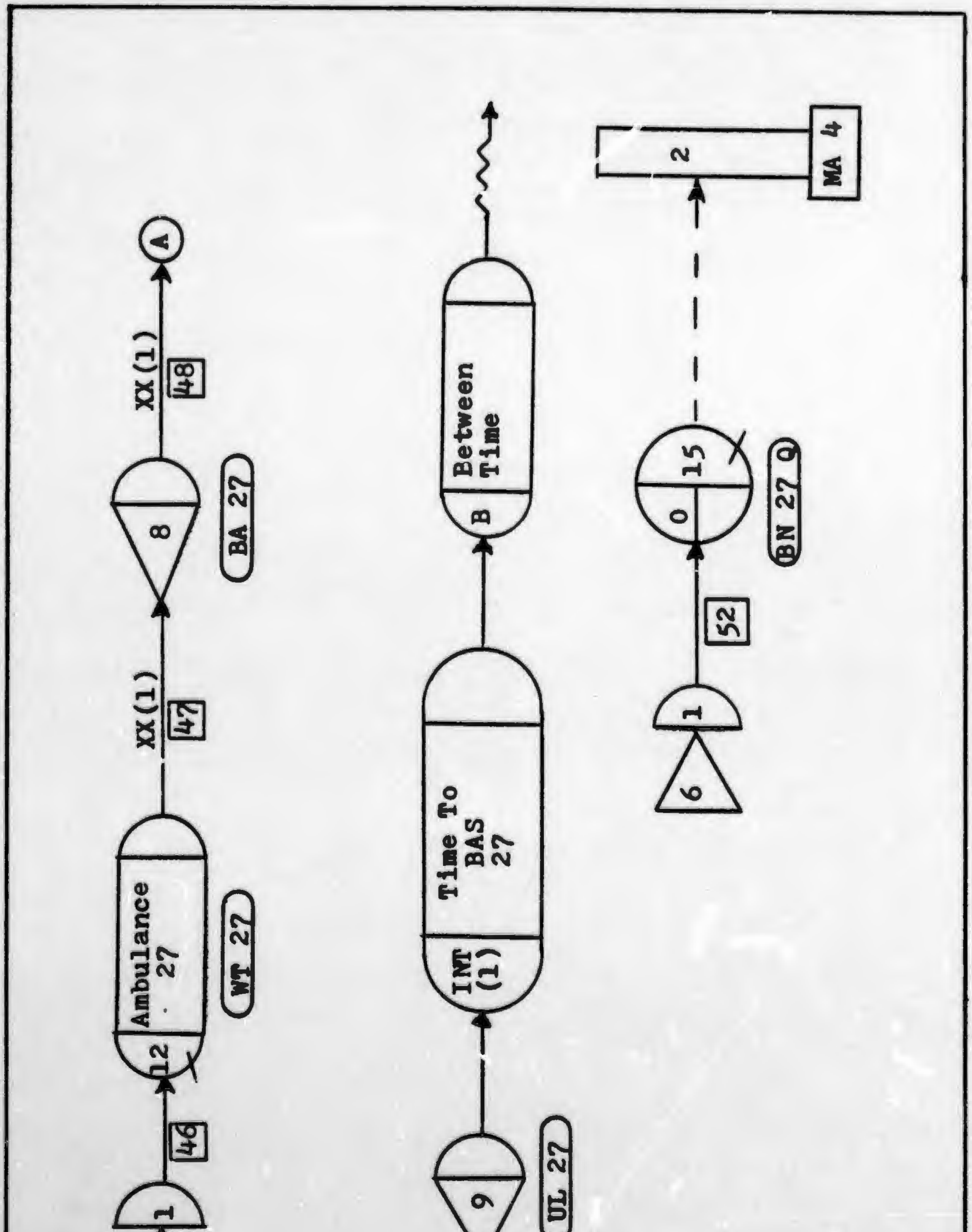

EXPON(.54)
.03
1
37
Atrib(2)=127.0
A27
2
39
0.05
38
0
9
A27 Q
7
R3
EXPON(.54)
.06
1
40
Atrib(2)=227.0
B27
2
42
0.05
41
0
10
B27 Q
7
R3
EXPON(.54)
.09
1
43
Atrib(2)=327.0
C27
2
45
0.05
44
0
11
C27 Q
7
R3
2
MA 3

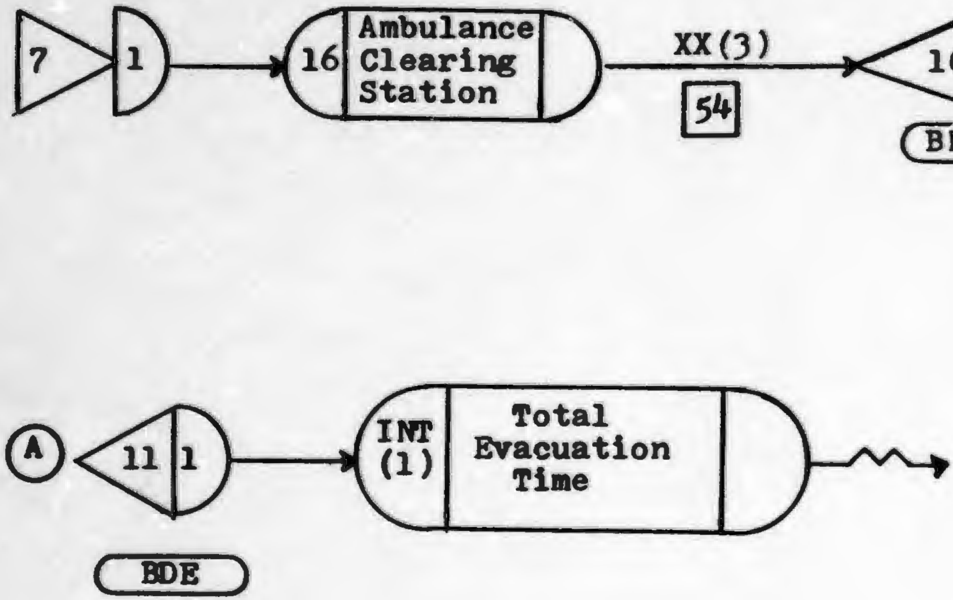


1
1
4
4
Ambulance
5
WT 5
XX(1)
7
2
BA 5
XX(1)
10
A
A
3
UL 5
INT
(1)
Time To
BAS
5
B
Between
Time
4
1
50
0
13
BN 5 Q
2
MA 4



2
1
26
8
Ambulance 19
WT 19
XX(1)
27
5
1
BA 19
XX(1)
28
A
A
6
1
UL 19
INT (1)
Time To BAS 19
B
Between Time
5
1
51
0
14
BN 19 Q
2
MA 4


3
1
46
12
Ambulance
27
WT 27
XX(1)
47
8
BA 27
XX(1)
48
A
A
9
UL 27
INT
(1)
Time To
BAS
27
B
Between
Time
6
1
52
0
15
BN 27 Q
2
MA 4



Resources	Await File
Ambulance 5	4
Ambulance 19	8
Ambulance 27	12
Ambulance Brigade	16

Appendix B

Evacuation Program Listing

SLAM Statements

FORTRAN Code

In this appendix, Appendix B, complete listings of the SLAM input and network statements, and the FORTRAN Code for the evacuation model are presented. The SLAM statements are presented first; the FORTRAN code follows. Comments have been added to the statements and to the code to facilitate model translation.

```
;
;
;
;
;
;SLAM INPUT STATEMENTS FOR EVACUATION MODEL
;
;******************************************
;
;  SLAM SIMULATION CONTROL STATEMENTS
;
gen,v. w. cook,evacuation,Ø1/1Ø/84,1Ø;       GENERAL INFORMATION
;                                            ANALYST- CPT V. W. COOK
;                                            MODEL- EVACUATION SIMULATION
;                                            DATE- 1Ø JAN 1984
;                                            1Ø RUNS
;
limits,16,5,5ØØ;                             LIMITS STATEMENT
;                                            MAXIMUM 16 FILES
;                                            MAXIMUM 5 ATTRIBUTES
;                                            MAXIMUM 5ØØ CONCURRENT ENTRIES
;
init,Ø,24Ø;                                  INITIALIZE STATEMENT
;                                            BEGIN TIME = Ø HOURS
;                                            END TIME = 24Ø HOURS (1Ø DAYS)
;
intlc,xx(1)=Ø.25,xx(3)=1.ØØ;                 INITIALIZE STATEMENT
;                                            XX(1) = AMBULANCE(BAS) RATE
;                                            XX(3) = AMBULANCE(BDE) RATE
;
record,tnow,time hours,1Ø,p,5.Ø,Ø.Ø,24Ø.Ø;
var,xx(2Ø),T,evac time,Ø.Ø,2Ø.Ø;
record,tnow,time hours,11,p,24.Ø;
var,xx(4),E,evacuees;
;
;  NETWORK STATEMENTS
;
network;                                     BEGIN NETWORK STATEMENTS
     resource/amb15(4),4;                    RESOURCE STATEMENT
;                                            AMBL5 = BATTALION 5 VEHICLES
;                                            FILE 4
     resource/amb19(4),8;                    AMBL19 = BATALION 19 VEHICLES
;                                            FILE 8
     resource/amb27(4),12;                   AMBL27 = BATTALION 27 VEHICLES
;                                            FILE 12
     resource/ambde(8),16;                   AMBDE = BRIGADE VEHICLES
     create,expon(Ø.54,1),Ø.Ø1,1,,1;         CREATE NODE A 1/5
       act/1,,,a5;                           ACTIVITY NUMBER 1
a5   assign,atrib(2)=15.Ø,2;                 ASSIGN NODE
;                                            UNIT ID = ATRIB(2) = 15 = A 1/5
       act/11,Ø.Ø5,,r1;                      ACTIVITY NUMBER 11
       act/12,,,a5q;                         ACTIVITY NUMBER 12
r1   event,1,1;                              EVENT NUMBER 1
       term;                                 TERMINATE ENTITY--NO OUTPUT
a5q  que(1),,,,ma1;                          QUEUE NODE - FILE 1
     create,expon(Ø.54,1),Ø.Ø4,1,,1;         CREATE NODE UNIT=B 1/5
       act/2,,,b5;                           ACTIVITY NUMBER 2
b5   assign,atrib(2)=25.Ø,2;                 ASSIGN NODE
;                                            UNIT ID = ATRIB(2) = 25 = B 1/5
       act/13,Ø.Ø5,,r1;                      ACTIVITY NUMBER 13
       act/14,,,b5q;                         ACTIVITY NUMBER 14
b5q  que(2),,,,ma1;                          QUEUE NODE - FILE 2
```

```
        create,expon(Ø.54,1),Ø.Ø7,1,,1;       CREATE NODE UNIT=C 1/5
          act/3,,,c5;                          ACTIVITY NUMBER 3
c5      assign,atrib(2)=35.Ø,2;               ASSIGN NODE
;                                             UNIT ID = ATRIB(2) = 35 = C 1/5
          act/15,Ø.Ø5,,r1;                     ACTIVITY NUMBER 15
          act/16,,,c5q;                        ACTIVITY NUMBER 16
c5q     que(3),,,,ma1;                        QUEUE NODE - FILE 3
ma1     match,2,a5q,b5q,c5q;                  MATCH NODE
          term;                                TERMINATE ENTITY--NO OUTPUT
        enter,1,1;                            ENTER NODE
          act/4,,,wt5;                         ACTIVITY NUMBER 4
  wt5 await(4),amb15/1,1;                     AWAIT NODE
;                                             ENTITY WAITS FOR 1 RESOURCE
          act/7,xx(1),,ba5;                    ACTIVITY NUMBER 7
;                                             ACTIVITY TIME = XX(1)
  ba5 event,2,1;                              EVENT NUMBER 2
          act/1Ø,xx(1),,u15;                   ACTIVITY NUMBER 1Ø
;                                             ACTIVITY TIME = XX(1)
u15       event,3,1;                          EVENT NUMBER 3
          colct,int(1),time to bas;            COLCT NODE
                                              COLLECT INTERVAL STATISTICS FOR
;                                             ARRIVALS TO BAS
;                                             TIME TO BAS = EVACUATION TIME
          colct,between,between time bas;      COLCT NODE
;                                             COLLECT BETWEEN STATISTICS FOR
;                                             ARRIVALS TO BAS
;                                             BETWEEN TIME BAS = TIME BETWEEN
;                                                                  ARRIVALS
          term;                                TERMINATE ENTITY--NO OUTPUT
        create,expon(Ø.54,1),Ø.Ø2,1,,1;       CREATE NODE UNIT=A 1/19
          act/17,,,a19;                        ACTIVITY NUMBER 17
a19     assign,atrib(2)=119.Ø,2;              ASSIGN NODE
;                                             UNIT ID = ATRIB(2) = 119 = A 1/19
          act/18,Ø.Ø5,,r2;                     ACTIVITY NUMBER 18
          act/19,,,a19q;                       ACTIVITY NUMBER 19
r2      event,4,1;                            EVENT NUMBER 4
          term; a                              TERMINATE ENTITY--NO OUTPUT
a19q    que(5),,,,ma2;                        QUEUE NODE - FILE 5
        create,expon(Ø.54,1),Ø.Ø5,1,,1;       CREATE NODE UNIT = B 1/19
          act/2Ø,,,b19;                        ACTIVITY NUMBER 2Ø
b19     assign,atrib(2)=219.Ø,2;              ASSIGN NODE
;                                             UNIT ID = ATRIB(2) = 219 = B 1/19
          act/21,Ø.Ø5,,r2;                     ACTIVITY NUMBER 21
          act/22,,,b19q;                       ACTIVITY NUMBER 22
b19q    que(6),,,,ma2;                        QUEUE NODE - FILE 6
        create,expon(Ø.54,1),Ø.Ø8,1,,1;       CREATE NODE UNIT = C 1/19
          act/23,,,c19;                        ACTIVITY NUMBER 23
c19     assign,atrib(2)=319.9,2;              ASSSIGN NODE
;                                             UNIT ID = ATRIB(2) = 319 = C 1/19
          act/24,Ø.Ø5,,r2;                     ACTIVITY NUMBER 24
          act/25,,,c19q;                       ACTIVITY NUMBER 25
c19q    que(7),,,,ma2;                        QUEUE NODE - FILE 7
ma2     match,2,a19q,b19q,c19q;               MATCH NODE
;                                             USED AS A DUMMY NODE
          term;                                TERMINATE ENTITY--NO OUTPUT
        enter,2,1;                            ENTER NODE NUMBER 2
          act/26,,,wt19;                       ACTIVITY NUMBER 26
wt19    await(8),amb19/1,1;                   AWAIT NODE - FILE 8
;                                             ENTITY WAITS FOR 1 RESOURCE
          act/27,xx(1),,ba19;                  ACTIVITY NUMBER 27
ba19    event,5,1;                            EVENT NUMBER 5
          act/28,xx(1),,u119;                  ACTIVITY NUMBER 28
u119     event,6,1;                           EVENT NUMBER 6
          colct,int(1),time to 19th bas;       COLLECT NODE
```

```
;                                                STATISTICS FOR EVACUATION TIME
;                                                TO BAS (19TH INF)
          colct,between,between time 19t;        COLLECT NODE
;                                                STATISTICS FOR INTERARRIVAL TIME
;                                                AT BAS (19TH INF)
          term;                                  TERMINATE ENTITY--NO OUTPUT
        create,expon(Ø.5^,1),Ø.Ø3,1,,1;          CREATE NODE A 1/27
          act/37,,,a27;                          ACTIVITY NUMBER 37
a27     assign,atrib(2)=127.Ø,2;                 ASSIGN NODE
;                                                UNIT ID = ATRIB(2) = 127 = A 1/27
          act/38,Ø.Ø5,,r3;                       ACTIVITY NUMBER 38
          act/39,,,a27q;                         ACTIVITY NUMBER 39
r3      event,7,1;                               EVENT NUMBER 7
          term;                                  TERMINATE ENTITY--NO OUTPUT
a27q    que(9),,,,ma3;                           QUEUE NODE - FILE 9
        create,expon(Ø.54,1),Ø.Ø6,1,,1;          CREATE NODE UNIT = B 1/27
          act/4Ø,,,b27;                          ACTIVITY NUMBER 4Ø
b27     assign,atrib(2)=227.Ø,2;                 ASSIGN NODE
;                                                UNIT ID = ATRIB(2) = 227 = B 1/27
          act/41,Ø.Ø5,,r3;                       ACTIVITY NUMBER 41
          act/42,,,b27q;                         ACTIVITY NUMBER 42
b27q    que(1Ø),,,,ma3;                          QUEUE NODE - FILE 1Ø
        create,expon(Ø.54,1),Ø.Ø9,1,,1;          CREATE NODE UNIT = C 1/27
          act/43,,,c27;                          ACTIVITY NUMBER 43
c27     assign,atrib(2)=327.Ø,2;                 ASSIGN NODE
;                                                UNIT ID = ATRIB(2) = 327 = C 1/27
          act/44,Ø.Ø5,,r3;                       ACTIVITY NUMBER 44
          act/45,,,c27q;                         ACTIVITY NUMBER 45
c27q    que(11),,,,ma3;                          QUEUE NODE - FILE 11
ma3     match,2,a27q,b27q,c27q;                  MATCH NODE
;                                                USED AS A DUMMY NODE
          term;                                  TERMINATE ENTITY--NO OUTPUT
        enter,3,1;                               ENTER NODE NUMBER 3
          act/46,,,wt27;                         ACTIVITY NUMBER 46
wt27    await(12),amb27/1,1;                     AWAIT NODE - FILE 12
;                                                ENTITY WAITS FOR 1 RESOURCE
          act/47,xx(1),,ba27;                    ACTIVITY NUMBER 47
ba27    event,8,1;                               EVENT NUMBER 8
          act/48,xx(1),,u127;                    ACTIVITY NUMBER 48
u127     event,9,1;                              EVENT NUMBER 9
          colct,int(1),time to 27th bas;         COLLECT NODE
;                                                STATISTICS FOR EVACUATION TIME
;                                                TO BAS (27TH INF)
          colct,between,between time 27t;        COLLECT NODE
;                                                STATISTICS FOR INTERARRIVAL TIME
;                                                TO BAS (27TH INF)
          term;                                  TERMINATE ENTITY--NO OUTPUT
        enter,4,1;                               ENTER NODE NUMBER 4
          act/5Ø,,,bn5q;                         ACTIVITY NUMBER 5Ø
bn5q    que(13),,,,ma4;                          QUEUE NODE - FILE 13
        enter,5,1;                               ENTER NODE NUMBER 5
          act/51,,,bn19q;                        ACTIVITY NUMBER 51
bn19q   que(14),,,,ma4;                          QUEUE NODE - FILE 14
        enter,6,1;                               ENTER NODE NUMBER 6
          act/52,,,bn27q;                        ACTIVITY NUMBER 52
bn27q   que(15),,,,ma4;                          QUEUE NODE - FILE 15
ma4     match,2,bn5q,bn19q,bn27q;                MATCH NODE
;                                                USED AS A DUMMY NODE
          term;                                  TERMINATE NODE--NO OUTPUT
        enter,7,1;                               ENTER NODE NUMBER 7
        await(16),ambde/1,1;                     AWAIT NODE - FILE 16
;                                                ENTITY WAITS FOR 1 RESOURCE
          act/54,xx(3),,bnpu;                    ACTIVITY NUMBER 54
bnpu    event,1Ø,1;                              EVENT NUMBER 1Ø
```

```
        act/55,xx(3),,bde;                  ACTIVITY NUMBER 55
bde     event,11,1;                         EVENT NUMBER 11
        colct,int(1),totl evac time;        COLLECT NODE
;                                           STATISTICS FOR EVACUATION TIME
;                                           TO BDE CLEARING STATION
;                                           THIS PROVIDES INFORMATION ABOUT
;                                           THE PRIMARY MOE
        term;                               TERMINATE ENTITY--NO OUTPUT
        endnetwork;                         THIS IS THE END OF
;                                           THE SLAM NETWORK STATEMENTS
fin;                                        FINISH - FINAL STATEMENT
```

```
c
c
c
c
c     ******************************************************************
c
c     THIS IS THE MAIN PROGRAM FOR THE EVACUATION MODEL.  IT PROVIDES
c     THE MAIN STRUCTURE FOR THE FORTRAN CODE USED TO MODEL THE
c     DISCRETE EVENTS IN THE COMBINED NETWORK-DISCRETE EVENT MODEL.
c     THE MAIN PROGRAM MAKES A CALL TO "SLAM" WHICH PROVIDES THE EXECUTIVE
c     CONTROL FOR THE SIMULATION.  FILE 9 IS USED AS AN OUTPUT FILE.
c
c     PROGRAM MAIN  ****************************************************
c
      program main
      dimension nset(9000)
      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      common qset(9000)
      equivalence(nset(1),qset(1))
      nnset=9000
      ncrdr=5
      nprnt=6
      ntape=7
      open (9,file='plot.rslts',status='new')
      open (7,status='scratch')
      call slam
      stop
      end
c     END OF PROGRAM MAIN  *********************************************
c
c
c     THIS IS THE SLAM SUBROUTINE INTLC WHICH IS USED FOR THE INITIALIZATION
c     PROCESS AT THE BEGINNING OF EACH SIMULATION RUN.  ALL SLAM GLOBAL
c     VARIABLES, XX(*), ARE SET TO ZERO.
c
c     SUBROUTINE INTLC  ************************************************
c
      subroutine intlc
      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      xx(2)=0.0
      do 10 i=4,16
        xx(i)=0.0
   10 continue
      return
      end
c     END SUBROUTINE INTLC  ********************************************
c
c     THIS IS THE SLAM OUTPUT SUBROUTINE.  IN THIS SUBROUTINE, TWO CALLS
c     ARE MADE TO TWO SLAM ROUTINES, PRNTF(0) AND PRNTR(0).  ROUTINE
c     PRNTF(0) CAUSES STATISTICS FOR ALL FILES IN THE MODEL TO BE
c     PRINTED IN THE SLAM SUMMARY REPORT.  SIMILARLY, PRNTR(0)
c     CAUSES STATISTICS FOR ALL RESOURCES IN THE MODEL TO BE PRINTED IN
c     THE SLAM SUMMARY REPORT.  THE WRITE STATEMENT CUASES THE AVERAGE
c     EVACUATION TIME TO THE BRIGADE CLEARING STATION TO BE RECORDED IN
c     FILE 9.  CCAVG(7) IS A SLAM FUNCTION THAT RETURNS THE AVERAGE
c     EVACUATION TIME WHICH IS RECORDED IN THE 7th COLCT NODE IN THE
c     LIST OF SLAM NETWORK STATEMENTS.
c
c     SUBROUTINE OTPUT  ************************************************
c
      subroutine otput
```

```
      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      print*,'total patients evacuated = ',xx(2)
      print*,'ttotal patients evacuated to bde = ',xx(4)
      call prntf(0)
      call prntr(0)
      write (unit=9,fmt=100)ccavg(7)
100   format (6x,f5.2)
      return
      end
c     END OF SUBROUTINE OTPUT ******************************************
c
c     THE NEXT SUBROUTINE IS SUBROUTINE EVENT(I).  THIS SUBROUTINE
c     PROVIDES THE MAIN INTERFACE WITH THE NETWORK PORTION OF THE MODEL.
c
      subroutine event(i)
      common/scom1/atrib(100),dd(100),ddl(100),dtnow,ii,mfa,mstop,nclnr
     1,ncrdr,nprnt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
      real a(7),b(7),c(7),d(7)
       goto (1,2,3,4,5,6,7,8,9,10,11),i
    1 id=int(atrib(2))
      if(id.eq.15) then
        xx(5)=xx(5)+1.0
        check=xx(5)/4.0
        rem=check-int(check)
        if (rem.eq.0.25) call enter(1,atrib)
      else if (id.eq.25) then
        xx(6)=xx(6)+1.0
        check=xx(6)/4.0
        rem=check-int(check)
        if (rem.eq.0.25) call enter(1,atrib)
      else if (id.eq.35) then
        xx(7)=xx(7)+1.0
        check=xx(7)/4.0
        rem=check-int(check)
        if(rem.eq.0.25)call enter(1,atrib)
      else
        print*,'warning: event 1 out of range!'
      endif
      return
    2 id=int(atrib(2))
      if (id.eq.15) then
        num=nnq(1)
        load=min(num,4)
        atrib(3)=real(load)
        xx(5)=xx(5)-atrib(3)
        do 200 i=1,load
        call rmove(1,1,a)
  200 continue
      else if (id.eq.25) then
        num=nnq(2)
        load=min(num,4)
        atrib(3)=real(load)
        xx(6)=xx(6)-atrib(3)
        do 210 i=1,load
        call rmove(1,2,a)
  210 continue
      else if (id.eq.35) then
        num=nnq(3)
        load=min(num,4)
        atrib(3)=real(load)
        xx(7)=xx(7)-atrib(3)
        do 220 i=1,load
        call rmove(1,3,a)
```

```
220   continue
    else
      print*,'warning: event 2 out of range!'
    endif
    return
  3 xx(2)=xx(2)+atrib(3)
c   xx(2) is total number patients evacuated
    call free(1,1)
    load=atrib(3)
    atrib(5)=5.0
    do 300 i=1,load
      call enter(4,atrib)
      xx(14)=xx(14)+1.0
      check=xx(14)/4.0
      rem=check-int(check)
      if(rem.eq.0.25)call enter(7,atrib)
300 continue
    return
  4 id=int(atrib(2))
    if (id.eq.119) then
      xx(8)=xx(8)+1.0
      check=xx(8)/4.0
      rem=check-int(check)
      if (rem.eq.0.25)call enter(2,atrib)
    else if (id.eq.219) then
      xx(9)=xx(9)+1.0
      check=xx(9)/4.0
      rem=check-int(check)
      if(rem.eq.0.25)call enter(2,atrib)
    else if(id.eq.319) then
      xx(10)=xx(10)+1.0
      check=xx(10)/4.0
      rem=check-int(check)
      if(rem.eq.0.25)call enter(2,atrib)
    else
      print*,'warning: event 4 out of range!'
    endif
    return
  5 id=int(atrib(2))
    if (id.eq.119) then
      num=nnq(5)
       load=min(num,4)
       atrib(3)=real(load)
      xx(8)=xx(6)-atrib(3)
      do 500 i=1,load
      call rmove(1,5,b)
500   continue
    else if (id.eq.219) then
      num=nnq(6)
      load=min(num,4)
      atrib(3)=real(load)
      xx(9)=xx(9)-atrib(3)
      do 510 i=1,load
      call rmove(1,6,b)
510   continue
    else
      num=nnq(7)
      load=min(num,4)
      atrib(3)=real(load)
     xx(10)=xx(10)-atrib(3)
      do 520 i=1,load
      call rmove(1,7,b)
520   continue
    endif
```

```
      return
    6 xx(2)=xx(2)+atrib(3)
      call free (2,1)
      load=atrib(3)
      atrib(5)=19.0
      do 600 i=1,load
        call enter (5,atrib)
        xx(15)=xx(15)+1.0
        check=xx(15)/4.0
        rem=check-int(check)
        if(rem.eq.0.25)call enter(7,atrib)
  600 continue
      return
    7 id=int(atrib(2))
        if(id.eq.127) then
        xx(11)=xx(11)+1.0
        check=xx(11)/4.0
        rem=check-int(check)
        if(rem.eq.0.25)call enter(3,atrib)
      else if(id.eq.227)then
        xx(12)=xx(12)+1.0
        check=xx(12)/4.0
        rem=check-int(check)
        if(rem.eq.0.25)call enter(3,atrib)
      else if(id.eq.327) then
        xx(13)=xx(13)+1.0
        check=xx(13)/4.0
        rem=check-int(check)
        if(rem.eq.0.25)call enter(3,atrib)
      else
        print*,'warning: event 7 out of range!'
      endif
      return
    8 id=int(atrib(2))
       if (id.eq.127) then
        num=nnq(9)
        load=min(num,4)
        atrib(3)=real(load)
        xx(11)=xx(11)-atrib(3)
        do 800 i=1,load
        call rmove (1,9,c)
  800 continue
      else if (id.eq.227) then
        num=nnq(10)
        load=min(num,4)
        atrib(3)=real(load)
        xx(12)=xx(12)-atrib(3)
        do 810 i=1,load
        call rmove(1,10,c)
  810  continue
      else
        num=nnq(11)
        load=min(num,4)
        atrib(3)=real(load)
        xx(13)=xx(13)-atrib(3)
        do 820 i=1,load
        call rmove(1,11,c)
  820   continue
      endif
      return
    9 xx(2)=xx(2)+atrib(3)
      call free (3,1)
      load=atrib(3)
      atrib(5)=27.0
```

```
      do 900 i=1,load
        call enter (6,atrib)
        xx(16)=xx(16)+1.0
        check=xx(16)/4.0
        rem=check-int(check)
        if(rem.eq.0.25)call enter(7,atrib)
900   continue
      return
10    id=int(atrib(5))
      if (id.eq.5) then
        num=nnq(13)
         load=min(num,4)
        atrib(4)=real(load)
        xx(14)=xx(14)-atrib(4)
        do 1000 i=1,load
          call rmove(1,13,d)
1000    continue
      else if (id.eq.19) then
        num=nnq(14)
        load=min(num,4)
        atrib(4)=real(load)
        xx(15)=xx(15)-atrib(4)
        do 1010 i=1,load
          call rmove (1,14,d)
1010  continue
      else
        num=nnq(15)
        load=min(num,4)
        atrib(4)=real(load)
        xx(16)=xx(16)-atrib(4)
        do 1020 i=1,load
          call rmove(1,15,d)
1020  continue
      endif
      return
   11 xx(4)=xx(4)+atrib(4)
      xx(20)=ccavg(7)
      call free(4,1)
      return
      end
c
c
c
*************************************************************************
*                                                                       *
*                          END OF FORTRAN CODE                          *
*                                                                       *
*************************************************************************
```

Appendix C

Sample SLAM Program Output

In this appendix, Appendix C, there is a complete listing of one simulation run of the evacuation model. The output header includes the copyright for SLAM. The first part of the output is the listing of the SLAM statements. The SLAM ECHO REPORT is listed next. Following the ECHO REPORT is the listing of the intermediate results. Finally, the SLAM SUMMARY REPORT is presented.

slam ii version 2.0

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1

```
gen,v. w. cook,evacuation,01/10/84,1,,,,,,72;
limits,16,5,500;
init,0,240;
intlc,xx(1)=0.28,xx(3)=0.57;
record,tnow,time hours,11,p,24.0;
var,xx(20),t,evac time;
var,xx(4),c,evacuees;
```

```
network;
           resource/amb15(6),4;
           resource/amb19(6),8;
           resource/amb27(6),12;
           resource/ambde(10),16;
           create,expon(0.54,1),0.01,1,,1;
              act/1,,,a5;
a5         assign,atrib(2)=15.0,2;
              act/11,0.05,,r1;
              act/12,,,a5q;
r1         event,1,1;
              term;
a5q        que(1),,,,ma1;
           create,expon(0.54,1),0.04,1,,1;
              act/2,,,b5;
b5         assign,atrib(2)=25.0,2;
              act/13,0.05,,r1;
              act/14,,,b5q;
b5q        que(2),,,,ma1;
           create,expon(0.54,1),0.07,1,,1;
              act/3,,,c5;
c5         assign,atrib(2)=35.0,2;
              act/15,0.05,,r1;
              act/16,,,c5q;
c5q        que(3),,,,ma1;
ma1        match,2,a5q,b5q,c5q;
              term;
           enter,1,1;
              act/4,,,wt5;
   wt5     await(4),amb15/1,1;
              act/7,xx(1),,ba5;
   ba5     event,2,1;
              act/10,xx(1),,u15;
u15        event,3,1;
              colct,int(1),time to bas;
              colct,between,between time bas;
              term;
           create,expon(0.54,1),0.02,1,,1;
              act/17,,,a19;
a19        assign,atrib(2)=119.0,2;
              act/18,0.05,,r2;
              act/19,,,a19q;
r2         event,4,1;
              term;
a19q       que(5),,,,ma2;
           create,expon(0.54,1),0.05,1,,1;
              act/20,,,b19;
b19        assign,atrib(2)=219.0,2;
              act/21,0.05,,r2;
              act/22,,,b19q;
b19q       que(6),,,,ma2;
           create,expon(0.54,1),0.08,1,,1;
              act/23,,,c19;
c19        assign,atrib(2)=319.9,2;
              act/24,0.05,,r2;
              act/25,,,c19q;
c19q       que(7),,,,ma2;
ma2        match,2,a19q,b19q,c19q;
              term;
           enter,2,1;
              act/26,,,wt19;
wt19       await(8),amb19/1,1;
              act/27,xx(1),,ba19;
ba19       event,5,1;
```

```
            act/28,xx(1),,u119;
u119        event,6,1;
            colct,int(1),time to 19th bas;
            colct,between,between time 19t;
            term;
        create,expon(0.54,1),0.03,1,,1;
            act/37,,,,a27;
a27     assign,atrib(2)=127.0,2;
            act/38,0.05,,r3;
            act/39,,,a27q;
r3      event,7,1;
            term;
a27q    que(9),,,,ma3;
        create,expon(0.54,1),0.06,1,,1;
            act/40,,,b27;
b27     assign,atrib(2)=227.0,2;
            act/41,0.05,,r3;
            act/42,,,b27q;
b27q    que(10),,,,ma3;
        create,expon(0.54,1),0.09,1,,1;
            act/43,,,c27;
c27     assign,atrib(2)=327.0,2;
            act/44,0.05,,r3;
            act/45,,,c27q;
c27q    que(11),,,,ma3;
ma3     match,2,a27q,b27q,c27q;
            term;
        enter,3,1;
            act/46,,,wt27;
wt27    await(12),amb27/1,1;
            act/47,xx(1),,ba27;
ba27    event,8,1;
            act/48,xx(1),,u127;
u127        event,9,1;
            colct,int(1),time to 27th bas;
            colct,between,between time 27!;
            term;
        enter,4,1;
            act/50,,,bn5q;
bn5q    que(13),,,,ma4;
        enter,5,1;
            act/51,,,bn19q;
bn19q   que(14),,,,ma4;
        enter,6,1;
            act/52,,,bn27q;
bn27q   que(15),,,,ma4;
ma4     match,2,bn5q,bn19q,bn27q;
            term;
        enter,7,1;
        await(16),ambde/1,1;
            act/54,xx(3),,bnpu;
bnpu    event,10,1;
            act/55,xx(3),,bde;
bde     event,11,1;
        colct,int(1),totl evac time;
            term;
        endnetwork;
seeds,42895(1);
simulate;
```

s l a m   e c h o   r e p o r t

simulation project evacuation   by v. w. cook

date 1/10/1984   run number 1 of 1

slam version jul 83

general options

print input statements (ilist): yes
print echo report (iecho): yes
execute simulations (ixqt): yes
print intermediate results heading (ipirh): yes
print summary report (ismry): yes

limits on files

maximum number of user files (mfils): 16
maximum number of user attributes (matr): 5
maximum number of concurrent entries (mntry): 500

file summary

file number	initial entries	ranking criterion
1	0	fifo
2	0	fifo
3	0	fifo
4	0	fifo
5	0	fifo
6	0	fifo
7	0	fifo
8	0	fifo
9	0	fifo
10	0	fifo
11	0	fifo
12	0	fifo
13	0	fifo
14	0	fifo
15	0	fifo
16	0	fifo

statistics based on observations

colct number	collection mode	identifier	histogram specifications ncel	hlow	hwid
1	network	time to bas			
2	network	between time bas			
3	network	time to 19th bas			
4	network	between time 19t			
5	network	time to 27th bas			
6	network	between time 271			
7	network	totl evac time			

continuous variables

number of dd equations (nneqd): 0
number of ss equations (nneqs): 0

minimum step size (dtmin):	.1000e+19
maximum step size (dtmax):	.1000e+21
time between save points (dtsav):	.2400e+02
accuracy error specification (llerr):	warning
absolute error limit (aaerr):	.1000e-04
relative error limit (rrerr):	.1000e-04

recording of plots/tables

plot/table number 1

independent variable:	tnow
identifier:	time hours
data storage unit:	tape/disc 11
data output format:	plot
time between plot points (dtplt):	.2400e+02
starting time of plot (ttsrt):	.0000e+00
ending time of plot (ttend):	.2400e+03
data points at events (kkevt):	yes

dependent variables

variable	sym	identifier	low ord value	high ord value
xx(20)	t	evac time	min near .0e+00	max near .0e+00
xx(4)	c	evacuees	min near .0e+00	max near .0e+00

random number streams

stream number	seed value	reinitialization of stream
1	42895	no
2	1954324947	no
3	1145661099	no
4	1835732737	no
5	794161987	no
6	1329531353	no
7	200496737	no
8	633816299	no
9	1410143363	no
10	1282538739	no

initialization options

beginning time of simulation (ttbeg):	.0000e+00
ending time of simulation (ttfin):	.2400e+03
statistical arrays cleared (jjclr):	yes
variables initialized (jjvar):	yes
files initialized (jjfil):	yes

nset/qset storage allocation

dimension of nset/qset (nnset):	9000
words allocated to filing system:	4500
words allocated to indexed list tags:	390
words allocated to network:	1127
words available for plots/tables:	2983

input errors detected: 0

execution will be attempted

1 **intermediate results**

total patients evacuated = .4050000000e+04
ttotal patients evacuated to bde = .4028000000e+04

file statistics

file number	associated node type	average length	standard deviation	maximum length	current length	average wait time
1	queue	.522	.745	4	0	.268
2	queue	.496	.701	5	1	.270
3	queue	.524	.764	6	1	.275
4	await	.000	.000	1	0	.000
5	queue	.502	.741	6	0	.265
6	queue	.502	.716	5	2	.272
7	queue	.501	.734	4	0	.264
8	await	.000	.000	1	0	.000
9	queue	.492	.747	5	0	.269
10	queue	.511	.744	5	1	.272
11	queue	.507	.748	4	0	.270
12	await	.000	.000	1	0	.000
13	queue	2.382	1.956	12	3	.419
14	queue	2.401	2.001	11	2	.426
15	queue	2.293	1.933	14	3	.412
16	await	.000	.000	1	0	.000
17	calendar	21.409	2.114	32	22	.097

resource statistics

resource number	resource label	current capacity	average util	standard deviation	maximum util	current util
1	amb15	6	2.00	.986	5	2
2	amb19	6	1.96	.990	6	1
3	amb27	6	1.92	.959	5	2
4	ambde	10	5.69	1.270	10	7

resource number	resource label	current available	average available	minimum available	maximum available
1	amb15	4	4.0036	1	6
2	amb19	5	4.0376	0	6
3	amb27	4	4.0817	1	6
4	ambde	3	4.3149	0	10

1

s l a m   s u m m a r y   r e p o r t

simulation project evacuation   by v. w. cook

date 1/10/1984   run number   1 of   1

current time   .2400e+03
statistical arrays cleared at time   .0000e+00

statistics for variables based on observation

	mean value	standard deviation	coeff. of variation	minimum value	maximum value	no.of obs
time to bas	.610e+00	.000e+00	.000e+00	.610e+00	.610e+00	855
between time bas	.280e+00	.211e+00	.752e+00	.488e-03	.150e+01	854
time to 19th bas	.610e+00	.000e+00	.000e+00	.610e+00	.610e+00	841
between time 19t	.285e+00	.212e+00	.743e+00	.418e-03	.112e+01	840
time to 27th bas	.610e+00	.000e+00	.000e+00	.610e+00	.610e+00	821
between time 27t	.292e+00	.214e+00	.733e+00	.136e-02	.142e+01	820
totl evac time	.175e+01	.453e-03	.259e-03	.175e+01	.175e+01	1193

file statistics

file number	associated node type	average length	standard deviation	maximum length	current length	average wait time
1	queue	.522	.745	4	0	.268
2	queue	.496	.701	5	1	.270
3	queue	.524	.764	6	1	.275
4	await	.000	.000	1	0	.000
5	queue	.502	.741	6	0	.265
6	queue	.502	.716	5	2	.272
7	queue	.501	.734	4	0	.264
8	await	.000	.000	1	0	.000
9	queue	.492	.747	5	0	.269
10	queue	.511	.744	5	1	.272
11	queue	.507	.748	4	0	.270
12	await	.000	.000	1	0	.000
13	queue	2.382	1.956	12	3	.419
14	queue	2.401	2.001	11	2	.426
15	queue	2.293	1.933	14	3	.412
16	await	.000	.000	1	0	.000
17	calendar	21.409	2.114	32	22	.097

regular activity statistics

activity index	average utilization	standard deviation	maximum utilization	current utilization	entity count
1	.0000	.0000	1	0	467
2	.0000	.0000	1	0	441
3	.0000	.0000	1	0	458
4	.0000	.0000	1	0	857
7	.9989	.8062	3	2	855
10	.9975	.8063	3	0	855
11	.0973	.3143	3	0	467
12	.0000	.0000	1	0	467
13	.0919	.2989	2	0	441
14	.0000	.0000	1	0	441
15	.0954	.3142	3	0	458
16	.0000	.0000	1	0	458
17	.0000	.0000	1	0	454
18	.0946	.3051	2	0	454

19	.0000	.0000	1	0	454
20	.0000	.0000	1	0	443
21	.0922	.3048	4	1	442
22	.0000	.0000	1	0	443
23	.0000	.0000	1	0	456
24	.0950	.3065	3	0	456
25	.0000	.0000	1	0	456
26	.0000	.0000	1	0	842
27	.9813	.8242	3	1	841
28	.9812	.8242	3	0	841
37	.0000	.0000	1	0	439
38	.0915	.3070	3	0	439
39	.0000	.0000	1	0	439
40	.0000	.0000	1	0	450
41	.0938	.3101	3	0	450
42	.0000	.0000	1	0	450
43	.0000	.0000	1	0	451
44	.0940	.3128	3	0	451
45	.0000	.0000	1	0	451
46	.0000	.0000	1	0	823
47	.9594	.7981	3	1	822
48	.9589	.7983	3	1	821
50	.0000	.0000	4	0	1364
51	.0000	.0000	4	0	1351
52	.0000	.0000	4	0	1335
54	2.8460	1.0527	7	3	1197
55	2.8392	1.0614	7	4	1193

resource statistics

resource number	resource label	current capacity	average util	standard deviation	maximum util	current util
1	amb15	6	2.00	.986	5	2
2	amb19	6	1.96	.990	6	1
3	amb27	6	1.92	.959	5	2
4	ambde	10	5.69	1.270	10	7

resource number	resource label	current available	average available	minimum available	maximum available
1	amb15	4	4.0036	1	6
2	amb19	5	4.0376	0	6
3	amb27	4	4.0817	1	6
4	ambde	3	4.3149	0	10

table number 1
run number 1

	time hou rs	evac tim e	evacuees
minimum		.0000e+00	.0000e+00
maximum		.1750e+01	.4028e+04

```
                         **plot number  1**
                           run  number  1

                                   scales of plot
t=evac time     .000e+00            .875e+00              .175e+01
c=evacuees      .000e+00            .201e+04              .403e+04
                0    10   20   30   40   50   60   70   80   90   100 dups
time hours

   .0000e+00    t                        +                        + tc
   .2400e+02    +    c                   +                        t
   .4800e+02    +         c              +                        t
   .7200e+02    +              c         +                        t
   .9600e+02    +                   c    +                        t
   .1200e+03    +                        c                        t
   .1440e+03    +                        +    c                   t
   .1680e+03    +                        +         c              t
   .1920e+03    +                        +              c         t
   .2160e+03    +                        +                   c    t
   .2400e+03    +                        +                        t tc
                0    10   20   30   40   50   60   70   80   90   100 dups
time hours


    output  consists  of     11 point sets (     22 points)
```

Appendix D

FORTRAN Program for Variance Reduction

In this appendix, Appendix D, there is a complete listing of the program used to calculate the sample means and sample variances of the 32 cell factorial design. The program reads the 10 observations per cell from an external file established by the user. It then calculates both the standard variance and the reduced variance and displays the results at the user's monitor (CRT).

```
c
c     ****************************************************************
c
c     THIS PROGRAM COMPUTES THE SAMPLE MEAN AND THE SAMPLE VARIANCE
c     FOR THE 10 OBSERVATIONS OBTAINED FROM THE ANTITHETIC SEQUENCE.
c     IT READS AN EXTERNAL DATA FILE THAT CONTAINS THE 10 OBSERVATIONS.
c     THE OUTPUT OF THE PROGRAM INCLUDES THE SAMPLE MEAN AND THE
c     SAMPLE VARIANCE OF THE 10 OBSERVATIONS, THE 5 PAIRED OBSERVATION
c     AVERAGES, AND THE REDUCED VARAINCE OF THE 5 PAIRED OBSERVATIONS.
c
c     ****************************************************************
c
      program data
      real x(10),v(5)
      do 10 i=1,10
      read(5,*) x(i)
10    continue
      sum=0.0
      do 20 i=1,10
      sum=sum+x(i)
20    continue
      xbar=sum/10.0
      print 100,xbar
      sum=0.0
      do 30 i=1,10
      sum=sum+(x(i)-xbar)**2.0
30    continue
      varx=sum/9.0
      print 300,varx
      do 40 i=1,9,2
      v(i)=(x(i)+x(i+1))/2.0
      print*,v(i)
40    continue
      sum=0.0
      do 50 i=1,9,2
      sum=sum+v(i)
50    continue
      vbar=sum/5.0
      sum=0.0
      do 60 i=1,9,2
      sum=sum+(v(i)-vbar)**2.0
60    continue
      varv=sum/4.0
      print 400,vbar
      print 500,varv
100   format (6x,f5.2,' is the sample mean')
300   format (6x,f6.3,' is the sample variance')
400   format (6x,f5.2,' is the AT sample mean')
500   format (6x,f6.3,' is the AT sample variance')
      end
c
c     ****************************************************************
c     THIS IS THE END OF THE PROGRAM USED TO CHECK THE SIMUALTION DATA.
c     ****************************************************************
```

```
% ckdata<data
      3.96 is the sample mean
      1.976 is the sample variance
  8.15999985
  9.07999992
  9.77999973
  9.39000034
  8.39499950
      8.96 is the AT sample mean
       .458 is the AT sample variance
```

```
% cat data
This is the data file used with for the sample results above.

     8.63
     7.69
     6.86
     11.30
     10.40
     9.16
     10.30
     8.48
     7.56
     9.23
```

Appendix E

SPSS ANOVA

In this appendix, Appendix E, the important results from SPSS ANOVA are presented. Included in this appendix are the SPSS program statements for ANOVA. The first illustration is for the 5-WAY ANOVA. The resulting ANOVA table is presented next. The 4-WAY ANOVA TABLE is presented afer the 5-WAY ANOVA. In the 4-WAY ANOVA, only the main effects, 2-way interactions and 3-way interactions are shown since the 4-way and 5-way interactions were not significant as illustrated in the 5-way table. Also, the graphic presentations of the main factor effects and the 2-way interactions are illustrated. Finally, the cell means for the significant 3-way interaction is presented.

```
AFIT COMPUTING CENTER
WRIGHT-PATTERSON AFB

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

VERSION 8.3 (NOS/BE) -- MAY 04, 1982

133330 CM MAXIMUM FIELD LENGTH REQUEST


RUN NAME        5 WAY ANOVA OF EVACUATION MODEL
VARIABLE LIST   RATE AMBLBAS DISTBAS AMBLBDE DISTBDE RESPONSE
VAR LABELS      RATE      AMBULANCE TRAVEL RATE/
                AMBLBAS  NUMBER OF AMBULANCES AT BAS/
                DISTBAS  DISTANCE TO BAS/
                 AMBLBDE  NUMBER OF AMBULANCES AT BDE/
                 DISTBDE  DISTANCE TO BDE CLEARING STATION/
                 RESPONSE EVACUATION TIME/
INPUT FORMAT    FREEFIELD
N OF CASES      16:
INPUT MEDIUM    CARD

CPU TIME REQUIRED..       .393 SECONDS


ANOVA           RESPONSE BY RATE AMBLBAS DISTBAS AMBLBDE DISTBDE (1,2)
OPTIONS         5
STATISTICS      ALL
READ INPUT DATA

0052333 CM NEEDED FOR ANOVA


    - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


    5 WAY ANOVA OF EVACUATION MODEL             01/25/84  21.32.15.

    FILE - NONAME   (CREATED - 01/25/84)

    * * * * * * * * * * * *   C E L L   M E A N S   * * * * * *
                    RESPONSE  EVACUATION TIME
                 BY RATE      AMBULANCE TRAVEL RATE
                    AMBLBAS   NUMBER OF AMBULANCES AT BAS
                    DISTBAS   DISTANCE TO BAS
                    AMBLBDE   NUMBER OF AMBULANCES AT BDE
                    DISTBDE   DISTANCE TO BDE CLEARING STATION
    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	44[illegible].964	5	88.393	1187.792	.001
RATE	233.401	1	233.401	2739.4[illegible]7	.001
AMBLBAS	.001	1	.001	.013	.908
DISTBAS	6.899	1	6.899	92.731	.001
AMBLBDE	61.752	1	61.752	831.680	.001
DISTBDE	169.921	1	169.921	2275.030	.001
2-WAY INTERACTIONS	2[illegible].729	10	23.573	291.116	.001
RATE AMBLBAS	.001	1	.001	.013	.908
RATE DISTBAS	.529	1	.529	7.125	.009
RATE AMBLBDE	61.752	1	61.752	831.680	.001
RATE DISTBDE	84.631	1	84.631	1140.465	.001
AMBLBAS DISTBAS	.001	1	.001	.013	.908
AMBLBAS AMBLBDE	.002	1	.002	.030	.862
AMBLBAS DISTBDE	.001	1	.001	.013	.909
DISTBAS AMBLBDE	.000	1	.000	.003	.954
DISTBAS DISTBDE	.009	1	.009	.121	.729
AMBLBDE DISTBDE	61.752	1	61.752	831.680	.001
3-WAY INTERACTIONS	61.772	10	6.177	83.194	.001
RATE AMBLBAS DISTBAS	.001	1	.001	.013	.909
RATE AMBLBAS AMBLBDE	.002	1	.002	.030	.862
RATE AMBLBAS DISTBDE	.001	1	.001	.013	.909
RATE DISTBAS AMBLBDE	.000	1	.000	.003	.954
RATE DISTBAS DISTBDE	.009	1	.009	.121	.729
RATE AMBLBDE DISTBDE	61.752	1	61.752	831.680	.001
AMBLBAS DISTBAS AMBLBDE	.002	1	.002	.030	.862
AMBLBAS DISTBAS DISTBDE	.001	1	.001	.013	.909
AMBLBAS AMBLBDE DISTBDE	.002	1	.002	.030	.862
DISTBAS AMBLBDE DISTBDE	.000	1	.000	.003	.954
4-WAY INTERACTIONS	.0[illegible]9	5	.002	.022	.99[illegible]
RATE AMBLBAS DISTBAS AMBLBDE	.002	1	.002	.030	.862
RATE AMBLBAS DISTBAS DISTBDE	.001	1	.001	.013	.909
RATE AMBLBAS AMBLBDE DISTBDE	.002	1	.002	.030	.862
RATE DISTBAS AMBLBDE DISTBDE	.000	1	.000	.003	.954
AMBLBAS DISTBAS AMBLBDE DISTBDE	.002	1	.002	.030	.862
5-WAY INTERACTIONS	.002	1	.002	.030	.862

- -

5 WAY ANOVA OF EVACUATION MODEL 01/25/84 21.22.15. PAGE 19

RATE AMBLBAS DISTBAS AMBLBDE DISTBDE	.002	1	.002	.030	.862
EXPLAINED	711.475	31	22.951	3[illegible]9.1[illegible]2	.001
RESIDUAL	9.5[illegible]4	128	.074		
TOTAL	720.979	159	4.534		

4 WAY ANOVA OF EVACUATION MODEL 01/25/84 21.16.11. PAGE 6

FILE - NONAME (CREATED - 01/25/84)

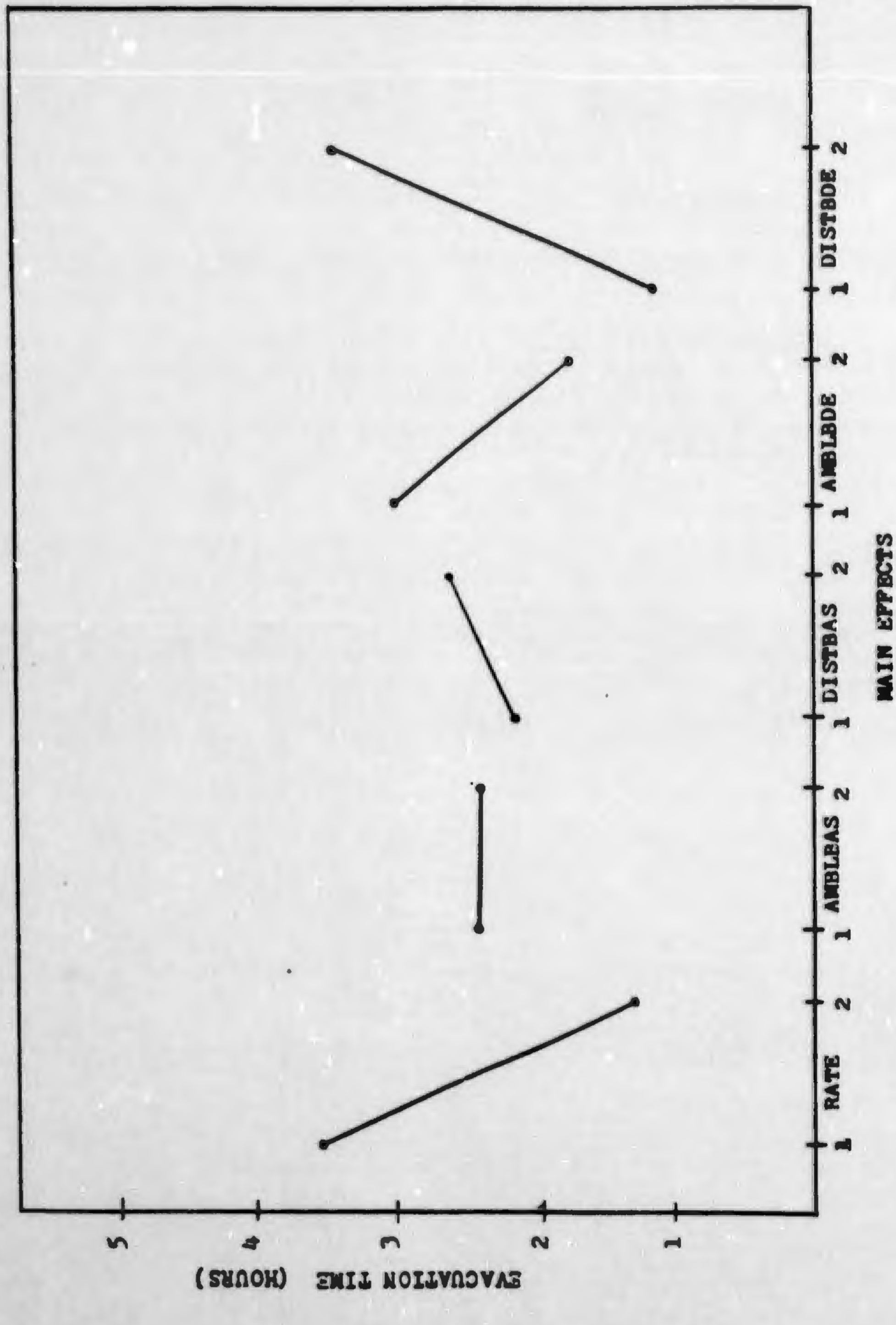
* * * * * * * * * A N A L Y S I S O F V A R I A N C E * * * * * * * * *

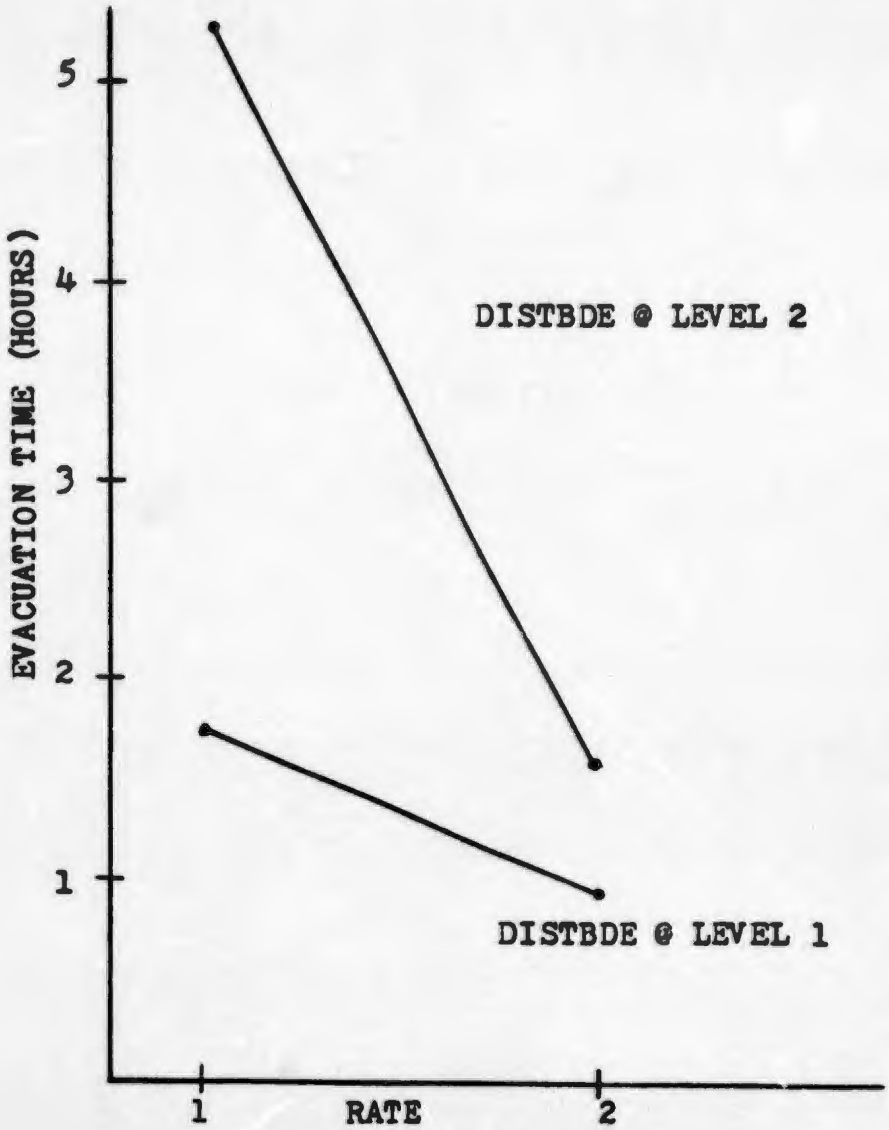
```
            RESPONSE  EVACUATION TIME
         BY RATE      AMBULANCE TRAVEL RATE
            DISTBAS   DISTANCE TO BAS
            AMBLBDE   NUMBER OF AMBULANCES AT BDE
            DISTBDE   DISTANCE TO BDE CLEARING STATION
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	44 .963	4	112.241	1677.282	.001
RATE	203.411	1	203.411	3094.687	.001
DISTBAS	6.889	1	6.889	104.814	.001
AMBLBDE	61.752	1	61.752	939.543	.001
DISTBDE	168.921	1	168.921	2573.394	.001
2-WAY INTERACTIONS	208.724	6	34.787	529.279	.001
RATE DISTBAS	.529	1	.529	8.049	.005
RATE AMBLBDE	61.752	1	61.752	939.543	.001
RATE DISTBDE	84.631	1	84.631	1288.397	.001
DISTBAS AMBLBDE	.000	1	.000	.004	.951
DISTBAS DISTBDE	.009	1	.009	.137	.712
AMBLBDE DISTBDE	61.752	1	61.752	939.543	.001
3-WAY INTERACTIONS	61.762	4	15.440	234.922	.001
RATE DISTBAS AMBLBDE	.000	1	.000	.004	.951
RATE DISTBAS DISTBDE	.009	1	.009	.137	.712
RATE AMBLBDE DISTBDE	61.752	1	61.752	939.543	.001
DISTBAS AMBLBDE DISTBDE	.000	1	.000	.004	.951
EXPLAINED	711.449	14	50.818	773.178	.001
RESIDUAL	9.530	145	.066		
TOTAL	72 .979	159	4.534		

160 CASES WERE PROCESSED.
0 CASES (PCT) WERE MISSING.

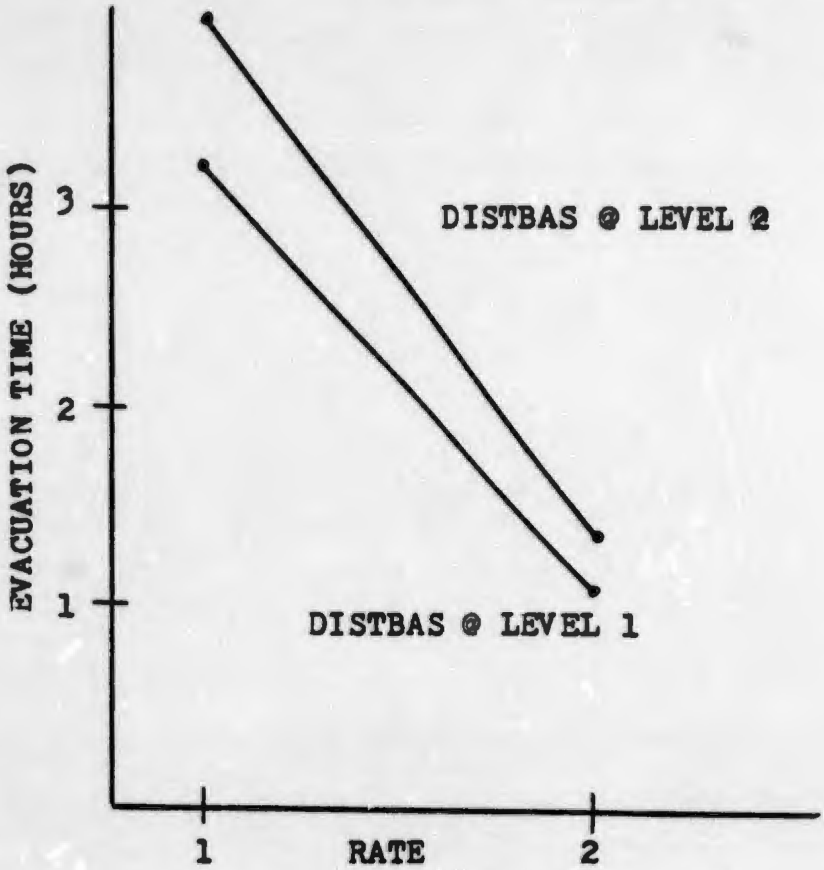
- -


EVACUATION TIME (HOURS)
1
2
3
4
5
RATE
AMBLBAS
DISTBAS
AMBLBDE
DISTBDE
MAIN EFFECTS



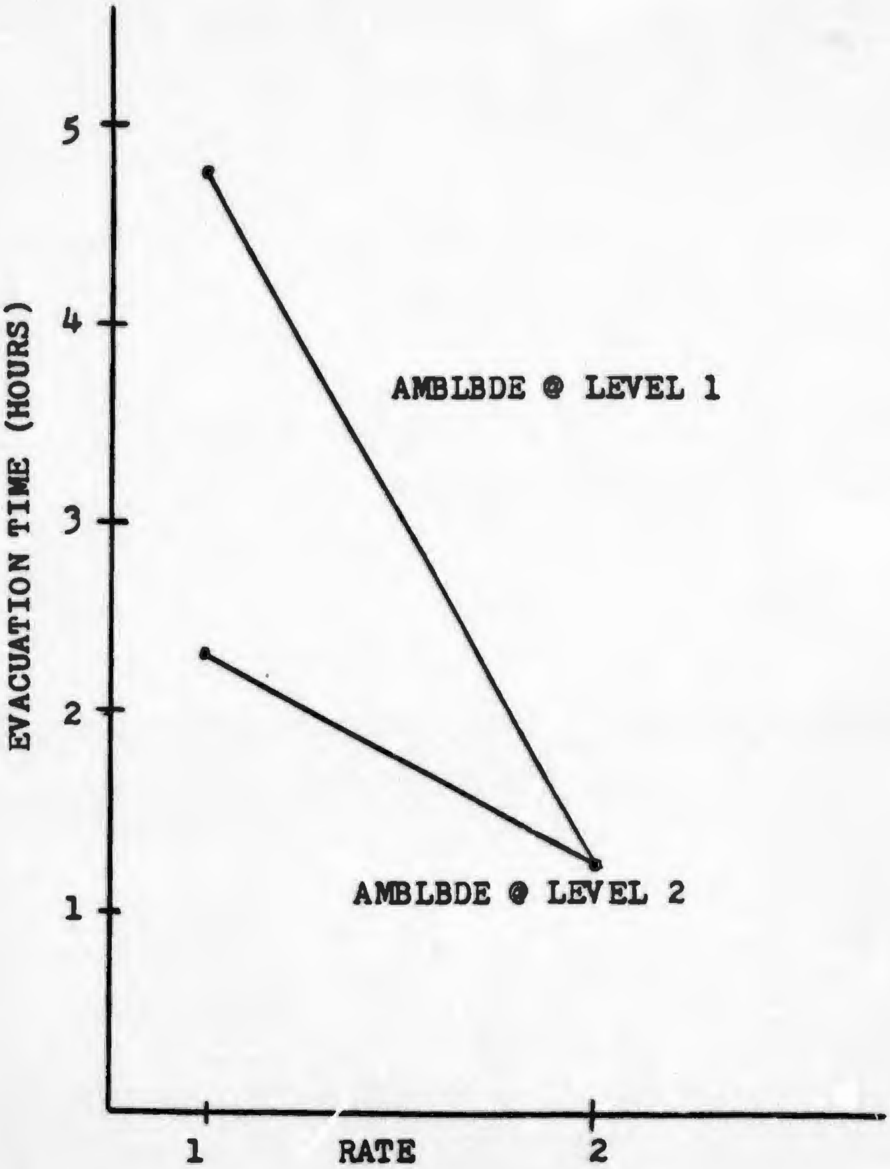
2-WAY INTERACTION
RATE by DISTBDE

		DISTBDE 1	DISTBDE 2
RATE	1	1.75	5.26
		(40)	(40)
	2	.95	1.55
		(40)	(40)



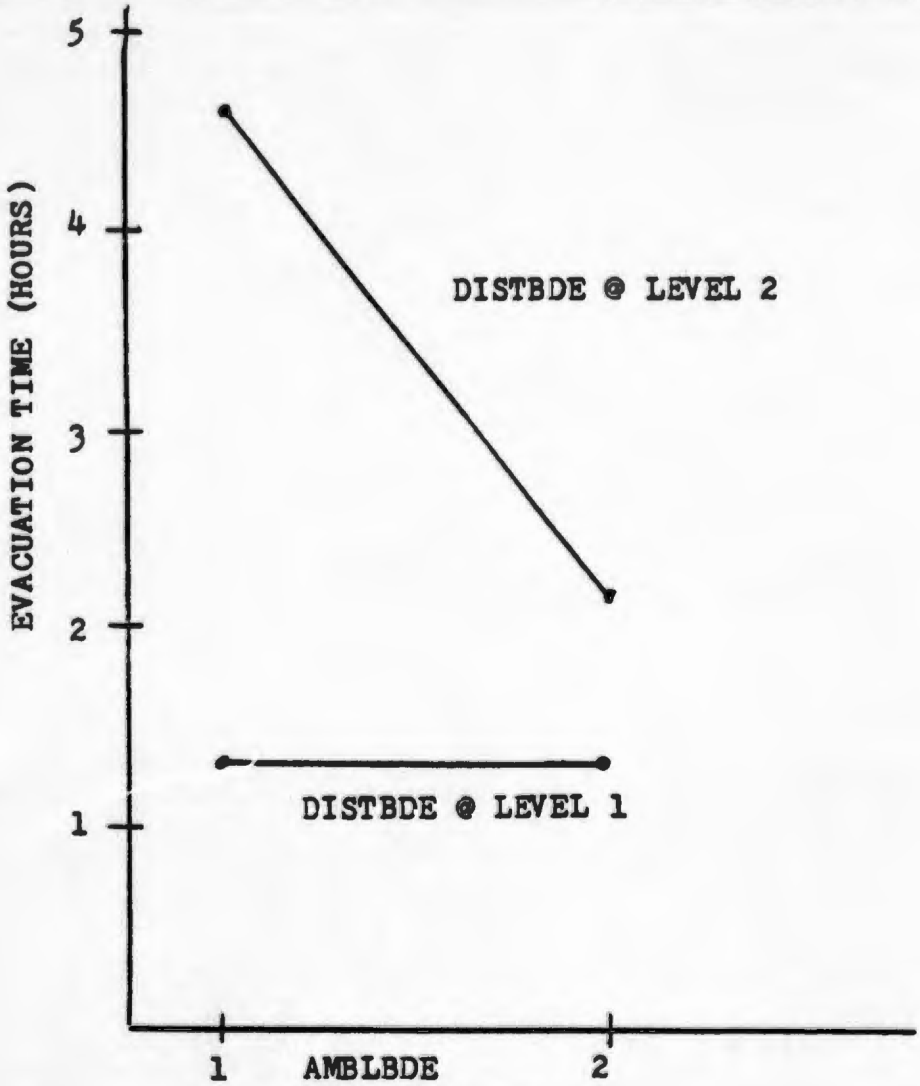
2-WAY INTERACTION
RATE by DISTBAS

		DISTBAS 1	DISTBAS 2
RATE			
	1	3.24	3.77
		(40)	(40)
	2	1.10	1.4[illegible]
		(40)	(40)



2-WAY INTERACTION
RATE by AMBLBDE

		AMBLBDE 1	AMBLBDE 2
RATE	1	4.75 (40)	2.26 (40)
	2	1.25 (40)	1.25 (40)



2-WAY INTERACTION
AMBLBDE by DISTBDE

AMBLBDE	DISTBDE 1	DISTBDE 2
1	1.35 (40)	4.65 (40)
2	1.35 (40)	2.16 (40)

DISTBDE = 1

RATE	AMBLBDE 1	AMBLBDE 2
1	1.75 (20)	1.75 (20)
2	.95 (20)	.95 (20)

DISTBDE = 2

RATE	AMBLBDE 1	AMBLBDE 2
1	7.74 (20)	2.77 (20)
2	1.55 (20)	1.55 (20)

Three way interaction.

Appendix F

SPSS MANOVA

In this appendix, Appendix F, the SPSS statements for the MANOVA program used to produce the plots described in Chapter 4 are presented.

```
                                                   84/02/15. 12.41.41. PAGE
          ASD COMPUTER CENTER
          WRIGHT-PATTERSON AFB,OHIO

          S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

          VERSION 8.3 (NOS) -- MAY 04, 1982

          376500 CM MAXIMUM FIELD LENGTH REQUEST


RUN NAME          5WAY MANOVA FOR EVACUATION MODEL
VARIABLE LIST     RATE AMBAS DISTBAS AMBDE DISTBDE RESPONSE
INPUT FORMAT      FREEFIELD
N OF CASES        160
INPUT MEDIUM      CARD
VAR LABELS        RATE         AMBULANCE TRAVEL RATE/
                  AMBAS        NUMBER OF AMBULANCES AT BAS/
                  DISTBAS      DIATANCE TO BAS/
                  AMBDE        NUMBER OF AMBULANCES AT BDE/
                  DISTBDE      DISTANCE TO BDE CLEARING STATION/
                  RESPONSE     EVACUATION TIME/

CPU TIME REQUIRED..        .029 SECONDS


MANOVA            RESPONSE BY RATE AMBAS DISTBAS AMBDE DISTBDE (1,2)/
                  PRINT=HOMOGENEITY(COCHRAN)/
                  PRINT=POBS/
                  PLOT=POBS/
                  PRINT=PMEANS/
                  PLOT=PMEANS/
                    PLOT=CELLPLOTS/
                  PLOT=BOXPLOTS/
                  PLOT=NORMAL/
```

Vita

Virgil W. Cook, Jr. [redacted] He graduated from Ferndale High School, Ferndale, Michigan, in June 1968. He attended Western Michigan University and then entered the US Army in January 1971. While on active duty, he graduated from the United States Military Academy Prepatory School, Fort Belvoir, Virginia in May 1972. He then attended the United States Military Academy, West Point, New York where in June 1976 he was awarded a Bachelor of Science degree and was commissioned a Second Lieutenant in the Infantry. Following completion of the Infantry Officer Basic Course and Ranger Course at Fort Benning, Georgia, he served in various positions including assignments as a battalion staff officer and rifle company commander with the 1st Battalion 5th Infantry, 25th Infantry Division. After completion of the Infantry Officer Advanced Course at Fort Benning in 1982, he was assigned to the School of Engineering, Air Force Institute of Technology.

[redacted]