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A SIMULATION MODEL FOR HELICOPTER MAINTENANCE MANAGEMENT

A THESIS

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by

Joel Roger Steine

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A SIMULATION MODEL FOR HELICOPTER MAINTENANCE MANAGEMENT

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SUMMARY

Airmobile operations through the use of helicopters are the latest development in the conduct of ground warfare. Proper troop employment requires the landing of relatively large groups of men and equipment on the ground within a short time span. In order to accomplish this objective, sufficient helicopters must be available.

This research involves a comparison of four maintenance management alternatives to determine their effect upon the rate of helicopter availability. Through the construction of a computerized model and the subsequent analysis of data generated by simulation, the research was aimed at determining the maintenance policy producing the greatest helicopter availability under given conditions. This information will aid commanders and maintenance personnel in solving maintenance management problems.

The model was programmed for the Univac 1108 digital computer system utilizing General Purpose System Simulator II (GPSS II), a special purpose programming language. The maintenance workload was generated by the simulated flight of 25 helicopters and included both scheduled and random maintenance. The per cent of available helicopters flown was varied to determine the effect upon the helicopter availability rate.

It was found that the helicopter availability rate reacts in an approximate linear manner to a change in the flying program. The capabilities and limitations of direct support detachments and companies to support the flying program were also determined.

CHAPTER I

INTRODUCTION

The Environment

Airmobile operations through the use of helicopters are the latest development in the conduct of ground warfare. Their use in South-East Asia, where the terrain is highly untraversable by surface vehicle, has been highly successful. Proper employment requires the landing of relatively large groups of men and equipment on the ground within a short time span. In order to accomplish this objective, sufficient helicopters must be available, and therefore, the operational availability of helicopters is of prime concern to commanders at all levels.

Operational availability as defined by Sikorsky's R. W. Caseria at the Fifth Reliability and Maintainability Conference (3) is as follows:

> Operational availability is the proportion of time an aircraft is available to perform its intended functions within a given set of operational constraints. It is the reflection of inherent failure and repair traits of the aircraft, scheduled maintenance policies, maintenance manpower force, logistic and ground support equipment resources, and flight operational demands.

Given specific resources and the number of helicopters with known inherent traits, availability becomes a function of maintenance policies and operational demands.

Statement of Objectives

This thesis consists of two related efforts. One is the simulation of an operational helicopter company with supporting maintenance units, followed by the study of several specific maintenance management policy alternatives. The first project is reported in Chapter III. The second project takes specific maintenance policies, and through the use of the simulation model, investigates each policy through the means of simulation experiments. The maintenance policies are in essence managerial alternatives available to those responsible for the maintenance effort within military helicopter organizations. These alternatives are:

1. The reduction of non-essential flights so as to assure a more predictable availability of helicopters.

2. The employment of several Direct Support Detachments* as opposed to one Direct Support Company.**

3. The reduction of inspection intervals in an effort to increase availability.

4. The performance of all periodic inspections by direct support units.

The objective of this project is an investigation of these alternatives to determine their effect upon the system. The results of this research are reported in Chapter V.

The Maintenance Management Problem

A helicopter unit exists to provide operational capability in one or more of the following ways:

1. Performance of missions.

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*A Direct Support Detachment is structured to perform direct support maintenance for a separate helicopter company.

**A Direct Support Company is structured to perform direct support maintenance for a helicopter battalion consisting of four helicopter companies.

2. The maintenance of helicopters in a high state of mission readiness (equipment readiness).

3. Performance of training flights for aviator proficiency (manpower readiness).

All maintenance activity results directly or indirectly from trying to accomplish these activities.

Maximum operational availability, consistent with the resources available, is the objective of maintenance management. Operational availability has different meanings for each of the three areas mentioned above. In combat, the commander of an armed helicopter reaction force may be faced with the difficult decision of total deployment or of retaining a portion of his force for possible contingencies. An uncommitted unit strives to achieve a balance between training and the maintenance of a mission ready force. A training unit simply measures the quantity and quality of training flights. These problems require that the management system recognize and respond to different objectives both among missions and over a period of time.

It is the premise of this thesis that the key to greater helicopter availability lies in the joint effort of both commanders and maintenance managers. Of the four alternatives previously mentioned, the first two are the direct concern of commanders while the latter two are the responsibility of maintenance personnel. Through the manipulation of the simulation model, the effect of changing these alternatives on the system will be assessed.

Scope

While this research is directed towards tactical military helicopter organizations it is not limited to that role. Any organization employing helicopters or conventional aircraft should find the results useful. The operator of a commercial helicopter service might find that through decreasing the inspection interval he has improved operational availability.

This research is limited to the exploration of management alternatives, and is not applicable to the study of other maintenance problems such as stockage levels of repair parts or skill levels of mechanics. However, with some effort the model could be restructured to include these variables.

Assumptions

There are numerous variables associated with a helicopter maintenance system. The development of a simulation model considering them all would be a vast undertaking. In addition it is difficult and time-consuming to assimilate the input data describing them. The model was structured to consider only the aforementioned management facets and certain simplifying assumptions were made concerning the remaining variables. While these assumptions will certainly bias the results of the simulation all areas to be studied will be affected to the same degree. The assumptions are:

1. There is an inexhaustible supply of repair parts.
2. All units operate at authorized strength with authorized equipment.

Once these assumptions have been made it is possible to construct a computer simulation of a tactical helicopter company with its organic maintenance element and a supporting maintenance unit.

Approach

There are two likely techniques for modeling maintenance management systems. One is the application of purely analytical techniques while the other is simulation using Monte Carlo methods. Two characteristics of any management problem make analytical and judgmental solutions very difficult to obtain. These are:

1. A large number of relevant factors which interact with each other in a complex manner.
2. A number of elements in the system whose behavior is stochastic.

Helicopter maintenance management exhibits both these characteristics. Two examples of the first condition are: the interactions between such factors as operational plans and levels of available resources or among shift policies and levels of available resources. Examples of the second condition are: frequencies of malfunctions, the malfunction repair time, and flight lengths. As a result, simulation appears to be the most useful technique for this research. Purely analytical solutions to problems exhibiting the above characteristics can sometimes be obtained by simplifying assumptions. These assumptions usually neglect the interactions of some of the factors and ignore the stochastic behavior of all or most of the elements.

CHAPTER II

LITERATURE SURVEY

Introduction

Because of the vast amount of Department of Defense resources devoted to maintenance and the relationship between these activities and operational effectiveness, many studies have been undertaken to examine ways of improving maintenance management. Besides those studies concerned directly with maintenance management per se there are others that examine overall system effectiveness in which maintenance management performs a vital role. The methods employed to investigate this area include both simulation through Monte Carlo analysis and purely analytical techniques.

Simulation Models

An early maintenance management simulation used in logistics research by the Rand Corporation was the "Base Maintenance - Operations Model" which was developed to study the interaction of aircraft operations and base level logistics, particularly direct maintenance.

> In measuring the effects of Air Force maintenance and operations policies, the model improves upon past methods, which had limited success in dealing with random real-world events. It does so by using Air Force data of two sorts: fixed numbers, such as the number of planes in a squadron, the number of personnel in a squadron, etc.; and probability distributions, such as the distribution of times needed to repair a jet engine. From the probability distributions, random-number draws reproduce real-world events which happen in random patterns. The principal draws determine (1) whether or not a malfunction occurs on an aircraft, (2) the kind of malfunction and thus the maintenance skill-type demanded,

and (3) the time it will take to correct the malfunction. (For example, a random draw may determine that two hours are to be spent in engine repair at a particular time.)

In this way, the model simulates the random nature of real-world maintenance and operations events, and produces data from which credible short-range predictions of the behavior of random phenomena becomes possible; in turn, these predictions enable reasonably accurate estimates of the effects of proper manning and of the immediate effects of policy changes. (9, iii)

A second generation simulation concerned with maintenance management is the Base Operations-Maintenance Simulator (BOMS) which models the essential characteristics of an Air Force Base employing a SAC B-52/KC-135 organization.

To study complex base maintenance management systems, analytical techniques (e.g., linear and dynamic programming, queueing theory) are, as yet, of limited use. Simulation techniques, on the other hand show greater promise. Not only do they afford better understanding of such systems but also they can predict, with relatively high degrees of confidence, how a system will react to various changes such as variations in policies (decision rules) or in levels of resources (sensitivity tests). We are presently using the BOMS to study both these kinds of changes. We are exploring ways of improving the effectiveness of the base at little or no extra cost, or maintaining the effectiveness at reduced cost. This simulation technique allows us to look at long periods of simulated activity and also supplies certain output data which cannot be obtained from present base data systems. (4,-V-)

One of the latest simulations for maintenance management is the Support-Availability Multi-System Operations Model (SAMSOM). SAMSOM is a very general simulation model that has been used effectively in studies of aircraft weapon systems (tactical fighters) and aircraft support systems (cargo aircraft). The model inputs include system and subsystem reliability and maintainability parameters and desired quantities of support resources (personnel, parts, equipment and facilities). Activated by flying schedules, sortie requirements, alert commitments, and operations policies, it simulates weapon system operations and logistic support requirements at one or more bases. It also provides outputs reflecting the capability of an aircraft organization to maintain selected readiness and alert postures (12).

Simulations of aerospace maintenance systems have also been accomplished. One model is concerned with both pre-launch maintenance activity performed to prepare an aerospace system for launch and post-launch maintenance activity performed during the mission. A distinct sub-model was developed for each phase. The model routines are written on a general basis, employing the SIMSCRIPT program language, to enable model application to a variety of aerospace programs. The model flow patterns are generally deterministic with allowances for disruptive events caused at random times by hardware malfunctions. The model is assigned to produce predictive output information regarding the operation and efficiency of the maintenance system during the time period of interest and its contribution to the aerospace program in terms of schedule fulfillment (11).

The continued increase in both quantity and complexity of Army automotive equipment, coupled with critical personnel shortages, necessitates development of improved methods of support, which will reduce the time to perform maintenance, the skills required, and the logistic load generated in support of the field army. To this end, a maintenance model, representative of the maintenance concept proposed for a modular vehicle, was first constructed. Then a General Purpose System Simulation (GPSS III) model based on the maintenance model and an infantry brigade organization was developed. Experience data and estimated data appropriate to the new modular vehicles were used as inputs to the simulation model. Failures were randomly generated and assigned among the 13 user units of the brigade (10).

RAND's Logistics System Laboratory developed a malfunction-generation model for a manned-simulation of an ICBM operational tactical unit. The model's inputs consists of three kinds of information; reliability, supply and maintenance. All three are needed for each of the parts of a weapon system capable of being supported at the base-level echelon of support. The model's outputs are a realistic maintenance workload and the logistic requirements this workload demanded.

> We believe the use of a manned-simulation provided a more realistic environment for the testing of typotheses about these logistic policies and that the model discussed here provided a good approximation of a workload required to develop the necessary management procedures (2, p. 24).

Mathematical Models

A simplified model of aircraft sortie generation was developed by the Rand Corporation as a means by which to generate input data for larger maintenance management models. A single aircraft is subjected to a maximum daytime flying effort under the condition of unlimited maintenance resources. Several uses may be made of the model. First, the daytime sortie generation capability of a squadron of an aircraft may be determined from that of a single aircraft. Second, the model determines the load on maintenance under the conditions of maximum continued daytime stress. And third, the model can readily be used to determine the sensitivity of the performance of the aircraft to variations in several parameters. This information is useful to the designer of much more complex operations-maintenance models, as it helps him decide what to include and what to exclude from such models (10).

Maintenance on aircraft systems usually consists of two kinds of tasks: (1) those that may be started at the same time and (2) those that must wait either for other tasks to be completed or for some time to elapse after other tasks have been started. These maintenance durations are consolidated through two programmed techniques for use in maintenance management and related models.

> CONCUR is used to determine statistical properties of the longest time required among a group of tasks that begin at the same time and proceed together (concurrently), i.e., the time to complete all tasks. CONVOL deals with the total time required to complete a set of tasks that occur one after the other (sequentially); again, the concern is with the time to complete all tasks. Used together, CONCUR and CONVOL allow probability distributions of times required for distinct maintenance actions to be compressed into a single distribution corresponding to the total down time for the system. In addition to revealing characteristics of the total down time (e.g., mean and variance), the consolidated distribution provides a compact input to sortie generation, simulation and analytic models (8,V).

In regard to scheduled maintenance, a key consideration in deciding what to inspect, and how often to inspect, is the nature and duration of warnings which different kinds of hardware present before they actually fail.

> It is suggested that inspection processes can be improved when recognized as comprising a "Predict and Preclude" objective, based upon case-by-case warning analysis (7, p. 416).
>
> In pursuit of the concept outlined above, we have been building an analytical approach which would initially apply to items on which firm time-related failure rates are known (e.g., the actuarially computed rates on aircraft engines) (7, p. 417).

CHAPTER III

MODEL CONSTRUCTION

Introduction

The research described in this thesis was performed in two related phases. The initial phase consisted of translating the real world system into a representative model and then testing the model to determine how closely it represents that system. The simulation of the system in a general purpose language such as ALGOL would be a tedious chore. Instead, a special purpose language was chosen. The GPSS II language that is the mainspring of this model was developed by IBM over a period of several years. Specifically developed for simulation models, it is a higher level computer language than ALGOL or FORTRAN, consequently greatly reducing programming time and difficulty. The result of this development effort, culminating in GPSS II, is the ability to design much more efficient, more flexible, more representative simulation models in a fraction of the previous time spent.

The second phase, described in Chapter IV, considered experimentation with the model to determine its response to changes in several environmental factors.

Construction and Validation of the Model

The operational system outlined in Chapter I and shown in Figure 1 was transformed into a computer model by constructing a logic flow

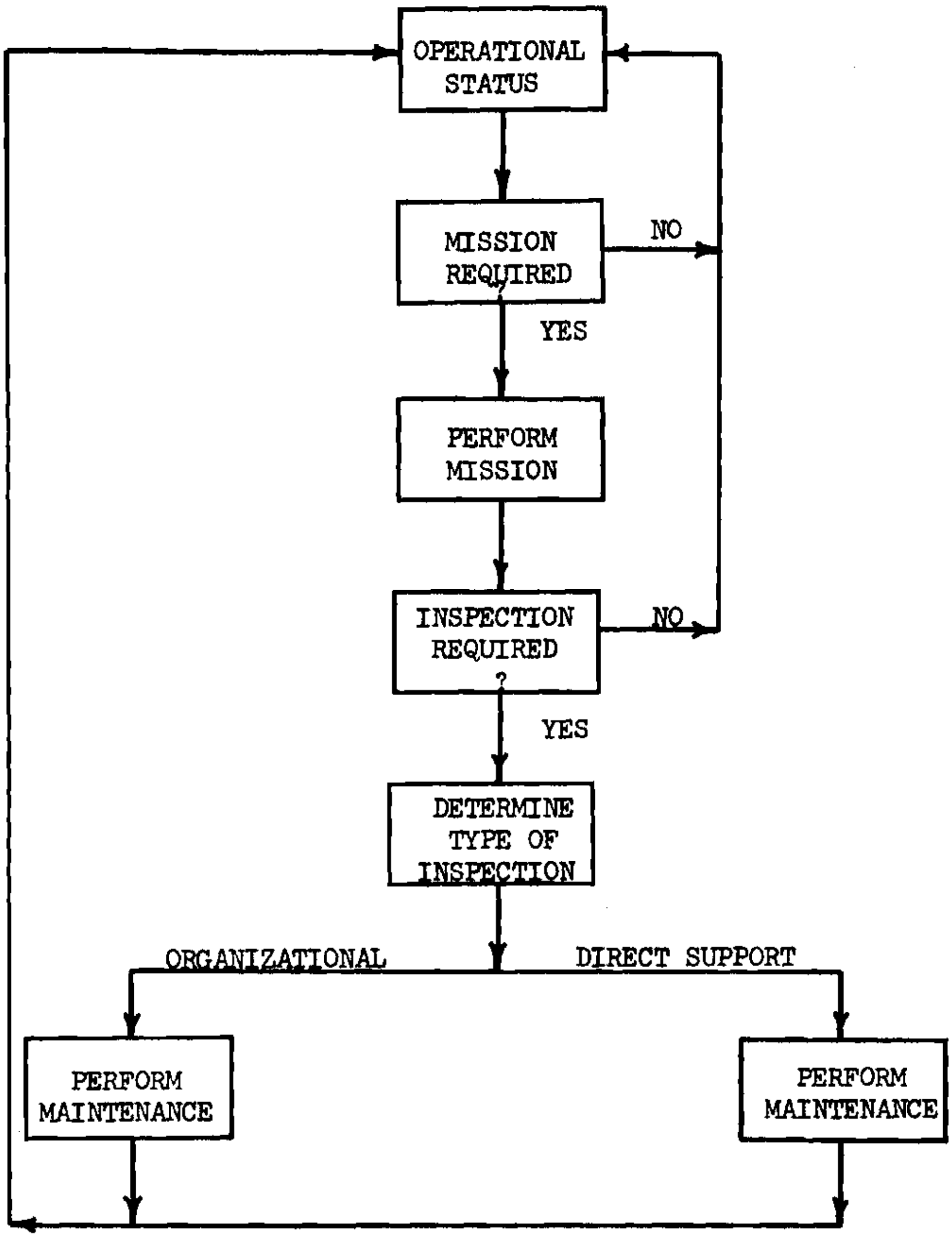


Figure 1. Operational System.

diagram with translation into a GPSS II computer program.

Model Construction

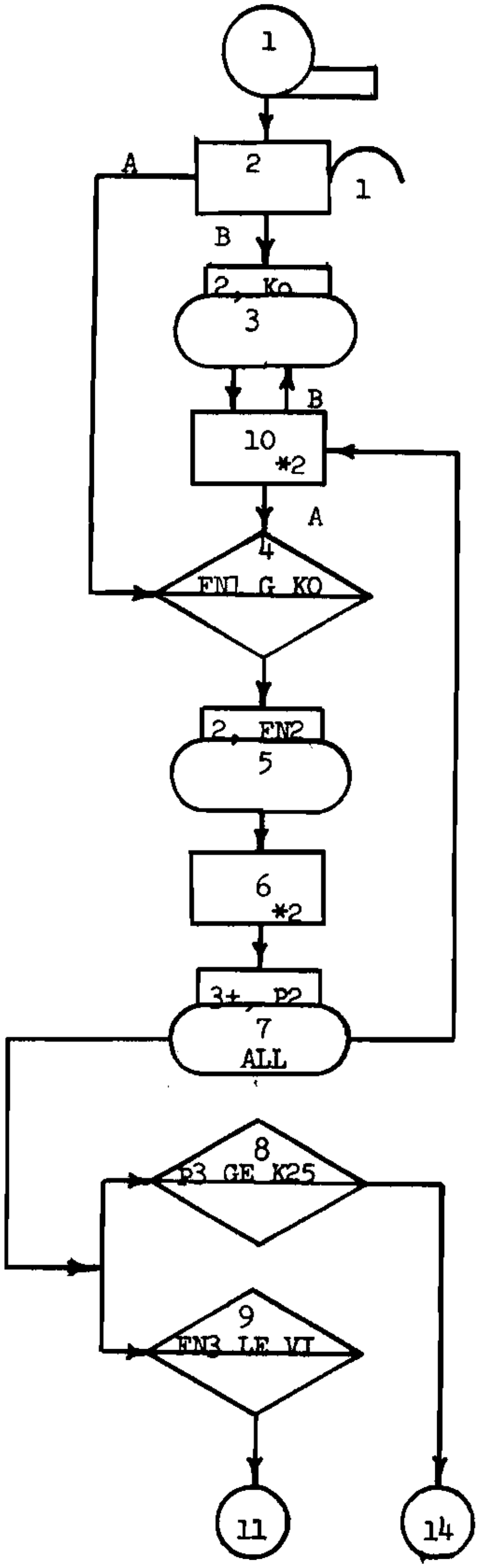
The operation and maintenance of a company of 25 helicopters has been simulated. It was assumed that the helicopters in the system were either in operational status,* flying a mission or undergoing maintenance at one of two echelons. Since scheduled inspections occur as a result of cumulative hours flown, the simulation could be accomplished by having the helicopters revolve within the closed loop of flying or undergoing maintenance. This approach necessitated the use of two auxilliary systems - the first to place the simulation on a 24 hour basis and the second to assimilate data. Once this method of procedure was chosen, the construction of the flow diagram remained a matter of matching routing procedures, decision factors and components of the subject system with the appropriate CPSS II logic. The GPSS flow diagram is shown in Figure 2. Each block of the diagram includes a brief description of the block's function in the model and a unique block number.** Figure 2*** contains the flow diagram for the system being simulated while Figures 3 and 4 contain the flow diagrams for the real-time clock and data compilation, respectively.

While the symbology of GPSS II is easy to follow, an examination of its role in the model and the decision logic employed requires some

*Operational status of the helicopter refers to it being ready and available for flight in all respects.

**Block types perform operations in a model of the system equivalent to the actions occurring in the real system.

***Figure 2 begins on page 14 and ends on page 20.



Originates a predetermined number of helicopters.

Helicopter enters operational environment

Assigns zero hours daily usage.

Delay remainder of day.

Tests for operational helicopters flown depending upon predetermined percentage.

Assigns mission length.

Helicopter flies mission.

Increments cumulative hours flown.

Tests for 25 hour inspection interval.

Tests for random failure.

Figure 2. System Flow Diagram

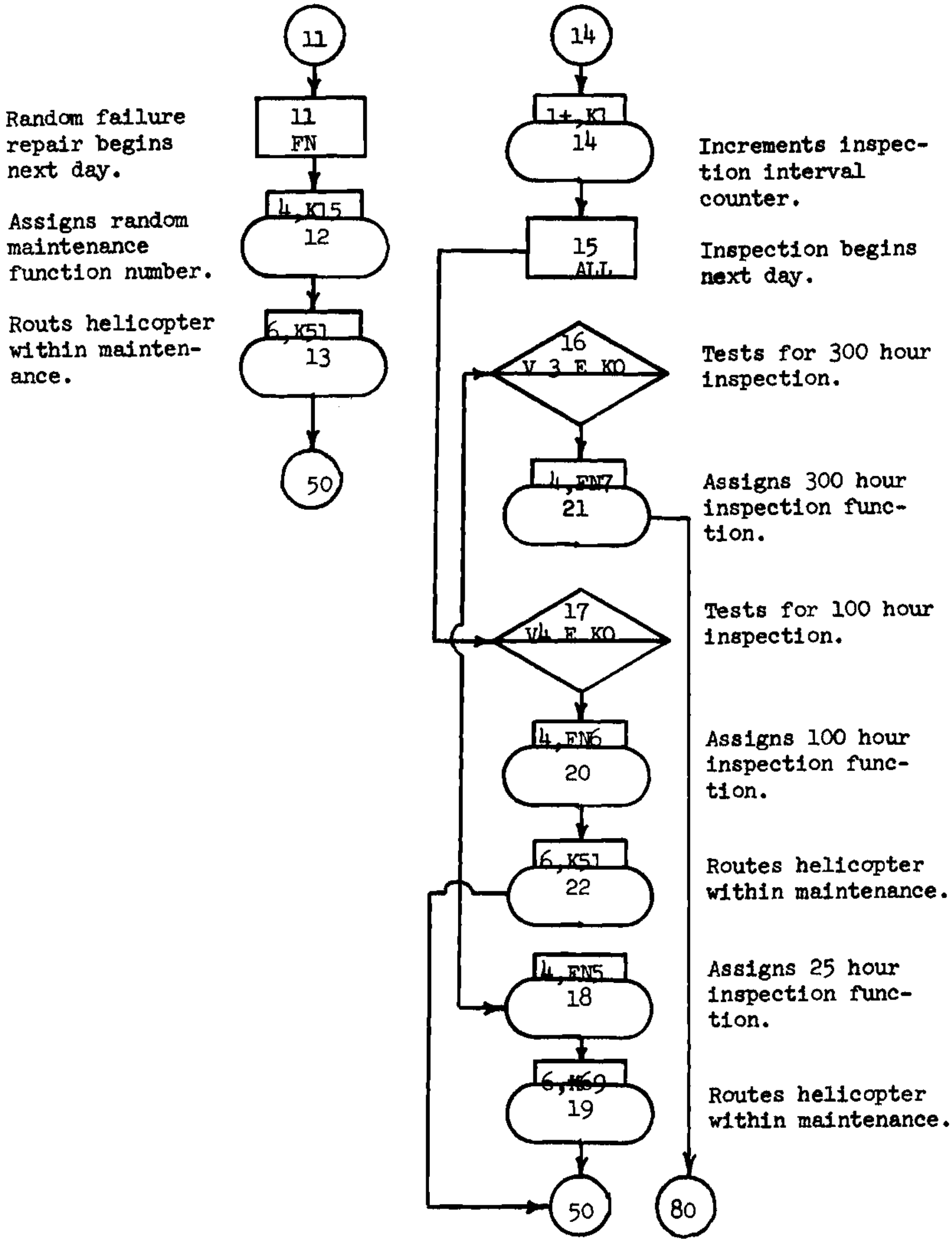
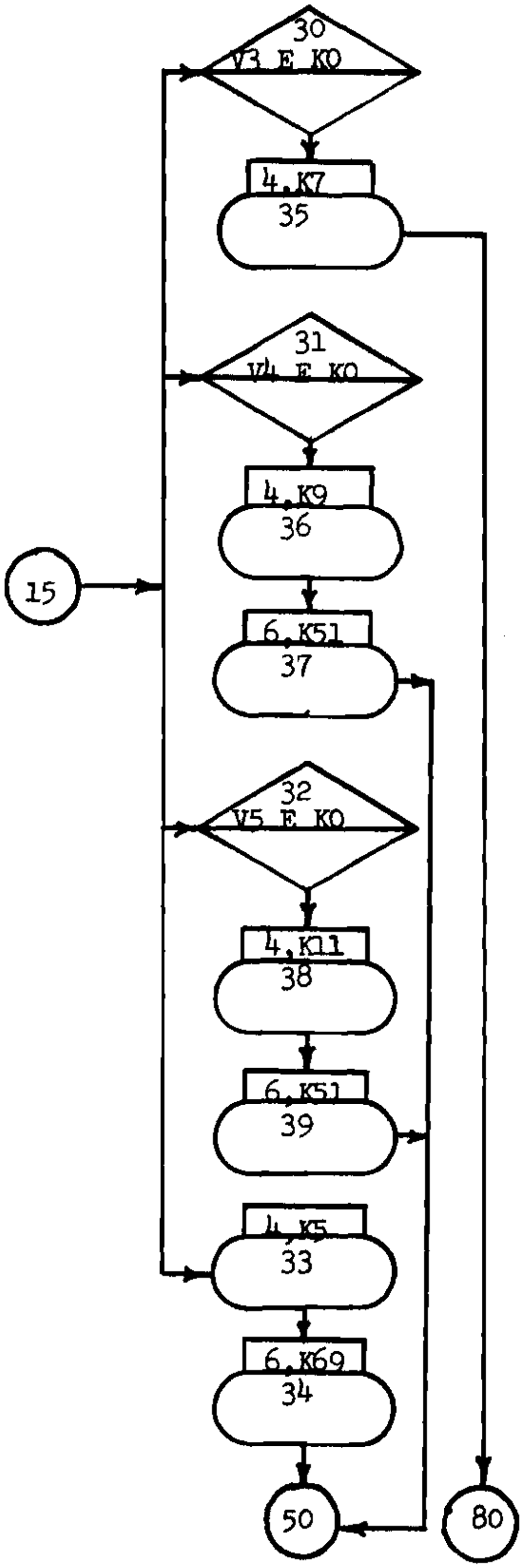


Figure 2. System Flow Diagram (Continued).



Tests for 300 hour inspection.

Assigns 300 hour inspection function.

Tests for modified 100 hour inspection.

Assigns modified 100 hour inspection function.

Foutes helicopter within measurements.

Tests for modified 50 hour inspection.

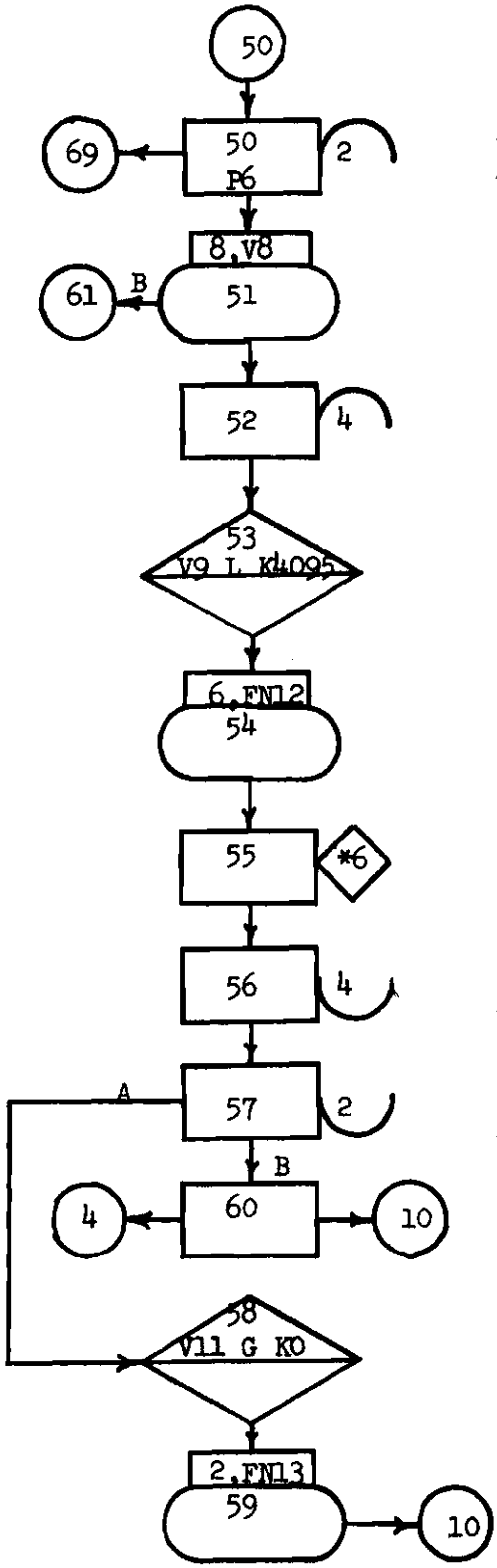
Assigns modified 50 hour inspection function.

Routes helicopter within maintenance.

Assigns 25 hour inspection function.

Routes helicopter within maintenance.

Figure 2. System Flow Diagram (Continued).



Helicopter enters organizational maintenance.

Assigns work hours 100 hour inspection, work crew maintenance.

Helicopter enters work crew maintenance

Determines the availability of work crews.

Assigns specific work crew.

Inspection performed.

Helicopter departs work crew maintenance.

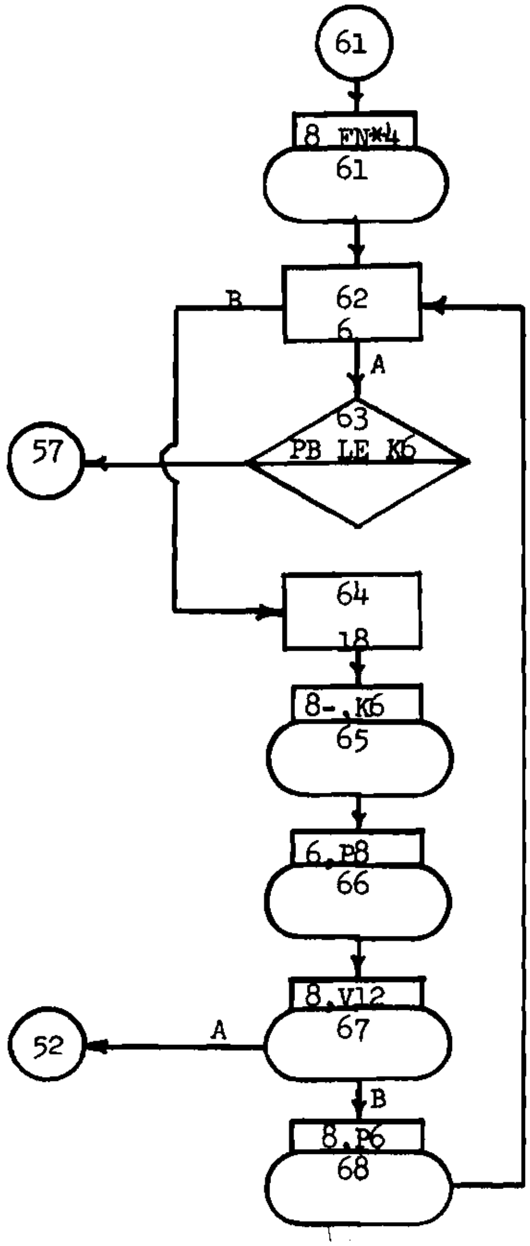
Helicopter departs organizational maintenance.

Determines mission requirement.

Tests for completion of work day.

Assigns portion of work day remaining.

Figure 2. System Flow Diagram (Continued).



Assigns work hours, 100 hour inspection, crew chief maintenance.

One work day elapses.

Tests for completion of inspection.

Delay non-work hours.

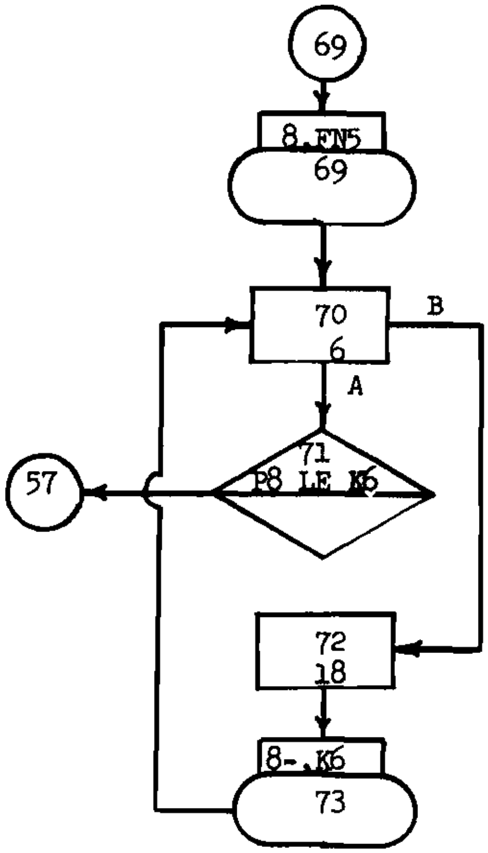
Decrements work hours.

Retains work remaining: crew chief.

Assigns work remaining: work crew. Tests for availability work crew.

Reassigns work remaining: crew chief.

Figure 2. System Flow Diagram (Continued).



Assigns work hours 25 hour inspection.

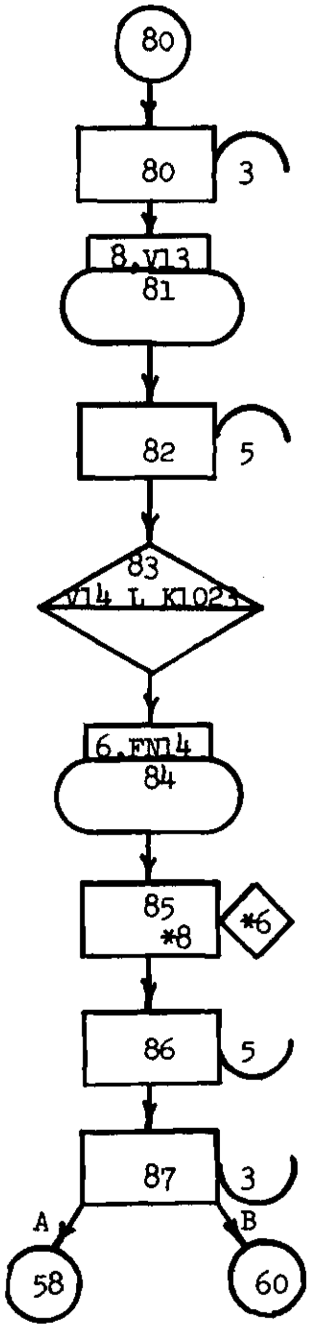
One work day elapses.

Tests for completion of inspection.

Delay non-work hours.

Decrements work hours.

Figure 2. System Flow Diagram (Continued).



Helicopter enters direct support maintenance.

Assigns work hours.

Helicopter enters work.

Determines the availability of work crews.

Assigns specific work crew

Inspection performed.

Helicopter departs work.

Helicopter departs direct support maintenance.

Figure 2. System Flow Diagram (Concluded).

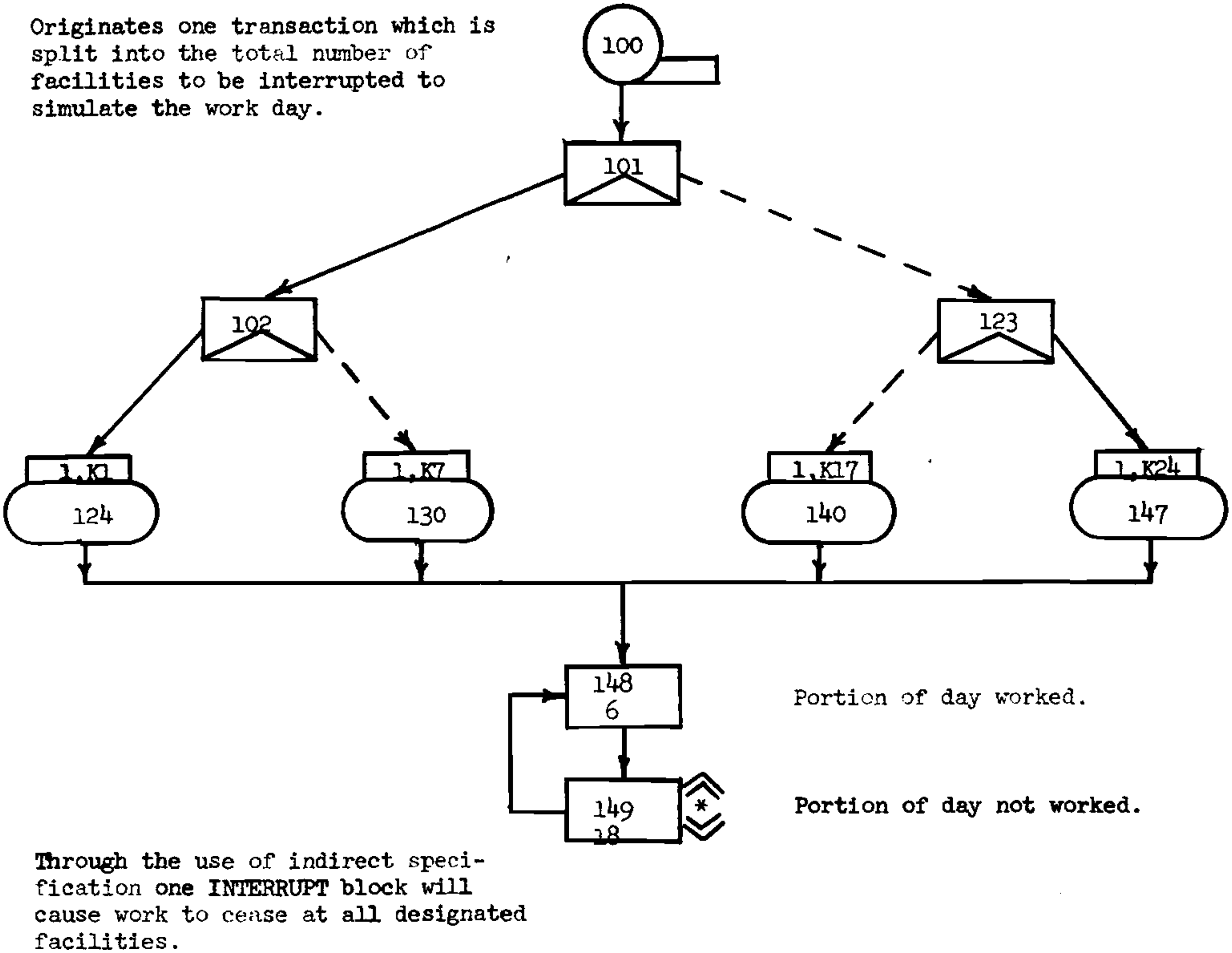
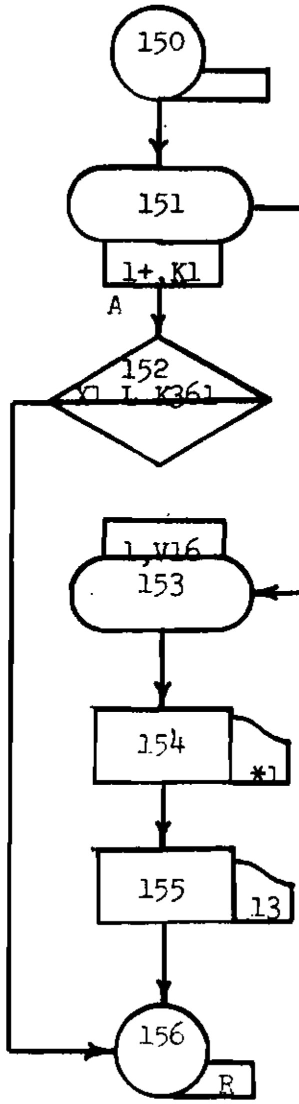


Figure 3. Real-Time Flow Diagram.



Originates one transaction every 24 hours to measure the availability rate.

Cumulative count of transactions.

Tests for "burn-in" period.

Assigns to each transaction a month number, according to cumulative number of transactions.

Tabulates the availability rate for each day of the month.

Tabulates the availability rate for each day of the year.

Terminates the simulation run.

Figure 2. Data Assimilation Flow Diagram.

explanation. Each of the three sub-programs will be discussed.

The first block of the primary sub-program, entitled ORIGINATE, creates a predetermined number of helicopters to operate within the system. During this phase of the simulation 25 helicopters, the authorized strength of a helicopter company, were employed. Their rate of input was incidental since the model was allowed to reach steady-state conditions prior to the compilation of statistics. The helicopters then pass through an ENTER block into the simulated system.

GPSS II maintains a count of the number of transactions* within the ENTER-LEAVE block combination. This combination is again used when a helicopter undergoes maintenance. The ratio of these counts is the availability rate of operational helicopters. FN1 is then tested on a daily basis to determine mission requirements for each operational helicopter. Fn1 refers to FUNCTION 1, a definitive entry,** which is a set of three discrete pairs of numbers and whose argument is a random number in the interval from 0 to 1. FUNCTION 1 describes the per cent of operational helicopters flown each day and in different models varies from 50 to 100 per cent in increments of 10 (see Figure 5). If the helicopter is not selected for a flight, a 24 hour period elapses before the selection process may reoccur. The reduction of several real-world

---

*The units of traffic that are created and processed by the simulator are called transactions. The terms, transaction and helicopter, are used interchangeably in this simulation.

**Describes or defines an activity or action within the program. Definitive entries are not assigned block numbers and are not considered a part of the operational section of the program. Other definitive entries later mentioned are VARIABLE and TABLE statements.

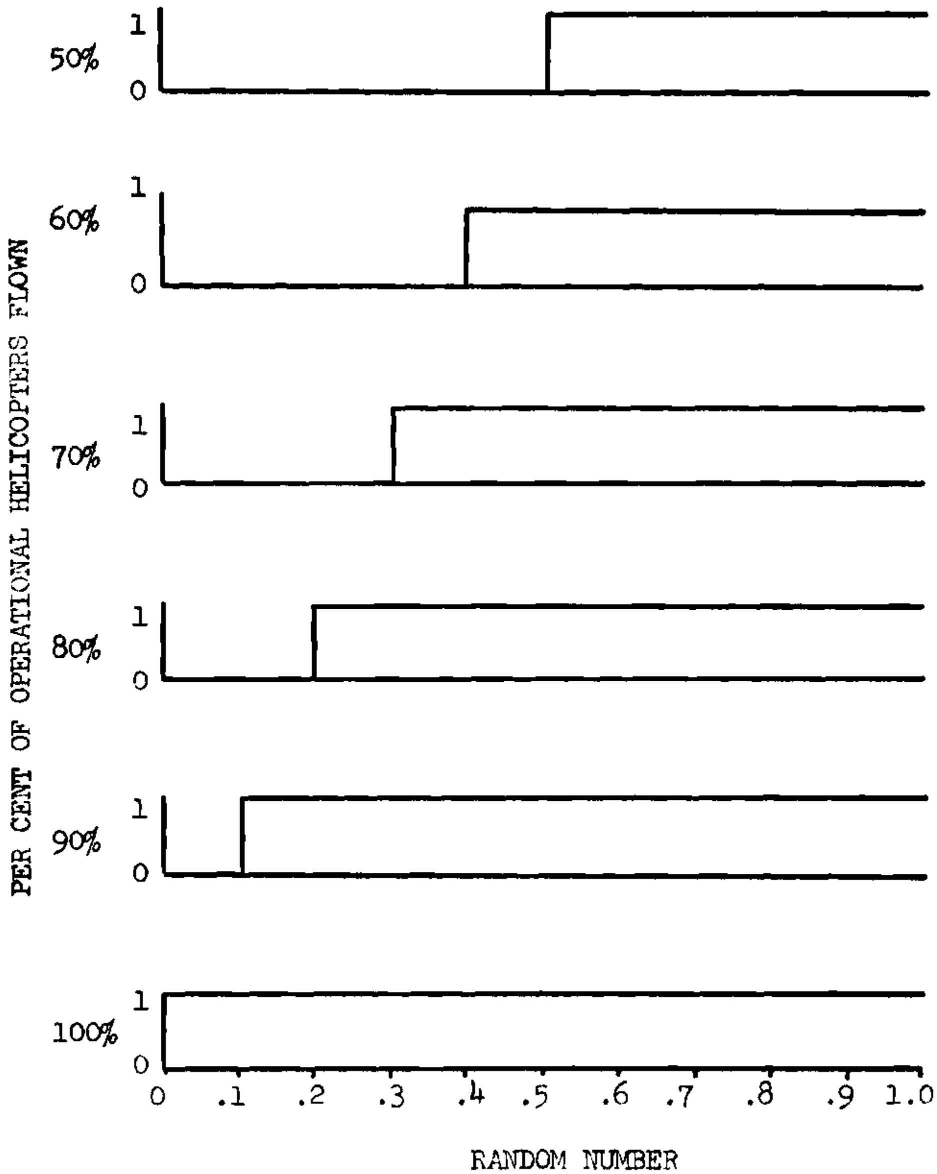


Figure 5. FUNCTION 1 -- Per Cent of Operational Helicopters Flown.

flights per day into one is justified by summing the flying times of the several flights into one since the cumulative flying hourse will be the same.

If the helicopter is selected for flight its mission duration is derived from FN2, (see Figure 6), and assigned to parameter 2* of the transaction representing the helicopter. FN2 was plotted from empirical data gathered from an operational helicopter company.** Two hours was considered to be the minimum length of one flight since that is the fuel duration of the type helicopter being simulated and it is a common procedure to schedule missions by this method. The simulated flight is accomplished through the use of an ADVANCE block whose mean time is the value of parameter 2 of the helicopter (transaction) being flown. At the termination of the flight, parameter 3 of the transaction is incremented by the value of parameter 2. Parameter 3 contains the cumulative hours flown which is then tested to determine if 25 hours flying time, the inspection interval, has been accomplished. If the criteria has not been met, a further test is performed to determine the occurrence of a random failure. If the helicopter is still in operational status the remainder of the 24 hour period is allowed to elapse before the helicopter may again fly.

If an inspection is due the helicopter is prepared for the inspection during the remainder of the 24 hour period. Tests are then

*Parameters are positive integers that can be attached to a transaction.

**181st Aviation Company (Hel) (Lt) Fort Benning, Georgia, 1967.

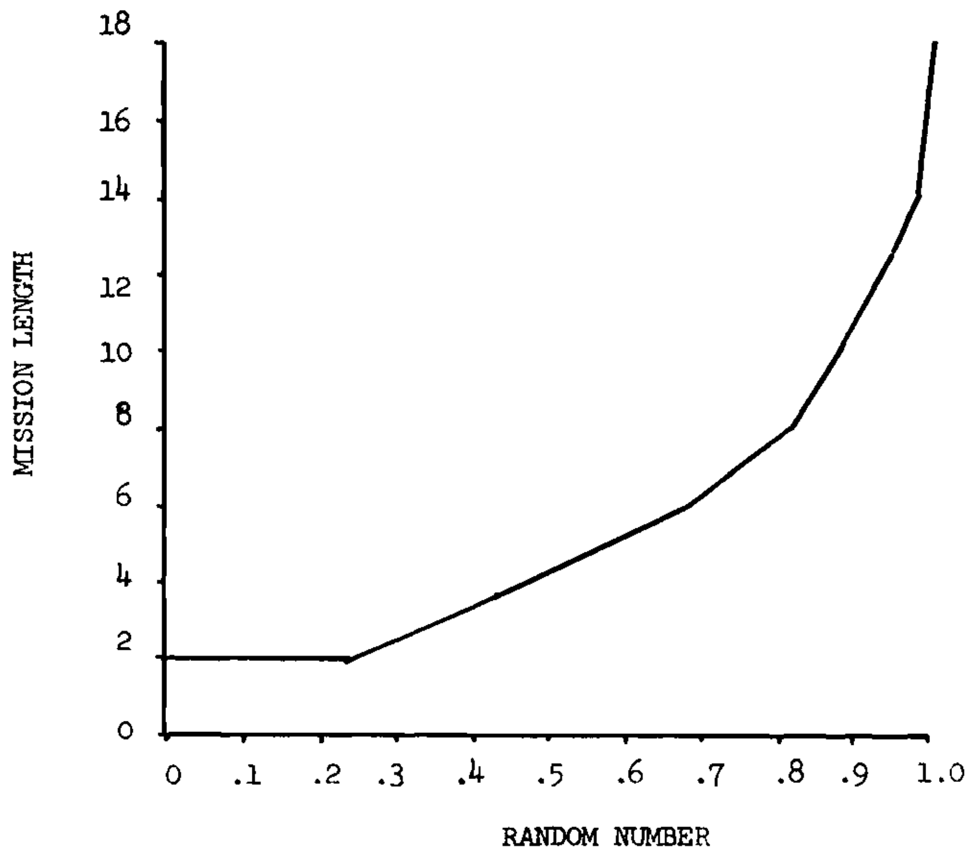


Figure 6. Function 2 -- Duration of Mission

performed to determine the type of inspection due, and the proper inspection functions are then assigned to parameter 4 (see Figures 7, 8, 9). These functions were plotted from data extracted from the maintenance records of operational helicopter companies and supporting maintenance units, and collated with data taken from a maintenance study prepared for the Department of Army (1). If a random failure has occurred, the random maintenance duration function is assigned to parameter 4 (see Figure 10). The helicopter then enters the appropriate maintenance facility.

There are two maintenance facilities supporting the helicopter company within this model. First, there is organizational maintenance peformed by the service element of the helicopter company and, second, direct support maintenance performed by either a direct support detachment or a direct support company, depending upon the experiment being performed. Organizational maintenance will be discussed first.

When the helicopter enters organizational maintenance it is routed according to the inspection to be performed. Intermediate (#2) inspections on the helicopter are accomplished by the crew chief alone. The number of hours required for the inspection are assigned from FN3 and work commences. Since it is possible for a large number of helicopters to be undergoing intermediate inspections simultaneously, this portion of the model contains its own real-time clock. This is accomplished through the use of ADVANCE blocks that will always allow entry to a transaction. As before, GPSS II maintains separate data for each of them. After the inspection has been completed, the helicopter is returned to operational status. Periodic (#3) inspections are accomplished by the

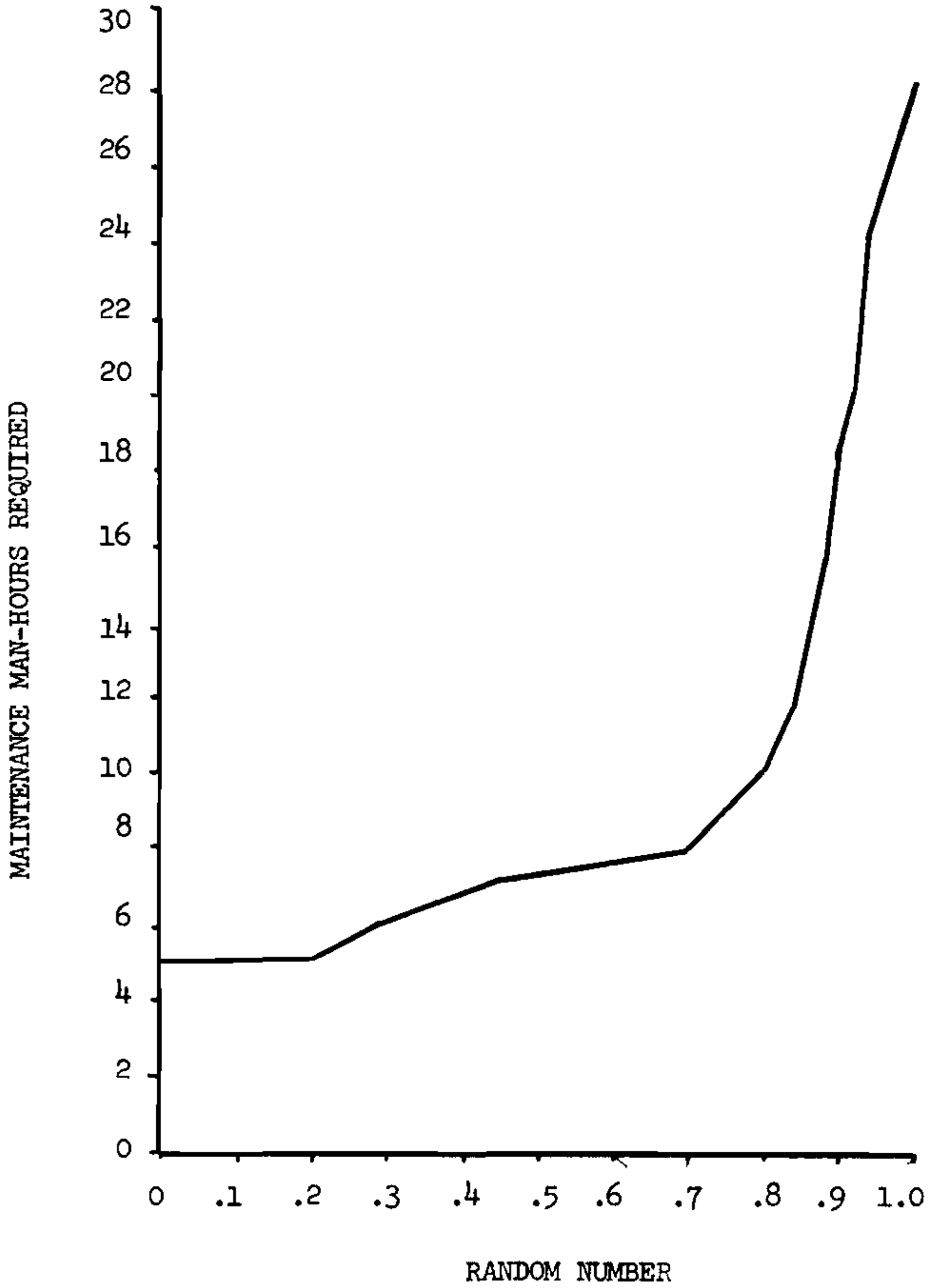


Figure 7. FUNCTION 3 -- Intermediate (#2) Inspection Duration.

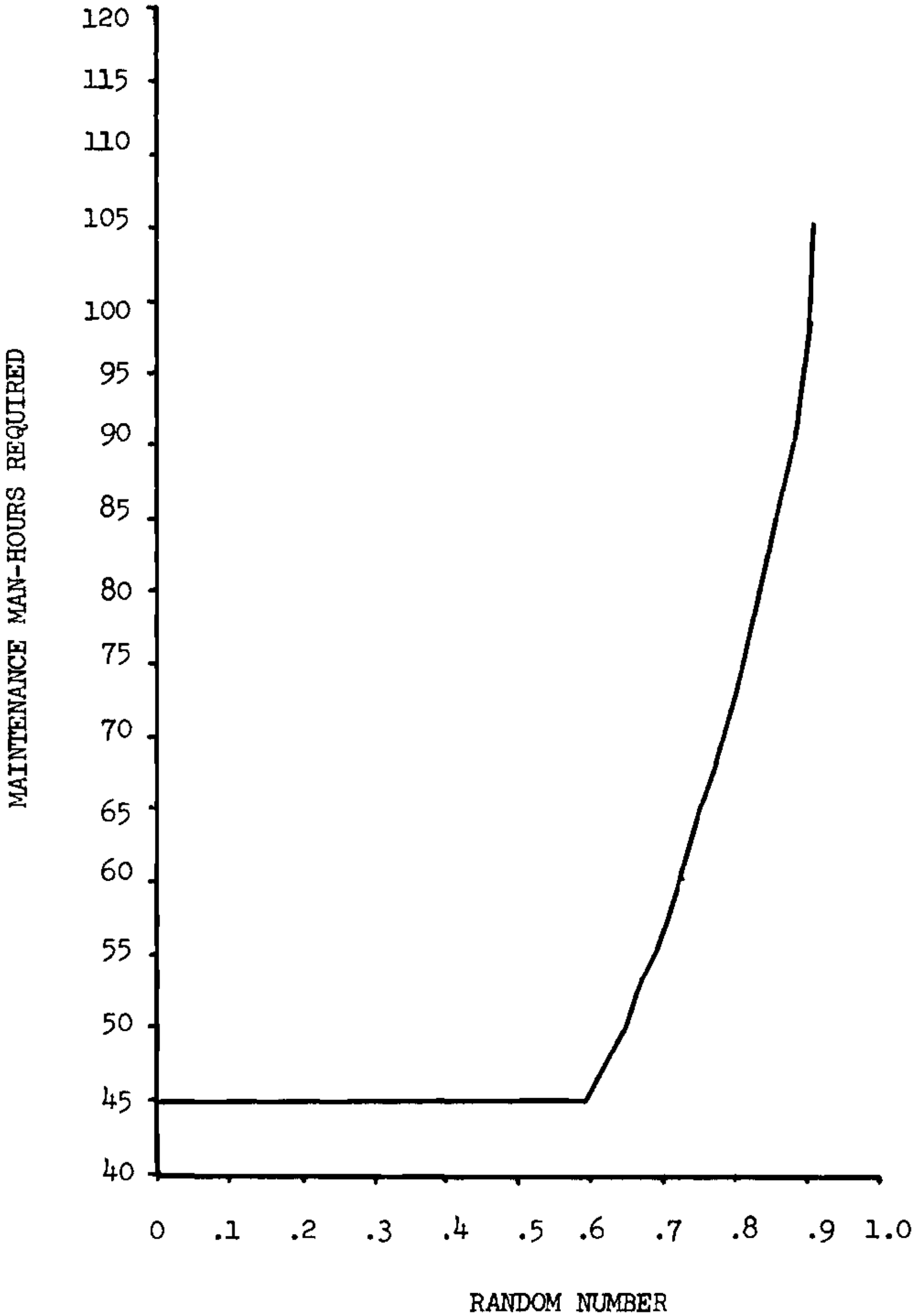


Figure 8. FUNCTION 4 -- Periodic (#3) Inspection Duration.

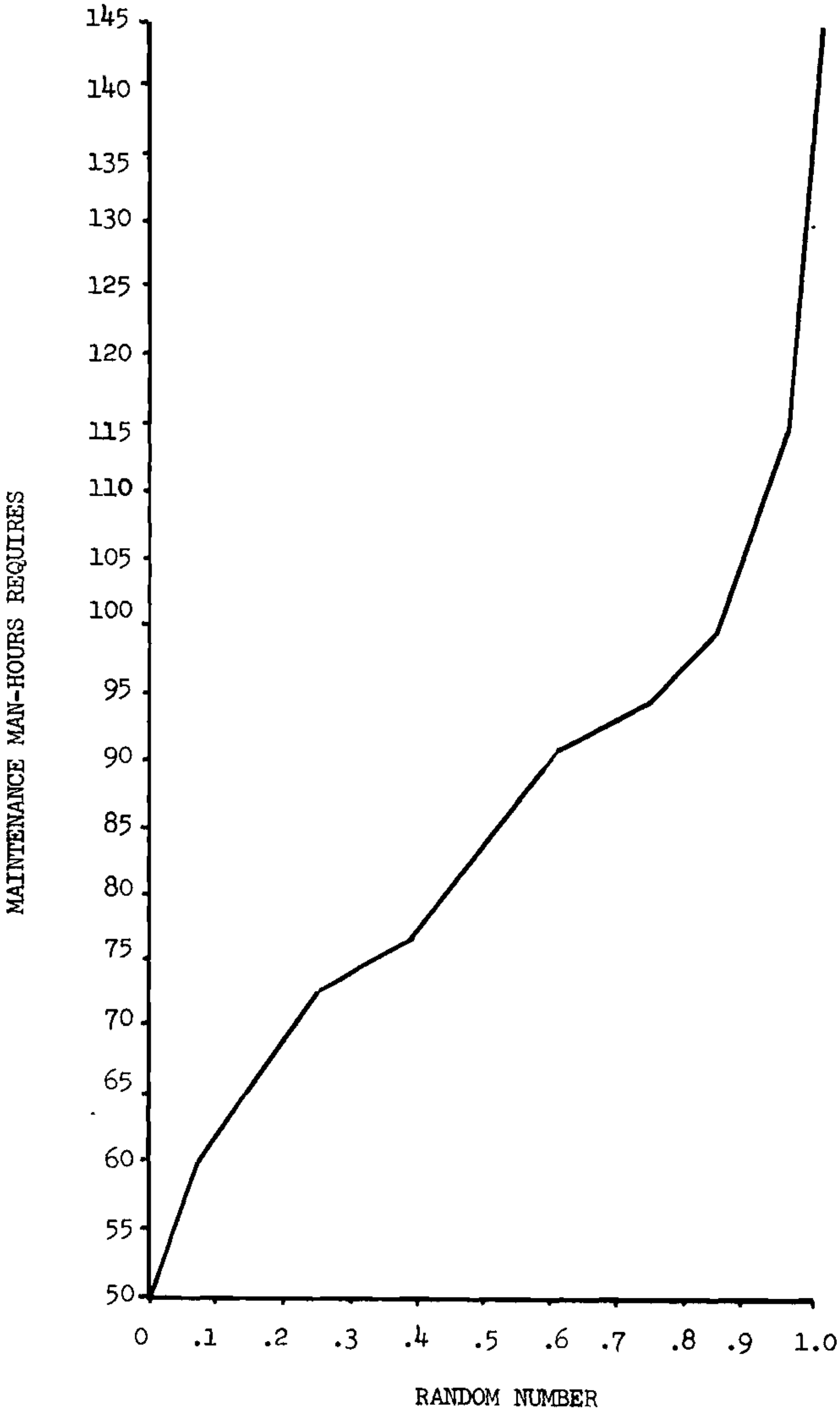


Figure 9. FUNCTION 5 -- Periodic (#4) Inspection Duration.

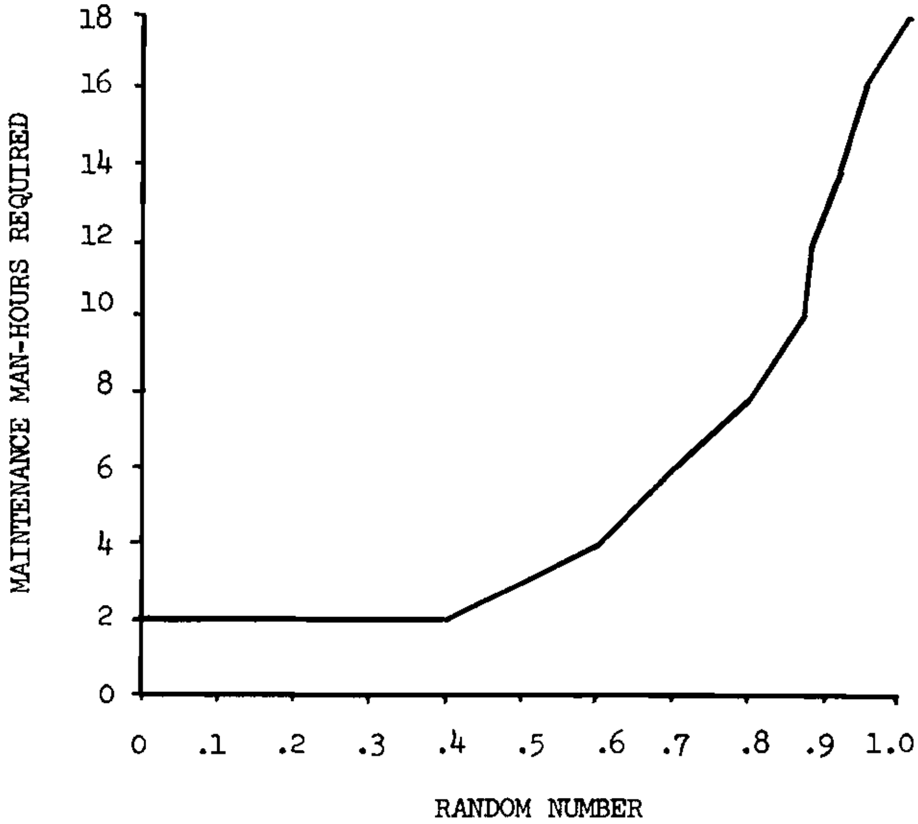


Figure 10. FUNCTION 15 -- Random Maintenance Duration.

crew chief with the assistance of two mechanics, if available. If the mechanics are not available the inspection is begun by the crew chief alone. In this situation the model tests for the availability of mechanics each day until the inspection is completed. If they become available the remainder of the inspection is performed with their assistance.

The number of maintenance man-hours required is derived from FN4 and converted into total hours by V8.* The inspections are periodically interrupted to simulate the work day by the "Real-Time" portion of the model. Upon completion of work, the helicopter is returned to operational status.

The helicopter enters the direct support maintenance facility and is assigned a certain number of maintenance hours depending upon the type inspection and the number of maintenance men in a work crew. This is accomplished through the use of V13, which refers to VARIABLE 13 and is the quotient of FN*4, a particular inspection function, and K8, the number of men in a work crew. The helicopter then enters a false storage. This simulation technique is employed so that one model will depict both a direct support detachment or a direct support company, depending upon the designated capacity of the storage. If a work crew is not available the helicopter waits until one is, if a work crew is available the inspection commences. Since the organization and

---

*VARIABLE 8 equals FN*4/K3 which is a value derived from the function described in parameter 4 of the transaction and divided by 3, the strength of the work crew. Variable statements are algebraic combinations of system variables and/or other variable statements.

functioning of each work crew is identical, indirect specifications* is employed to simulate their performance. GPSS II maintains the status of each facility within the block diagram. This value is 0 if the facility is available; otherwise it is 1. VARIABLE 14** determines the availability of a facility (a work crew) and whenever its value is less than 1,023 a work crew is available. The number of the work crew available, or the lowest numbered one if several are available, is then determined by FN14 (see Figure 11) and assigned to parameter 6. The inspection is then performed by the designated work crew. Although several crews may be working at the same time, GPSS II maintains the associated data separately. The work is periodically interrupted to simulate an actual work day. The details of this process will be discussed in the "Real-Time" portion of the simulation. When the inspection is completed the helicopter is returned to operational status and may be assigned a mission the next day. The "Real-Time" section simulates a working day by interrupting facilities during non-work portions of the day. This is accomplished by originating one transaction and then splitting it into the total number of facilities to be interrupted. Each sub-transaction is then assigned a facility number. Through the use of indirect specification one INTERRUPT block will cause works to cease at all

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*Indirect specification is the use of parameters to determine such factors as facility numbers, time spent in a block, and the next blocks. In this way one set of blocks may be used in place of several identical sets.

**VARIABLE 14 equals K512*F13+K256*F14+K128*F15.....+K4*F20+K2*F21 +22 where the constant 512 is multiplied (*) by the status of facility (F) 13 and so on.

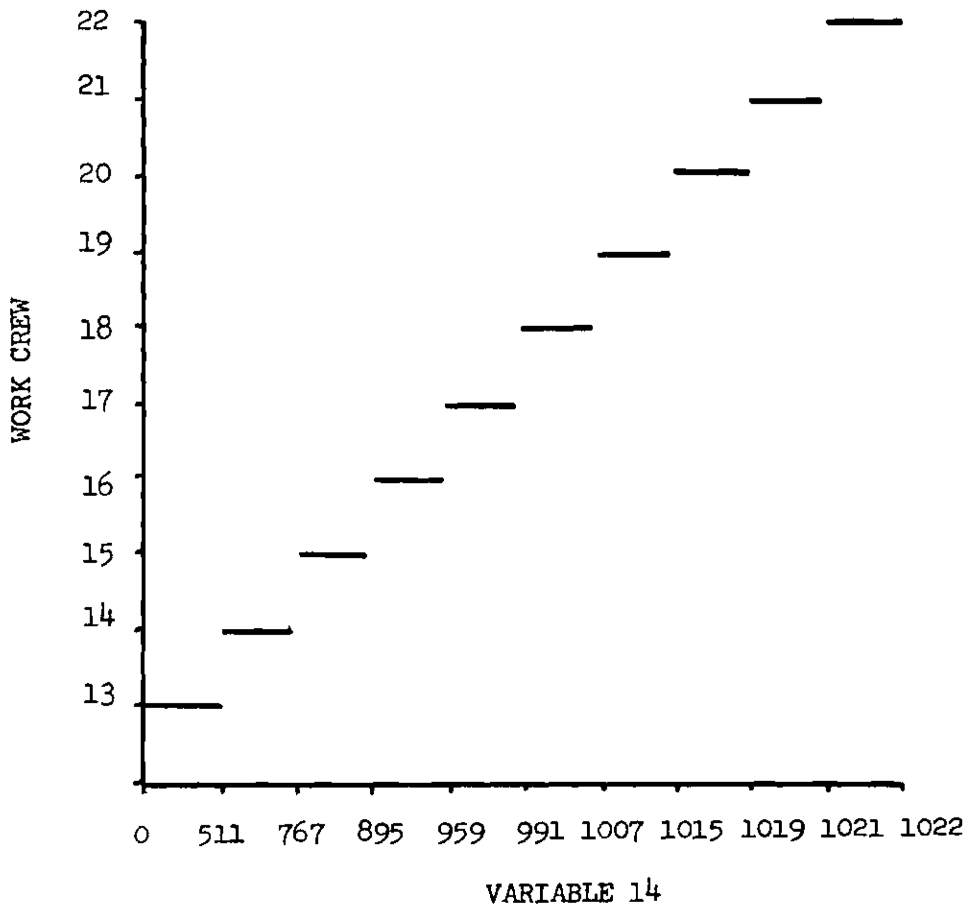

Figure 11. FUNCTION 14 -- Direct Support Work Crew.

designated facilities.

The data compilation section measures the helicopter availability rate each day. This criteria of maintenance performance is the ratio of operational helicopters to total helicopters within the system. These figures are tabulated in thirteen tables, representing each month and the total year. In addition this section ends the simulation when the prescribed number of transactions reach the TERMINATE block.

Validation

The primary objective of the first phase of this thesis is the construction of a basic model to be later used in the comparison of several maintenance management policies and concepts. The secondary objective is the validation of the model. To this end a standard helicopter company with standard supporting maintenance units was modeled. The maintenance policies simulated are similar to those commonly employed. The basic model should accurately portray the real world if it is to serve as a realistic point of departure for conceptual innovations.

A total of six basic models were operated, being identical in all respects with the exception that the percentage of available helicopters flown varied from 50 to 100 per cent in increments of 10. The basic model program is contained in Appendix A. Transient effect was eliminated by allowing the model to operate for a simulated year, reaching steady-state conditions. All statistics were then reset to zero, leaving the helicopters, or transactions, spread throughout the system. The model was then allowed to operate for another year to compile data for the validation.

The model functioned normally and the results were those that could be expected from actual operations. The availability rate of helicopters followed an inverse relationship with the level of available helicopters flown (see Figure 12). Of significance is the increasing steepness of the curve. This indicates increasing fluctuations in short-run availability as the level of helicopters flown increases. This concept is further substantiated by the direct relationship of the coefficient of variation of the helicopter availability rate (standard deviation / mean) to increasing levels of operation. Table 1 indicates the coefficient of variation and corresponding levels.

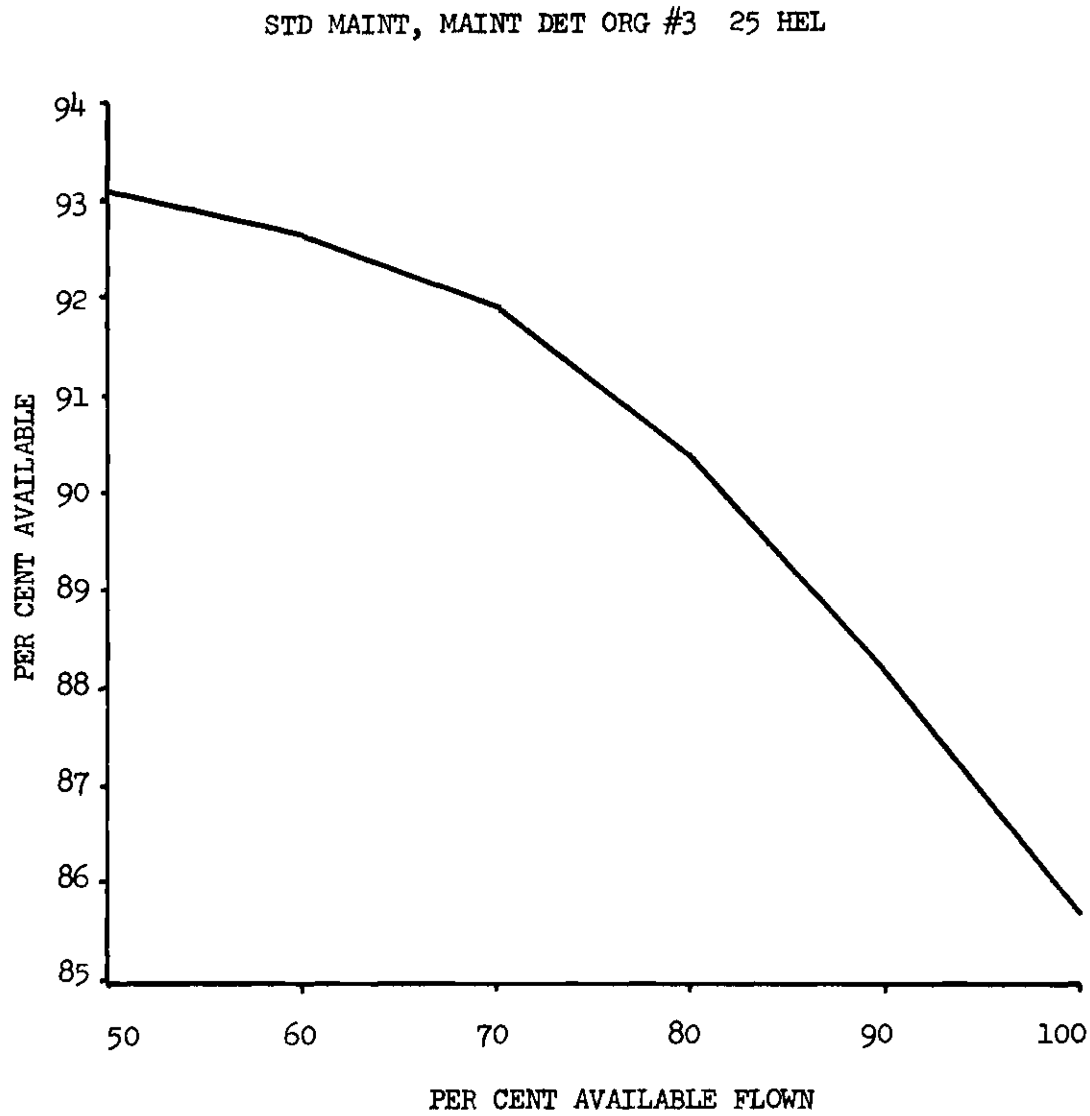

Figure 12. Ratio of Per Cent Available Helicopters to Per Cent Available Helicopters Flown.

Table 1. Coefficient of Variation of the Helicopter Availability Rate for Each Operating Level of Basic Model

OPERATING LEVEL %	AVAILABILITY RATE %	COEFFICIENT OF VARIATION
50	92.831	.0596
60	91.169	.0521
70	89.923	.0604
80	87.913	.0671
90	86.667	.0770
100	85.027	.0893

The divergence at the 60% level is a result of randomness. Of note are the relatively high availability rates. It must be recalled that the model assumes both an inexhaustible supply of spare parts and the absence of random maintenance. Both of these assumptions are valid since conclusions will be drawn from comparisons rather than absolute values.

CHAPTER IV

THE EXPERIMENTS

Introduction

The several objectives of this research are now restated as options available to commanders and maintenance officers in performance of the maintenance function. They are:

1. Given a constant environment, the helicopters' availability rate has been shown to be inversely related to the percentage of operational helicopters flown, therefore commanders may assure higher availability by limiting missions flown.

2. There exist two distinct types of direct support maintenance units, the Direct Support Detachment, and the Direct Support Company. The first supports one helicopter company while the second supports four. Depending upon the operational situation, commanders might desire to combine several detachments or fragment one company.

3. Regulations specify the maximum allowable time between inspections. Maintenance officers may wish to reduce this interval if increased availability will result.

4. Under normal conditions direct support units perform every third periodic inspection while organizational maintenance performs the remaining periodic inspections. It is possible for the direct support unit to perform all periodic inspections.

A fixed factorial design (see Figure 13) was selected as a design

PER CENT OPERATING LEVEL	STANDARD INSPECTION DURATION			
	COMPANY PERFORMS #3		DIRECT SUPPORT PERFORMS #3	
	D/S DET	D/S CO	D/S DET	D/S CO
50 60 70 80 90 100	I	II	III	IV

PER CENT OPERATING LEVEL	NON-STANDARD INSPECTION DURATION			
	COMPANY PERFORMS #3		DIRECT SUPPORT PERFORMS #3	
	D/S DET	D/S CO	D/S DET	D/S CO
50 60 70 80 90 100	V	VI	VII	VIII

Figure 13. Organization of Experiments.

for experimentation, varying each variable over all factor level combinations. This is necessary for a complete investigation of the system since there may be occasions when two or more operating conditions produce similar results. A total of 144 years operating time for one helicopter company was simulated, a duration considered sufficiently large to validate the conclusions.

Experimentation

Experiment 1

Experiment 1 consists of operating varying percentages of available helicopters to determine to what degree this will effect short and long-run availability. While it has been shown that availability decreases as operations increase, there should be some limiting point below which a further reduction in operations would result in only a negligible increase in availability.

Experiment 2

The second experiment was designed to compare the availability resulting from the use of Direct Support Detachments as opposed to that of the Direct Support Company. Since the company was designed to support four helicopter companies the model will be modified to simulate this condition.

Experiment 3

Experiment 3 was designed to test a modified inspection concept. Under normal maintenance procedures, intermediate (#2) inspections are performed every 25 hours and periodic (#3) inspections are performed every 100 hours. The modified inspection program consists of three types of inspections. Type I is the standard intermediate inspection and is performed at odd 25 hour intervals. Type II is performed at 50 hours and every 100 hours thereafter while Type III inspections are performed every 100 hours. Type II inspections consist of the standard intermediate inspection plus the airframe, power train and flight control elements of the periodic inspection. Type III inspections consist of the standard intermediate inspection plus the engine elements of the periodic inspection.

Experiment 4

The fourth and final experiment concerns performance of periodic inspections. There are two types of periodic inspections: the first occurs every 100 hours and is normally performed by the helicopter companies' organic maintenance element while the second occurs at 300 hour intervals and is normally performed by the direct support unit since an internal engine inspection is required. This experiment will place the entire periodic inspection work load upon the direct support unit in order to assess the availability resulting from this method of performance.

CHAPTER V

RESULTS

The objective is an investigation of the four previously mentioned management alternatives to determine their effect upon the modeled system. The criteria for the selection of one alternative over another will be the helicopter availability rate. The mean availability rates of all experiments are contained in Table 2.

Experiment 1

The results of Experiment 1, variation of the percent of available helicopters flown, are graphically presented in Figures 14 through 21. The effect upon availability of increasing the per cent of available helicopters flown is readily apparent. With the exception of the tests concerning the performance of periodic and modified inspections by the direct support company, the slope of the curve of the availability rate was relatively constant. The standard deviations of these differences were computed and found to be small. This indicates a rather linear relationship between the percentage of helicopters flown and the number of helicopters entering maintenance. Those percentages and standard deviations are contained in Table 3.

The curves associated with the test concerning the performance of all periodic and modified inspections by the direct support company indicate that the company's capabilities were exceeded in each case. This will be discussed under Experiment 2.

Table 2. Mean Availability Rates

	Per Cent of Available Helicopters Flown					
Test	50	60	70	80	90	100
I	92.831	91.169	89.923	87.913	86.667	85.027
II	95.279	94.175	93.475	93.115	91.803	91.333
III	91.774	88.838	86.314	84.091	82.732	81.212
IV	76.721	75.617	75.104	62.754	53.923	51.322
V	92.208	91.443	88.842	86.634	86.044	84.251
VI	94.557	93.781	92.284	91.344	90.962	89.836
VII	91.148	87.951	86.306	83.339	82.098	80.333
VIII	75.923	74.781	73.290	61.525	52.831	50.814

The tests correspond to the cells of Figure 13.

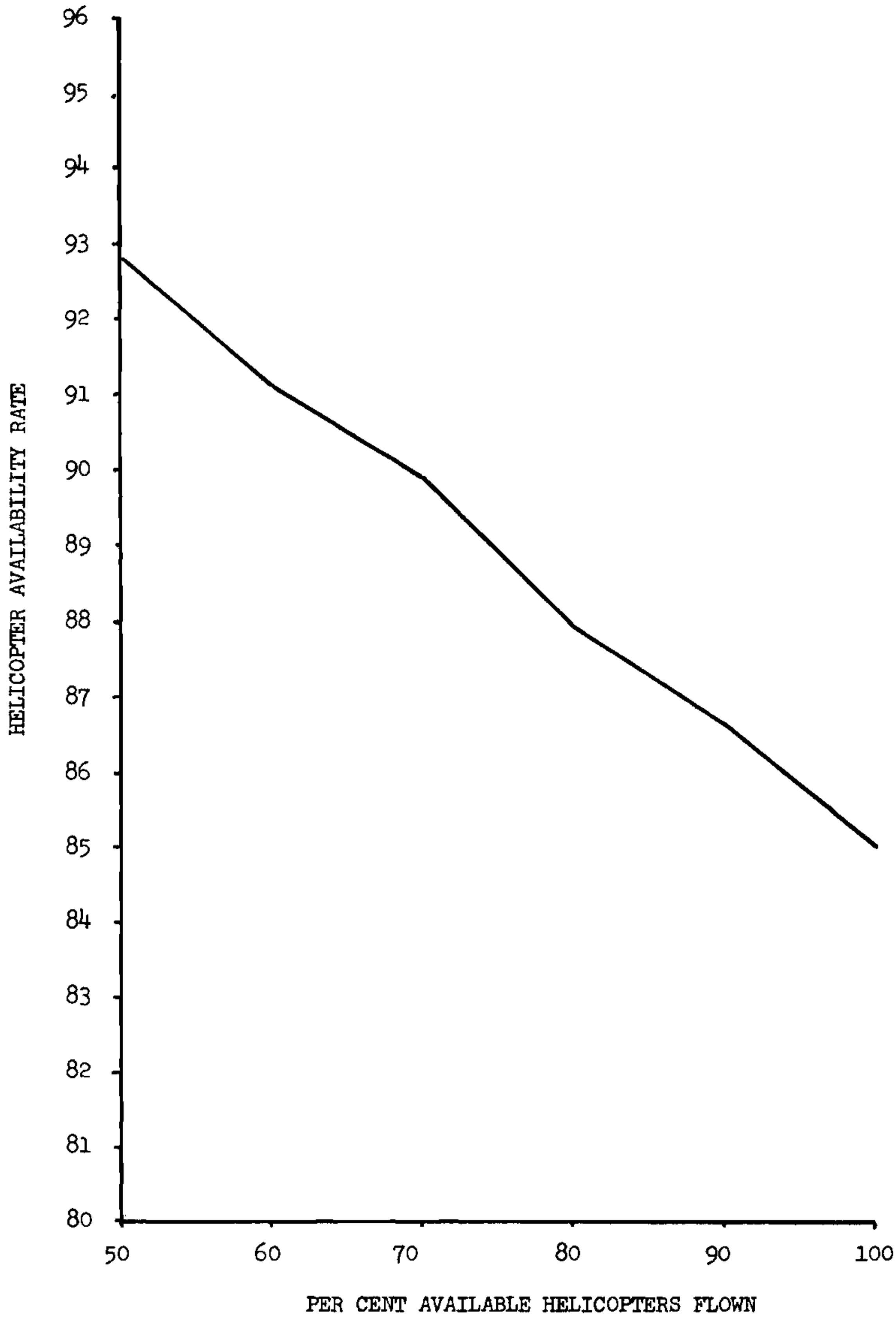

Figure 14. Standard Inspection Direct Support Detachment Helicopter Company Performs Periodic Inspection.

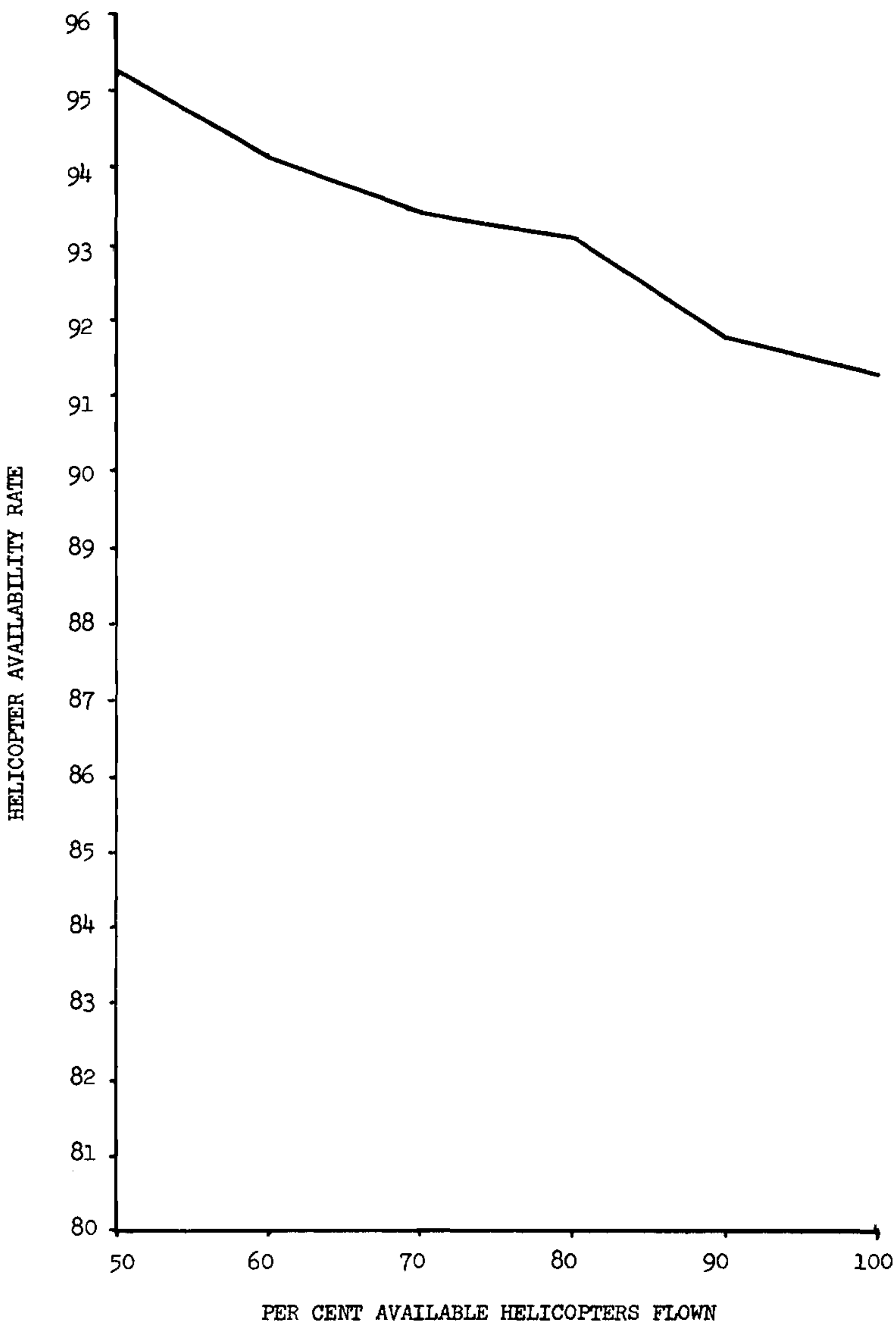

Figure 15. Standard Inspection Direct Support Detachment Direct Support Performs Periodic Inspection.

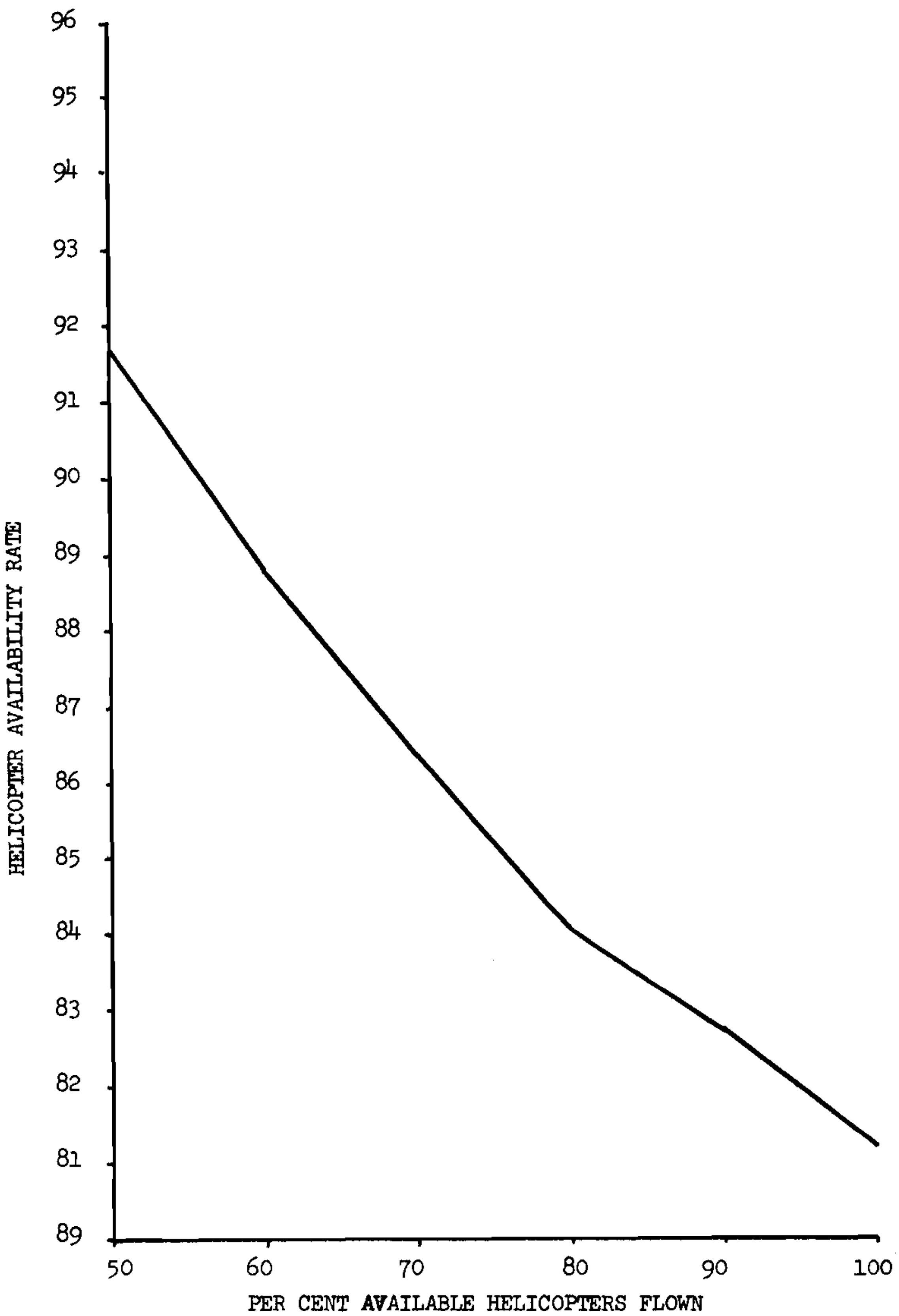

Figure 16. Standard Inspection Direct Support Company Helicopter Company Performs Periodic Inspection.

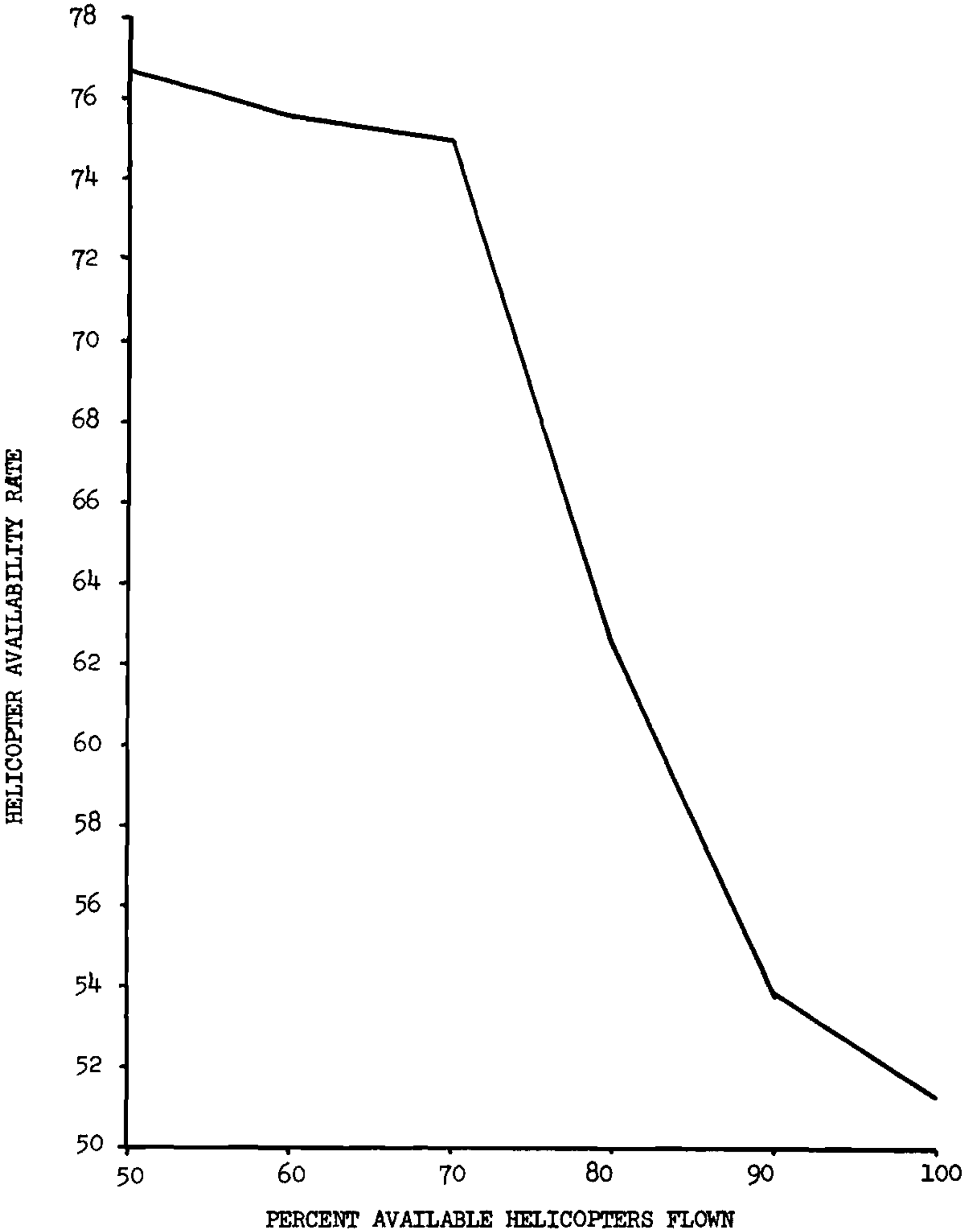

Figure 17. Standard Inspection Direct Support Company Direct Support Performs Periodic Inspection.

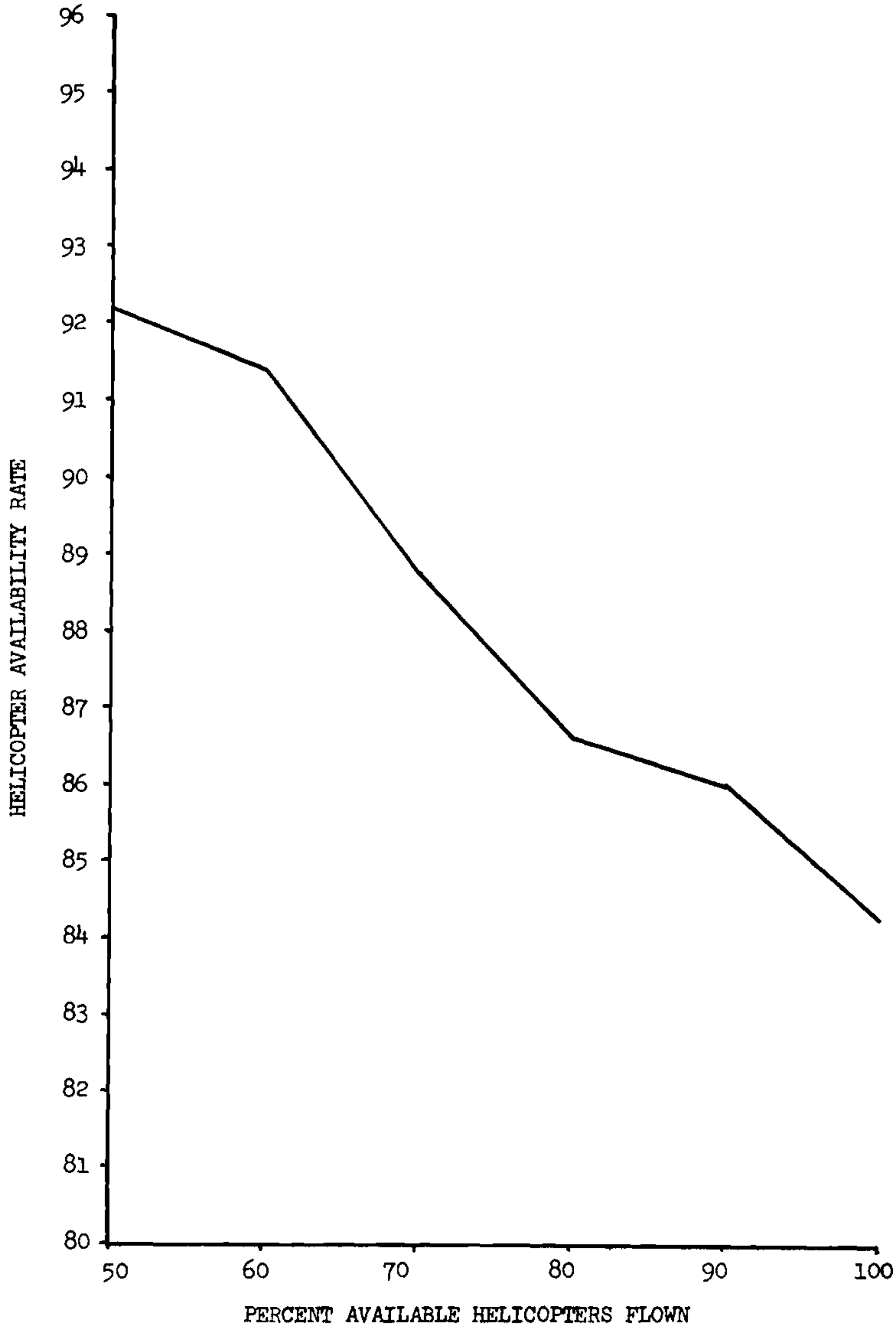

Figure 18. Modified Inspection Direct Support Detachment Helicopter Company Performs Modified Inspections.

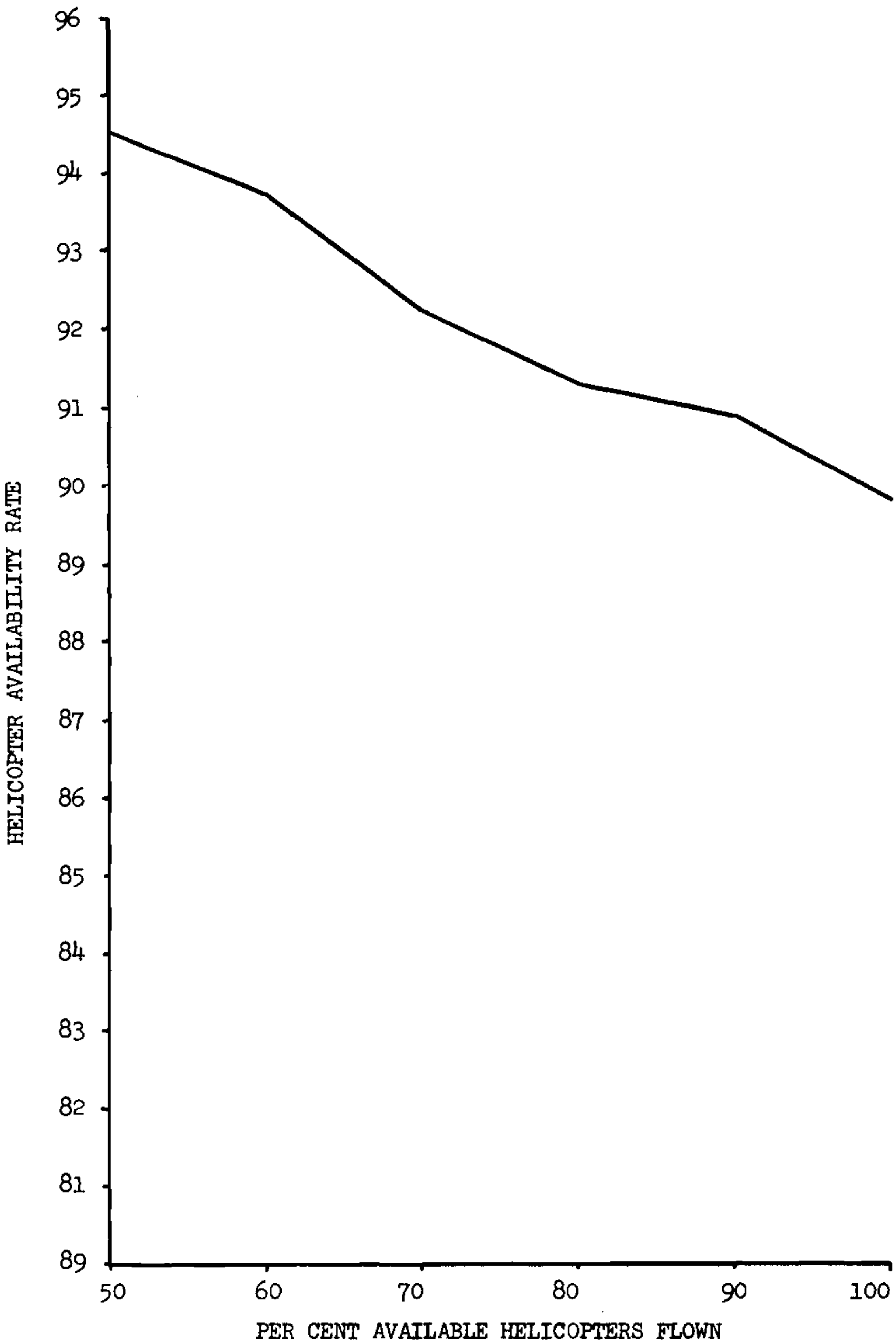

Figure 19. Modified Inspection Direct Support Detachment Direct Support Performs Modified Inspections.

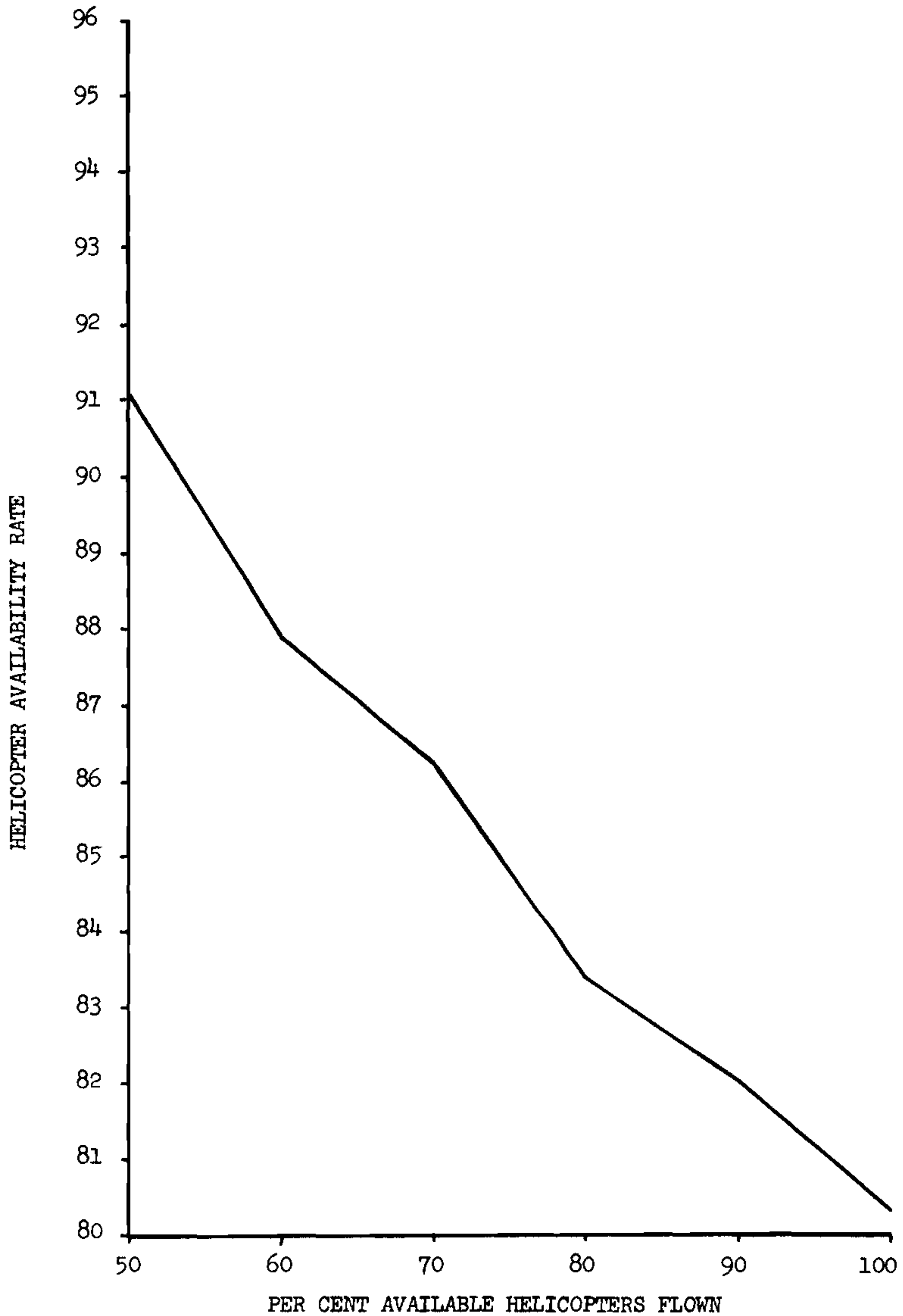

Figure 20. Modified Inspection Direct Support Company Helicopter Company Perform's Modified Inspections.

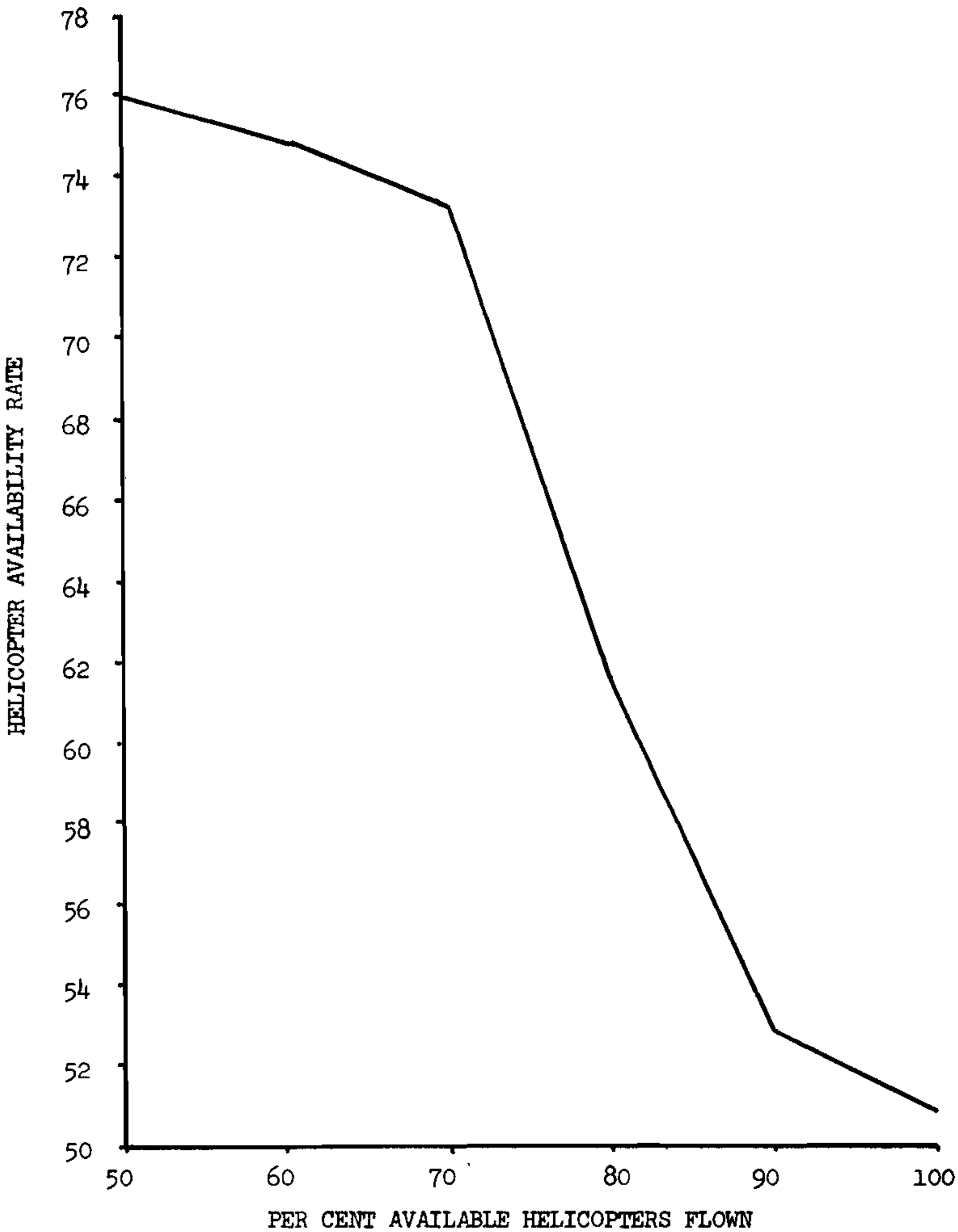

Figure 21. Modified Inspection Direct Support Company Direct Support Performs Modified Inspections.

Table 3. Average Percentages of Helicopters Undergoing Maintenance

Test	Per Cent of Available Helicopters Flown 50	60	70	80	90	100	Std. Devn.
I	1.73	2.13	2.46	2.93	3.11	3.40	.10
II	1.11	1.32	1.50	1.66	1.89	2.11	.026
III	9.81	11.11	12.89	13.22	14.01	15.63	.54
V	1.66	1.81	2.37	2.85	2.99	3.52	.19
VI	.92	1.05	1.25	1.39	1.51	1.62	.03
VII	9.72	11.77	13.46	13.39	14.05	14.76	.7

The tests correspond to the cells of Figure 13.

Experiment 2

Experiment 2 was conducted to compare the availability resulting from the use of direct support detachments as opposed to that of the direct support company. The comparisons are shown in Figures 22 through 25.

It is readily apparent that the direct support detachment supporting one helicopter company provides greater availability than the direct support company supporting a battalion of four helicopter companies. This result is not surprising since there is a cumulative total of 16 workcrews in four detachments as opposed to 10 workcrews in a company (5, 6). A comparison of the curves for the two tests where the helicopter company performed the periodic or modified inspections indicates that the employment of the direct support company will result in the same availability rate as that yielded by the detachment if the percent of available helicopters flown is reduced an average of 15 per cent. Under normal management policies where the helicopter company performs the periodic or modified inspections, the availability rate resulting from the use of the direct support company ranged from one to four per cent lower than that of the detachment. Under some circumstances this may be an acceptable condition since there is an appreciable saving in equipment and personnel when employing the direct support company rather than four detachments.

The availability rate resulting from the use of the direct support company to perform all periodic or modified inspections is significantly lower than that of the direct support detachment, ranging from 19 to 40

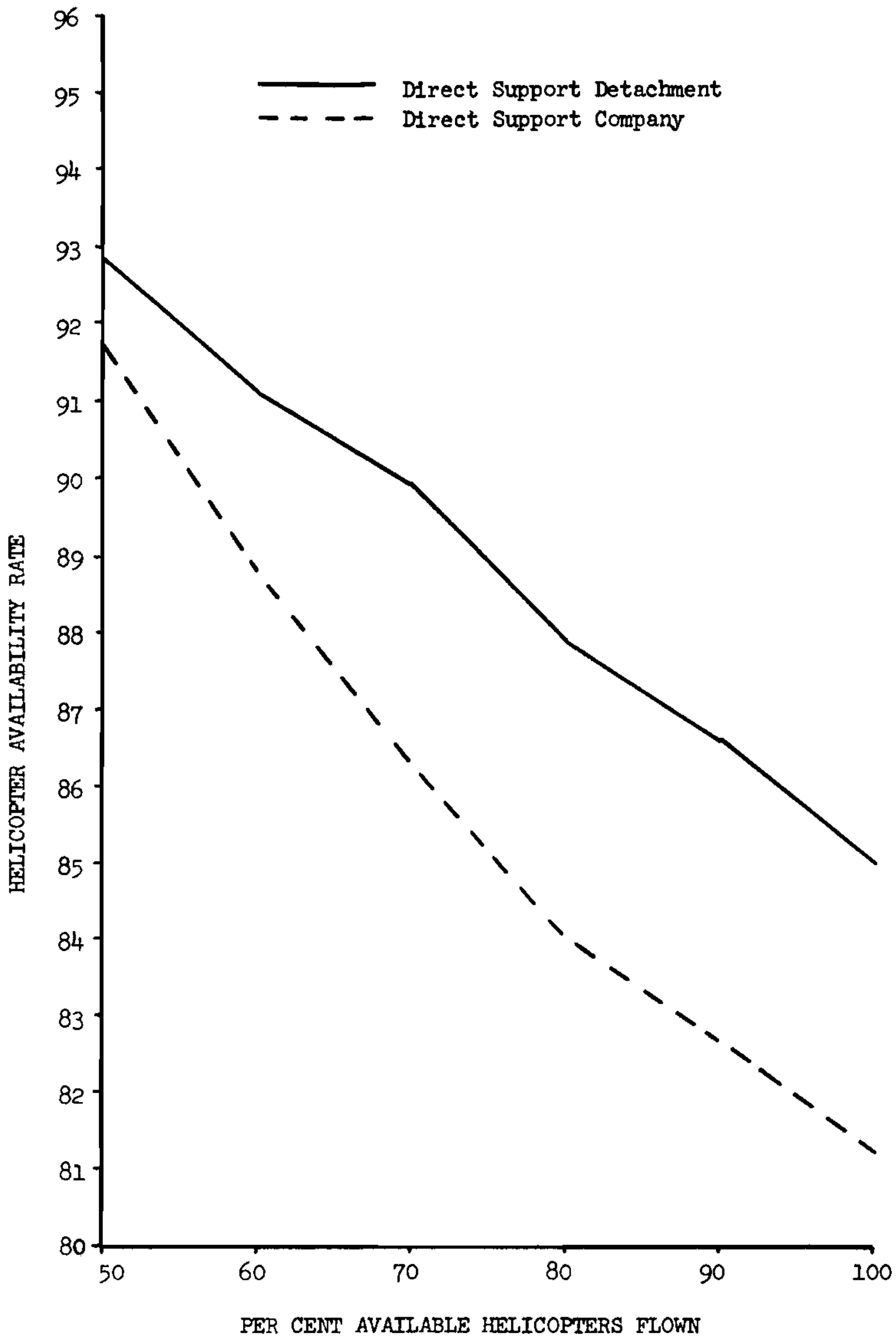

Figure 22. Comparison of Company versus Detachment Standard Inspection, Helicopter Company Performs Periodic Inspection.

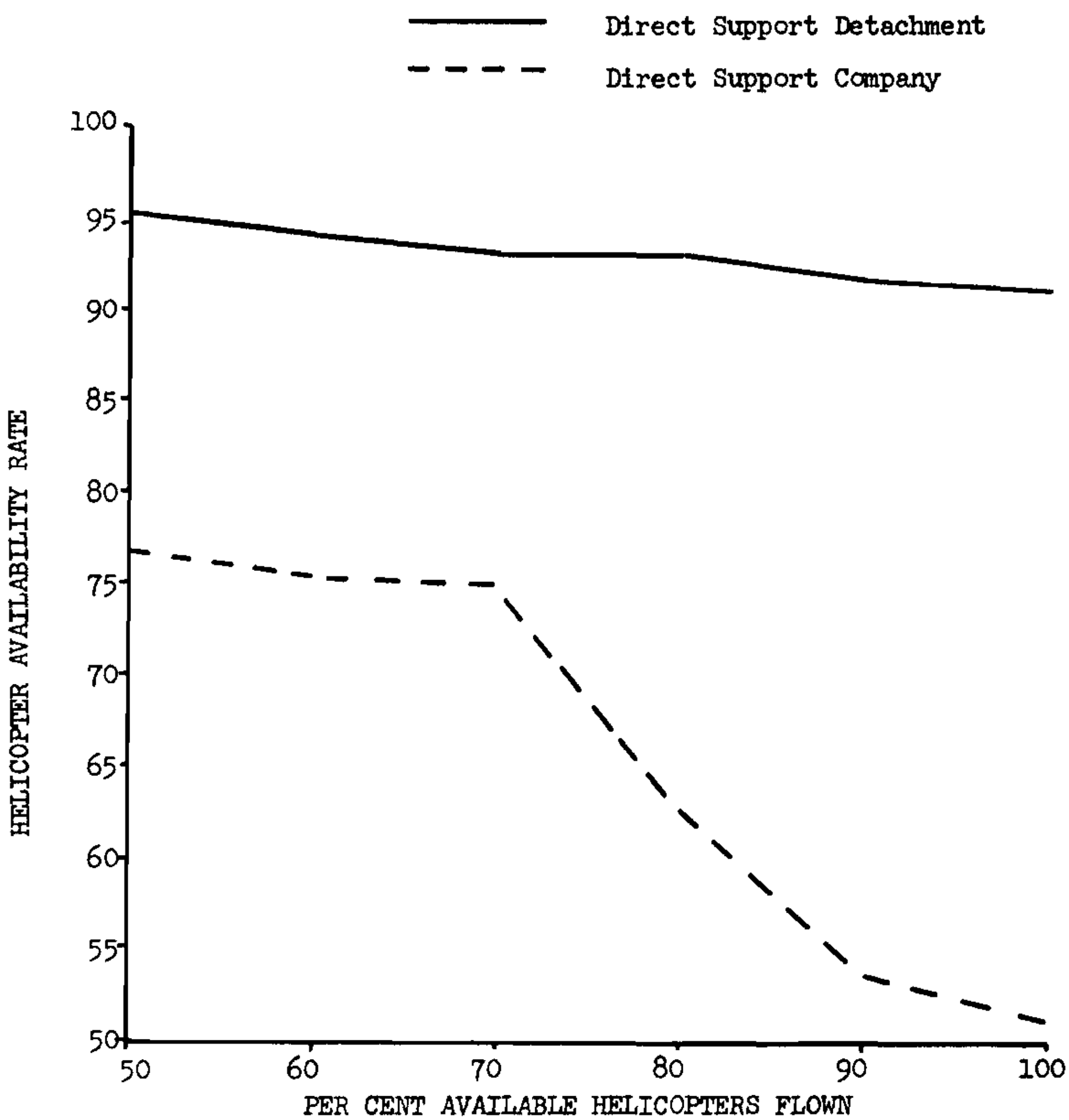

Figure 23. Comparison of Company versus Detachment, Standard Inspection Direct Support Performs Periodic Inspection.

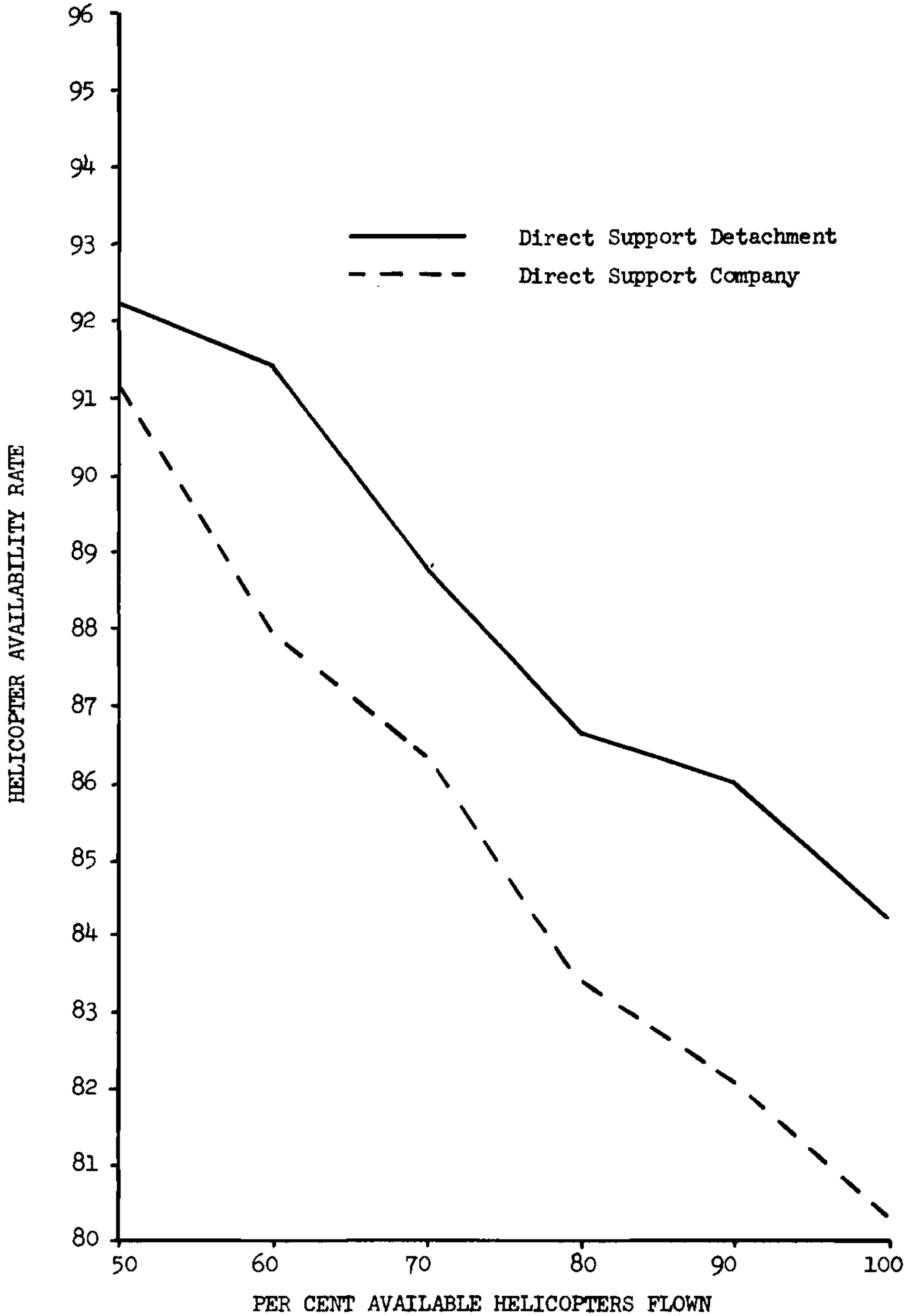

Figure 24. Comparison of Company versus Detachment, Modified Inspection, Helicopter Company Performs Modified Inspection.

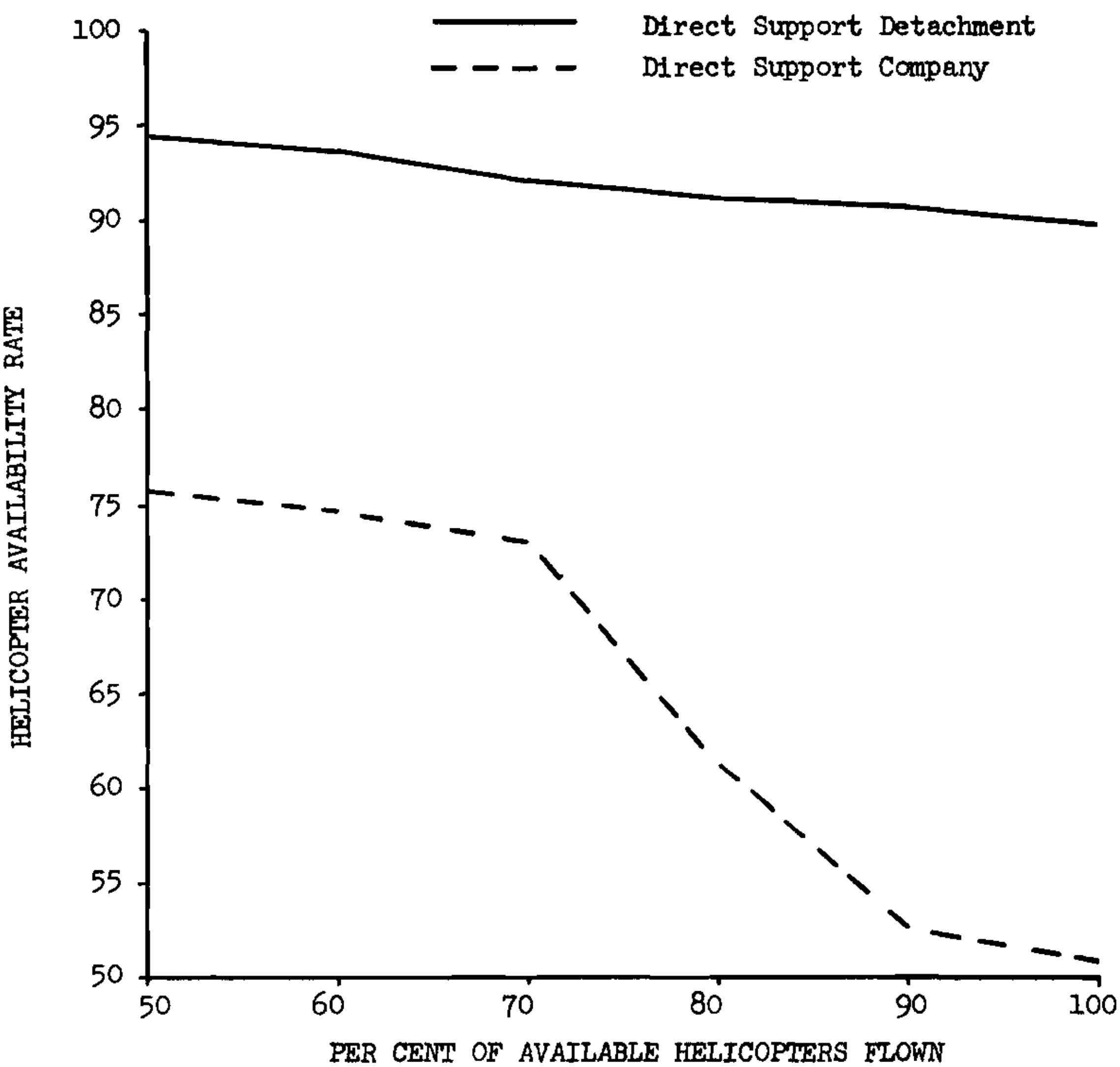

Figure 25. Comparison of Detachment versus Company, Modified Inspection, Direct Support Performs Modified Inspection.

per cent lower. The maximum capacity of the direct support company is exceeded when more than 70 per cent of the available helicopters are flown. This indicates that the direct support company is capable of providing adequate support but only when performing their own echelon of maintenance.

Experiment 3

Experiment 3 was designed to test the feasibility of a modified maintenance program. Rather than perform a major inspection every 100 hours, a system was devised to perform a minor inspection every 25 hours, incorporating all elements of the major inspection over four inspection intervals. The results of this experiment are shown in Figures 26 through 29. The modified inspection availability rates compared favorably with those of the standard inspection. While a slight decrease in availability occurred in most cases, a modified inspection system does appear feasible. Of particular interest is a comparison of the average contents and the number of entries into the maintenance facilities for each inspection system. The number of helicopters undergoing maintenance simultaneously is higher for the standard inspection system while the total number of helicopters having undergone maintenance is higher for the modified system. This is caused by the longer inspection duration of the standard inspection.

Experiment 4

The fourth experiment was conducted to determine the practicability of having the direct support element perform all periodic and modified inspections. Since this method of operation is seldom employed

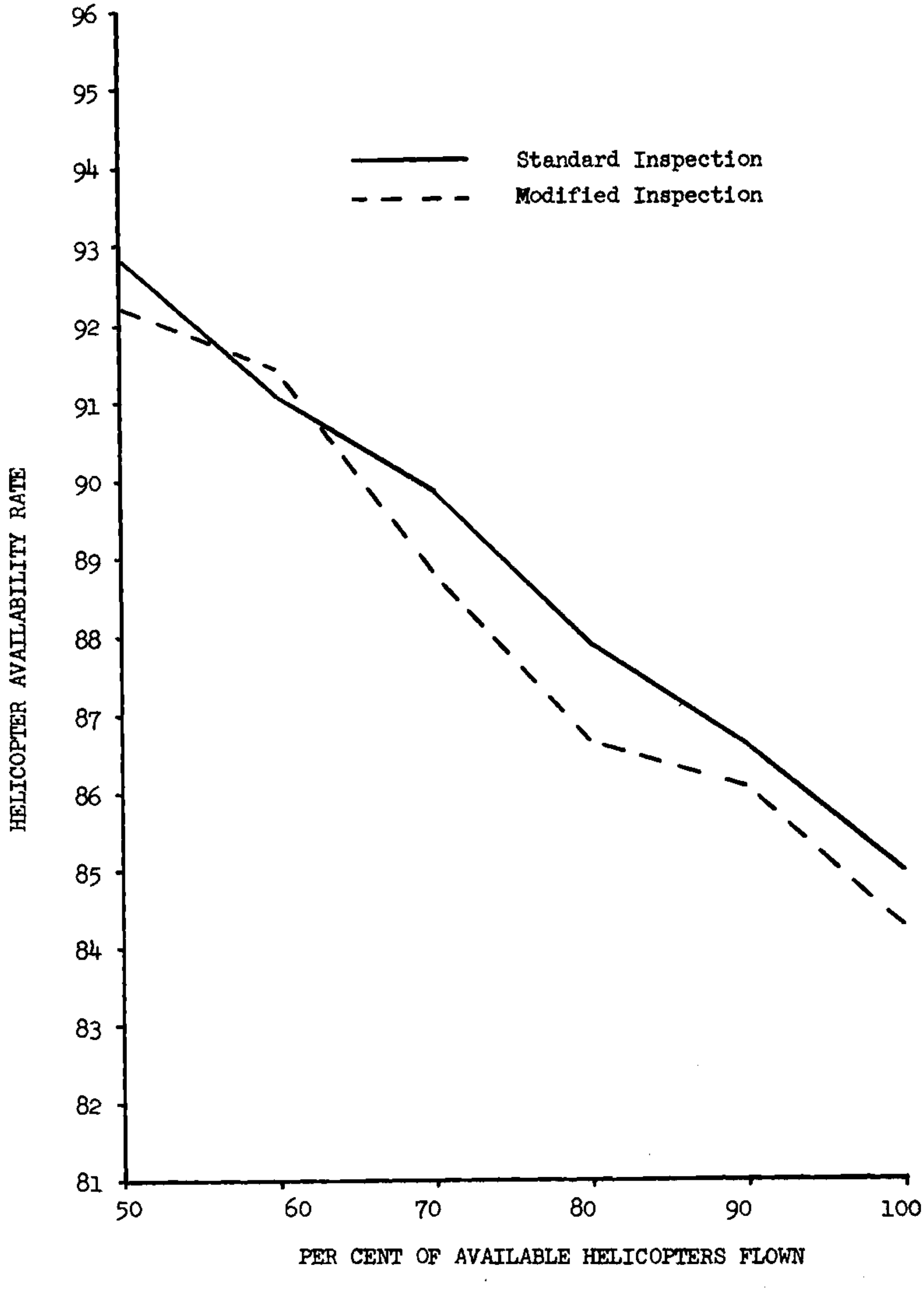

Figure 26. Comparison of Standard versus Modified Inspections, Direct Support Detachment Helicopter Company Performs Inspections.

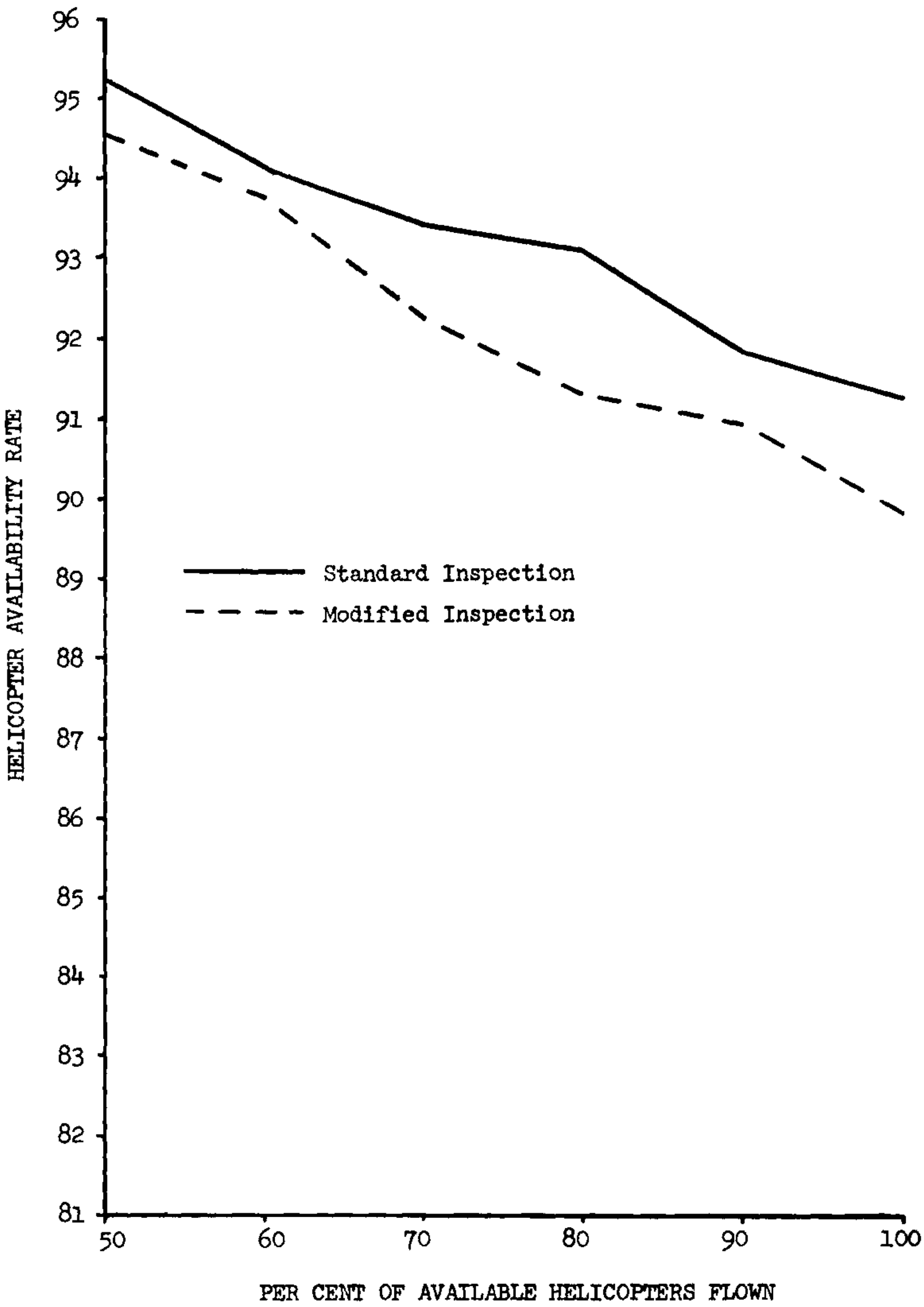

Figure 27. Comparison of Standard versus Modified Inspections, Direct Support Detachment, Direct Support Performs Inspections.

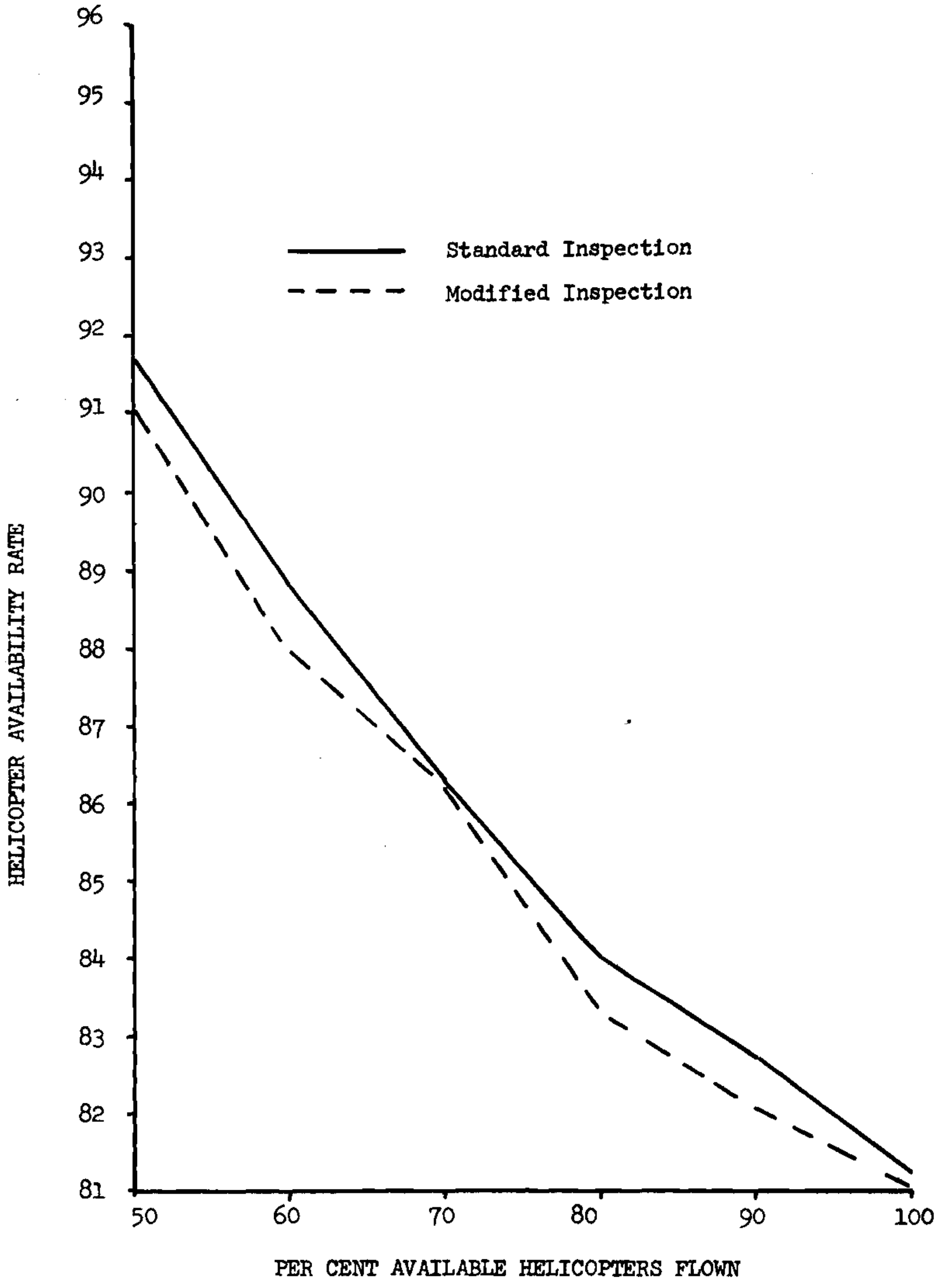

Figure 28. Comparison of Standard versus Modified Inspections, Direct Support Company, helicopter company performs inspections.

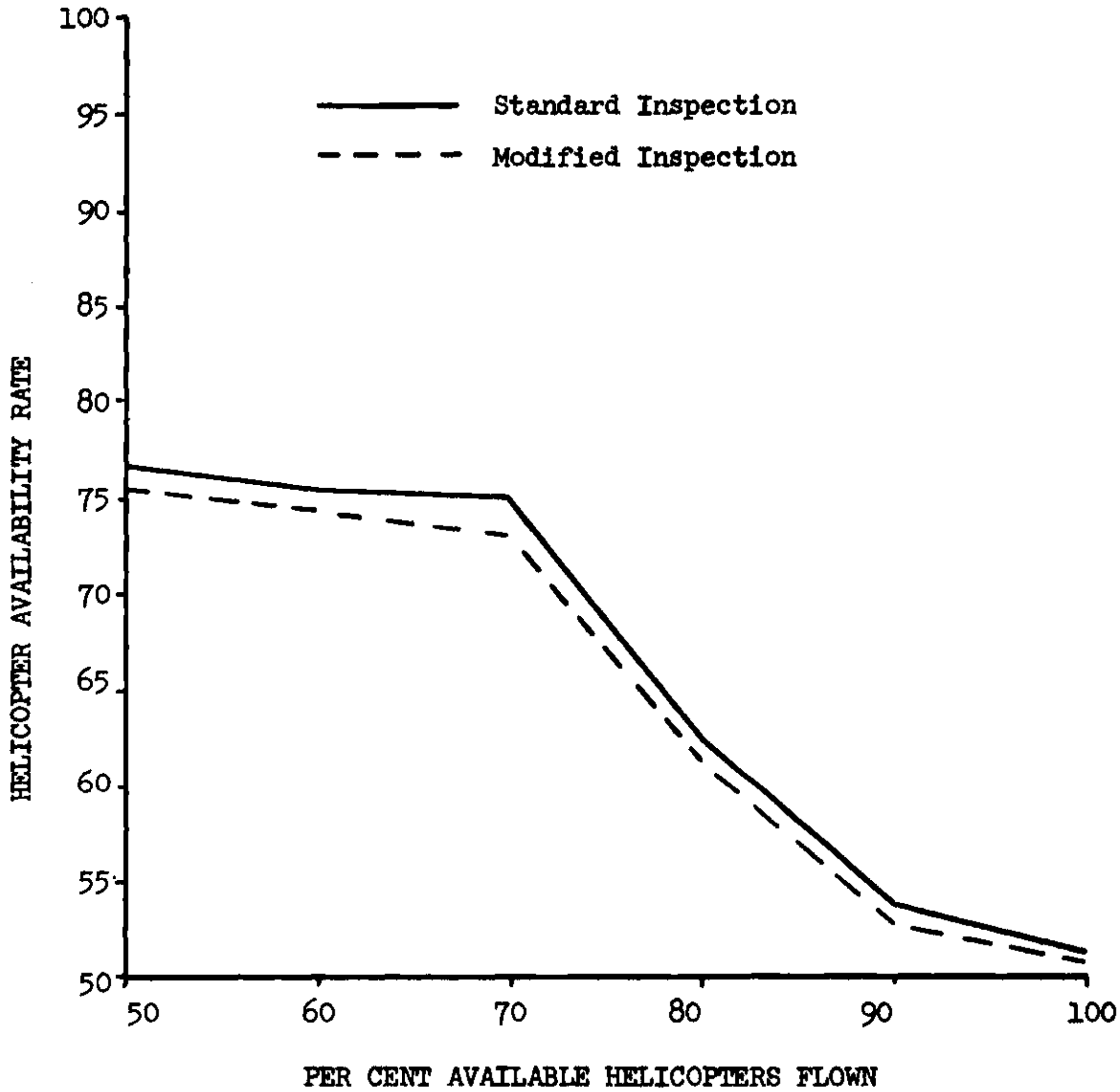

Figure 29. Comparison of Standard versus Modified Inspections, Direct Support Company, Direct Support Performs Inspections.

by helicopter units its effect upon availability is suspect. The results of this experiment are shown in Figures 30 through 33. The availability rate was increased from two to six per cent over the existing rate when the direct support detachment performed the inspections rather than the helicopter company. This was true for both the standard and modified inspections. This occurs because the detachment has capacity for a greater workload than is placed upon it during normal operations. The opposite was true in the case of the direct support company. The availability rate decreased from 15 to 30 per cent when the direct support company performed the periodic and modified inspections. As noted in Experiment 2 the direct support company is structured to perform only these maintenance tasks normal to its echelon.

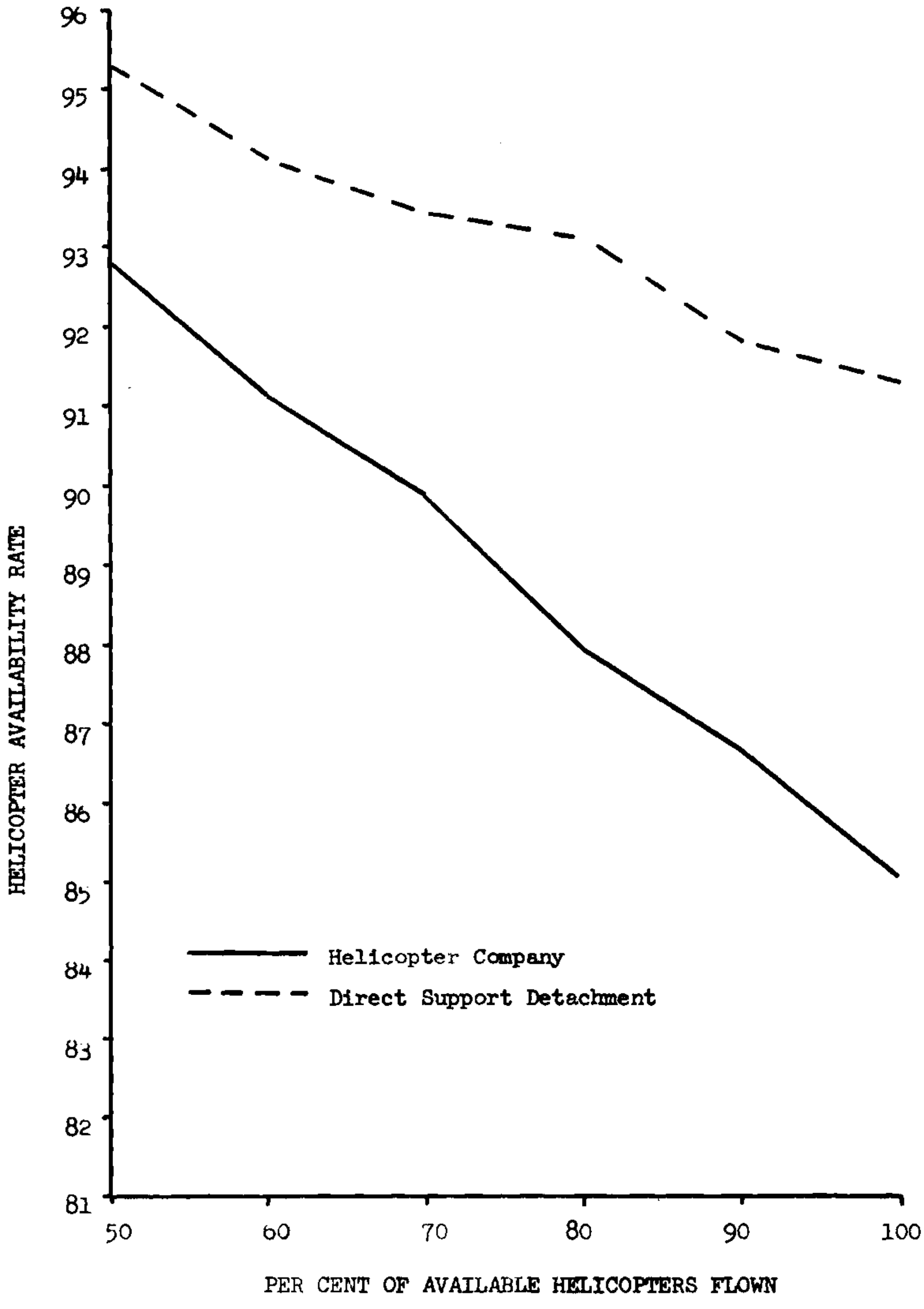

Figure 30. Comparisons of Helicopter Company versus Direct Support Performing Periodic and Modified Inspections, Direct Support Detachment, Standard Inspection.

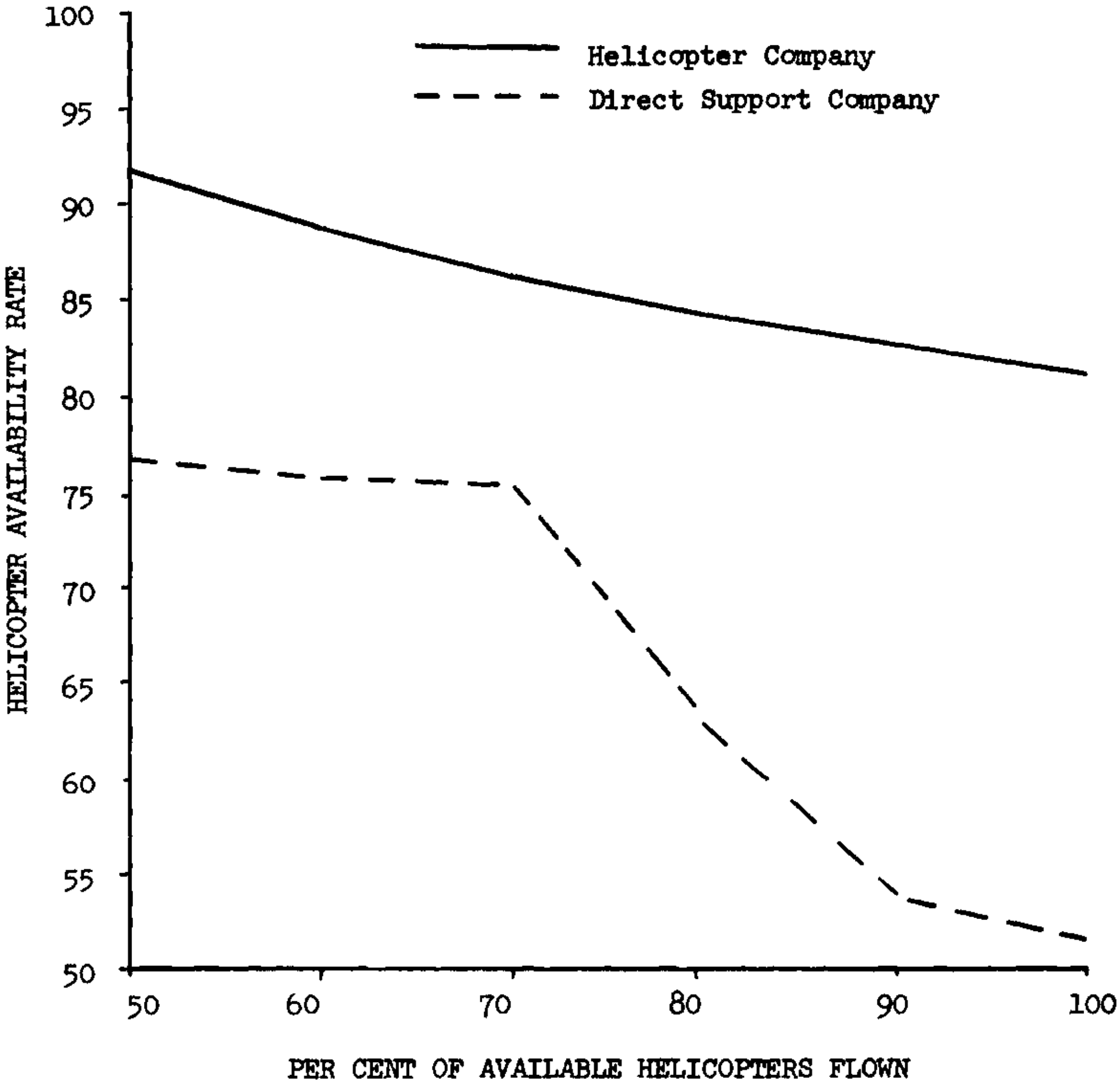

Figure 31. Comparison of Helicopter Company versus Direct Support Performing Periodic and Modified Inspections, Direct Support Company, Standard Inspection.

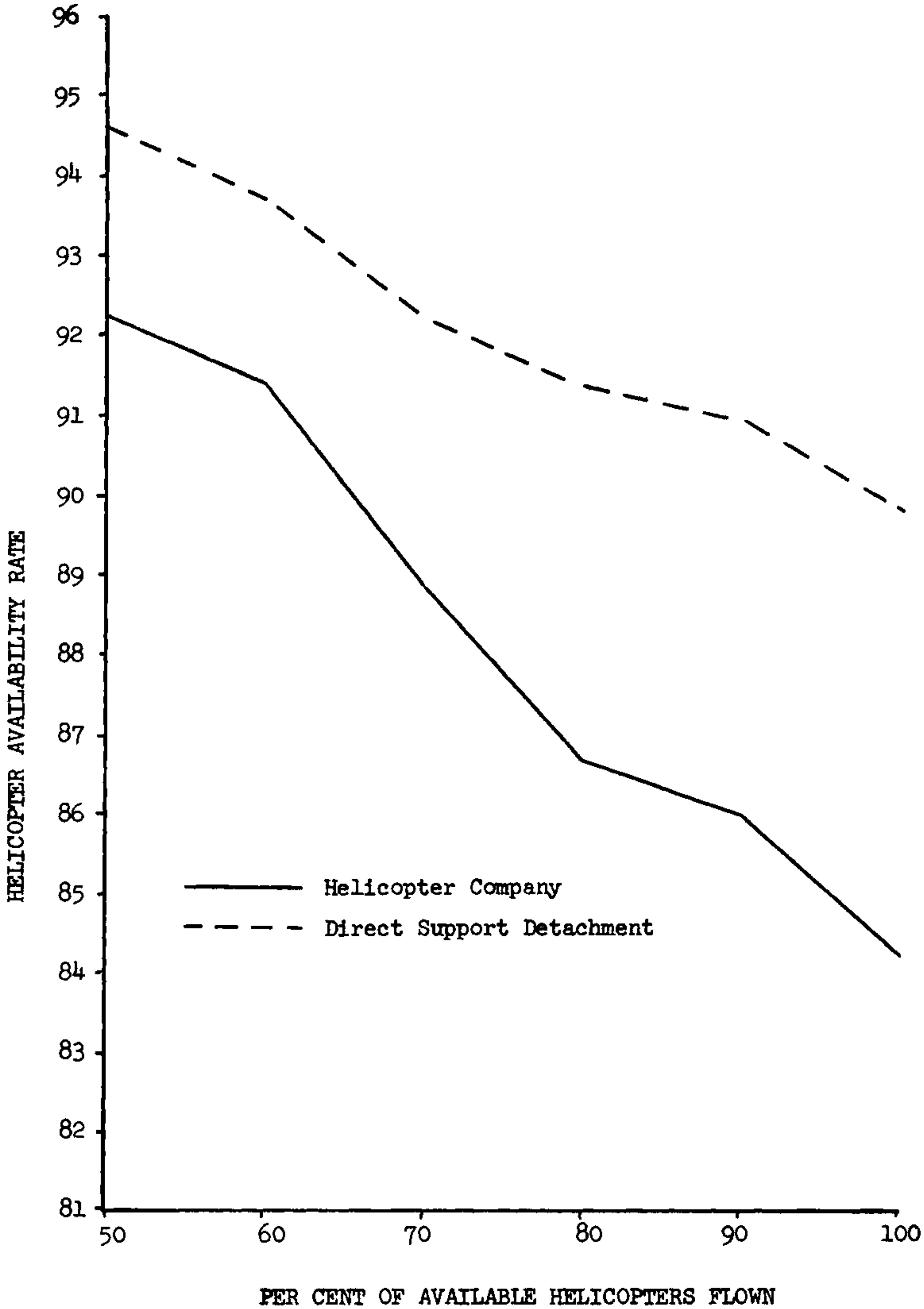

Figure 32. Comparison of Helicopter Company versus Direct Support Performing Periodic and Modified Inspections, Direct Support Detachment, Modified Inspection.

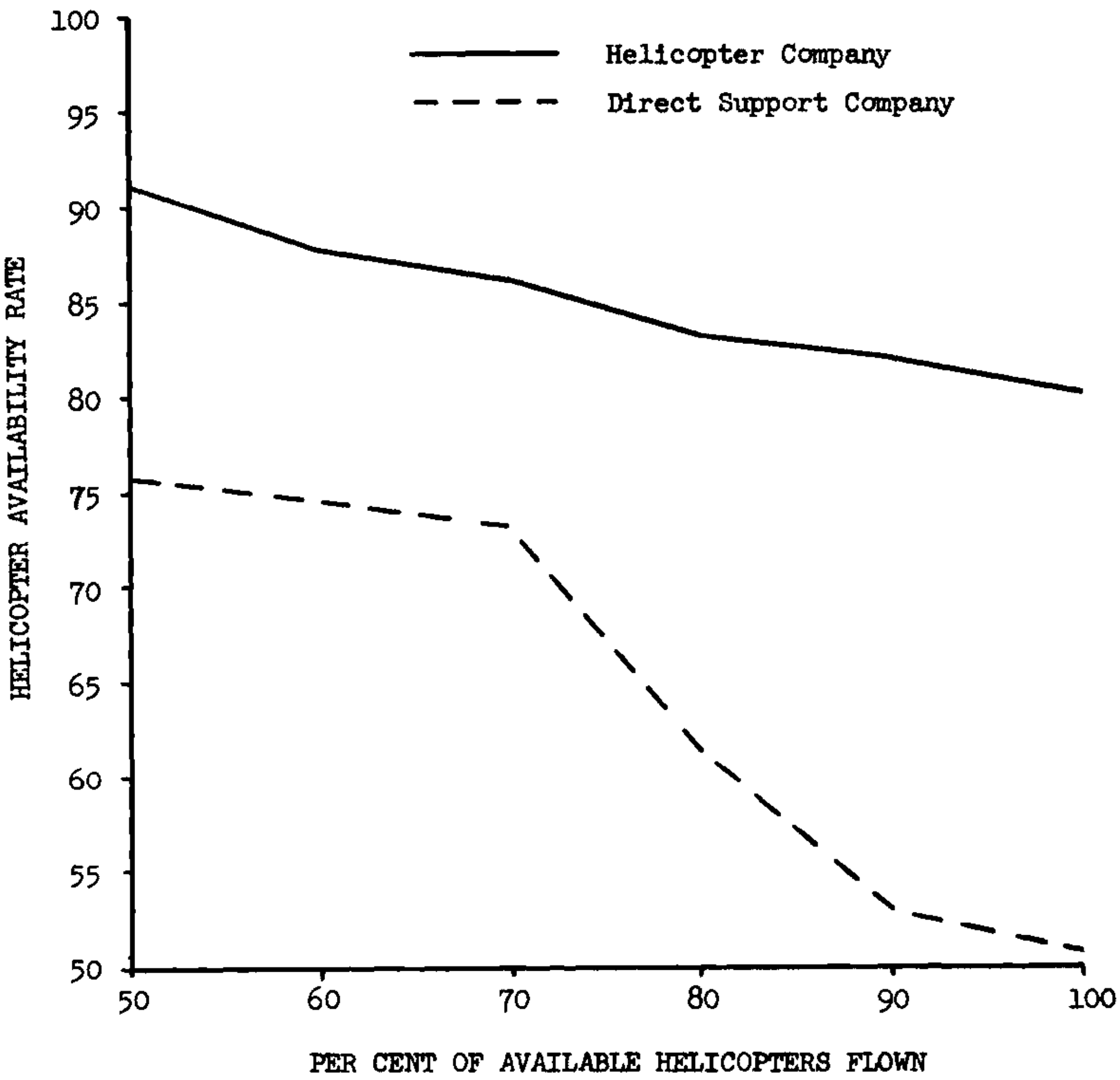

Figure 33. Comparison of Helicopter Company versus Direct Support Performing Periodic and Modified Inspections, Direct Support Company, Modified Inspection.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Introduction

In the preceding chapters, each experiment was designed to measure the effect of certain management alternatives upon the helicopter availability rate.

Experiment 1 showed that as the percentage of available helicopters flown increased, the availability rate decreased. It was also shown that the availability rate reacted to changes in flying program in an approximately linear manner.

In Experiment 2, it was found that the use of four Direct Support Detachments yielded a higher availability rate than that of one Direct Support Company. In addition, a comparison of corresponding availability curves revealed that the company would yield the same availability as the detachment for an average 15 per cent decrease in the rate of available helicopters flown.

Experiment 3 indicated that a modified or restructured inspection system is feasible and one might be devised that would produce an increased availability rate.

By having the Direct Support Detachment perform all periodic and modified inspections, it was found in Experiment 4 that the availability rate was increased by an average of four per cent. However, when the direct support company performed the same inspections the availability rate decreased by an average of 22 per cent.

Conclusions

1. The helicopter availability rate reacts in an approximate linear manner to a change in the flying program.

2. A direct support detachment will adequately support one helicopter company to include the performance of all periodic inspections. A direct support company will adequately support a battalion of four helicopter companies so long as it performs only its own level of maintenance.

Recommendations

1. Because of the high cost of maintenance in all resources, the field of maintenance management is a likely research area. To pursue this study the simulation model should be expanded to include levels of spare parts, fluctuating manpower and skill levels, and cannibalization.* However, the model should only include those system variables for which accurate data is available. GPSS II is an excellent language for this type endeavor. Should the model exceed the size limitations, subprograms may be run with their output serving as input functions to the main program.

2. Another excellent research area concerns the combination of items to be examined during an inspection. Inspection intervals are

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*Cannibalization is an expedient means of relieving a parts shortage by removing a good part from one equipment and installing it on another.

initially determined by reliability engineers and are subsequently modified by operating experience. An inspection schedule is developed by grouping items that are located in the same area of the equipment. Time is required to gain access to the inspection area and once this has been accomplished it is feasible to inspect all items within that area, even if a reduced inspection interval for some items results.

3. It is recommended that a study be undertaken to compare the overall system cost of replacing all items in a set when one fails as opposed to the cost of the unavailability of a helicopter when a second item of the set fails. Some trade-offs to examine are the initial cost of increased spare part levels, the cost of overhauling the unfailed items and the cost of the unavailability of a helicopter under the conditions of combat, medical evacuation missions and training flights.

APPENDIX A

GPSS II PROGRAM

```
*       A SIMULATION OF A HELICOPTER COMPANY
*       AS AN AID TO MAINTENANCE MANAGEMENT
 1      FUNCTION    RN1     D2
.2      0      1.0   1
 2      FUNCTION    RN1     C9
.236 2      .476    4       .688    6       .816    8       .881    10      .931    12
.978 14     .997    16      1.0     18
 3      FUNCTION    RN1     C2
            1       13.6
 4      FUNCTION    V2      C2
            24      24
 5      FUNCTION    RN1     C13
        5       .05     5       .30     6       .45     7       .70     8       .75     9
.8      10      .85     12      .88     16      .90     18      .92     20      .94     24
1.0     28
 6      FUNCTION    RN1     C14
        45      .60     45      .65     50      .67     53      .70     56      .72     60
.75     65      .77     68      .80     73      .85     85      .87     90      .69     98
.90     105     1.0     120
 7      FUNCTION    RN1     C12
        50      .05     53      .08     60      .16     66      .26     73      .39     77
.52     85      .62     92      .75     95      .85     100     .95     115     1.0     145
 8      FUNCTION    V6      C2
            200     200
 9      FUNCTION    RN1     C2
        10      1       15
 10     FUNCTION    RN1     C2
        7       1       12
 11     FUNCTION    V7      C2
            200     200
 12     FUNCTION    V9      D12
2047 1      3071    2       3583    3       3839    4       3967    5       4031    6
4067 7      4079    8       4087    9       4091    10      4093    11      4094    12
 13     FUNCTION    V11     D5
.17     1       .34     2       .51     3       .68     4       1.0     5
 14     FUNCTION    V14     D10
511     13      767     14      895     15      959     16      991     17      1007    18
1015 19     1019    20      1021    21      1022    22
 15     FUNCTION    RN1     D10
        2       .4      2       .6      4       .7      6       .8      8       .85     10
.87     12      .9      14      .92     16      1       18
*
*       FLYING PORTION OF SIMULATION MODEL BEGINS
 1      ORIGINATE           25                      2               24
 2      ENTER       1                       BOTH    4       3
 1      CAPACITY    100
 3      ASSIGN      2       K0                      10
 4      COMPARE     FN1     G       K0              5
 5      ASSIGN      2       FN2                     6
 6      ADVANCE                                     7               *2
 7      ASSIGN      3+      P2              ALL     8       10
 8      COMPARE     P3      GE      K25             15
 9      COMPARE     FN3     LE      V1              11
 10     ADVANCE                             BOTH    4       3       1       FN4
 11     ADVANCE                                     12              1       FN4
 12     ASSIGN      4       K8                      13
 13     ASSIGN      6       K51                     50
 14     ASSIGN      1+      K1                      15
 15     ASSIGN      3       K0              ALL     16      18      1       FN4
 16     COMPARE     V3      E       K0              21
 17     COMPARE     V4      E       K0              20
 18     ASSIGN      4       K5                      19
 19     ASSIGN      6       K69                     50


 20     ASSIGN      4       K6                      22
 21     ASSIGN      4       K7                      80
 22     ASSIGN      6       K51                     50
 30     COMPARE     V3      E       K0              35
 31     COMPARE     V4      E       K0              36
 32     COMPARE     V5      E       K0              38
 33     ASSIGN      4       K5                      34
 34     ASSIGN      6       K69                     50
 35     ASSIGN      4       K7                      80
 36     ASSIGN      4       K8                      37
 37     ASSIGN      6       K51                     50
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 38    ASSIGN      4     K11                  39
 39    ASSIGN      6     K51                  50
*      FLYING PORTION OF SIMULATION MODEL ENDS
*
*
*      ORGANIZATIONAL MAINTENANCE PORTION
*      OF SIMULATION BEGINS
 50    ENTER       2                   P      6
 2     CAPACITY    100
 51    ASSIGN      8     V8            BOTH   52      61
 52    ENTER       4                          53
 4     CAPACITY    3
 53    COMPARE     V9    L     K4095          54
 54    ASSIGN      6     FN12                 55
 55    HOLD        *6                         56              *8
 56    LEAVE       4                          57
 57    LEAVE       2                   BOTH   58      60
 58    COMPARE     V11   G     K0             59
 59    ASSIGN      2     FN13                 10
 60    ADVANCE                         BOTH   4       10
 61    ASSIGN      8     FN*4                 62
 62    ADVANCE                         BOTH   63      64      6
 63    COMPARE     P8    LE    K6             57
 64    ADVANCE                                65              18
 65    ASSIGN      8-    K6                   66
 66    ASSIGN      6     P8                   67
 67    ASSIGN      8     V12           BOTH   52      68
 68    ASSIGN      8     P6                   62
 69    ASSIGN      8     FN5                  70
 70    ADVANCE                         BOTH   71      72      6
 71.   COMPARE     P8    LE    K6             57
 72    ADVANCE                                73              18
 73    ASSIGN      8-    K6                   70
*      ORGANIZATIONAL MAINTENANCE PORTION
*      OF SIMULATION MODEL ENDS
*
*
*      DIRECT SUPPORT )DET* MAINTENANCE PORTION
*      OF SIMULATION MODEL BEGINS
 80    ENTER       3                          81
 3     CAPACITY    100
 81    ASSIGN      8     V13                  82
 82    ENTER       5                          83
 5     CAPACITY    4
 83    COMPARE     V14   L     K1023          84
 84    ASSIGN      6     FN14                 85
 85    HOLD        *6                         86              *8
 86    LEAVE       5                          87
 87    LEAVE       3                   BOTH   58      60
*      DIRECT SUPPORT )DET* MAINTENANCE PORTION
*      OF SIMULATION MODEL ENDS



*
*
*      REAL TIME CLOCK BEGINS
 100   ORIGINATE         1                    101             1
 101   SPLIT                                  102     105
 102   SPLIT                                  103     104
 103   SPLIT                                  106     107
 104   SPLIT                                  108     109
 105   SPLIT                                  110     111
 106   SPLIT                                  112     113
 107   SPLIT                                  114     115
 108   SPLIT                                  116     117
 109   SPLIT                                  118     119
 110   SPLIT                                  120     121
 111   SPLIT                                  122     123
 112   SPLIT                                  124     125
 113   SPLIT                                  126     127
 114   SPLIT                                  128     129
 115   SPLIT                                  130     131
 116   SPLIT                                  132     133
 117   SPLIT                                  134     135
 118   SPLIT                                  136     137
 119   SPLIT                                  138     139
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 120   SPLIT                                       140    141
 121   SPLIT                                       142    143
 122   SPLIT                                       144    145
 123   SPLIT                                       146    147
 124   ASSIGN       1       K1                     148
 125   ASSIGN       1       K2                     148
 126   ASSIGN       1       K3                     148
 127   ASSIGN       1       K4                     148
 128   ASSIGN       1       K5                     148
 129   ASSIGN       1       K6                     148
 130   ASSIGN       1       K7                     148
 131   ASSIGN       1       K8                     148
 132   ASSIGN       1       K9                     148
 133   ASSIGN       1       K10                    148
 134   ASSIGN       1       K11                    148
 135   ASSIGN       1       K12                    148
 136   ASSIGN       1       K13                    148
 137   ASSIGN       1       K14                    148
 138   ASSIGN       1       K15                    148
 139   ASSIGN       1       K16                    148
 140   ASSIGN       1       K17                    148
 141   ASSIGN       1       K18                    148
 142   ASSIGN       1       K19                    148
 143   ASSIGN       1       K20                    148
 144   ASSIGN       1       K21                    148
 145   ASSIGN       1       K22                    148
 146   ASSIGN       1       K23                    148
 147   ASSIGN       1       K24                    148
 148   ADVANCE                                     149           6
 149   INTERRUPT    *1                             148           18
*      REAL TIME CLOCK ENDS
*
*
*      DATA COLLECTION PORTION OF MODEL BEGINS
 150   ORIGINATE    24                             151           24
 151   SAVEX        1+      K1              BOTH   152    153
 152   COMPARE      X1      L       K361           156
 153   ASSIGN       1       V16                    154
 154   TABULATE     *1                             155
 155   TABULATE     13                             156


 156   TERMINATE    R
*      DATA COLLECTION PORTION OF MODEL ENDS
 1     VARIABLE     K100*S2/K735+K100*S3/K735
 2     VARIABLE     K24-P2
 3     VARIABLE     P1(K12
 4     VARIABLE     P1(K4
 5     VARIABLE     P1(K2
 6     VARIABLE     FN6-FN9
 7     VARIABLE     FN6-FN10
 8     VARIABLE     FN*4/K3
 9     VARIABLE     V10+K32*F7+K16*F8+K8*F9+K4*F10+K2*F11+F12
 10    VARIABLE     K2048*F1+K1024*F2+K512*F3+K256*F4+K128*F5+K64*F6
 11    VARIABLE     P8(K6
 12    VARIABLE     P8/K3
 13    VARIABLE     FN*4/K8
 14    VARIABLE     V15+K8*F19+K4*F20+K2*F21+F22
 15    VARIABLE     K512*F13+K256*F14+K128*F15+K64*F16+K32*F17+K16*F1
 16    VARIABLE     V17/K30+K1
 17    VARIABLE     X1-K360
 18    VARIABLE     S1-S2-S3
 19    VARIABLE     K100*V18/S1
 1     TABLE        V19    0      1       101
 2     TABLE        V19    0      1       101
 3     TABLE        V19    0      1       101
 4     TABLE        V19    0      1       101
 5     TABLE        V19    0      1       101
 6     TABLE        V19    0      1       101
 7     TABLE        V19    0      1       101
 8     TABLE        V19    0      1       101
 9     TABLE        V19    0      1       101
 10    TABLE        V19    0      1       101
 11    TABLE        V19    0      1       101
 12    TABLE        V19    0      1       101
 13    TABLE        V19    0      1       101
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