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A GPSS II SIMULATION OF AN AIR DEFENSE PROBLEM

A THESIS

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by

Jimmie Kendall Boles

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SUMMARY

An air defense system is composed of a complex combination of stochastic processes. It is difficult to determine strategies that will optimize the system performance. Decisions concerning the utilization and deployment of the defensive forces are often based on intuition.

This investigation studies the effect of defense line location on combat results to determine if an optimum position exists. The system is studied through the construction of a computer model and subsequent analysis of the data generated by simulation. The model is programmed for the Univac 1108 computer, utilizing the General Purpose System Simulator II (GPSS II). A hypothetical air defense system, composed of 25 interceptor aircraft, opposes an attacking force of 75 manned bombers. The defense line location is varied systematically to study the response at six different positions. The average numbers of escaping bombers for each defense line location are statistically analysed.

Results of the study indicate that defense line location does have a significant effect on overall system performance; and, for a specified system, there exists some optimum location of the defense perimeter. Sensitivity analysis indicates that the optimum position is sensitive to the intercept time parameter. Results of the study imply that consistent performance of an air defense system may be an unattainable goal.

CHAPTER I

INTRODUCTION

Purpose

Since a nation's very existence may depend on its ability to defend itself against a single massive air attack, the problem of maintaining an effective air defense capability is obviously a vital one. Military analyst and research groups have made numerous studies of the air defense system with the intent of increasing its effectiveness through better employment of the weapons available. New defensive weapons are continually being developed to counter the expected technological improvements in the offensive forces. War games and exercises are conducted periodically to evaluate and update existing systems and to suggest needs for future systems.

This highly complex, rapidly changing defense system is the responsibility of an air defense commander who, in the course of a battle, must make many difficult decisions with far-reaching consequences. He must resolve such issues as which enemy bombers constitute the greatest threat; which interceptors to utilize against which targets; and where, as well as when, to deploy his interceptor force to meet the invaders. To further confound the situation, the very nature of battle creates many elements of uncertainty. Clausewitz (1) has said that war is largely a matter of chance. In war, a larger margin must be left for error than in any other sphere of human activity. Thus it is essential that the defense commander be provided with the maximum amount of sound quantitative analysis in order to minimize the number of decisions that must be made under a high degree of uncertainty.

It is the purpose of this investigation to add to the knowledge of air defense theory by quantitatively analyzing one aspect of the defense system. Namely, an attempt will be made to determine the most effective location of the air battle defense line, which is the line where defensive forces engage the penetrating offensive forces. This information is expected to assist the air defense commander in establishing the defensive posture so that efficient utilization of interceptor aircraft will be realized. In addition, the research will be of value in analyzing air defense exercises and in planning future defense system modifications.

Background

The history of warfare is as old as the history of man himself. From the dawn of civilization, man has been faced with the necessity of defending both his territory and his life against the onslaughts of his enemies.

When small groups of armed men first began to fight under the leadership of a single man, that man did not have to be a learned and skilled strategist. His chief assets were his physical prowess and his proficiency in wielding the implements of war. These factors, plus the ability to inspire and dominate his followers, were all the tools he required to be a successful military leader. As the art of war became more sophisticated, with growing armies and more destructive weapons, military strategy began to play an important role in the conduct of warfare. As early as 500 B.C., an oriental general named Sun Tzu is reported to have said:

"The general who wins a battle makes many calculations in his temple ere the battle is fought (2)." Thus the science of war began to emerge with the accumulation of a body of scientific knowledge upon which to base military strategy.

In the 1800's, Prussian military leaders contributed greatly to the development of war as a science. Their elaborate war games were crude forerunners of the computerized war games that are so widely used in military analysis today. Thus, at the dawn of the twentieth century, a large amount of information and theory (not necessarily valid) was available concerning the conduct of ground warfare as well as naval warfare. Battles in the air, with the exception of balloon warfare, were still confined largely to the imagination.

Air defense is a relative infant in the family of general warfare and so does not have an extensively developed body of knowledge. Yet, sound strategy is probably more vital to the air defense commander than to a commander of ground forces. The destructive potential and high speed of an attacking bomber force serve to magnify the effects of poor defensive strategy. It was not until World War II, when the British Royal Air Force defended Great Britain against overwhelming German air attacks, that air defense became a noted element of warfare.

In past military conflicts, as in most ground battles fought today, the initial engagement with the enemy was seldom decisive. Usually there was time for the defender to re-group his forces and revise his strategy in the light of the most recent situation. This is no longer so. We are now faced with the prospect of an initial air attack also being the final battle, or even barring that eventuality, the loser of the initial battle could be expected to suffer such disastrous casualties that further military efforts would be ineffectual at best. The air defense system cannot be evaluated under actual combat conditions, and thus, one sees that the task of determining effective strategies under uncertain conditions and with untried weapons poses a formidable problem.

Fortunately, the growth of operations research and systems analysis during and after World War II provides at least a partial solution to the problem. By using analytical tools, such as war games and computer simulation models, the systems analyst can propose and investigate theories which may prove fruitful. Clausewitz, who placed more reliance on tactics than on strategy, is quoted as saying:

> If theory investigates the subjects which constitute War; if it separates more distinctly that which at first sight seems amalgamated; if it explains fully the properties of the means; if it shows their probable effects; if it makes evident the nature of objects; if it brings to bear all over the field of War the light of essentially critical investigation -- then it has fulfilled the chief duties of its province. (3)

Of course, the soundest theory or strategy will not provide a final solution to a battle problem and it certainly cannot make an actual decision. The military commander is an executive who, in the final essence, must make decisions based on his experience, his judgment of the situation, and his intuition. Fisher (4) accurately assesses the role that systems analysis should play in decision making. He suggests that the main role of analysis should be to sharpen the intuition and judgment of the decision maker.

Air Defense Scenario

To prepare the reader for the development and discussion of the simulation model in following chapters, it is appropriate to give here a brief description of a typical air defense situation. A more comprehensive description is given by Mallan (5).

An attacking force of bomber aircraft is detected by the defending force's warning network at the "warning line." The attacking force is allowed to penetrate unopposed until reaching the "defense line," at which position the defensive force of interceptor aircraft engages the bomber force. Each bomber is attacked by an individual interceptor, and there is a certain probability that the bomber will be destroyed. If not destroyed, it continues its penetration and must be re-attacked.

The objective of the defensive force is to neutralize, or "kill," each of the attacking aircraft before the bombers reach the "bomb release line." Each interceptor has a certain airborne endurance capability and can carry a given quantity of armament. Therefore, its time spent at the defense line is limited by both endurance (fuel) and by armament (number of firing passes). Interceptors are shuttled between the defense line and the "interceptor base," where they are re-fueled and re-armed for return to the battle area. An illustration of the general battle setting is shown in Figure 1.

Study Objectives

From the foregoing description of an air defense situation, it can be seen that there are many parameters that may affect the outcome of the battle. Only a few of these parameters are directly under the control of the defense commander. One controllable parameter might logically be the location of the defense line. At one extreme, this battle line would be located at the maximum radius of action of the interceptors, or at the other extreme, it would be located at the bomb release

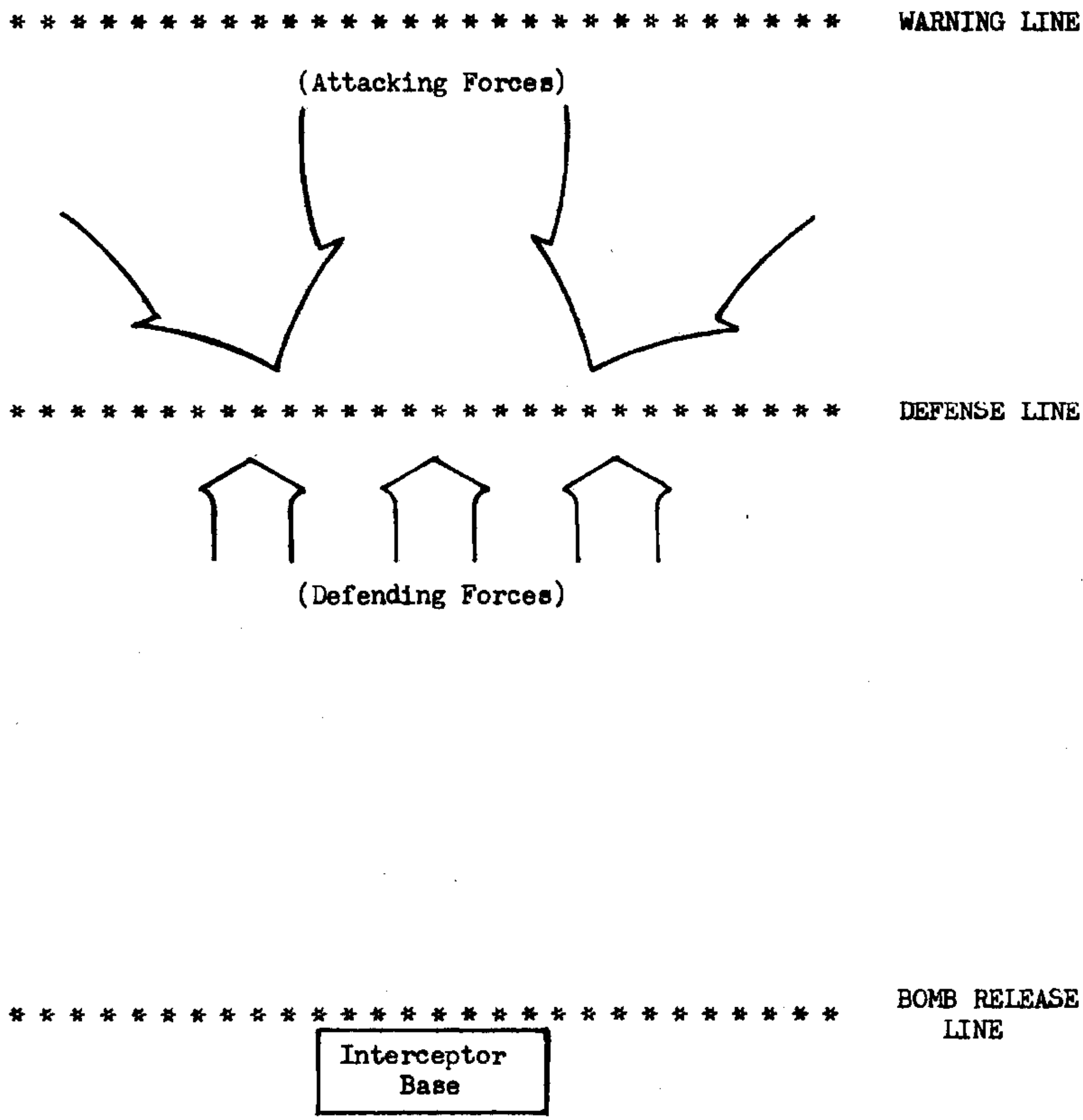

Figure 1. General Air Defense Situation.

line. It is likely that some intermediate position would produce better results than either extreme. The overall objective of this study is to determine which location, of all the alternatives considered, yields the best battle results.

The specific objectives of this study in the order of their investigation are:

(1) Formulate a relevant system of quantitative relationships that adequately describe an air defense problem.

(2) Construct a computer simulation model of the system using the GPSS II simulation language.

(3) Utilize the computer model to simulate the system and obtain battle results for selected values of defense line distance, as measured from the bomb release line.

(4) Analyze the data obtained from the simulations to determine which defense line position is most advantageous for the defenders.

The measure of effectiveness used in evaluating the simulated battle results is the number of bombers that reach the bomb release line. The average bomber neutralization distance, measured from the bomb release line, will be used to gain additional insight into the system behavior.

Scope and Limitations

The computer simulation model developed in this study considers only a small scale air battle involving the lower operational levels of the air defense structure. The conditions under which the experiments are run imply a strategic defense concept. That is, a long range detection capability is assumed and the defensive forces operate under a single commander. However, the model can easily be expanded to a larger scale problem, or can be adapted to a tactical situation. The model is so constructed as to enable an expansion of the interceptor force to 100 aircraft, and the size of the attacking force is limited only by the GPSS II restriction that no more than 1000 transactions can be in the system at one time. Other parameters such as detection range, speeds of all aircraft, time functions, kill probabilities, etc. can be readily changed to adapt the model to a variety of situations.

The system modeled is restricted to manned aircraft. No consideration is given to either surface-to-air missiles or air-to-ground missiles. The interceptor armament, however, could be missiles or conventional aircraft guns.

The following assumptions were made in modeling the air defense system.

(1) All bombers are detected at the same range and are tracked continually with no lost contact at any time.

(2) All bomber aircraft penetrate on a straight line in a direction perpendicular to the defense line and bomb release line.

(3) The probability of obtaining a kill is constant for all intercept attempts.

(4) Interceptor aircraft are considered to have the necessary speed advantage over the bombers to overtake them and complete intercepts, even though the bombers may have penetrated behind the defense line.

(5) All intercept attempts result in a firing pass. That is, no intercept is broken off because of some error by the defense.

(6) No interceptors are lost due to direct enemy action. The only

interceptor losses are assumed to occur at the interceptor base during the turnaround.

(7) Interceptor service and turnaround times at the interceptor base are independent of the number of interceptors requiring service at any given time.

(8) Bomber altitude is not considered to have any direct effect on the time required to complete an intercept.

The first assumption is probably the most unrealistic. However, in most circumstances only a small percentage of the attacking force would present a detection and tracking problem. Since the problem would exist for all defense line locations, it should have little effect on the optimum location of the defense perimeter. The last assumption is partially compensated for by using a probability distribution for the time required to complete an intercept. The other assumptions are felt to be reasonably realistic.

CHAPTER II

LITERATURE SEARCH

Simulation Literature

History of Simulation

An examination of the literature reveals that the word simulation has many different meanings. Because of the prominent role played by the electronic digital computer in our modern world, it has become fairly common to consider simulation as being a recent development made possible by the computer. Naylor (6) gives a definition of the term which embodies the common concepts of simulation:

> Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of a business or economic system (or some component thereof) over extended periods of real time.

A less restricted definition of the term, however, is necessary in order to view simulation in its true historical perspective. McCoy (7) suggests that simulation was probably one of man's earliest techniques for studying complex problems. Dalkey (8) provides a more general definition of simulation: "The word 'simulation,' a distant relative of the term 'similar,' refers to a construct which resembles the process or system to be studied but which is easier to manipulate or investigate." Geisler and Ginsberg (9) define simulation in a similar sense, although they consider three separate categories:

(1) One-to-one simulation which encompasses most mock-up training devices;

(2) Game-type simulation which involves the human element; and

(3) All-computer simulation into which category this research simulation model would fall.

When viewed in the proper perspective, simulation is seen to be an old and established technique for solving complex problems that cannot be analytically determined. Evans (10) indicates that simulation has its origin in the study of systems. According to McLeod (11), man has been simulating since he first began to use his imagination. Forrester (12) points out that simulation was used in man's early history to obtain celestial navigation tables that were used for world exploration. The development of elaborate war games to study military operations was one of the earlier uses of simulation techniques.

However, until the electronic computer became available, the cost of simulation rendered it generally unsuitable as a method of analyzing complex systems. Two developments probably acted in conjunction with one another to account for the tremendous utilization of simulation in recent years. One, previously mentioned, was the development of the electronic digital computer which made it economically feasible to perform simulations involving vast numbers of computations that previously could not have been accomplished readily by hand. The other factor was the rapid growth of the field of operations research during and after World War II. The increased emphasis on the study of systems and the growing utilization of the tools of the systems analyst opened up new horizons for the technique of simulation.

Military Applications

Simulation has long been a widely used tool of the military strategist. One of its early applications involved the development of battle plans utilizing the "sandbox battlefield." This technique made use of an iconic model (often actually created in a sandbox) to simulate possible battles in order to study the effects of various strategies on the outcome of the battle. Today one has only to make a cursory review of the relevant literature to see the widespread influence of simulation on military analysis and planning.

Military simulations run the gamut from huge, highly sophisticated strategic war games to very small simulations of individual actions. Dalkey (13) describes two extremes developed by the RAND Corporation. At one extreme is the global air war model designated STAGE, which requires several hours of computer time on the IBM 7090 computer for a single run. The preparation of inputs alone requires the investment of hundreds of man-days. At the other end of the scale is FLIOP, which simulates a single bomber during a single attack mission.

Military applications of simulation are not restricted to war gaming and battle simulation. Other areas of military operations also make extensive use of simulation. Management studies, cost-effectiveness studies, logistics planning, and research and development programs are only a few of the areas particularly suitable for simulation study.

Geisler and Ginsberg (14) give a reasonable explanation of why simulation has such wide military application. They state that there are usually two system characteristics which lead to the use of simulation, and military systems normally possess both characteristics. These characteristics are complex relationships among the system variables and the existence of a number of stochastic processes.

Evans (15) explains why analytical techniques, such as computer simulation, must often be used as a scientific basis for analyzing military conflicts. Battles are never replicated, and very rarely are they adequately observed and recorded. These facts render them inadequate as scientific experiments, and the information gained from them can seldom be used to guide scientific analysis or support scientific conclusions. Thus, simulation is frequently the only method available to the military analyst for studying complex military problems.

Problems and Limitations

Despite its widespread application to problem analysis, simulation does have limitations, just as any other analytical technique. One needs to take into consideration several important factors regarding its application. Sheppard (16) warns of the tendency to view simulation as a universal problem solver. All too often, operations research practitioners are swept away by their enthusiasm and begin to view simulated problems as a pseudo-real world. Ancker (17) cautions against overcomplicating simulation models by pointing out that as the complexity of the model increases, the complexity of the solution also increases. Clement (18) claims that the results obtained from simulation models are often over-emphasized. He claims that while very useful inferences can be made from a study of a model, it should be kept in mind that the model is only an approximation of the actual system and the results should be treated accordingly. Quade (19) discusses the problems associated with model development in general, which of course applies to simulation modeling. Specifically, he mentions two aspects of model building that often cause problems. These two aspects are quantification and the treatment of uncertainty.

A serious drawback to simulation using Monte Carlo techniques is the problem of statistical analysis. Fishman and Kiviat (20) raise several statistical questions which are common to all problem analyses and to model structural verification and validation as well. One question raised relates to the choice of the sampling interval. Another problem is obtaining statistically reliable results while avoiding huge sample sizes. Also troublesome is the determination of initial conditions and operating ranges for system variables. Thus, it is seen that simulation provides a way to approach some very difficult and complex problems, but it also has to be used with an element of caution.

Previous Studies

In the initial stage of the literature search, a bibliography search was requested from the Defense Documentation Center to obtain a comprehensive review of research previously done in the air defense analysis area. Since most study conducted on the subject of air defense would probably be performed under government direction, this bibliography search resulted in a good survey of the general research area. However, since the entire literature search for this study included only unclassified sources, one may logically assume that additional research has been conducted which is of a classified nature.

The literature search revealed that considerable effort has been directed toward the development of large scale war game models, such as STAGE. As this research was not intended to be a war game, these previous studies had only slight bearing on this investigation.

One of the early attempts at modeling an air defense battle was made by Quade (21) in 1949. This attempt made use of a mathematical model based on the expected values of individual battle events. The model was not designed for computer simulation as the electronic computer was still in the early stages of development.

Martin (22) describes an analog simulator device created at Johns Hopkins University in the early 1950's, which mechanically simulated an air battle between two opposing forces. This model was a crude forerunner of some computer simulation models that were developed a short time later.

Sheppard (23), in a paper presented at a N.A.T.O. sponsored conference in 1965, describes a simulation model designated ICS1. This model, programmed in FORTRAN II, was designed to simulate the air battle between manned interceptors and manned penetrators. The author describes the use of the model in comparing the effectiveness of four interceptors proposed for future U. S. Air Force use. At the same conference, Facey (24) presented a general air battle simulation model, COMO II. The model was designed to study the effectiveness of various weapon systems against low flying aircraft.

In 1967, Brodheim and Herzer (25) reported on a general dynamic model for air defense. The authors report on its application to trade-off problems, optimization of offensive strategies, and cost effectiveness studies.

Many other simulation studies have been made ranging from individual weapon simulation to global nuclear war simulation. The studies thus described are representative of those most closely related to this particular investigation.

Conclusions

The results of the literature survey show that simulation has wide application as a tool in military analysis, although there are some definite limitations to the technique. Simulation is readily applicable to the complex combination of stochastic processes which describe an air defense problem.

Simulation has been widely used for a variety of air defense studies in the past. Much of this effort has been directed toward large scale game-type simulations. Simulation has not been used previously to determine strategy with regard to selection of a defense line location. In fact, little effort has been made in using simulation to determine effective strategies at low operational echelons. Therefore, this research is expected to enlarge the dimensions of study in the area of air defense against manned bombers.

CHAPTER III

PROCEDURE

Approach to the Problem

To accomplish the objectives of this investigation, a specific air defense system must be analyzed. Security restrictions, however, force the system to be a hypothetical one. The parameters of the system are intended to be realistic but are not representative of any actual system or system component. Since this study is directed toward the lower operational elements of the defense system, a relatively small interceptor force of 25 aircraft has been created to oppose an attacking bomber force of 75 aircraft.

With a particular system well defined, it is then possible to formulate a set of relationships that describe the interactions among various elements of an air defense system. In this case, the description consisted of a flow diagram with probability density functions and some constants defining the relationships of the parts of the flow diagram.

After quantifying the problem, a computer simulation model was constructed to represent the overall process. The language chosen for the computer simulation was GPSS II. This language made it relatively simple to transform the flow diagram of the air defense system into a computer routine.

The completed computer simulation model was validated following the procedure suggested by Meier (26). The model was first run several times in order to detect and eliminate programming and logical errors. When the model appeared to be performing satisfactorily, a second stage of validation was begun. The computer program was designed to print out 18 tables of different system characteristics as well as printing out the values of 15 system variables each time a transaction (bomber) was processed by the system. This output made it possible to analyze sub-parts of the program to determine if, in fact, the sub-parts were performing as intended. After this stage of validation, the model was run with different sets of trial data to insure that the overall result was reasonable.

The completed simulation model was used to gather data which measured the air defense system's performance under predetermined experimental conditions. The system was simulated using six different values for defense line location. These distances, measured from the bomb release line, were 150 miles through 400 miles in 50-mile increments. Replications of the measure of effectiveness for each value of the defense line location could be obtained by using a different random number seed in the GPSS II program. The data could then be subjected to statistical tests to determine if defense line location significantly affected the battle results; and if so, to determine which location was best according to the criteria established previously.

System Variables

All system variables used in this investigation are hypothetical and are not intended to be descriptive of any actual system presently in being. However, an attempt was made to keep all data realistic, and the values used could be realized by existing equipment.

Participating aircraft are assumed to have certain flight characteristics. The attacking bomber speeds are determined to be either 400 knots (slow speed), 600 knots (medium speed), or 800 knots (high speed). The interceptor cruise speed, or the speed at which the interceptor travels to and from the battle area, is set at 400 knots. These aircraft speeds appear reasonable in the light of present day aircraft technology. Further, interceptor maximum endurance at cruise speed and interceptor armament capacity are fixed at 140 minutes and three firing attempts, respectively. The maximum range at which the bomber aircraft are detected by the defense is arbitrarily placed at 400 miles. Weapon kill probability is fixed at 0.75 for each intercept.

In addition to these aircraft characteristics, several other components of the defense system are best described by probability distributions. In GPSS II, these take the form of functions, and specific functional values are generated as random variables. One of these is the time required to complete an intercept after the interceptor and bomber are initially paired. This function (FUNCTION 1 in the computer program) is a combination of two other functions (FUNCTION 8 plus FUNCTION 9). FUNCTION 9 is the normal intercept time function, and FUNCTION 8 is a factor added to the normal time when the distance separating bomber and interceptor is large enough to necessitate unusual flight time. Figure 2 shows the density function of the normal intercept time. Figure 3 shows the additional time element plotted against the distance separating the two aircraft.

Another important variable is the combat endurance for each interceptor. Total combat time is considered to be the time from the interceptor's first attack

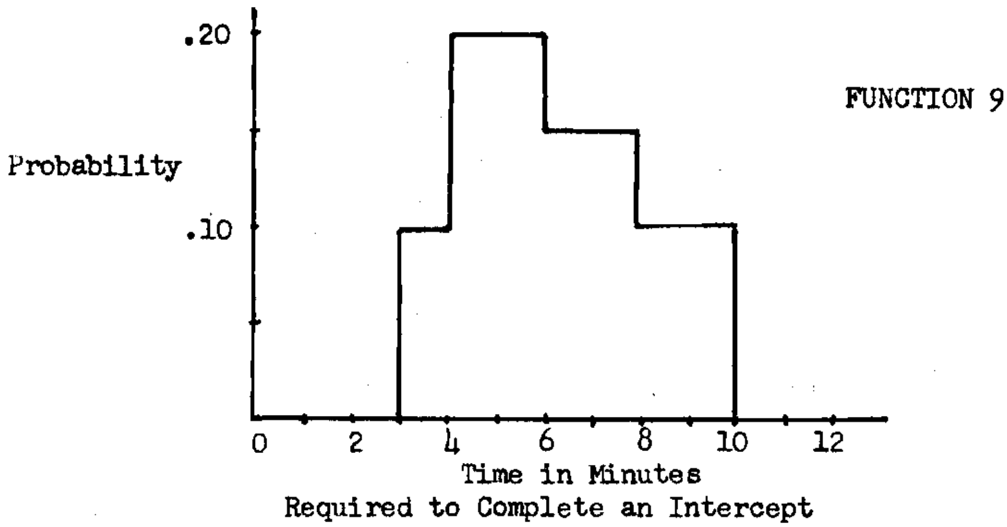

Figure 2. Density Function for Normal Intercept Time.

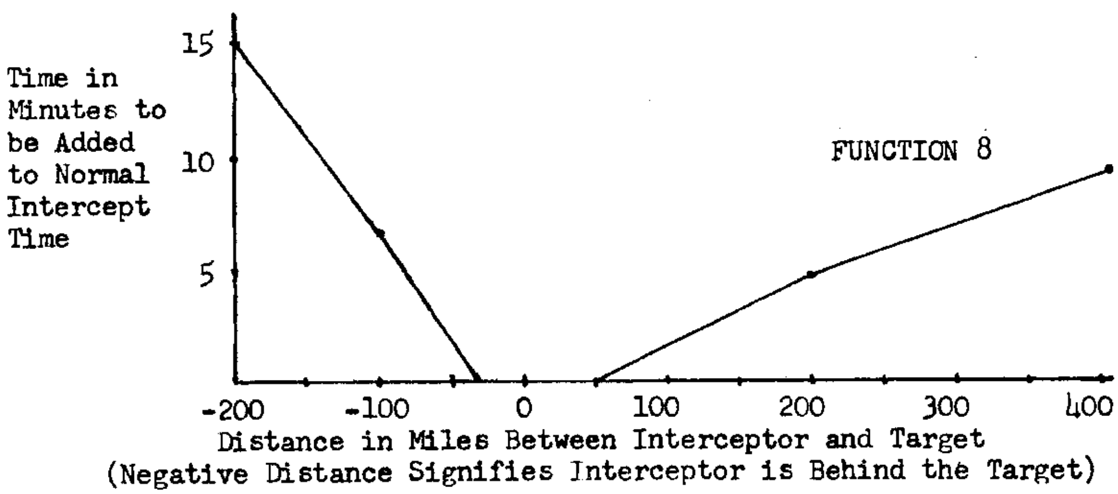

Figure 3. Time Element Added to Normal Intercept Time.

on a bomber until the time that the interceptor begins its return to base. Figure 4 shows the density function for the combat endurance factor. This factor is applied to that portion of total interceptor endurance which remains after the subtraction of the time spent going to and coming from the battle area. It will be noticed that the endurance factor is always less than one. This follows the reasoning that the interceptor, while in the battle area, cannot use optimum fuel flow power settings, and thus can only attain a fraction of the endurance that could be attained at cruising speeds.

Figure 5 shows the probability distribution for the interceptor turnaround times. Because of differing degrees of re-fueling, re-arming, and maintenance requirements for each interceptor, the time required to service an aircraft could normally be a random variable.

Simulation Language Employed

The computer simulation model for this investigation could have been programmed in almost any computer language; either a general purpose language such as ALGOL or FORTRAN, or one of several special purpose languages. GPSS II was ultimately chosen because the language is designed to describe a process with transactions moving through facilities, storages, and queues. The air defense system can be envisioned as such a process with the bombers being transactions serviced (intercepted) by facilities which represent the interceptors. A feature that makes GPSS II particularly useful in a study such as this is the capability of automatically gathering certain statistics which are important in the problem analysis.

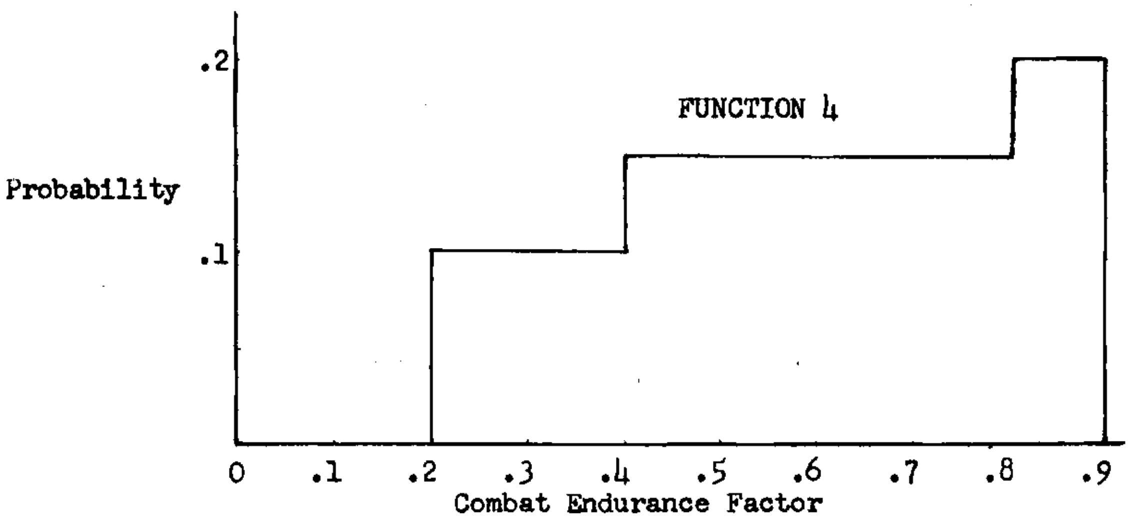

Figure 4. Density Function for Combat Endurance Factor.

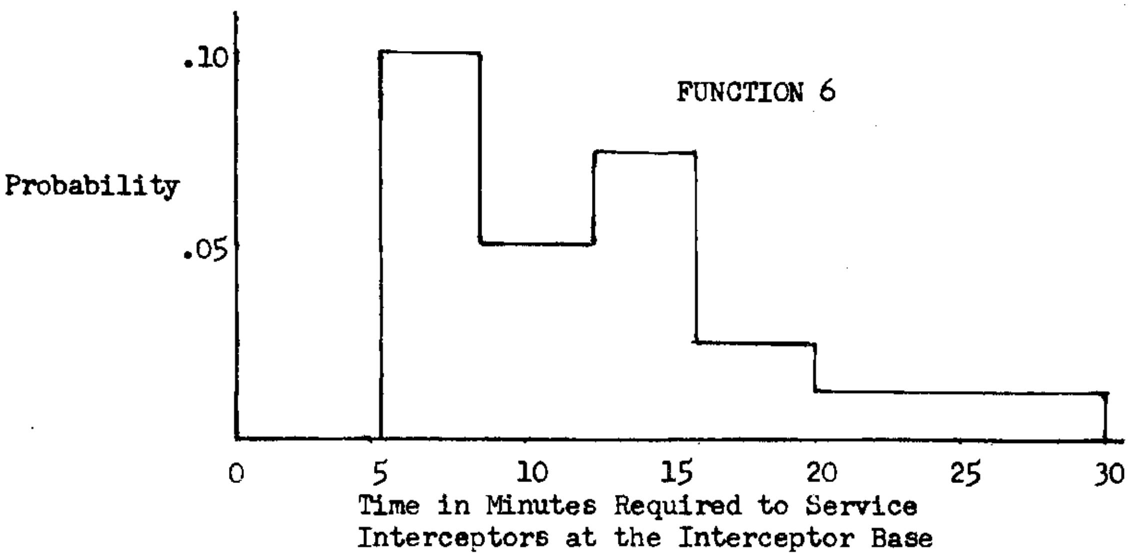

Figure 5. Density Function for Interceptor Turnaround Time.

A brief description of the major elements of the language will be given here. A more comprehensive treatment is contained in the GPSS II User Manual (27).

GPSS II is a computer programming language that is designed to facilitate the simulation and study of complex systems. The language describes a process whereby transactions move in time through a system composed essentially of facilities, storages, and queues. The use of COMPARE blocks allows a wide range of logical decision making processes to be simulated. The program automatically compiles and prints out certain statistics regarding facility utilization, storage utilization, queue contents, and number of transactions flowing through the blocks in the system. In addition, other information can be collected and printed out in table form as desired by the user.

In using GPSS II the normal procedure is to prepare a block diagram or flow diagram of the process to be studied. This diagram utilizes the block types allowed by the language. Block types such as HOLD, SEIZE, RELEASE, QUEUE, STORE, COMPARE, and others are usually adequate to describe a given process. The block diagram is then readily converted into a computer program by transforming the diagram into punched cards utilizing specified formats. Little, if any, formal programming experience is required.

In the simulation model developed for this study, the blocks HOLD, SEIZE, and RELEASE are used to simulate the utilization of a facility (interceptor) by a transaction (bomber). When a transaction enters a HOLD block or a SEIZE block, the interceptor represented by that particular facility is then considered to be engaged in an attack on that particular bomber. The interceptor remains engaged until the transaction exits the HOLD block or enters a RELEASE block, at which time the interceptor becomes available for intercept action against another bomber. A QUEUE block is utilized to simulate bombers which have penetrated to, or past, the defense line but still have not been engaged by an interceptor. Therefore, the bombers wait in the QUEUE block until some disposition is made of them. ASSIGN blocks are used to give some particular characteristic or identification number to transactions. This value is frequently used as a counter to keep a record of certain events. SAVEX blocks are used to store values in computer memory until some later use is necessary. COMPARE blocks are used liberally in the simulation model to simulate logical processes. The COMPARE block only allows a transaction to enter that block if the comparison specified is actually satisfied, so it acts to control the path of the transaction through the system. ORIGINATE blocks, as the name implies, create the transactions for the system. In this case, they are used to generate the target force of bombers, the interceptor force, and also are used to generate certain miscellaneous transactions that are used to control parts of the system.

CHAPTER IV

DESCRIPTION OF THE MODEL

General Description

The computer simulation model will be presented and briefly explained in this chapter. It is assumed that the reader has some knowledge of the GPSS II simulation language and can interpret the majority of the flow diagrams. Only the crucial blocks will be explained in detail. The complete computer program may be found in Appendix A.

The simulation model consists of six different sub-models, some of which, in turn, are composed of several sub-parts. Figure 6 shows a diagram of the air defense system with an input consisting of attacking bombers and an output of either neutralized bombers or escaping bombers that have reached the bomb release line. As can be seen from the diagram, the system itself is comprised of five sections. Three of them actually process bomber transactions and two sections serve only as decision-making and control elements. A general description of the function of these five sections as well as the Target Generating Section will aid in understanding the detailed description of each section which follows later.

The Target Generating Section, as its name implies, serves the purpose of generating the appropriate number of transactions, which then pass to the Pre-Intercept Section as the input to the air defense system. The Target Generating Section assigns each target the proper speed and a target identification number.

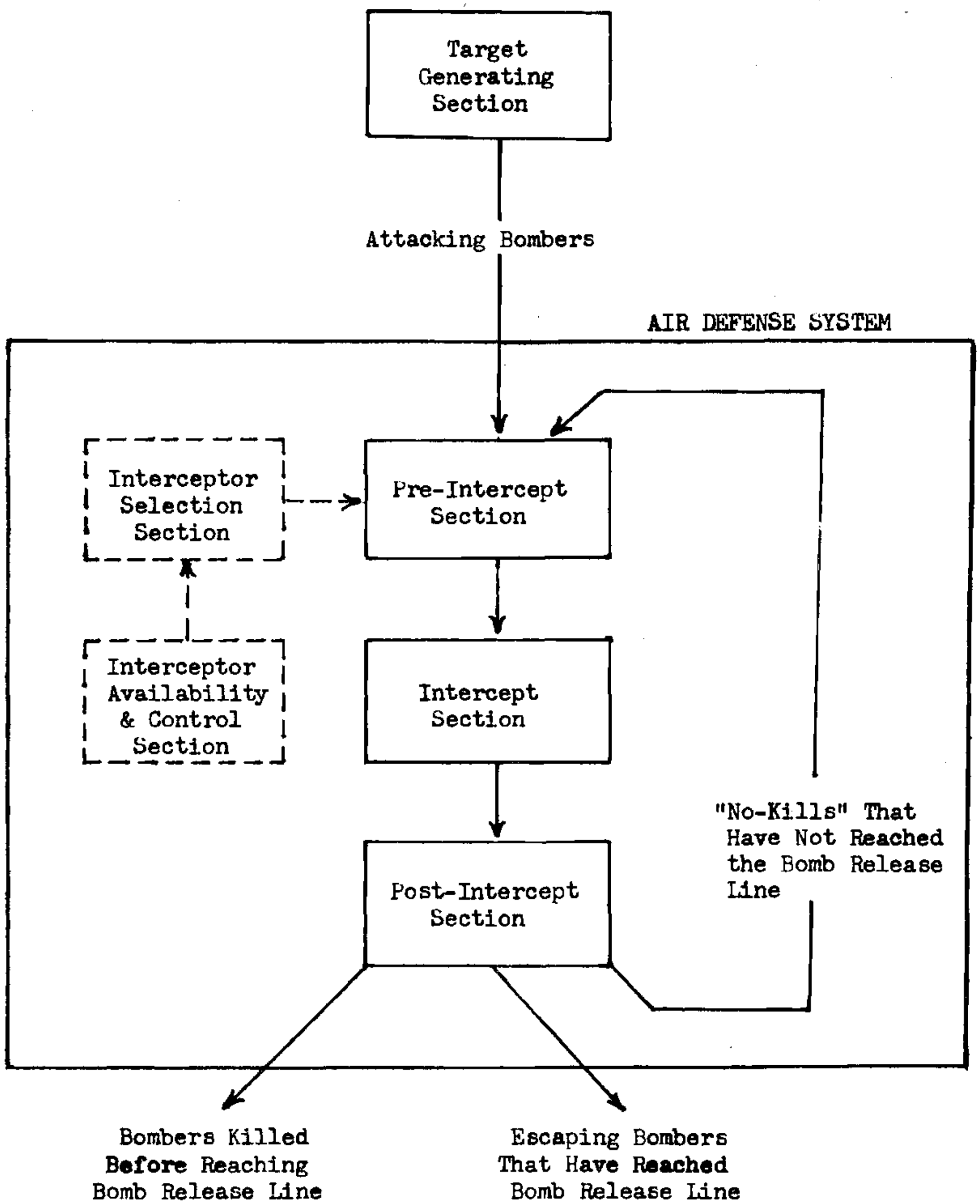

Figure 6. Flow Diagram of Air Defense System.

The Pre-Intercept Section accepts the targets as they enter the air defense system (at the defense line) and routes them to the selected interceptor for intercept action. This section also determines the priorities that should be assigned to each target, depending on its speed and penetration.

The particular interceptor chosen for assignment to any specific bomber is determined by the Interceptor Selection Section. This section receives an input (from the Interceptor Availability and Control Section) of which interceptors are airborne and have the necessary fuel and armament to be available for intercept duty.

When a bomber transaction has been assigned to an interceptor facility for action, the actual intercept phase begins. This occurs in the Intercept Section. In this section, the bomber transaction holds the interceptor facility until sufficient time has elapsed to complete the intercept.

At completion of intercept the transaction enters the Post-Intercept Section. Here it is determined whether a successful intercept has been accomplished or whether the attack failed to neutralize the bomber. If a "no-kill" results, the bomber transaction will recycle through the defense system, provided it has not yet reached the bomb release line.

Specific Sections

Target Generating Section

The block diagram of this section is shown in Figure 7. ORIGINATE blocks 1, 11, and 26 are used to create transactions which simulate bombers. In the final simulation model, additional ORIGINATE blocks were added (blocks 2 and

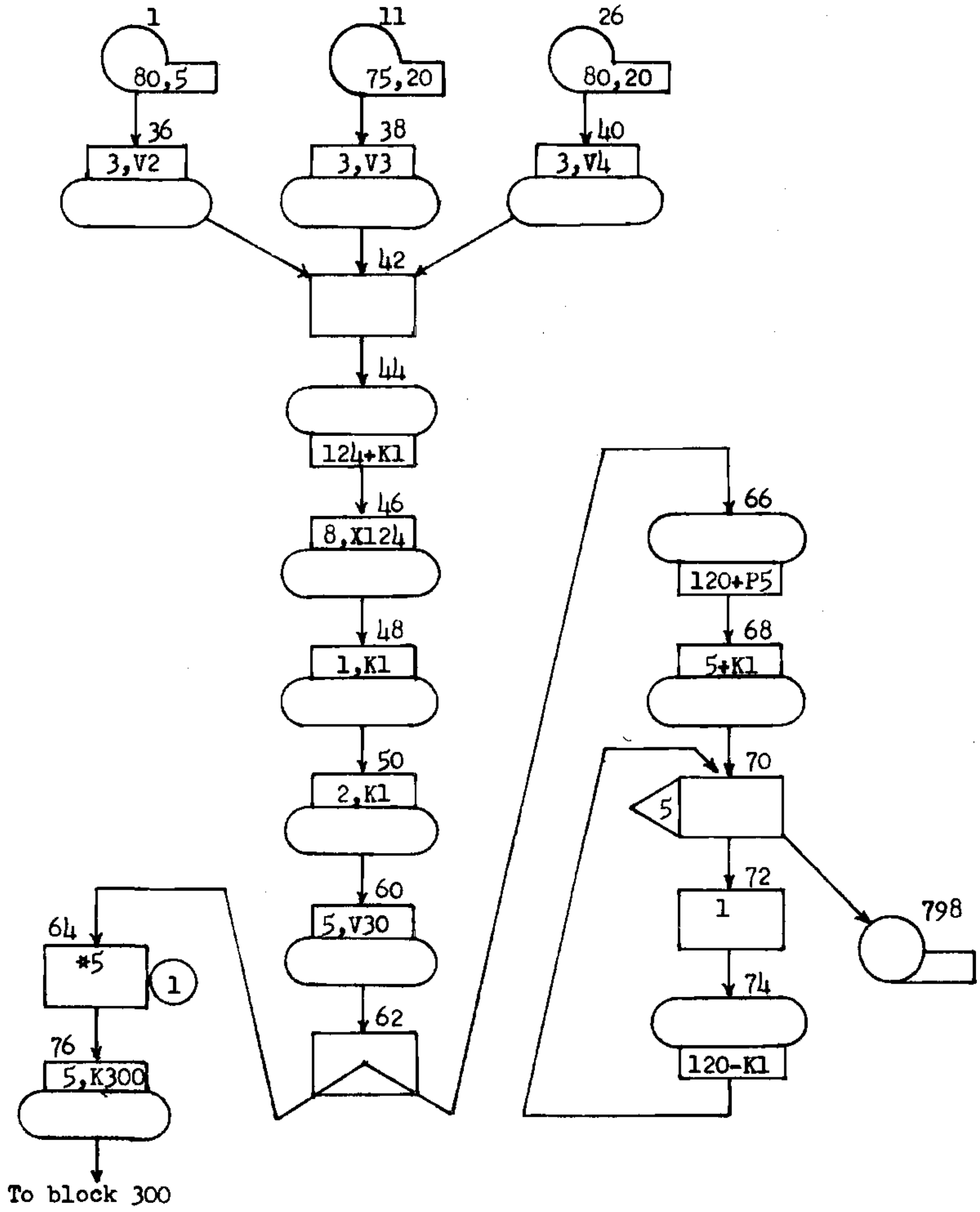

Figure 7. Diagram of Target Generating Section.

12) but their function is identical to the ones shown, so they were omitted to simplify the diagram. ASSIGN blocks 36, 38, and 40 assign the bomber speeds to parameter 3 of each transaction. VARIABLES 2, 3, and 4 correspond to target speeds of 800 knots, 600 knots, and 400 knots, respectively. SAVEX block 44 and ASSIGN block 46 serve to place a target identification number in parameter 8 of each target transaction. ASSIGN blocks 48 and 50 set parameters 1 and 2 initially to a value of one for use later in the system. ASSIGN block 60 places the value of VARIABLE 30 in parameter 5. VARIABLE 30 represents the time required for the bomber to penetrate from the detection line to the defense line. The bomber transaction is then held in STORE block 64 until sufficient time has elapsed for it to have reached the defense line, where it can then be attacked by the interceptor force. Block 76 assigns a constant of 300 to parameter 5 for later use in the program. Blocks 66, 68, 70, 72, and 74 serve to keep track of the time remaining until a bomber is due at the defense line. That is, each transaction entering block 66 adds to SAVEX 120 the time required for the corresponding bomber to reach the defense line. Then, each minute thereafter, one minute is subtracted from the total to achieve a "count-down." This is used later in the Interceptor Availability and Control Section as part of a decision-making process.

Pre-Intercept Section

Targets initially reaching the defense line enter QUEUE 1, block 300, as shown in Figure 8. There are five different possibilities for disposition of the transaction leaving block 300. COMPARE block 301 accepts those bomber transactions that have already penetrated to within 30 miles of the bomb release line.

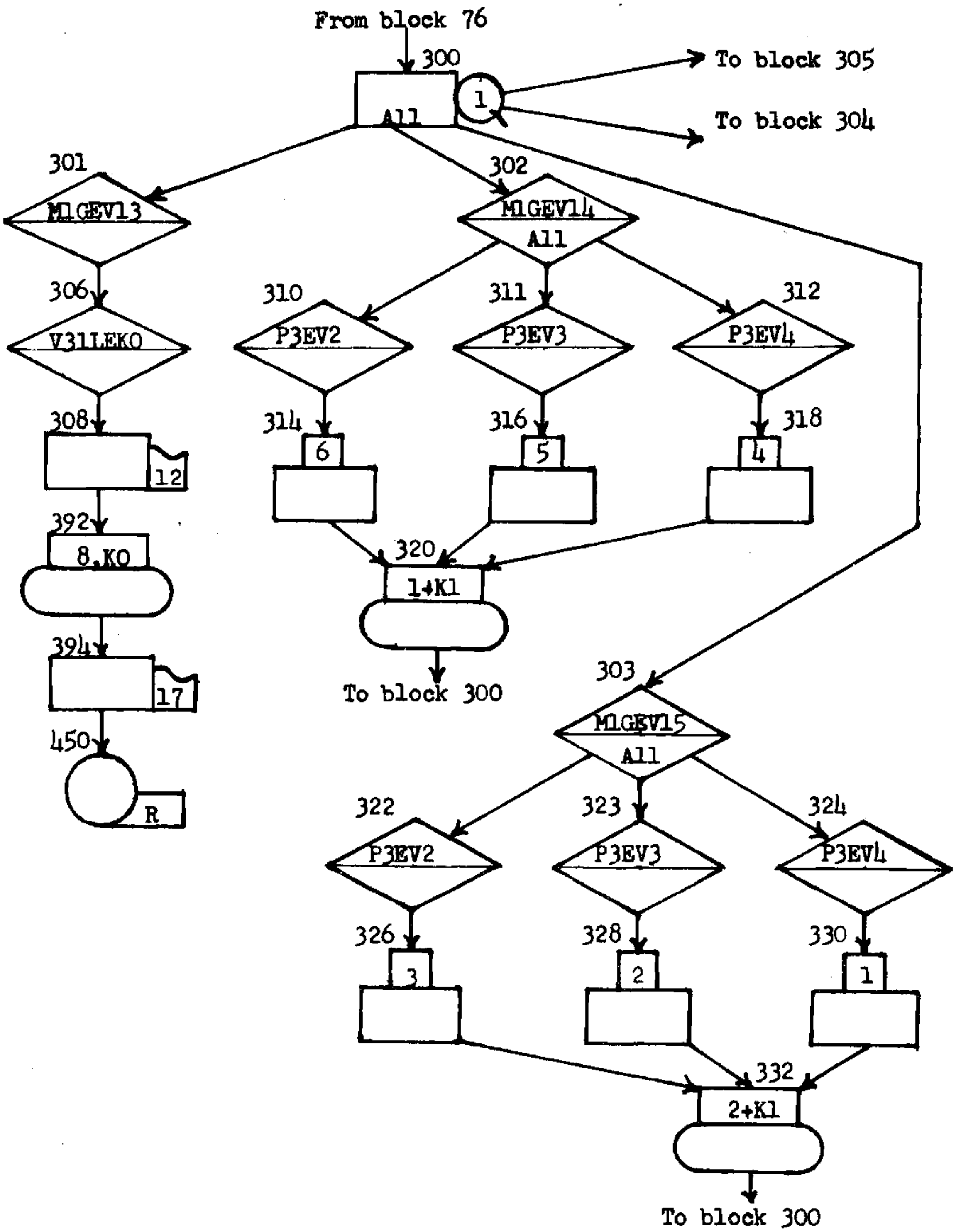

Figure 8. Diagram of Pre-Intercept Section.

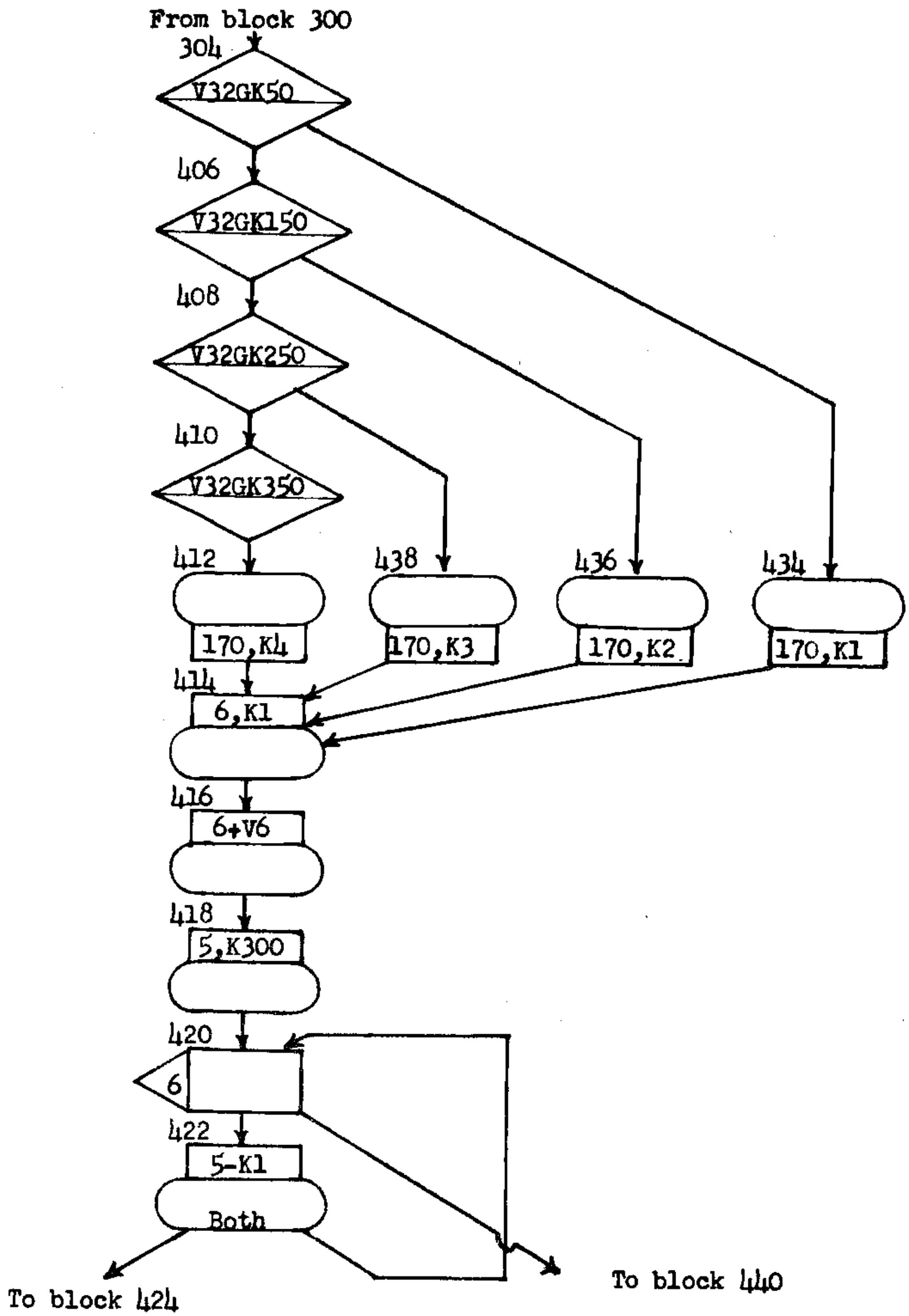

Figure 8 (Continued). Diagram of Pre-Intercept Section.

Since they are that near the bomb release line, it would not be feasible to attempt an intercept, so the bomber's time for reaching that point is tabulated in TABLE 12 (block 308), and TABLE 17 (block 394) records the distance of the bomber from the bomb release line, which in this case is zero.

The network headed by COMPARE block 302 accepts those bombers which have penetrated two-thirds of the distance from the defense line to the bomb release line. These targets are then assigned priorities (blocks 314, 316, 318) according to their speed. High speed targets receive highest priority of six, followed by medium speed and low speed targets with five and four respectively. Block 320 adds a constant to parameter 1 which, being part of VARIABLE 14, prevents the transaction from passing through that priority network after its return to block 300.

The network headed by block 303 performs a priority assigning function similar to the preceding section, with the difference being that it accepts those targets which have penetrated one-third of the distance to the bomb release line. Priorities assigned are three, two, and one to high speed, medium speed, and low speed targets respectively.

Before proceeding with a detailed description of the network entered through COMPARE block 304, a brief description of the overall function will be given. The network accepts bombers which have penetrated more than 50 miles past the defense line, and tries first to find an interceptor in approximately the same position. Failing in that, it attempts to find any interceptor behind the defense line to pair with the bomber. If this also fails, there is no other alternative but to accept any interceptor that is available.

In more detail, COMPARE blocks 304, 406, 408, and 410 and SAVEX blocks 412, 438, 436, and 434 all serve to place in SAVEX location 170 a zone number for the location of the bomber. For example, if the bomber has penetrated from 50 to 150 miles past the defense line, the constant one is placed in SAVEX 170 (signifying that the approximate location of the bomber is 100 miles past the defense line). Blocks 414, 416, 418, 420, and 422, in conjunction with the COMPARE block 424, constitute a search procedure through the SAVEX locations 301, 302, ..., 325. These SAVEX locations are used in other parts of the program to keep a record of each interceptor's location, using the same zone notation. If the search produces an interceptor with the same zone location as the target, the transaction passes through COMPARE block 424. Blocks 424, 428, 430, and 432 serve to pair the target with the appropriate interceptor by placing the interceptor identification number in parameter 4. Then, if that interceptor facility is not in use, the transaction is sent to block 337 in the Intercept Section where the intercept action will take place. Blocks 37 and 741 are involved only if the interceptor is in use and cannot be paired with the bomber. SAVEX block 37 sets the interceptor zone number to zero (all engaged or otherwise unavailable interceptors should always have zero in the zone SAVEX location). ASSIGN block 741 re-assigns the value 300 to parameter 5 and the transaction is returned to QUEUE 1 (block 300) for further disposition.

Block 440 is entered if the search to find an interceptor in the same zone proves fruitless. Blocks 440, 442, 444, 446, 448, and COMPARE block 452 again perform a search of interceptor zone SAVEX locations, but this time any interceptor located behind the defense line is accepted. If any such interceptor is found, the transaction goes to block 426 and repeats the procedure previously described.

If no interceptor is found behind the defense line, then the transaction enters ASSIGN block 454 which returns parameter 5 to a value of 300. If COMPARE block 455 accepts the transaction, this means that an interceptor has just become airborne and has not yet reached the defense line, but is available for action behind the line. The transaction then passes through blocks 457, 459, 461, 458, 460, and 52 which serve to pair the interceptor with that target by assigning the interceptor identification number to parameter 4 of the target transaction. The target then proceeds to block 335 in the Intercept Section.

ADVANCE block 463 accepts target transactions which were unable to find an available interceptor anywhere behind the line. An attempt is first made to send the transaction to block 305 (to an interceptor at the defense line) and if unable to go to block 305, the transaction is delayed for one minute at block 456, and then returned to block 300 to repeat the search cycle.

Intercept Section

The Intercept Section, shown in Figure 9, begins with GATE block 305 which accepts transactions only if logic switch 1 is set. This means that the Interceptor Selection Section has selected an available interceptor to engage the target and has stored the interceptor identification number in SAVEX location 200. ASSIGN block 334 then places the interceptor identification number in parameter 4

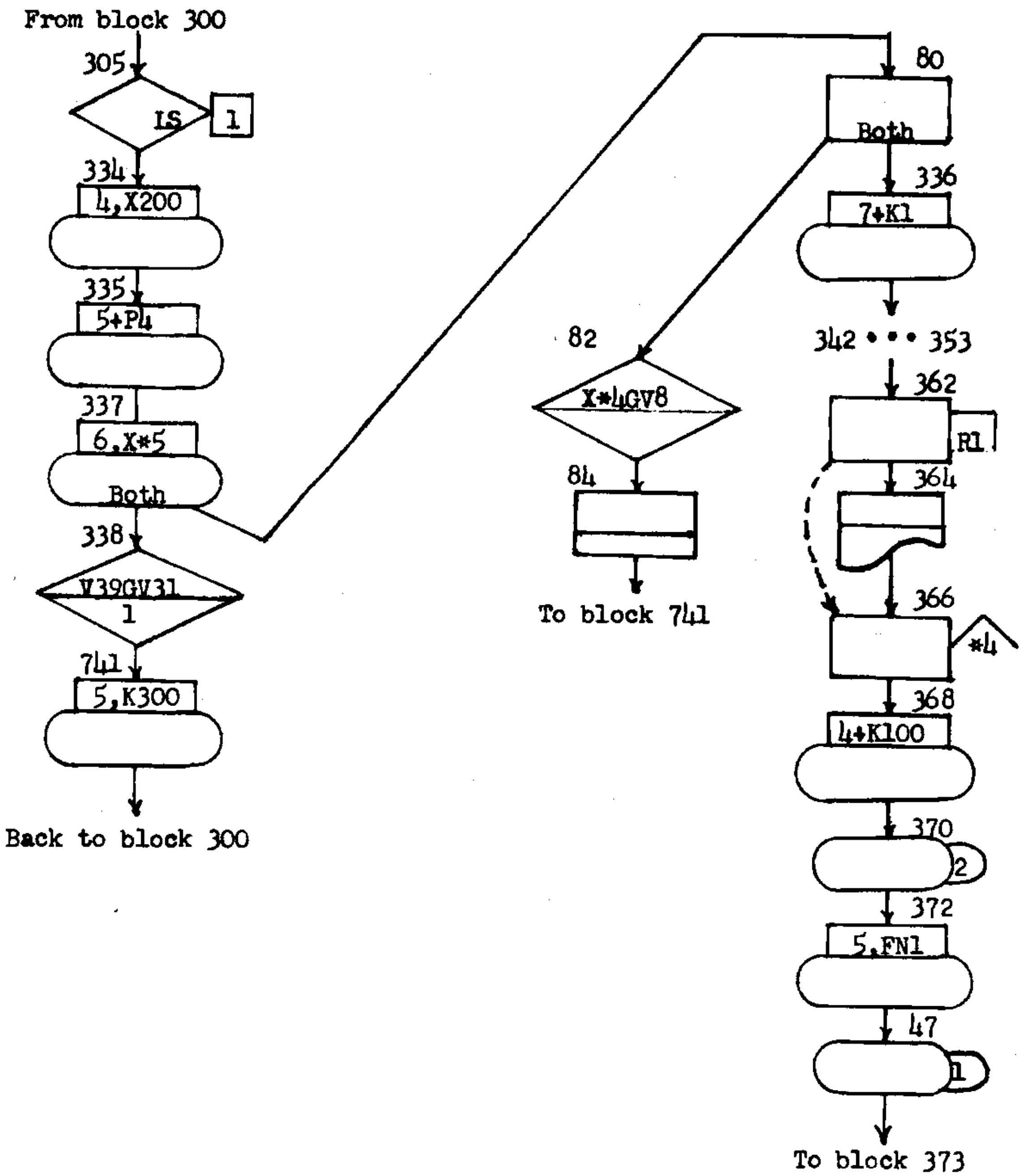

Figure 9. Diagram of Intercept Section.

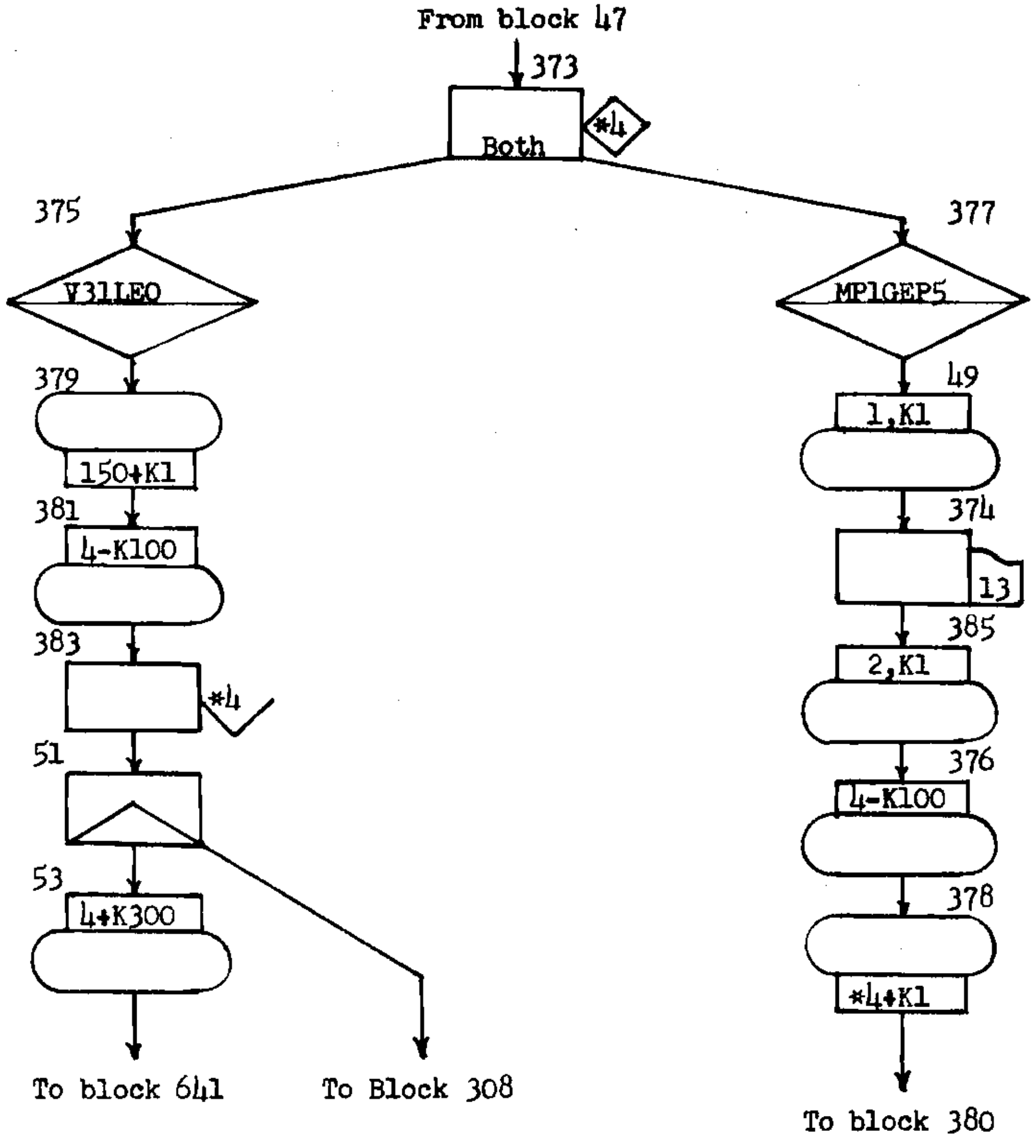

Figure 9 (Continued). Diagram of Intercept Section.

of the target. Then in ASSIGN block 335, the same identification number is added to parameter 5 (previously carrying a value of 300) so that parameter 5 now contains the interceptor zone SAVEX number (the appropriate 300 series SAVEX location). Block 337 assigns the value found in the zone SAVEX to parameter 6, where it is later considered in computing the intercept action time. Block 338 accepts those transactions that have penetrated too deeply for the assigned interceptor to overtake. The transaction is delayed one minute in block 338, the value 300 is restored to parameter 5 in block 741, and the transaction is returned to block 300.

Targets that are not removed from the Intercept Section via block 338 will proceed to ADVANCE block 80 which, with COMPARE block 82, verifies that the interceptor has armament remaining and can accomplish the intercept. ASSIGN block 336 stores in parameter 7 the total number of attempts made on each target. Blocks 342 through 353 were SAVEX blocks used in program trouble-shooting and have no functional effect on the model. LOGIC block 362 resets logic switch 1 to signal the Interceptor Selection Section to select another interceptor for the next target. PRINT block 364 was used in trouble-shooting and was bypassed in the completed program. When the target transaction enters block 366, it seizes the facility representing the assigned interceptor. ASSIGN block 368 adds 100 to the interceptor identification number in parameter 4 so that utilization statistics will be kept for facilities numbered 100, 101, ..., 125. The time required to complete the intercept is assigned to parameter 5, and the transaction is delayed in block 373 until either the bomber reaches the bomb release line

(COMPARE block 365), or the intercept is completed (COMPARE block 377). Targets that reach the bomb release line pass through blocks 375, 379, and 381 and release the facility in block 383. SPLIT block 51 sends one transaction through block 53 to block 641, where it is used in recording the interceptor's zone. The other transaction goes to block 308 in the Pre-Intercept Section where the bomb release time is tabulated.

Completed intercepts (block 377) pass through block 49 to TABULATE block 374 which tabulates the time required to complete the intercept. The transaction passes through blocks 385 and 376 to block 378, where the expenditure of an interceptor weapon is recorded in the appropriate SAVEX location. The transaction then enters the Post-Intercept Section.

Post-Intercept Section

This section is composed of one program segment which determines the outcome of the intercept, and a second segment which keeps a record of the interceptor's location after the intercept. The diagram is shown in Figure 10.

Targets passing from block 378 in the Intercept Section enter block 380 which releases the engaged interceptor. Block 630 adds 300 to the interceptor identification number stored in parameter 4 of the target. This gives parameter 4 the interceptor zone SAVEX number (the 300 series SAVEX locations). SPLIT block 631 sends one transaction to block 641 in the network which maintains the interceptor's location, and the other transaction passes to block 632 in the network which determines the outcome of the intercept.

Block 641 causes logic switch 5 to be set so that the Interceptor Selection

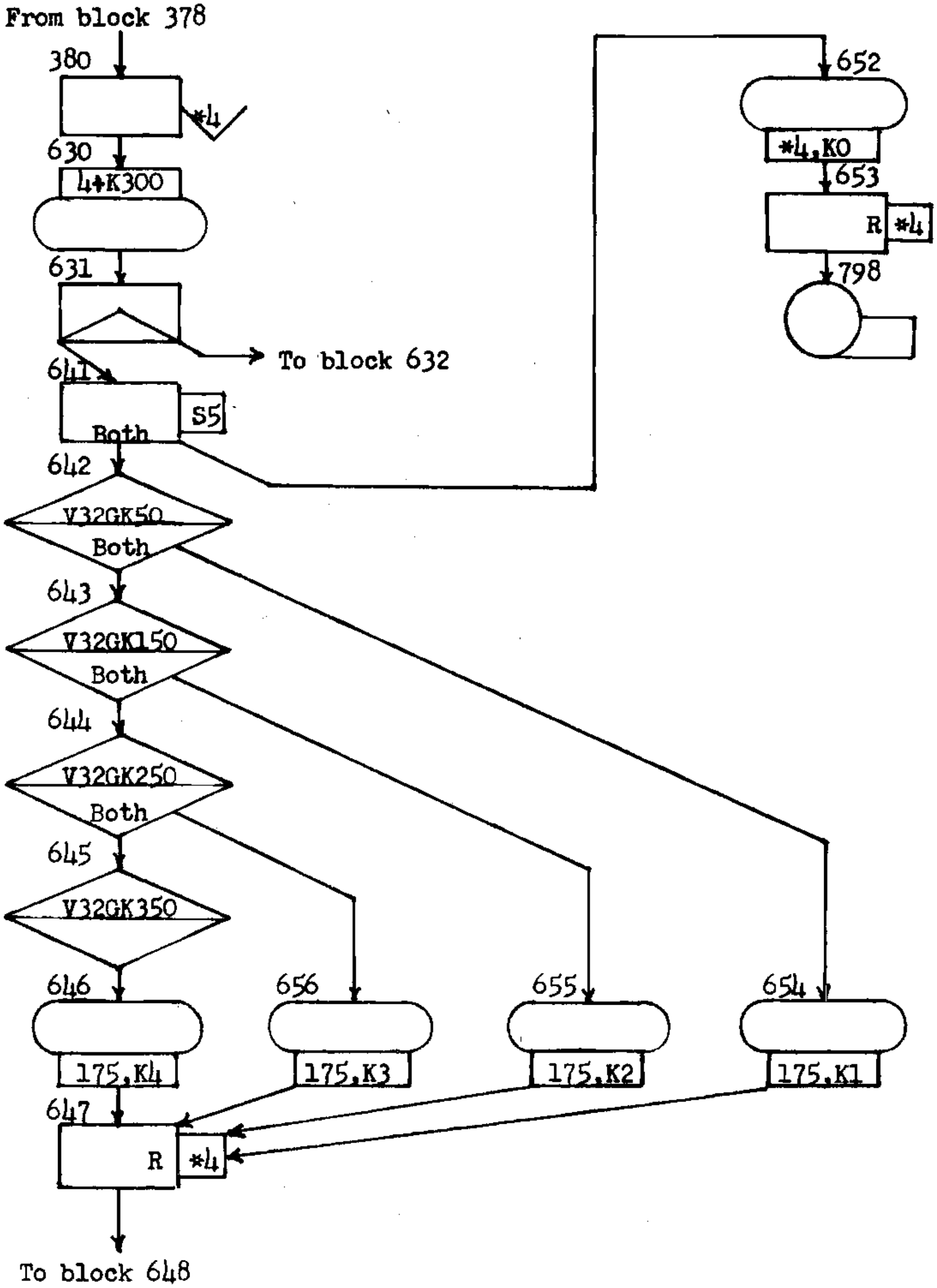

Figure 10. Diagram of Post-Intercept Section.

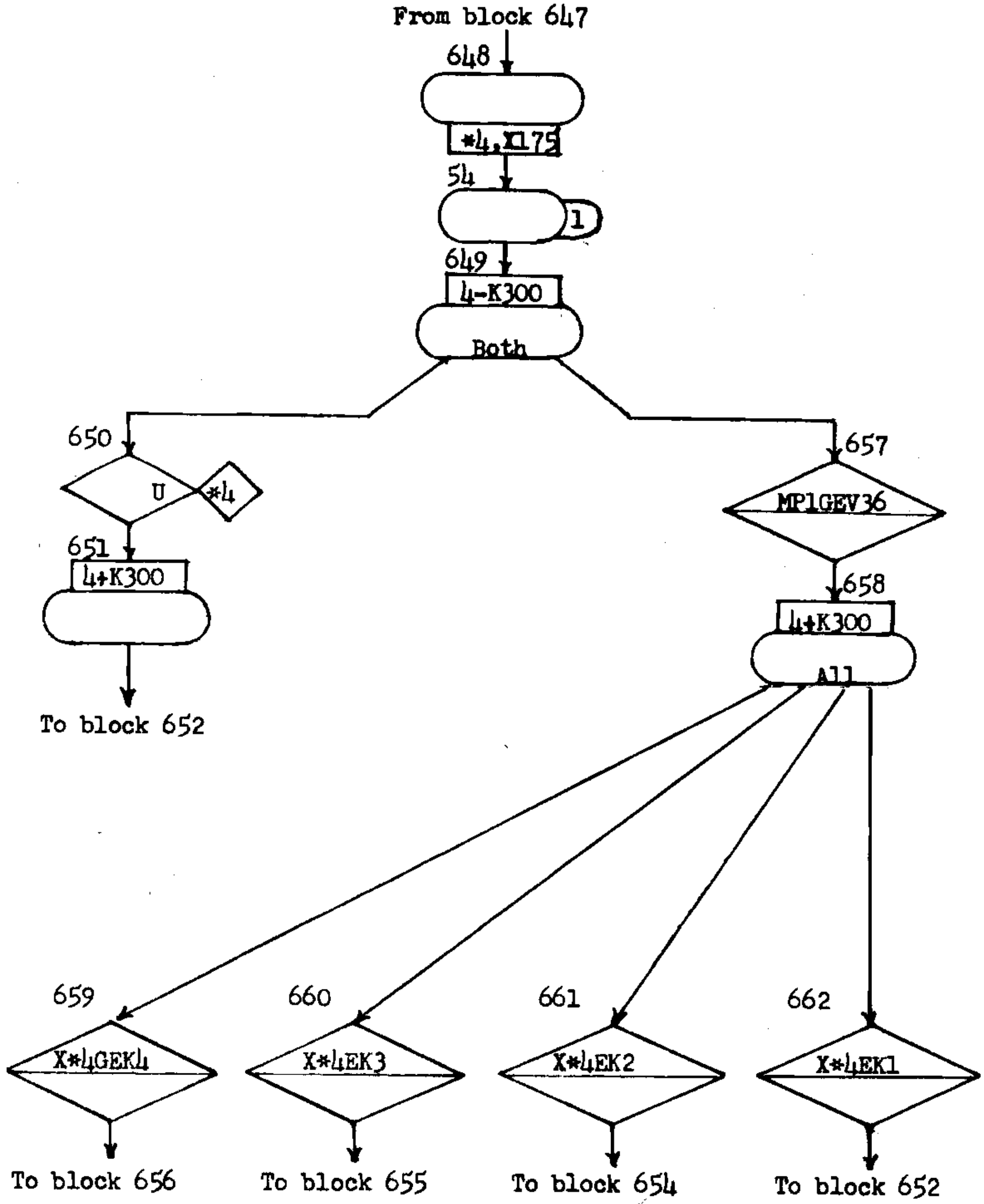

Figure 10 (Continued). Diagram of Post-Intercept Section.

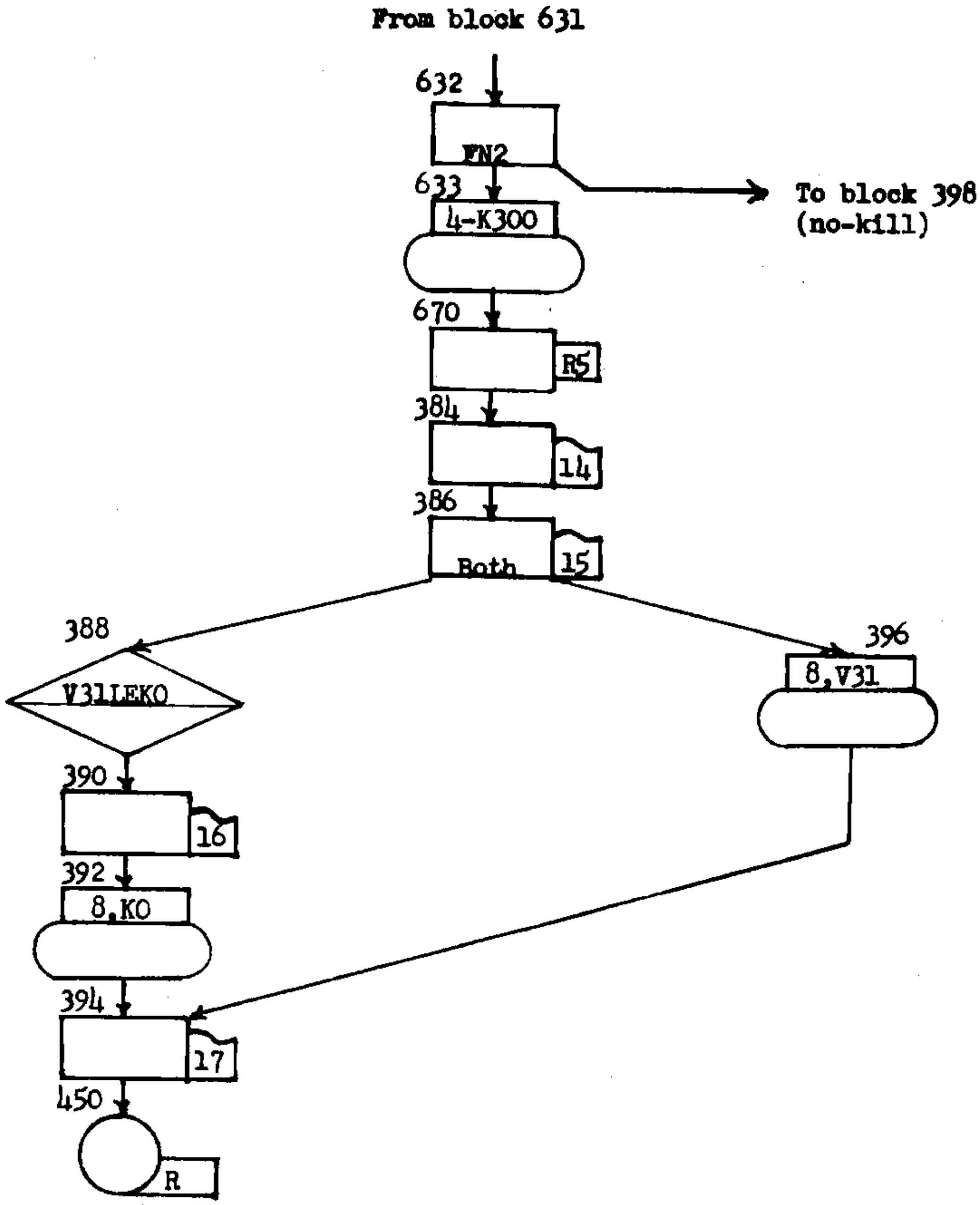

Figure 10 (Continued). Diagram of Post-Intercept Section.

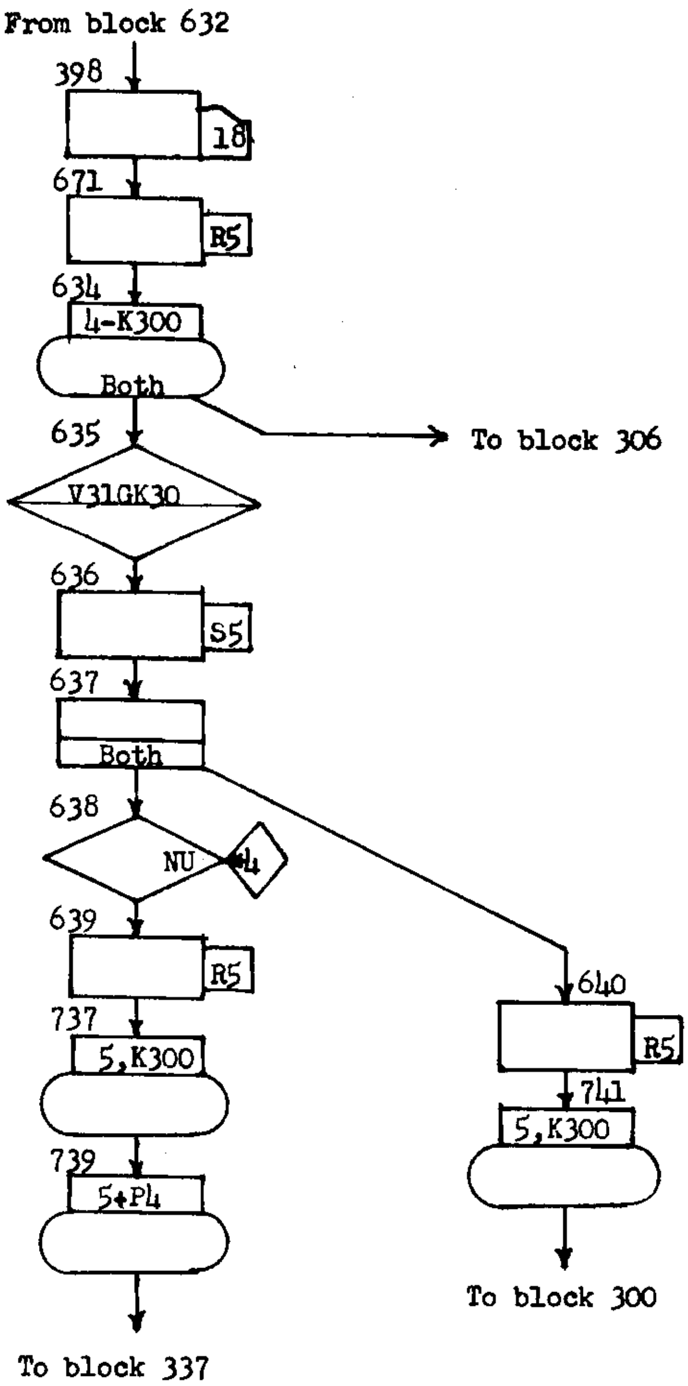

Figure 10 (Continued). Diagram of Post-Intercept Section.

Section will not be activated until both the transactions produced by SPLIT block 631 have been processed. Blocks 642, 643, 644, 645, 654, 655, and 656 act to place the appropriate zone location for the interceptor, at the termination of intercept, in SAVEX location 175. Block 647 resets the logic switch corresponding to the interceptor zone SAVEX number. This action indicates to the Interceptor Availability and Control Section that the interceptor is being given a new zone location number. The transaction passes through block 54 to block 649, where the subtraction of 300 from parameter 4 causes the interceptor identification number to be restored to that parameter. The transaction holds at block 649 until the interceptor is seized again (GATE block 650), either by intercept action or return to base, or until enough time has elapsed to enable the interceptor to move one zone nearer to the defense line (COMPARE block 657). As soon as the interceptor is utilized again, the zone location number is set to zero (blocks 651 and 652). Blocks 658, 659, 660, 661, and 662 decrease the zone location number by one when the interceptor has had enough time to traverse 100 miles.

The transaction going from SPLIT block 631 to ADVANCE block 632 determines the outcome of the intercept. The departure from block 632 is routed by FUNCTION 2 which randomly sends 75 percent of the transactions to block 633 (kill) and 25 percent of the transactions to block 398 (no-kill). The values of FUNCTION 2 correspond to the kill probability of the interceptor weapon.

If the target is destroyed (block 633), the transaction passes through block 670, which allows the Interceptor Selection Section to be re-activated, and then through TABULATE blocks 384 and 386, which record the number of kills per interceptor and the time of kill. Blocks 388, 390, and 392 were used for trouble-shooting. In the final program, all kills pass through blocks 396 and 394 which assign and record the kill distance from the bomb release line.

Targets that are not killed go to block 398 which tabulates the number of no-kills on each target. The transaction passes through block 671 and block 634 and then through block 635, only if the target distance from the bomb release line is greater than 30 miles. If the distance is less than 30 miles, the transaction passes to block 306 in the Pre-Intercept Section, where bomb release information is recorded. Targets still subject to intercept pass through block 635, through block 636 which de-activates the Interceptor Selection Section, through BUFFER block 637, and to either block 638 or 640. Blocks 638, 639, 737, and 739 allow the target to be re-engaged by the same interceptor for another attempt, and the transaction returns to block 337 in the Intercept Section. Blocks 640 and 741 allow the target transaction to return to QUEUE 1 because the interceptor from the prior attempt is no longer available.

Interceptor Selection Section

This section, diagrammed in Figure 11, performs the function of searching through the interceptors until one is found that is available for duty. That interceptor identification number is then stored in SAVEX location 200, and the Pre-Intercept Section is signaled that an interceptor has been selected. The selection method used provides a fairly uniform utilization of interceptors; but not completely uniform, which would be unrealistic. In an actual battle, a

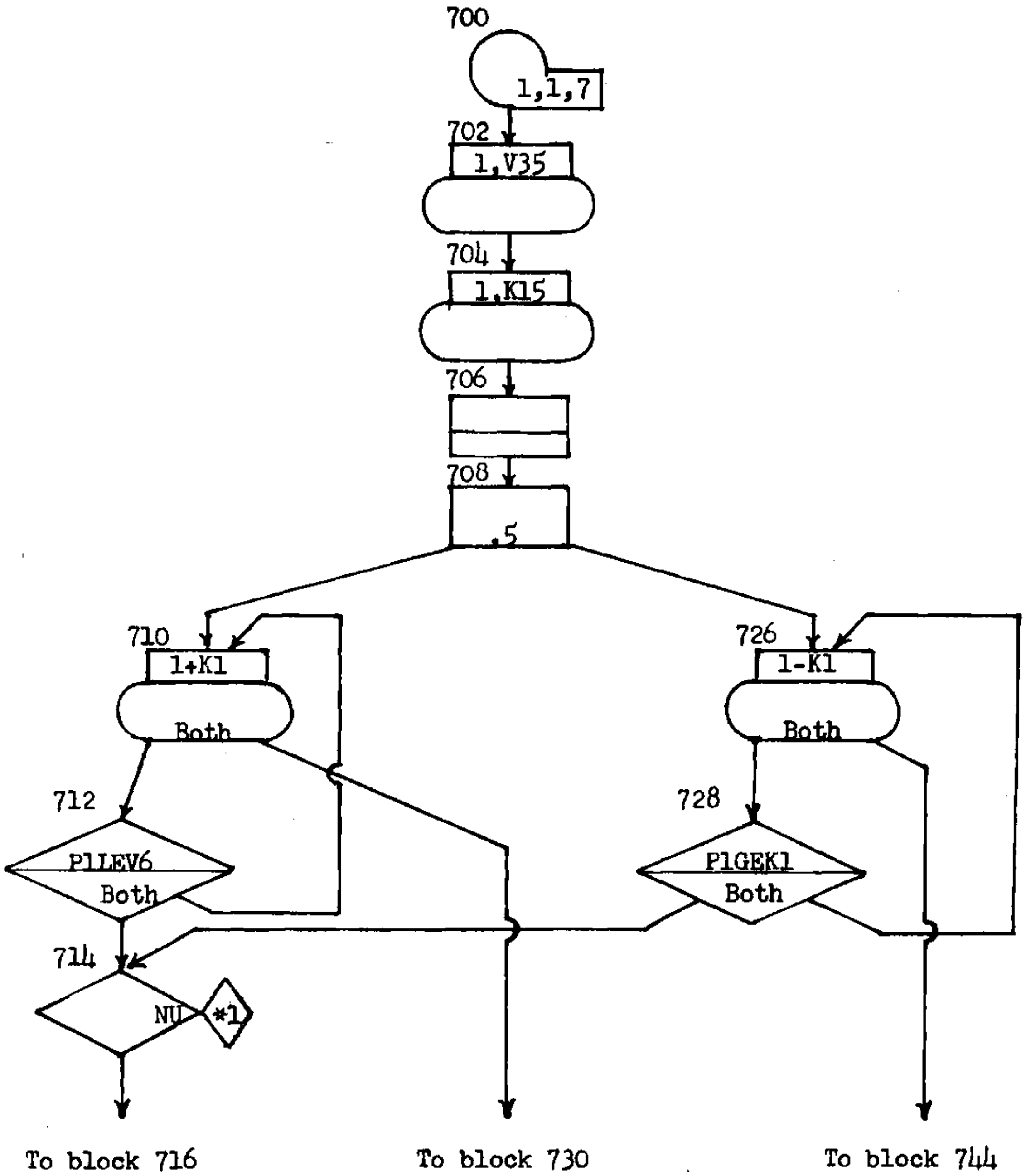

Figure 11. Diagram of Interceptor Selection Section.

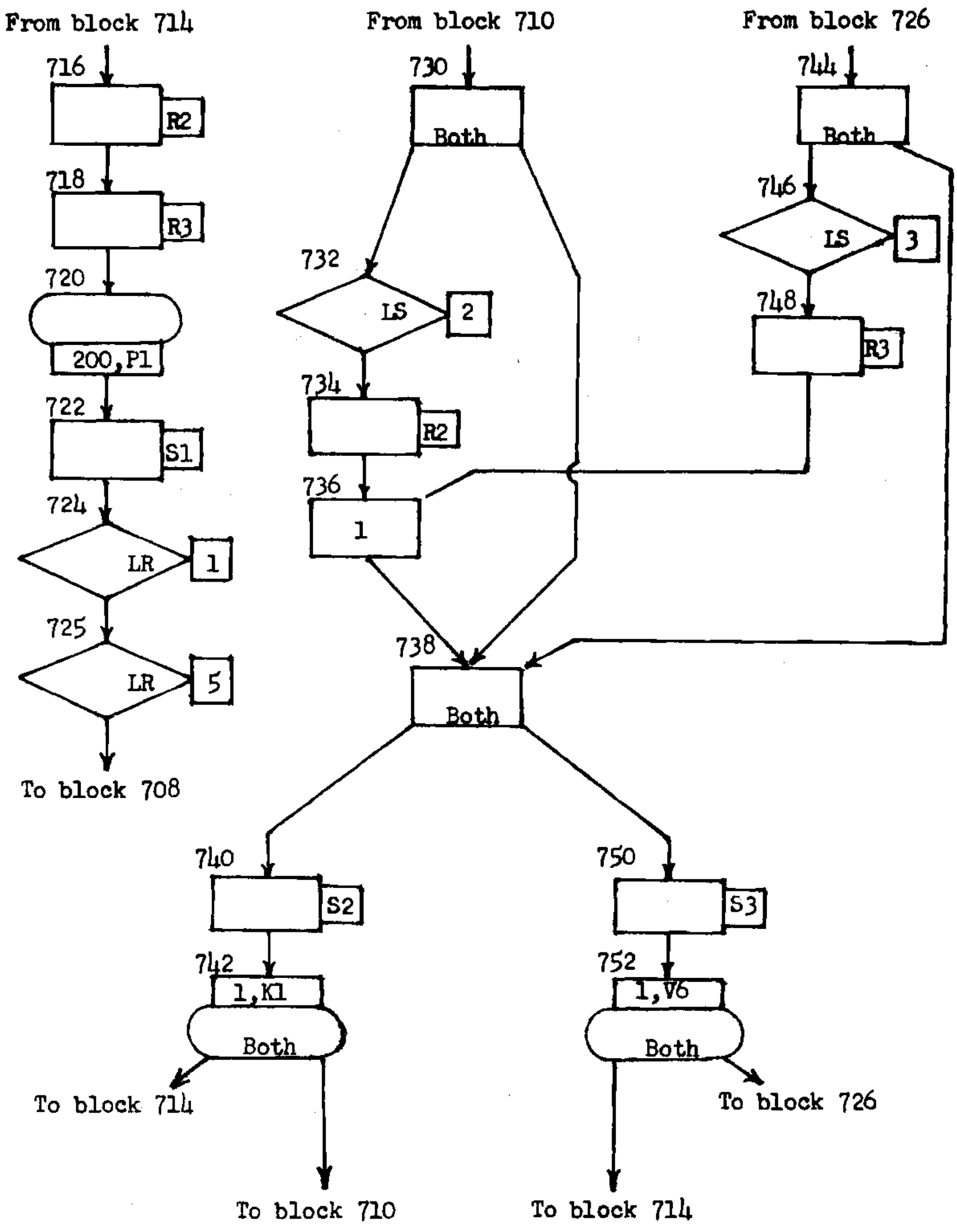

Figure 11 (Continued). Diagram of Interceptor Selection Section.

commander could not expect to position the interceptors so that the intercept attempts would be uniformly distributed. Nevertheless, wise deployment of forces would lead to an approximation of the desired even distribution.

ORIGINATE block 700 creates a single transaction at the beginning of the program. This is a "dummy" transaction in that it remains within this particular section, continually re-cycling during the simulation process, to control events taking place in other sections.

ASSIGN block 702 delays the transaction until time for the interceptors to begin battle (VARIABLE 35). Block 708 gives the control transaction a choice of passing to block 710, where a search is made in ascending order through the interceptor identification numbers; or to block 726, where the search is made in descending order. Blocks 710, 712, and 714 perform a search function by adding one to the interceptor identification number until an available interceptor is found, or until the search has been completed through the highest numbered interceptor in the system. When an interceptor is found (block 714), the control transaction passes through blocks 716, 718, 720, and 722 and is delayed at GATE block 724 until signaled by the Intercept Section that another search and selection is required. If the search is fruitless, the transaction would go from block 710 to block 730. If the search was a complete search of all interceptors, then the transaction passes through block 732 and block 734 and delays at block 736 for one minute before starting another search.

Blocks 726, 728, 744, 746, 748, 750, and 752 perform similar search functions to the procedure just described except the search is done in descending order.

Interceptor Availability and Control Section

The simulation model is directed from this section. It determines take-off times, landing times, combat times, interceptor availability, and makes logical decisions (according to programmed instructions) during the course of the battle. For ease of diagramming and description, this section will be sub-divided into seven sub-parts for discussion.

Sub-Section I. Figure 12 describes this network which originates the transactions that simulate the interceptor force. ORIGINATE block 500 originates a single transaction at the beginning of the simulation. Block 502 assigns the total number of interceptors (VARIABLE 6) to parameter 1. Blocks 504, 506, 508, 510, and 512 cause the initial transaction to split into the same number of transactions as there are interceptors. Each transaction is assigned an interceptor identification number in parameter 2 (ASSIGN block 510). Block 514 assigns VARIABLE 16, the time required for an interceptor to reach the defense line, to parameter 4. In blocks 516 and 518, VARIABLE 9 (the initial take-off time) is assigned to parameter 5 and all interceptors are seized until take-off time. From block 518, the transactions go either to block 520 in Sub-Section II or to block 578 in Sub-Section VII.

Sub-Section II. This section, shown in Figure 13, allows the interceptor force to take-off. Block 520, in conjunction with SAVEX block 522, allows the initial manning force to pass after release from Sub-Section I. Block 524 zeroes the flight time at take-off. SAVEX location 117 (block 526) records the total

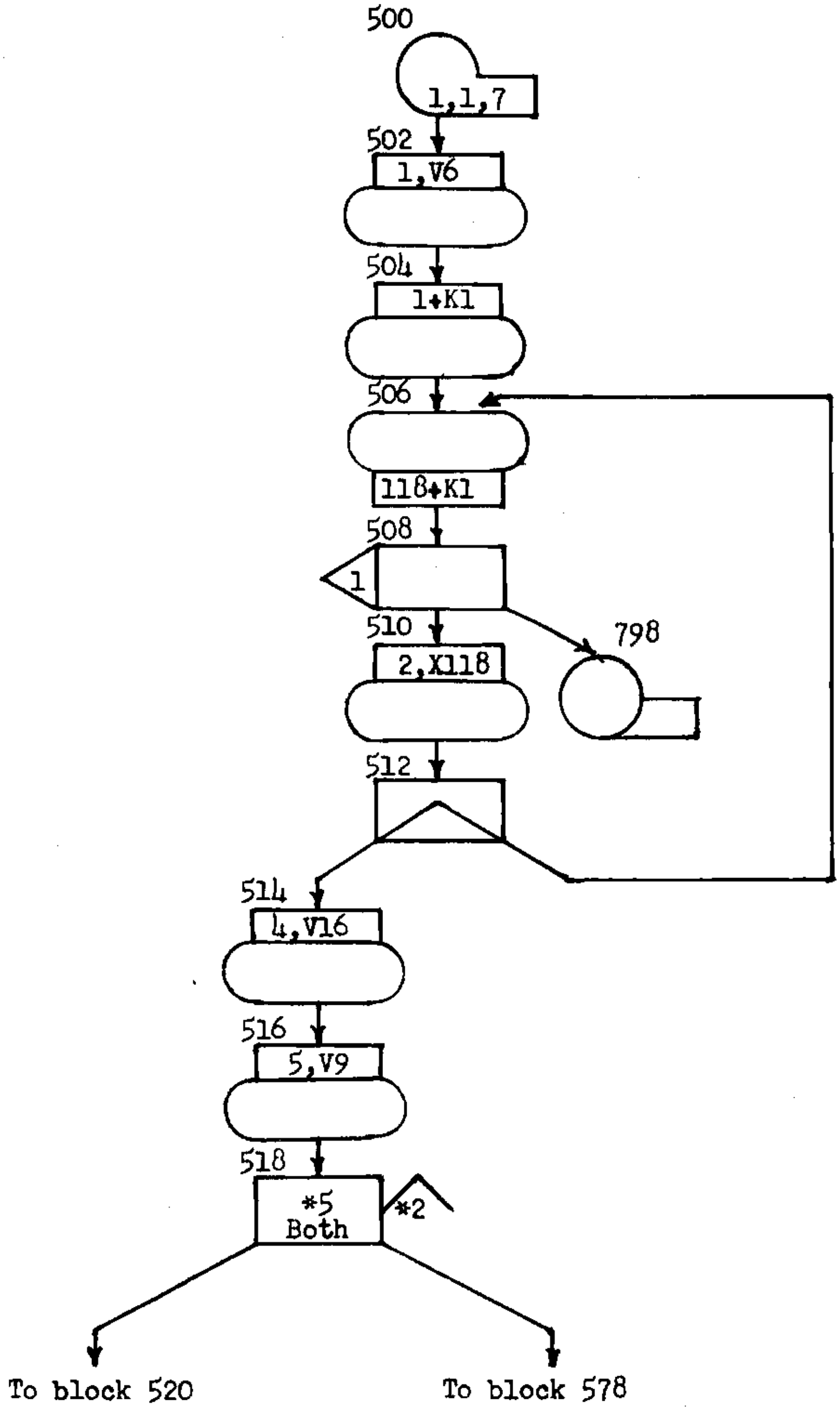

Figure 12. Sub-Section I

Interceptor Availability and Control Section.

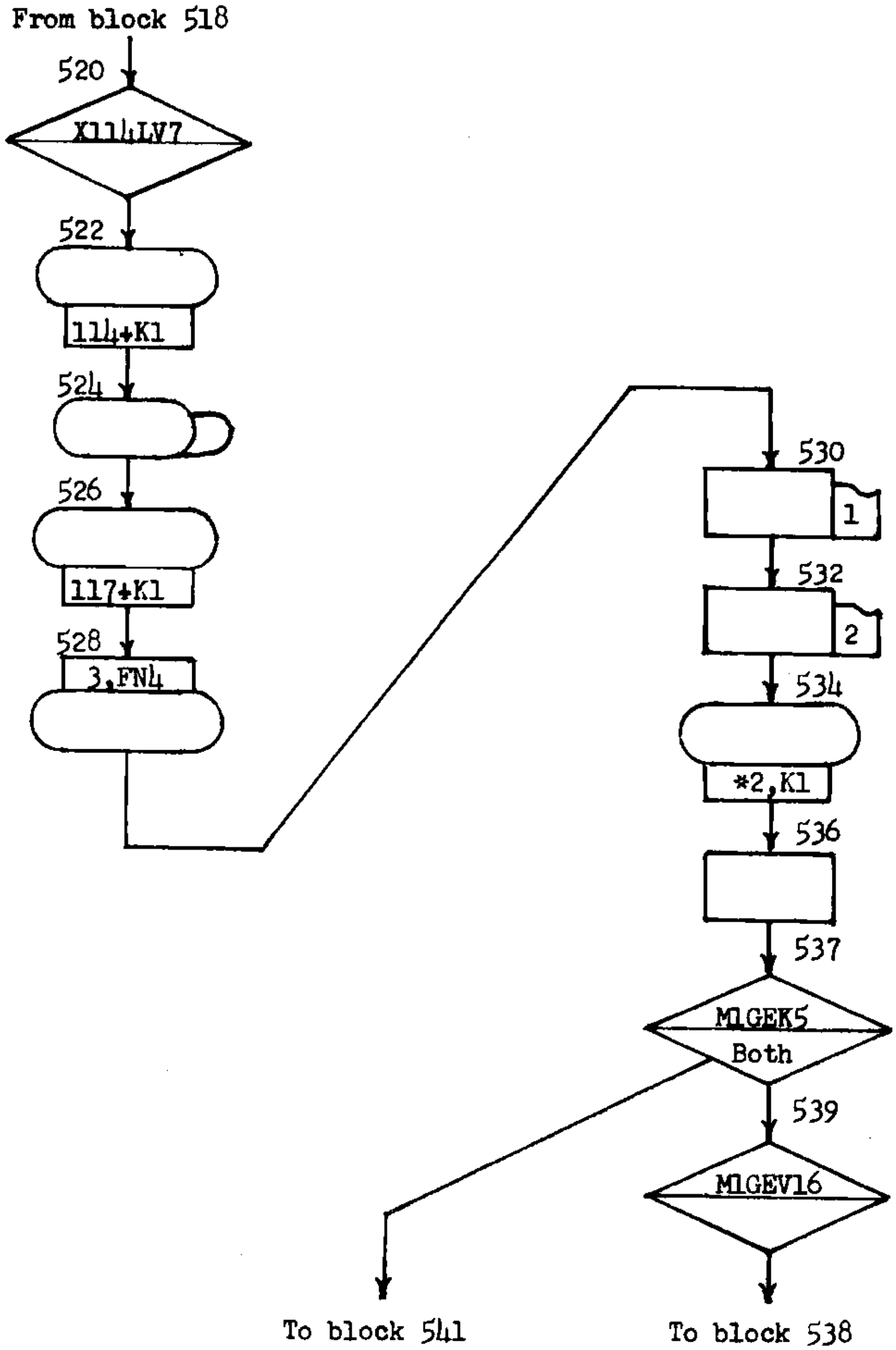

Figure 13. Sub-Section II

Interceptor Availability and Control Section.

number of interceptors committed to the battle. ASSIGN block 528 assigns the combat endurance factor to parameter 3. TABULATE blocks 520 and 532 record the number of sorties per interceptor and the take-off times. SAVEX block 534 sets the weapon expenditure counter initially to one. At block 537, the interceptor is delayed for five minutes, which simulates the time required to become airborne and established on course to the battle area. From block 537, the transaction can go either to block 541 in Sub-Section III, or to block 539, where it is delayed until reaching the defense line. After the delay it passes through block 539 to block 538 in Sub-Section IV.

Sub-Section III. The network diagrammed in Figure 14 is involved when a newly airborne interceptor is required to intercept a bomber that has penetrated past the defense line. GATE block 541 is a signal from the Pre-Intercept Section that the interceptor is required immediately for assignment. ASSIGN block 543 places the interceptor's zone location in parameter 4 and later, SAVEX block 549 places the zone location number in the appropriate SAVEX location. SAVEX block 545 provides a means of notifying the Pre-Intercept Section which interceptor is available. SPLIT block 553 and blocks 557, 620, 621, 622, and 623 send a transaction to the section which maintains zone location information. The original interceptor transaction passes through ASSIGN block 555 to block 538 in Sub-Section IV.

Sub-Section IV. Figure 15 illustrates this portion of the Interceptor Availability and Control Section. This sub-section releases the interceptor for intercept duty (block 538). TABULATE block 540 records the time the interceptor

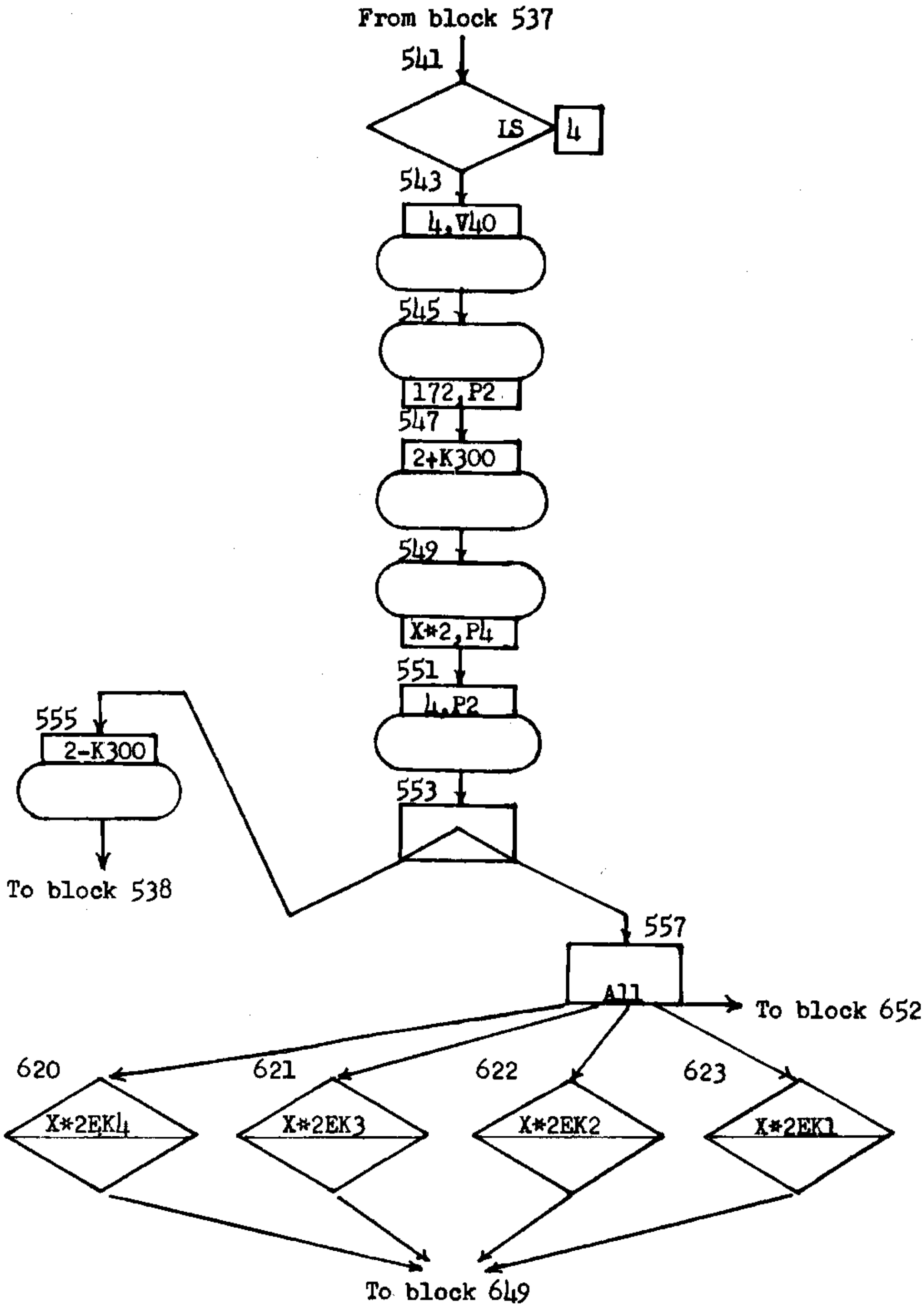

Figure 14. Sub-Section III

Interceptor Availability and Control Section.

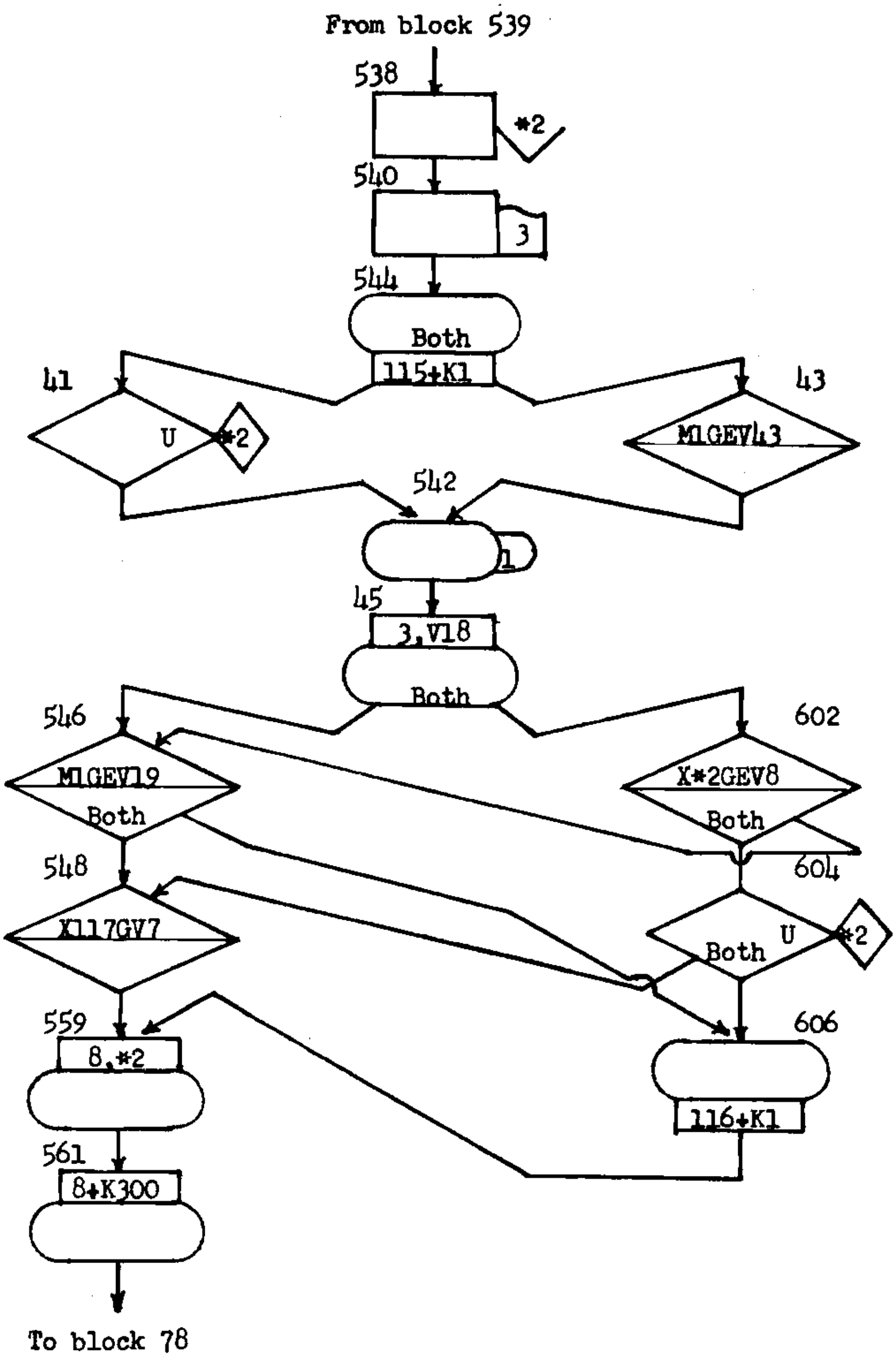

Figure 15. Sub-Section IV

Interceptor Availability and Control Section.

became available for action. SAVEX location 115 (block 544) records the number of interceptors in action. Block 41 simulates the interceptor being paired with a bomber, and block 542 marks parameter 1 to start recording combat endurance. A transaction passing through block 43 symbolizes an interceptor that has never been utilized but which has no more time available at the defense line. ASSIGN block 45 assigns the total remaining interceptor airborne time (VARIABLE 18) to parameter 3.

When the interceptor nears the end of its endurance (VARIABLE 19), block 546 allows passage to block 606, unless there are already surplus interceptors airborne (block 548). Block 606 provides a signal to Sub-Section VII that a replacement interceptor is needed. Similarly, blocks 602 and 604 allow a signal for replacement if the interceptor has only one weapon left and is in the process of using it. Blocks 559 and 561 assign the intercept zone SAVEX location to parameter 8, and the transaction passes to block 78 in Sub-Section V.

<u>Sub-Section V</u>. GATE block 78, in Figure 16, allows the interceptor transaction to pass as soon as any intercept in progress has been completed. Block 563 assigns the interceptor zone to parameter 7. Blocks 88, 90, 92, 94, 96, 93, and 95 assign the time required to return to base from the present interceptor location. Since the interceptor location is only approximate because of the zone system, VARIABLES 45, 46, and 47 are used to randomly add or subtract some increment of time from the time required to return to base.

The transaction remains at block 565 until either the interceptor moves from one zone to another (block 613); or the interceptor endurance is exhausted

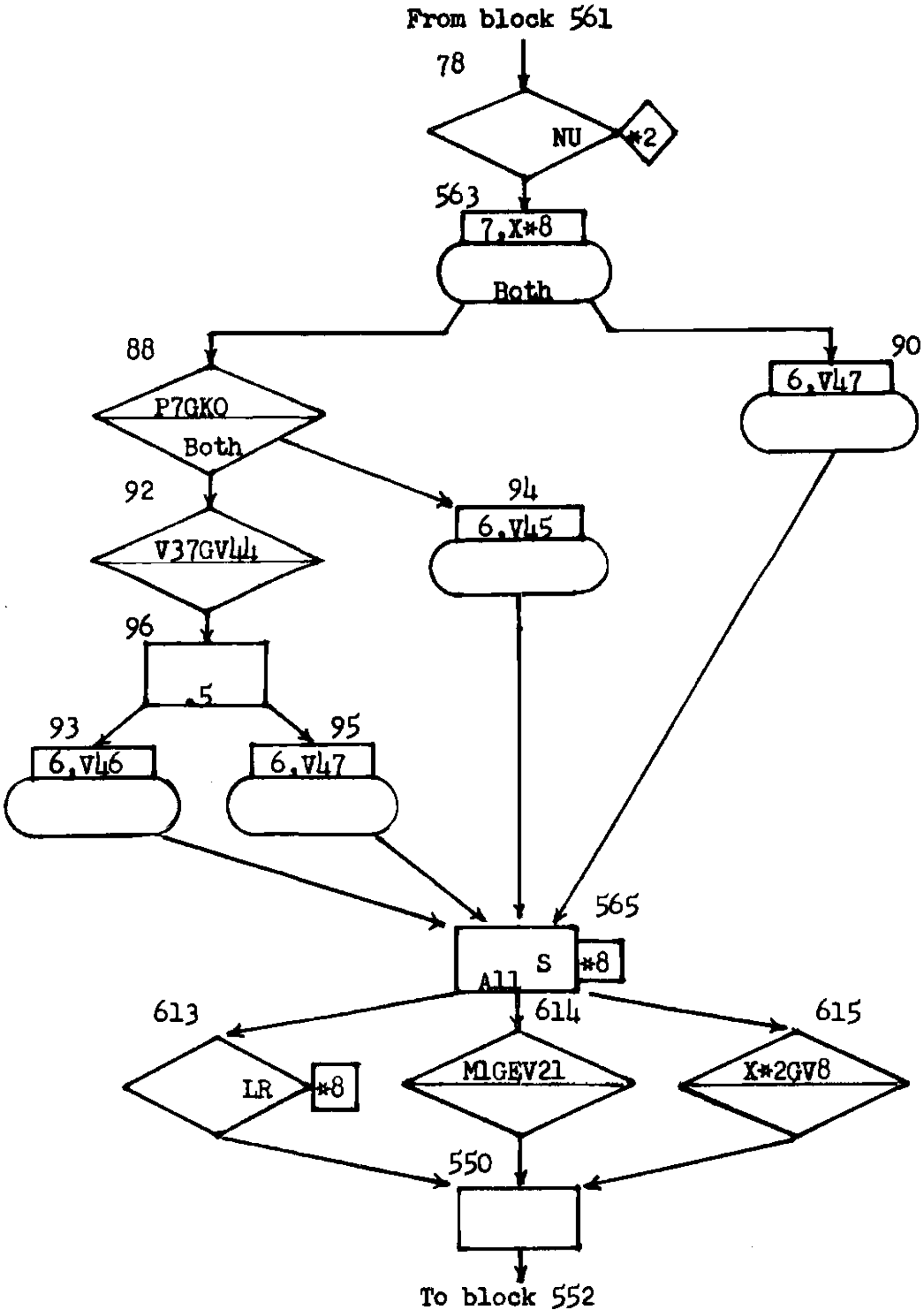

Figure 16. Sub-Section V

Interceptor Availability and Control Section.

(block 614); or the interceptor armament is expended (block 615). Block 613 lets the transaction re-cycle and receive a new return-to-base time when the interceptor zone location changes. Blocks 614 and 615 let the transaction pass through block 550 to block 552 in Sub-Section VI.

Sub-Section VI. This section simulates the interceptor leaving the battle area and returning to the interceptor base. The block diagram is shown in Figure 17. SEIZE block 552 places the interceptor facility in an unavailable status. TABULATE blocks 554, 558, 564, 568, and 570 record respectively the combat time per interceptor, the time departing the battle area, the time required to return to base, weapon expenditure, and flight time per interceptor. SAVEX block 556 subtracts one from the total of interceptors committed to battle. SAVEX block 560 subtracts one from the total of interceptors available for action, and also holds the transaction for the time required to return to base. Block 572 then marks parameter 8 for further use in recording turnaround times and the transaction passes to Sub-Section VII.

Sub-Section VII. Figure 18 illustrates the section which simulates the interceptor servicing and delay on the ground pending subsequent return to battle. ADVANCE block 574 holds the transaction until the service and turnaround time requirements are met (FUNCTION 6). Some transactions are then routed by FUNCTION 7 to blocks 610 and 612, which simulate permanent loss of an interceptor; and the interceptor identification number and time of loss are tabulated. All other transactions go to block 576 which tabulates turnaround times. ADVANCE block 578 holds the interceptor transactions until either a signal for a replacement

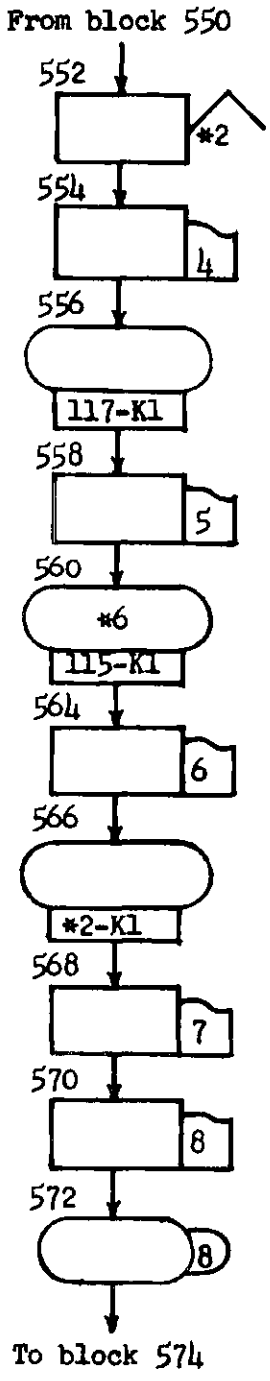

Figure 17. Sub-Section VI

Interceptor Availability and Control Section.

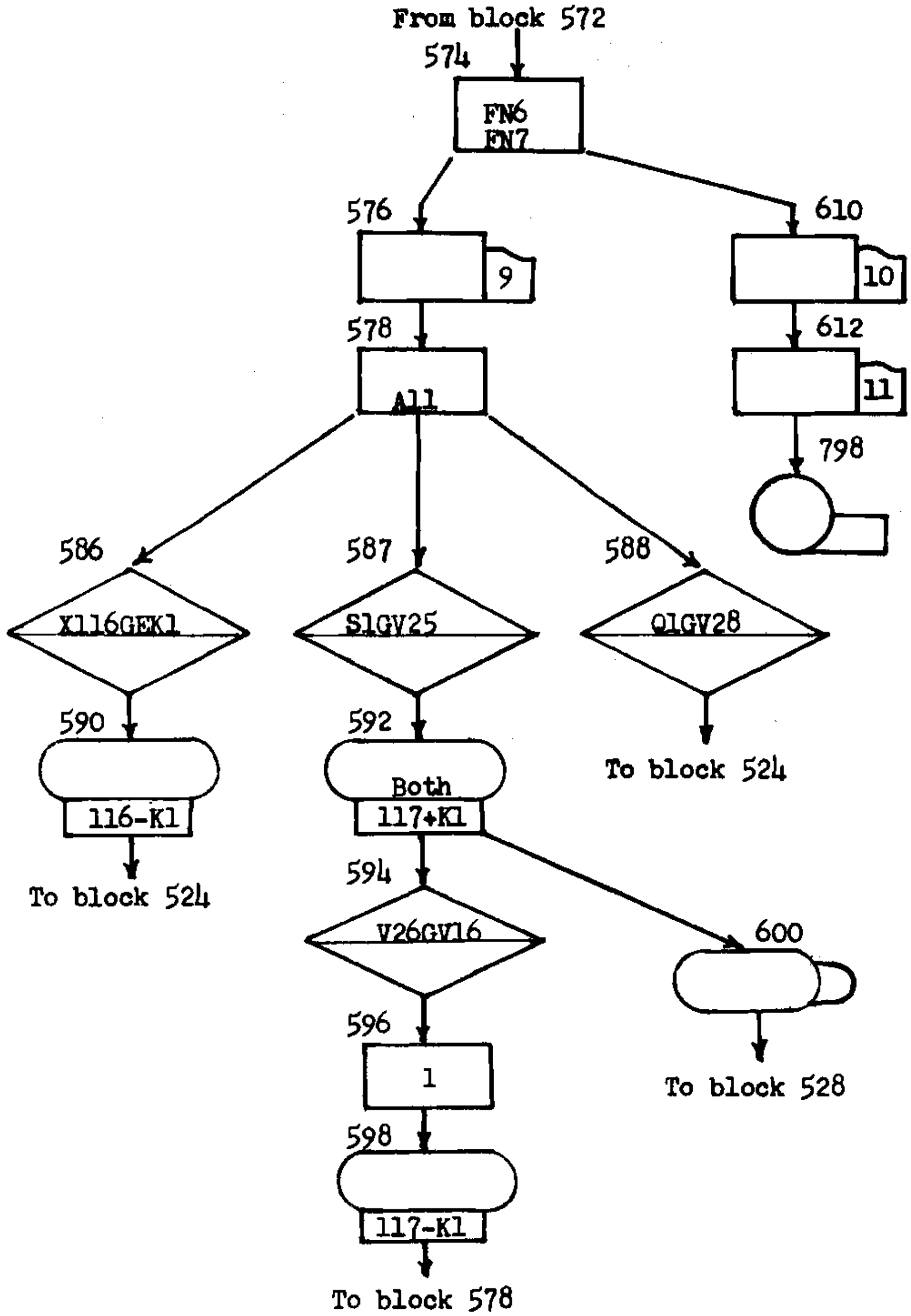

Figure 18. Sub-Section VII

Interceptor Availability and Control Section.

interceptor is received (block 586), or the arriving bomber force is too large for the available interceptor force (block 587), or three or more bombers are subject to being intercepted and no interceptors are available (block 388). In the first and last case above, the interceptor transaction is returned to block 524 in Sub-Section I for take-off. Blocks 592, 594, 596, 598, and 600 allow the interceptor to take-off (through block 600 to block 528) unless the attacking bomber force is still too far away from the defense line. In that case, block 596 delays the transaction one minute and returns it through block 598 to block 578.

CHAPTER V

EXPERIMENTATION

Introduction

To satisfy the objectives of this investigation, two experiments were performed. Each experiment consisted of repeated simulations of the air defense system to provide combat results for six pre-determined defense line locations. The analysis of variance was used to test for a significant difference in results obtained at these locations. The experimental design employed was a completely randomized single factor design with six treatment levels (defense line location) and 36 replications for each level. This yielded 216 observations for each experiment. Replications were obtained by changing the random number seed in the GPSS II program for successive simulation trials. Each simulation provided data in the form of the average number of bomber escapees and the average bomber neutralization distance from the bomb release line for each treatment level. The data concerning average number of escapees were subjected to a one-way analysis of variance to test the hypothesis that treatment effects were zero.

The two experiments differed only in the intercept time function. In the second experiment, the mean of the intercept density function was increased to study the sensitivity of the optimal defense line location to the intercept time function. The effect of changing the intercept time function would be analogous to an air defense system suffering more degradation during a battle than anticipated.

Factors such as heavy enemy electronic countermeasures, or even unfavorable weather conditions, could cause this decreased effectiveness.

The Initial Experiment

In this experiment, the intercept time function, previously shown in Figure 2, has a mean of 6.25 minutes and a range from 3.0 minutes to 10.0 minutes. The air defense system was simulated at six different defense line locations. The six values selected were 150 miles, 200 miles, 250 miles, 300 miles, 350 miles, and 400 miles. All distances were measured from the bomb release line. A value less than 150 miles was not considered, as it is likely that any lesser value would allow time for only one intercept attempt on each bomber. Thus, all "no-kills" would be almost certain escapees. On the other hand, 400 miles was the maximum value tested, as a defense line of 450 miles could not have been reached by the interceptor force with maximum endurance of 140 minutes at a speed of 400 knots.

The experiment yielded the results shown in Table 1. These data were obtained by averaging all 36 replications at each treatment level. Complete results are shown in Appendix B. Table 1 shows that the lowest average number of escapees was allowed when the defense line was at a distance of 250 miles from the bomb release line. Figure 19 shows the average number of escapees and the average neutralization distance plotted as a function of defense line location. It is observed that the average kill distance increases almost linearly as the defense line changes from 150 to 250 miles. The rate of increase in the kill distance drops off sharply as the defense line increases beyond the 250 mile distance.

Table 1. Results of First Experiment

	Defense Line Location					
	150	200	250	300	350	400
Average Number of Escapees	9.19	4.53	2.17	3.17	3.42	4.00
Average Bomber Kill Distance	70.56	113.86	155.47	181.01	202.52	206.93

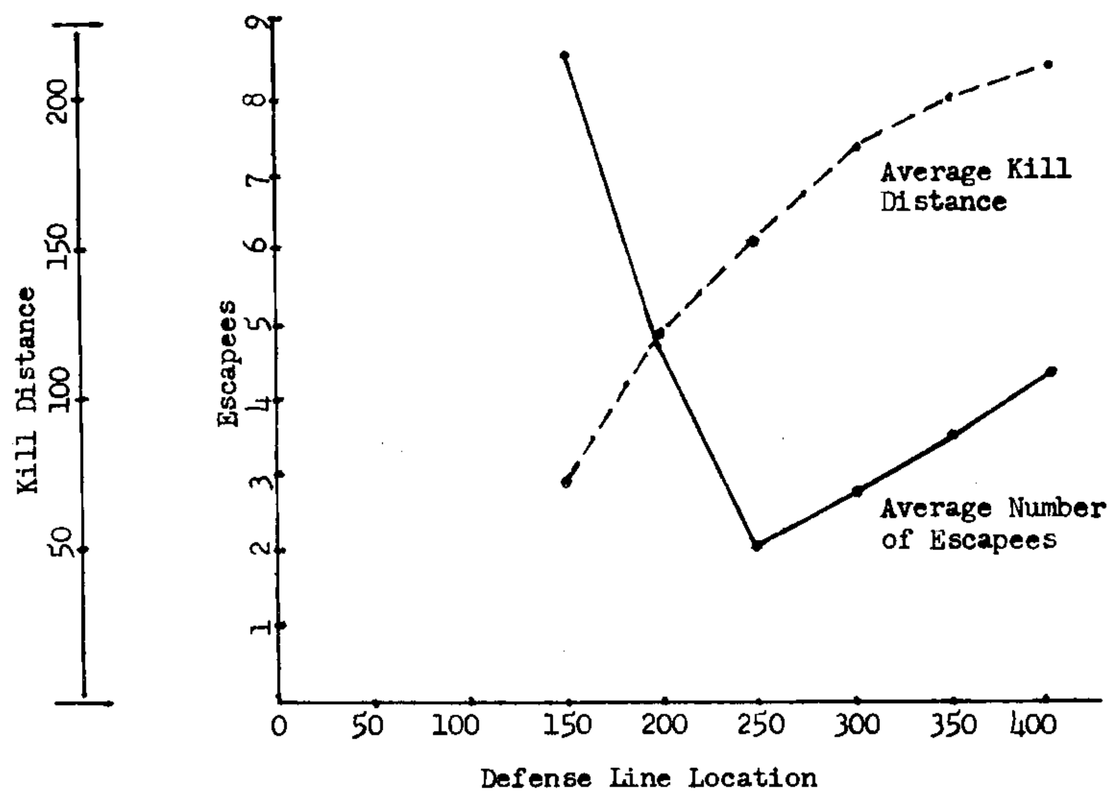

Figure 19. Graph of Results of First Experiment.

A one-way analysis of variance was conducted to determine if defense line location had a significant effect on system performance as measured by the number of escaping bombers allowed. Stated more rigorously, the hypotheses were

$$H_0: \; T_j = 0; \; j = 1, 2, \ldots, 6$$

$$H_1: \; \text{Above not true}$$

where T_j is the j^{th} treatment effect. The results of the analysis of variance are shown in Table 2. The test statistic is highly significant and leads to the

Table 2. ANOVA Table for First Experiment

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Between Treatments	5	1102.97	220.59	34.41 *
Error	210	1345.36	6.41	
Totals	215	2448.33		

* Significant at the .05 level

rejection of the null hypothesis. One comment should be injected here concerning the assumptions underlying the analysis of variance. The procedure assumes homogeneous error variances, and in this experiment it is likely that this assumption was violated. However, Sheffé (28) points out that the significance level is only slightly affected in the one-way classification as long as the number of observations is large and equal for all treatment levels. Such is the case in this experiment.

After performing the analysis of variance, further investigation was undertaken to determine if the minimum number of escapees, 2.17, differed significantly from the other five treatment means. Since this test was conducted after the analysis of variance, there exists some chance of affecting the significance level of the test. Hicks (29) suggests that Duncan's Multiple Range test be used in such circumstances. The results of this test are shown in Table 3. The test in its entirety involves the comparison of all possible combinations of treatment means, but in this case, the only comparisons of interest are those between the "optimum" mean and the other five treatment means. The minimum value of 2.17 escapees differs significantly from all other means except that of 3.17, as shown in Table 3.

Sensitivity Analysis

A second experiment was conducted to study the sensitivity of the optimal defense line location to the time required to complete an intercept. In this experiment, the mean of the intercept time function was increased to 9.20 with a range from 3.0 minutes to 14.0 minutes. A comparison of the intercept time function

Table 3. Comparison of Means for First Experiment

Defense Line Locations Compared	Average Number of Escapees Compared	Difference in Means	Duncan's Significant Range Value
250 vs 150	2.17 vs 9.19	7.02 *	1.3374
250 vs 200	2.17 vs 4.53	2.36 *	1.3121
250 vs 300	2.17 vs 3.17	1.00	1.1771
250 vs 350	2.17 vs 3.42	1.25 *	1.2403
250 vs 400	2.17 vs 4.00	1.83 *	1.2825

* Significant at .05 level

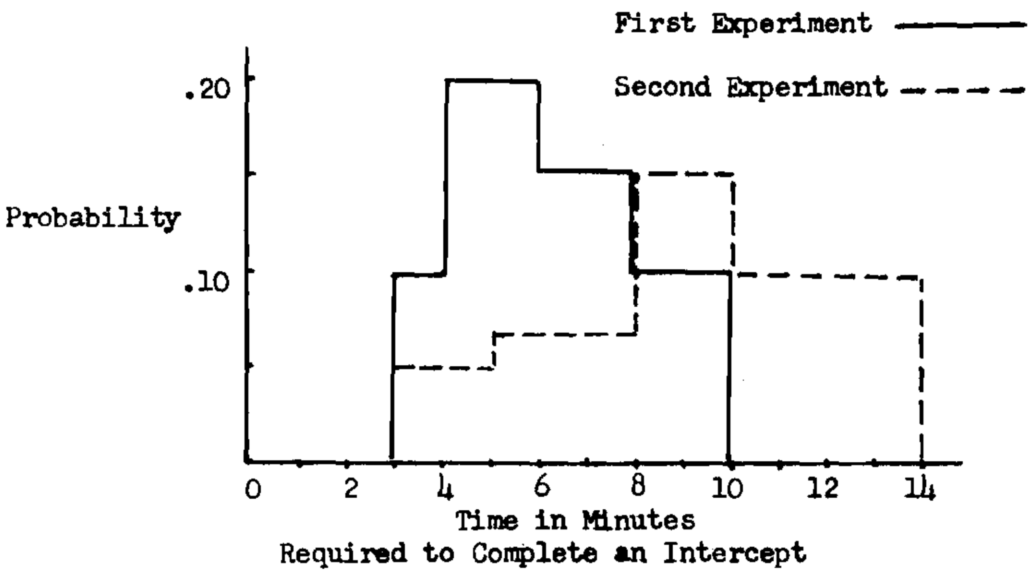

Figure 20. Intercept Time Functions for First and Second Experiments.

used in the first experiment with the function used in the second experiment is shown in Figure 20. Experimental design and analysis, as well as treatment levels, remained the same for both experiments. The average number of escapees and the average neutralization distance for the six treatment levels is shown in Table 4. Figure 21 shows the neutralization distance plotted against the defense line location. In this experiment, the air defense forces were most effective at destroying the attacking force when the defense perimeter was situated at 350 miles. Such a configuration resulted in an average of 5.83 escaping bombers.

An analysis of variance, conducted on the mean number of escapees at each treatment level, led to the rejection of the null hypothesis that treatment effects were zero (Table 5). Duncan's Multiple Range test showed (Table 6) that

Table 4. Results of Second Experiment

	Defense Line Location					
	150	200	250	300	350	400
Average Number of Escapees	20.44	13.42	8.89	8.79	5.83	7.42
Average Bomber Kill Distance	44.47	78.47	112.17	138.94	168.45	177.65

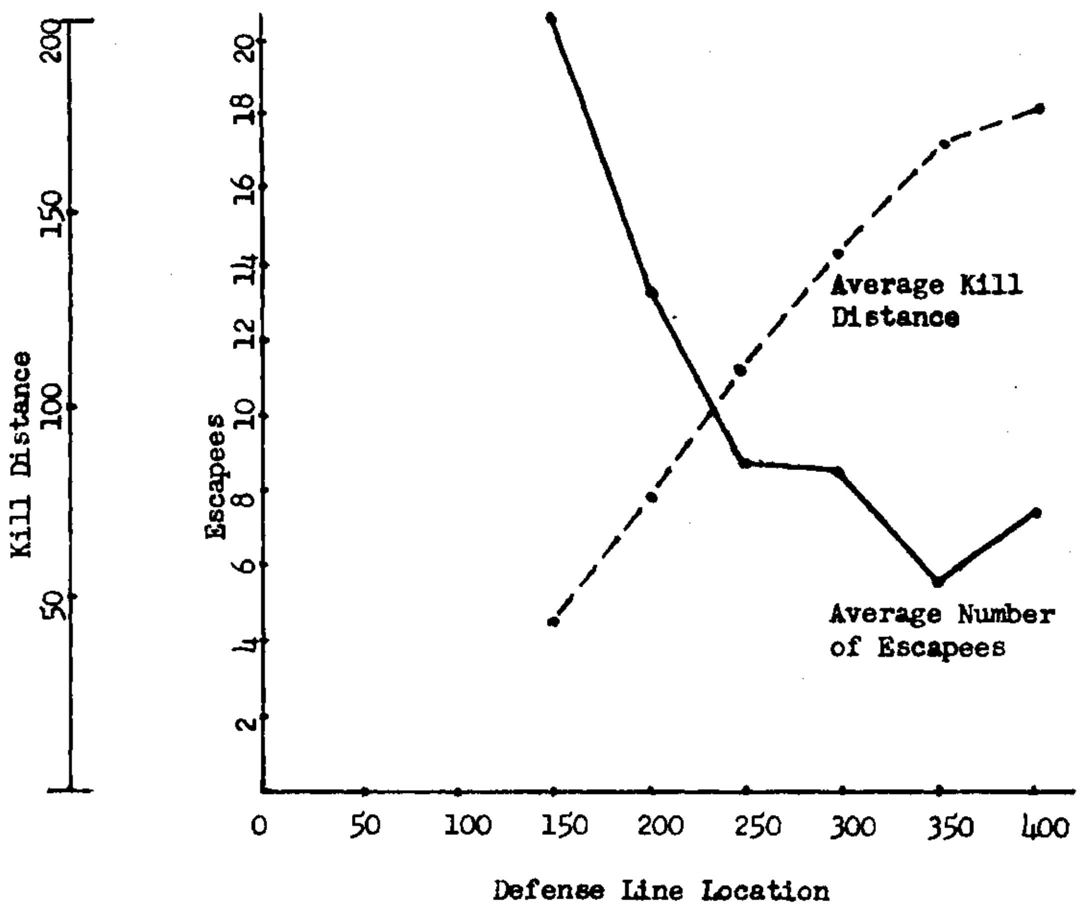

Figure 21. Graph of Results of Second Experiment.

Table 5. ANOVA Table for Second Experiment

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Between Treatments	5	5173.87	1034.77	76.99 *
Error	210	2823.17	13.44	
Totals	215	7997.04		

* Significant at the .05 level

Table 6. Comparison of Means for Second Experiment

Defense Line Locations Compared	Average Number of Escapees Compared	Difference in Means	Duncan's Significant Range Value
350 vs 150	5.83 vs 20.44	14.61 *	1.9372
350 vs 200	5.83 vs 13.42	7.59 *	1.9005
350 vs 250	5.83 vs 8.89	3.06 *	1.8577
350 vs 300	5.83 vs 8.79	2.96 *	1.7966
350 vs 400	5.83 vs 7.42	1.59	1.7050

* Significant at .05 level

the minimum number of escapees, 5.83, differed significantly from all other treatment means except that of 7.42.

Discussion of Results

In both experiments, the position of the defense line is shown to have an effect on the system performance. In each case, a defense line location was determined that minimized (at least for the alternatives considered) the number of escaping enemy bombers. In the first experiment the minimum of 2.17 escapees was obtained for a defense perimeter of 250 miles. The next lowest value of 3.17 escapees occurred for a defense line distance of 300 miles and did not differ significantly from 2.17. This lack of statistical significance probably means that the region containing the optimum is reasonably flat. That is a characteristic of many operations research problems. The second experiment also had two values for the lowest average number of escapees which were not significantly different. The minimum, 5.83, occurred for a defense line distance of 350 miles, and 7.42 escapees resulted with the defense line located at 400 miles.

Comparing the two experiments, it is seen that increasing the mean and variance of the intercept time function in the second experiment caused the defense line position for minimum number of escapees to shift from 250 miles to 350 miles. Also, the average number of escaping bombers increased from 2.17 to 5.83. There is a trade-off between extending the defense perimeter, which allows more time for re-attacks, and retracting the perimeter, which decreases the nonproductive interceptor time spent shuttling between the interceptor base and the defense line.

When the intercept time function was increased in the second experiment, it necessitated extending the defense perimeter to allow more time for re-attacks, but this in turn resulted in less efficient utilization of interceptor combat time, as evidenced by the higher number of escapees.

The results of this analysis illustrate a point discussed by Hitch and McKean (30). They mention the difficulty of arriving at exact solutions to military problems because of "incommensurables." Incommensurables are defined as quantitative criteria which cannot readily be translated into a common denominator. For example, in the first experiment, the minimum number of escaping bombers was 2.17. The next lowest figure was 3.17. Statistical analysis showed that these values do not differ significantly. In such circumstances, a military commander might well decide to accept the 3.17 average number of escapees in order to increase the average bomber neutralization distance by approximately 25 miles. The average kill distance and the average number of escapees are two incommensurables, and some qualitative judgment must be made as to the relative importance of each. The air defense commander must make the final decision, based on his personal experience, his intuition, and his evaluation of the situation.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

General Comments

The specific air defense system modeled was a hypothetical system and its parameters were somewhat arbitrarily assigned. The results obtained from the simulation trials are, strictly speaking, applicable only to the specific system modeled. Any attempt to draw general conclusions from this study must take this fact into consideration.

The system did not have all the components that would normally comprise most air defense systems. Such factors as the inclusion of surface-to-air missiles could significantly alter the relationships of system elements. The conclusions, then, should be read in the light of these factors.

Conclusions

1. The simulation model developed in this study is a realistic model for studying defense system response under a variety of conditions. The model is very flexible and can easily be adapted to a wide range of air defense situations.

2. An air defense system can be structured as a production-type process utilizing queues, facilities, and stores to represent system components.

3. GPSS II is an appropriate simulation language for modeling this type of system. The ease of programming and the automatic statistic gathering features

are some of the language's assets.

4. For the specific situation simulated, the defense line location has a significant effect on the performance of the air defense system.

5. The information gathered from this research indicates that, for a given set of conditions, there exists some optimum position at which the air defense commander should strive to deploy his interceptors for action against attacking bombers.

6. The study also indicates that the defense battle line is sensitive to at least one specific system parameter, the intercept time function. Presumably other parameters would also have some effect.

7. The performance of the simulated air defense system shows a substantial amount of random variation, particularly when the system is not operating near the best defense line location. Thus, statistical evaluation of an air defense system, using few replications, can easily be misleading.

8. From the limited information gained concerning the importance of the intercept time parameter on defense strategy, if intercept times during a battle are longer than anticipated, the best strategy would be to extend the defense perimeter. This contradicts the natural tendency to withdraw when the tide of battle is against the defense.

Recommendations

1. This study should be extended to other elements of the air defense system. More realistic results could be obtained if missiles and dynamic bomb damage were included in the model.

2. More sensitivity analysis should be undertaken to identify those system parameters that have the greatest effect on the optimum location of the defense line. It seems possible that some fairly simple relationship exists between the defense line distance and a few other major parameters.

3. More effort should be directed toward optimizing other elements of the system. The results obtained from this research indicate that additional system optimization studies should be made.

4. An attempt should be made to verify the results obtained from this simulation model by utilizing actual data. If that is not possible, it might be profitable to see if another, possibly more complex, simulation model would yield approximately the same results as obtained with this model.

5. In view of conclusion seven, it is recommended that evaluation teams give very little scoring emphasis to the number of escapees allowed in a single air defense evaluation exercise.

APPENDIX A

COMPUTER PROGRAM

COMPUTER PROGRAM

```
 1    FUNCTION   V33   C2    TIME REQUIRED TO COMPLETE AN INTERCEPT
3     3     24   24
 2    FUNCTION   RN1   D2    WEAPON EFFECTIVENESS (633 KILL/398 NO KILL)
.75   633   1.0  398
 4    FUNCTION   RN1   C6    COMBAT ENDURANCE FACTOR
.0    4     .2   8     .5    12    .8    .6    .9    17    1.0   18
 6    FUNCTION   RN1   C6    TURNAROUND TIME
.0    5     .3   8     .5    12    .8    16    .9    20    1.0   30
 7    FUNCTION   RN1   D2    INTERCEPTOR LOSS RATE (610 LOSS)
.9    575   1.0  610
 8    FUNCTION   V38   C6    INCREMENT ADDED TO NORMAL INTERCEPT TIME
-200  15    -100 7     -30   0     50    0     200   5     400   10
 9    FUNCTION   RN1   C6    NORMAL INTERCEPT TIME
.0    3     .1   5     .3    8     .6    10    .9    13    1.0   14
 10   FUNCTION   RN1   C2
.0    0     1.0  10
 1    VARIABLE   K200              DEFENSE LINE DISTANCE
 2    VARIABLE   K800              HI SPD TGT
 3    VARIABLE   K600              MED SPD TGT
 4    VARIABLE   K400              LO SPD TGT
 5    VARIABLE   K400              INTERCEPTOR CRUISE SPD
 6    VARIABLE   K25               TOTAL NUMBER OF INTERCEPTORS
 7    VARIABLE   K10               NUMBER DESIRED AIRBORNE AT ONE TIME
 8    VARIABLE   K3                WEAPON CAPACITY
 9    VARIABLE   K75+V20*K60/V2-V1*K60/V2-V23-V16
 10   VARIABLE   K3/K2
 11   VARIABLE   M1*P3/K60
 13   VARIABLE   V20*K60/P3-K30*K60/P3
 14   VARIABLE   P1*V20*K60/P3-V1/K3*K60/P3
 15   VARIABLE   P2*V20*K60/P3-V1*K2/K3*K60/P3
 16   VARIABLE   V1*K60/V5
 17   VARIABLE   K140
 18   VARIABLE   V17*P3/K20-M1*P3/K20-V16*P3/K20+V16
 19   VARIABLE   V18-K2*V16
 20   VARIABLE   K400
 21   VARIABLE   V18-V16+P7*K100*K60/V5
 22   VARIABLE   V16*FN5
 23   VARIABLE   K5
 24   VARIABLE   -V16-V23+K60/V3*V20-K60/V3*V1
 25   VARIABLE   X117*V10-Q1
 26   VARIABLE   X120/V27-V23
 27   VARIABLE   S1+K1
 28   VARIABLE   K1+W536
 30   VARIABLE   V20*K60/P3-V1*K60/P3
 31   VARIABLE   V20-V11
 32   VARIABLE   V11+V1-V20
 33   VARIABLE   FN8+FN9
 34   VARIABLE   V37+V47*V44-X181*FN5*V44*X180+V45
 35   VARIABLE   V9+V16
 36   VARIABLE   K100*K60/V5
 37   VARIABLE   V16-P7*K100*K60/V5
 38   VARIABLE   P6*K100-V32
 39   VARIABLE   -V38
 40   VARIABLE   V41/K100
 41   VARIABLE   V1-M1*V5/K60+K50
 42   VARIABLE   P4-M1
 43   VARIABLE   V17-V16
 44   VARIABLE   V36/K2
 45   VARIABLE   V37*FN10/K10+V44*FN10/K10+K3
 46   VARIABLE   V37+FN10*V44/K10+K3
 47   VARIABLE   V37-FN10*V44/K10+K3
```

```
*
*
*     START OF TARGET GENERATING SECTION
*
*
 1    ORIGINATE  80    5                     36          3    2
 2    ORIGINATE  115   10                    36          5    3
 11   ORIGINATE  75    20                    38          5    3
 12   ORIGINATE  125   20                    38          3    1
 26   ORIGINATE  80    20                    40          2    1
 36   ASSIGN     3     V2                    42
 38   ASSIGN     3     V3                    42
 40   ASSIGN     3     V4                    42
 42   ADVANCE                                44
 44   SAVEX      124+  K1                    46
 46   ASSIGN     8     X124                  48
 48   ASSIGN     1     K1                    50
 50   ASSIGN     2     K1                    60
 60   ASSIGN     5     V30                   62
 62   SPLIT                                  64    66
 64   STORE      1                           76          *5
 76   ASSIGN     5     K300                  300
 1    CAPACITY   200
 66   SAVEX      120+  P5                    68
 68   ASSIGN     5+    K1                    70
 70   LOOP       5                           72    798
 72   ADVANCE                                74          1
 74   SAVEX      120-  K1                    70
*
*
*     START OF PRE-INTERCEPT SECTION
*
*
 300  QUEUE      1                     ALL   301   305
 301  COMPARE    M1    GE    V13             306
 302  COMPARE    M1    GE    V14       ALL   310   312
 303  COMPARE    M1    GE    V15       ALL   322   324
 304  COMPARE    V32   G     K50       BOTH  406   434
 406  COMPARE    V32   G     K150      BOTH  408   436
 408  COMPARE    V32   G     K250      BOTH  410   438
 410  COMPARE    V32   G     K350            412
 412  SAVEX      170   K4                    414
 414  ASSIGN     6     K1                    416
 416  ASSIGN     6+    V6                    418
 418  ASSIGN     5     K300                  420
 420  LOOP       6                           422   440
 422  ASSIGN     5+    K1              BOTH  424   420
 424  COMPARE    X*5   E     X170            426
 426  ASSIGN     4     P5                    428
 428  ASSIGN     4-    K300                  430
 430  QUEUE      2                     BOTH  432   37
 37   SAVEX      *5    K0                    741
 432  GATE       NU*4                        337
 434  SAVEX      170   K1                    414
 436  SAVEX      170   K2                    414
 438  SAVEX      170   K3                    414
 440  ASSIGN     6     K1                    442
 442  ASSIGN     6+    V6                    444
 444  ASSIGN     5     K300                  446
 446  LOOP       6                           448   454
 448  ASSIGN     5+    K1              BOTH  452   446
 452  COMPARE    X*5   G     K0              426
 454  ASSIGN     5     K300            BOTH  455   463
 456  ADVANCE                                300         1
 458  COMPARE    X172  G     K0              460
 460  ASSIGN     4     X172                  52
 52   SAVEX      172   K0                    335
 455  COMPARE    W537  G     K0              457
 457  LOGIC      S4                          459
 459  BUFFER                                 461
 461  LOGIC      R4                    BOTH  458   463
 463  ADVANCE                          BOTH  305   456
```

```
*
*
*     START OF INTERCEPT SECTION
*
*
 305  GATE       LS1                                334
 334  ASSIGN     4      X200                        335
 335  ASSIGN     5+     P4                          337
 337  ASSIGN     6      X*5              BOTH       338    80
 338  COMPARE    V39    G       V31                 300           1
 80   ADVANCE                            BOTH       82     336
 82   COMPARE    X*4    G       V8                  84
 84   BUFFER                                        741
 336  ASSIGN     7+     K1                          342
 342  SAVEX      201    P8                          344
 344  SAVEX      202    V31                         346
 346  SAVEX      203    P3                          348
 348  SAVEX      204    C1                          350
 350  SAVEX      205    P7                          352
 352  SAVEX      206    P4                          354
 354  SAVEX      207    P6                          356
 356  SAVEX      208    Q1                          358
 358  SAVEX      209+   K1                          361
 361  SAVEX      210    X*5                         359
 359  SAVEX      211    P5                          357
 357  SAVEX      212    P2                          355
 355  SAVEX      213    X115                        353
 353  SAVEX      214    W585                        362
 362  LOGIC      R1                      BOTH       366    86
 86   ADVANCE                                       741
 364  PRINT      200    214                         366
 366  SEIZE      *4                                 368
 368  ASSIGN     4+     K100                        370
 370  MARK       2                                  372
 372  ASSIGN     5      FN1                         47
 47   MARK       1                                  373
 373  HOLD       *4                      BOTH       375    377
 375  COMPARE    V31    LE      K0                  379
 377  COMPARE    MP1    GE      P5                  49
 49   ASSIGN     1      K1                          374
 379  SAVEX      150+   K1                          381
 381  ASSIGN     4-     K100                        383
 383  RELEASE    *4                                 51
 51   SPLIT                                         53     308
 53   ASSIGN     4+     K300                        641
 374  TABULATE   13                                 385
 385  ASSIGN     2      K1                          376
 376  ASSIGN     4-     K100                        378
 378  SAVEX      *4+    K1                          380
*
*
*     START OF POST-INTERCEPT SECTION
*
*
 380  RELEASE    *4                                 630
 630  ASSIGN     4+     K300                        631
 631  SPLIT                                         641    632
 632  ADVANCE                            FN         2
 633  ASSIGN     4-     K300                        670
 670  LOGIC      R5                                 384
 634  ASSIGN     4-     K300             BOTH       635    306
 635  COMPARE    V31    G       K30                 636
 636  LOGIC      S5                                 637
 637  BUFFER                             BOTH       638    640
 638  GATE       NU*4                               639
 639  LOGIC      R5                                 737
 737  ASSIGN     5      K300                        739
 739  ASSIGN     5+     P4                          337
 640  LOGIC      R5                                 741
 741  ASSIGN     5      K300                        300
 641  LOGIC      S5                      BOTH       642    652
 642  COMPARE    V32    G       K50      BOTH       643    654
 643  COMPARE    V32    G       K150     BOTH       644    655
 644  COMPARE    V32    G       K250     BOTH       645    656
 645  COMPARE    V32    G       K350                646
 646  SAVEX      175    K4                          647
```

```
647  LOGIC      R*4                          648
648  SAVEX      *4     X175                  54
54   MARK       1                            649
649  ASSIGN     4-     K300          BOTH    650   657
650  GATE       U*4                          651
651  ASSIGN     4+     K300                  652
652  SAVEX      *4     K0                    653
653  LOGIC      R*4                          798
654  SAVEX      175    K1                    647
655  SAVEX      175    K2                    647
656  SAVEX      175    K3                    647
657  COMPARE    MF1    GE     V36            658
658  ASSIGN     4+     K300          ALL     659   662
659  COMPARE    X*4    GE     K4             656
660  COMPARE    X*4    E      K3             655
661  COMPARE    X*4    E      K2             654
662  COMPARE    X*4    E      K1             652
384  TABULATE   14                           386
386  TABULATE   15                   BOTH    388   396
388  COMPARE    V31    LE     K0             390
390  TABULATE   16                           392
392  ASSIGN     8      K0                    394
394  TABULATE   17                           450
396  ASSIGN     8      V31                   394
398  TABULATE   18                           671
671  LOGIC      R5                           634
*
*    START OF INTERCEPTOR AVAILABILITY AND CONTROL SECTION
*    SUB-SECTION I
*
*
500  ORIGINATE  1      1      7              502          1
502  ASSIGN     1      V6                    504
504  ASSIGN     1+     K1                    506
506  SAVEX      118+   K1                    508
508  LOOP       1                            510   798
510  ASSIGN     2      X118                  512
512  SPLIT                                   514   506
514  ASSIGN     4      V16                   516
516  ASSIGN     5      V9                    518
518  SEIZE      *2                   BOTH    520   578    *5
*
*
*    SUB-SECTION II
*
*
520  COMPARE    X114   L      V7             522
522  SAVEX      114+   K1                    524
524  MARK                                    526
526  SAVEX      117-   K1                    528
528  ASSIGN     3      FN4                   530
530  TABULATE   1                            532
532  TABULATE   2                            534
534  SAVEX      *2     K1                    536
536  ADVANCE                                 537
537  COMPARE    M1     GE     K5     BOTH    541   539
539  COMPARE    M1     GE     V16            538
*
*
*    SUB-SECTION III
*
*
541  GATE       LS4                          543
543  ASSIGN     4      V40                   545
545  SAVEX      172    P2                    547
547  ASSIGN     2+     K300                  549
549  SAVEX      *2     P4                    551
551  ASSIGN     4      P2                    553
553  SPLIT                                   555   557
555  ASSIGN     2-     K300                  538
557  ADVANCE                         ALL     620   624
620  COMPARE    X*2    GE     K4             649
621  COMPARE    X*2    E      K3             649
622  COMPARE    X*2    E      K2             649
623  COMPARE    X*2    E      K1             649
624  ADVANCE                                 652
```

```
*
*
*      SUB-SECTION IV
*
*
                                                 540
538  RELEASE    *2                               544
540  TABULATE   3                         BOTH   41     43
544  SAVEX      115+   K1                        542
41   GATE       U*2                              542
43   COMPARE    M1     GE     V43                45
542  MARK       1                         BOTH   546    602
45   ASSIGN     3      V18                BOTH   548    606
546  COMPARE    M1     GE     V19                559
548  COMPARE    X117   G      V7                 561
559  ASSIGN     8      P2                        78
561  ASSIGN     8+     K300               BOTH   604    546
602  COMPARE    X*2    GE     V8          BOTH   548    606
604  GATE       U*2                              559
606  SAVEX      116+   K1
*
*
*      SUB-SECTION V
*
*
                                                 563
78   GATE       NU*2                      BOTH   88     90
563  ASSIGN     7      X*8                BOTH   92     94
88   COMPARE    P7     G      KO                 96
92   COMPARE    V37    G      V44                565
95   ASSIGN     6      V47                       565
93   ASSIGN     6      V46                .5     93     95
96   ADVANCE                                     565
94   ASSIGN     6      V45                       565
90   ASSIGN     6      V47                ALL    613    615
565  LOGIC      S*8                              563
613  GATE       LR*8                             550
614  COMPARE    M1     GE     V21                550
615  COMPARE    X*2    G      V8                 552
550  ADVANCE
*
*
*      SUB-SECTION VI
*
*
                                                 554
552  SEIZE      *2                               556
554  TABULATE   4                                558
556  SAVEX      117-   K1                        560
558  TABULATE   5                                564
560  SAVEX      115-   K1                        566
564  TABULATE   6                                568
566  SAVEX      *2-    K1                        570
568  TABULATE   7                                572
570  TABULATE   8                                574
572  MARK       8
*
*
*      SUB-SECTION VII
*
*
574  ADVANCE                              FN     7                    FN6
576  TABULATE   9                                578
578  ADVANCE                              ALL    586    588
586  COMPARE    X116   GE     K1                 590
587  COMPARE    S1     G      V25                592
588  COMPARE    Q1     G      V28                524
590  SAVEX      116-   K1                        524
592  SAVEX      117+   K1                 BOTH   594    600
594  COMPARE    V26    G      V16                596
596  ADVANCE                                     598           1
598  SAVEX      117-   K1                        576
600  MARK                                        528
610  TABULATE   10                               612
612  TABULATE   11                               798
```

```
*
*
*     START OF INTERCEPTOR SELECTION SECTION
*
*
 700  ORIGINATE   1    1    7          702        1
 702  ASSIGN      1    V35             704        *1
 704  ASSIGN      1    K15             706
 706  BUFFER                           708
 708  ADVANCE                    .5    710   726
 710  ASSIGN      1+   K1        BOTH  712   730
 712  COMPARE     P1   LE   V6   BOTH  714   710
 714  GATE        NU*1                 716
 716  LOGIC       R2                   718
 718  LOGIC       R3                   720
 720  SAVEX       200  P1              722
 722  LOGIC       S1                   724
 724  GATE        LR1                  725
 725  GATE        LR5                  708
 726  ASSIGN      1-   K1        BOTH  728   744
 728  COMPARE     P1   GE   K1   BOTH  714   726
 730  ADVANCE                    BOTH  732   738
 732  GATE        LS2                  734
 734  LOGIC       R2                   736
 736  ADVANCE                          738        1
 738  ADVANCE                    .5    740   750
 740  LOGIC       S2                   742
 742  ASSIGN      1    K1        BOTH  714   710
 744  ADVANCE                    BOTH  746   738
 746  GATE        LS3                  748
 748  LOGIC       R3                   736
 750  LOGIC       S3                   752
 752  ASSIGN      1    V6        BOTH  714   726
*
*
 798  TERMINATE
 450  TERMINATE   R
```

APPENDIX B

EXPERIMENT RESULTS

RESULTS OF FIRST EXPERIMENT

Number of Escapees/ Bomber Neutralization Distance

Random Number Seed	Defense Line Distance					
	150	200	250	300	350	400
010615507775	13/64.45	5/117.87	1/153.84	1/205.39	7/193.25	5/198.96
202317042605	9/73.68	6/119.00	3/151.33	5/163.05	6/178.92	13/156.53
044116314421	10/64.20	2/117.51	3/149.53	7/164.16	0/224.68	4/227.09
226377405421	7/74.55	2/113.83	2/137.35	3/189.41	3/185.97	6/219.77
171105031661	9/71.33	6/115.31	1/153.89	7/183.83	1/221.95	1/235.20
026264452471	8/77.69	8/100.37	2/168.49	9/148.84	12/176.01	4/212.59
173336044731	9/68.88	7/101.40	2/155.60	0/193.75	2/230.57	6/205.64
143367137071	8/70.07	3/118.87	3/146.76	4/171.07	2/217.39	3/217.12
052023165611	11/68.64	3/122.07	3/148.45	0/212.24	0/233.15	4/228.05
013422615635	7/72.08	4/107.52	3/165.40	4/173.27	2/204.76	3/218.81
245360677361	10/69.99	11/ 94.03	1/157.07	3/191.17	3/231.80	2/214.95
044450752221	7/73.76	1/121.08	1/154.40	5/186.87	2/192.17	4/211.96
110007144221	3/76.28	5/110.61	2/153.99	2/177.56	1/213.27	1/228.39
335220550671	15/65.03	5/115.03	4/147.03	1/180.25	11/149.53	3/206.44
160102045615	6/79.81	4/119.43	0/165.37	0/189.44	6/195.36	5/211.23
237745234711	12/65.71	2/117.17	0/164.65	2/191.03	2/199.53	3/229.00
112740715001	8/69.23	2/116.11	6/139.45	2/183.16	3/233.56	3/240.16
165355600671	10/68.05	6/109.88	0/172.92	0/193.37	5/184.59	3/225.76
156527640721	4/74.87	8/104.11	1/163.67	2/178.67	4/202.27	6/190.60
223071705271	8/76.47	5/117.69	6/141.61	2/173.17	3/193.65	3/207.67
220077624231	12/67.89	7/105.47	2/157.07	3/202.76	1/217.09	8/214.73
272560041211	7/70.45	2/119.92	1/164.59	1/190.21	4/197.05	9/191.21
346013572671	8/70.39	3/121.92	2/167.04	4/160.67	2/208.68	5/195.77
247246142771	7/72.68	4/116.25	1/164.95	0/198.84	3/204.29	3/212.53
246427345311	9/73.28	3/111.36	1/160.21	3/177.84	4/207.03	4/209.72
024335140031	6/74.77	6/108.55	2/152.03	4/168.95	1/236.64	2/225.16
021401444321	15/57.65	4/123.87	3/144.97	4/171.65	4/185.92	3/234.48
066546144421	17/58.77	4/115.52	3/142.00	8/159.65	7/155.44	5/220.32
127261736601	7/75.32	6/114.45	1/156.79	1/208.35	1/215.09	3/193.43
066311763721	5/79.17	4/116.57	4/151.96	5/156.28	4/201.48	0/261.61
016070425121	10/75.16	5/115.91	5/160.23	4/167.60	3/199.99	4/197.89
262443724641	7/75.40	9/102.20	1/167.31	6/166.97	0/233.41	2/220.97
105347205201	12/67.33	3/115.67	2/150.64	8/167.45	8/169.91	4/213.67
236322260421	14/64.12	0/124.31	2/155.13	3/193.12	5/156.32	6/201.88
125363147761	13/63.99	4/117.41	2/158.69	1/189.40	1/211.41	1/223.76
142017261161	9/69.09	4/111.59	2/152.41	0/186.89	1/228.48	5/207.87

RESULTS OF SENSITIVITY ANALYSIS

Number of Escapees/ Bomber Neutralization Distance

Random Number Seed	Defense Line Distance 150	200	250	300	350	400
010615507775	20/46.16	9/78.11	7/116.76	6/150.27	4/191.37	2/203.31
202317042605	22/40.55	16/66.82	7/121.49	5/157.55	2/186.12	5/178.79
044116314421	27/36.67	15/80.29	10/108.31	6/147.31	5/163.90	8/191.33
226477405421	19/45.07	12/78.39	6/120.29	9/136.25	8/159.85	9/166.71
171105031661	23/39.88	8/87.60	5/129.83	11/141.47	7/168.07	4/192.11
026264452471	16/51.35	12/79.95	10/114.63	6/150.06	4/171.94	6/180.43
173336044731	31/29.69	15/76.13	7/109.65	5/155.09	4/180.57	10/170.27
143367137071	13/49.39	5/83.41	13/102.65	13/105.76	8/139.83	8/166.31
052023165611	12/55.08	10/83.24	7/120.64	6/142.43	10/139.20	5/194.31
013422615635	22/46.25	18/71.44	15/94.96	9/134.05	4/189.04	4/181.49
245360677361	20/48.61	16/67.28	7/118.83	13/134.25	1/203.51	5/163.79
044450752221	22/45.19	11/85.53	17/ 96.44	4/165.11	10/146.09	6/195.47
110007144221	24/35.09	19/76.43	9/118.63	3/151.81	3/203.47	8/162.48
335220055061	22/39.88	20/67.49	7/114.27	11/146.97	4/185.19	2/202.41
160102045615	15/54.21	11/83.65	6/121.27	10/135.61	5/156.35	13/135.08
237745234711	16/44.91	14/80.13	9/114.51	4/152.47	2/182.09	8/192.40
112740715001	27/38.67	18/70.56	10/104.31	9/117.67	6/166.27	8/165.68
165355600671	17/44.58	9/78.29	8/111.78	6/149.13	6/171.81	5/181.34
156527640721	20/46.92	15/80.92	7/122.60	18/119.31	3/191.28	7/178.60
223071705271	24/38.81	17/80.23	10/115.36	12/131.39	9/146.71	3/197.01
220077624231	15/46.85	12/78.59	7/119.93	4/146.19	10/162.71	7/182.99
272560041211	16/50.53	12/84.25	8/113.92	3/151.00	2/175.09	11/169.01
346013572671	22/43.91	12/85.31	12/105.25	6/151.60	8/165.88	9/187.27
247246142771	19/50.00	8 /90.21	8/121.87	21/103.48	8/150.01	8/172.87
246427345311	26/44.61	16/69.60	9/119.09	8/135.27	4/172.49	8/179.64
024335140031	17/47.33	8/92.33	6/114.03	6/151.75	7/165.68	0/239.80
021401444321	23/39.15	14/80.28	11/ 82.60	12/122.44	12/153.51	4/203.85
066546144421	20/53.23	12/91.00	11/105.16	11/132.97	11/137.15	6/189.59
127261736601	19/41.93	14/72.13	4/125.77	8/140.59	3/189.07	9/138.12
066311763721	21/47.85	17/71.79	11/106.99	14/130.81	9/137.23	7/183.53
016070425121	20/42.72	15/71.93	8/117.69	7/148.37	10/139.44	11/143.73
262443724641	23/37.07	15/72.61	9/101.55	8/142.45	7/170.84	11/189.28
105347205201	21/44.53	17/77.89	11/103.93	8/137.80	5/166.60	16/134.16
236322260421	18/50.51	8/89.20	9/104.36	17/110.79	5/166.33	20/152.59
125363147761	23/43.31	19/67.15	11/105.59	4/160.19	1/195.19	9/171.51
142017261161	21/43.27	14/74.85	8/113.15	13/112.19	3/173.29	6/158.09

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