1

STUDY ON IN-THEATER MAINTENANCE SUPPORT FOR POAF F-16

THESIS

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Preface

The purpose of this study was to evaluate the capacity to generate a desired level of sorties for the Portuguese Air Force F-16 weapon system. The capacity to generate sorties depends on the maintenance concept and structure. This maintenance concept defines a specific level of in-theater resources available. The study focused on the unscheduled maintenance tasks, in particular the engine and the avionics area. The resources under evaluation were manning, support equipment and spares levels. The TSAR simulation program was used to perform the evaluation of the sixteen different alternatives.

Although some limitations were found in the output data, the results show that the level of maintenance support defined in this study is insufficient to sustain the desired level of sorties. In the process of producing the database for the simulation, some assumptions had to be made. The reason is this study was concurrent with the PoAF and USAF discussions and decisions on the logistics support for the new fleet.

This study was only possible due to the support of my thesis advisor Maj Diener. Without his guidance and patient advice I would not be able to conclude this effort.

I want to thank the POLO representatives in WPAFB, Col Tomas Leitao, Capt Gil Barbeitos and SAJU Rui Ferreira and their families for the support and friendship they provided me while working on this study.

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Rui J. Gomes

Table of Contents

List of Tables

AFIT/GLM/LSM/91S-21

Abstract

The purpose of this study was to evaluate the capacity to generate a desired level of sorties of the F-16 weapon system. This capacity depends on the maintenance concept and structure, that defines a specific level of in-theater resources available. The theater is intended to reflect Portuguese Air Force logistic operations planned for the F-16, with one operational base and a possible Centralized Intermediate Repair Facility (CIRF), not co-located.

The TSAR simulation program and one USAF database was used to perform the evaluation of the different alternatives. Sixteen scenarios were defined and compared. The study focused on the unscheduled maintenance tasks and repairable items, in particular the engine and the avionics areas. The resources under evaluation were manning, support equipment and spares levels. The variables were the location of support equipment and the levels and scheduling of manpower.

Limitations on handling the TSAR program restricted the amount of data used in the analysis. However, the results show that the level of maintenance support defined in this study is insufficient to sustain the desired level of sortie generation, with little difference across the different scenarios. Data gathered covered only the short term (30 to 60 days) capability to support operations.

STUDY ON IN-THEATER MAINTENANCE SUPPORT FOR POAF F-16

I. Introduction

General Issue

The successful introduction and operation of a weapon system requires managers to make early, important decisions. These decisions must balance the tradeoffs between aircraft availability and support costs. The goal is to obtain maximum aircraft and spare parts availability, at minimum cost. Although these decisions affect the initial period of operation, the main concern is their impact throughout the system life cycle.

The Portuguese Air Force (PoAF) is planning to introduce the F-16 weapon system to the inventory. The current plan calls for only one squadron of 20 F-16 aircraft. They will operate from one main base, with possible forward detachments to other bases. The size of the fleet, plus the complexity of the aircraft and its systems, limit the amount of equipment planned. There is the need to evaluate the options on the equipment to obtain, and the degree to which outside support will impact aircraft availability. This research deals with the importance of logistics, and with the type of support required by the PoAF F-16. The desired outcome is to support the mission requirements with the least investment.

The introduction of this weapon system signifies changes in PoAF logistics support due to both financial constraints and technical limitations. PoAF's financial resources are scarce now and are not anticipated to grow in the future. The acquisition of equipment for in-country logistics support is limited by the funds available. In the past, PoAF has been able to acquire the necessary resources for in-country support of its weapon systems. PoAF now operates 13 different types of aircraft. In general, there is organic capability for the three levels of maintenance for these aircraft. The F-16 is the first major weapon system where there is no organic depot capability. In addition, PoAF needs to allocate the available resources and equipment needed for the F-16 to maximize its operation. This is particularly significant because contracting for support that exceeds organic capability will have to be done outside the country. The implications are both on support costs and on lead times for repairable items. The use of outside sources will require more financial resources, and increase the repair cycle. This, in turn, will limit the aircraft availability.

The F-16 is technologically superior to the majority of the current PoAF weapon systems. The F-16 is a design from the early 1970s. The current weapon systems in PoAF inventory are 1950s and 1960s design, a generation earlier.

This difference in technology, coupled with financial and manpower constraints, drives the location of the support resources. The operation of older aircraft designs, in small numbers of each type, led to bases with limited support capability, with the compliance of more complex maintenance tasks being done in PoAF depot facility. For some weapon systems, for instance, part of the Intermediate maintenance is performed in this facility due to the availability of support equipment and to a more stable and experienced civilian workforce. This is in contrast to the operating bases, where the military provides all the manpower for the logistics support activities. Due to PoAF manpower policy of rotation of personnel, this leads to some loss of accumulated experience.

Scope of Research

This research is directed toward determining the logistics support required for the F-16 weapon system. The focus is the maintenance support required. The analysis is further limited to the support required at base level with the emphasis on the Intermediate level. This is the level that usually requires the costly support equipment, which in turn governs availability of repairable items. Emphasis is placed on two main systems--powerplant and avionics. The ability of the aircraft to perform its mission depends greatly on these two systems. Furthermore, this study addresses primarily the unscheduled maintenance needs. This is because the unscheduled maintenance drives the unplanned need for repairs and support.

Manpower is one of the main forces that drives the level of support provided. Thus, the influence of manpower levels in the maintenance support is also addressed in this study.

Costs of different alternatives are not addressed in this study. Although the simulation model used in this simulation can include costs of parts, this area is too broad to be covered in the scope of this study. Other costs such as equipment costs, manpower costs, operation costs, or transportation costs would also need to be addressed, to allow a better analysis of the alternatives. These costs are not entries in the model used. Furthermore, tradeoffs between costs and aircraft availability may be dependent in factors beyond the scope of this study.

This study tests the influence of independent variables, controlled by the researcher, on the outcome. This is a one-time study, with the information and data available at the time of the study. As the conversations on the purchase and delivery of the weapon system were simultaneous with the study, some assumptions had to be made on the data entry.

Specific Problem

The focus of this analysis is on the maintenance concept for PoAF F-16; more specifically, on where to locate the in-country Intermediate level of maintenance. A weapon system consists of several subsystems, components and items. The items are the building blocks of any system, and so the analysis of their support provides an understanding of the weapon system support and availability. In particular, it is important to analyze the support available for the repairable items. These are the aircraft parts that are repaired and put back into the spares inventory. These items are important as they usually determine aircraft availability. In addition, they are high in value per unit, so their stock is kept to the lowest possible level. This restriction makes support equipment even more essential. The desired outcome is to support mission requirements with the least investment. Support equipment is understood, in this study, as equipment required to support the operation of the aircraft. The emphasis is on the main pieces of equipment that allow the execution of the repairs at the Organizational and Intermediate levels. Examples of this type of equipment are test stations to test electronic components, hydraulic cart to assist in troubleshooting the hydraulic system of the aircraft, and engine test cells.

The focus of the problem is on what is the achieved level of logistics support for weapon system operations, given the available quantities of resources. The resources under consideration are support equipment, manpower and spare parts. Attention is also focused on the location of the support equipment. The decision on the location ranges in combinations from all the equipment only on the operating base to a split between the operating base and PoAF's maintenance depot. More specifically, the question is how to best allocate the resources between the operating base and the PoAF depot facility. The analysis examines Intermediate maintenance for engine and avionics. This is justified by the importance of the parts and systems they support, and the volume and cost of the support equipment required.

Manning of the support equipment is as important as the availability of that equipment. Availability and scheduling of personnel are also decisive in achieving the required levels of maintenance support. PoAF traditionally operates on one day-time shift only. This is different from the USAF usage of two or even three shifts. Consequently, the achieved support levels are different, given the same level of material support. Thus, the other aspect under investigation in this study is the influence of the working scheduling (shifts), and the levels of manning.

Investigative Questions

The questions to be addressed are:

1. Where will the support equipment be located? Operating base or depot?

2. What is the level of support for operations with the available level of spare parts and support equipment?

3. What is the effect of manpower scheduling (one or two shifts), and of manning levels (100% or 80% desired levels)?

These questions are addressed within the constraints of the possible scenarios under investigation, which are:

1. All the capability at the base, with the repair shops operating full time, or two shifts.

2. All the capability at the base, and the shops operating only 1 shift a day.

3. Part of the Intermediate repair capability done at another facility, in country. In this case, the impact of different shifts is also investigated.

For each scenario, the effect of 100% percent manning or only 80% level is also investigated.

Limitations

The planned PoAF life cycle for the F-16 is not available. Although important because it determines some long term support options, it is not used in this study. The scenarios used in this simulation were designed according to the known F-16 requirements. The use of a USAF database allows the identification of the maintenance tasks times and probabilities of occurrence, critical parts, equipment and manpower demands. This allows one to validate the simulation, given data collected on this weapon system. These data were collected during peace time operation (12). Where applicable, the database was changed for this study for the specific planned conditions and applications.

The intent of this research is to quantitatively assess the influence of two important aspects of maintenance support: location of maintenance support equipment and manpower levels. This study is not intended as a basis for decisions on maintenance policies or structure for PoAF F-16. Its only intent is to provide some insight on the possible outcomes of different choices within a spectrum of options on the maintenance support area. It should be regarded as a complementary tool to base PoAF decisions on this area.

Definition of Terms

In order to provide and clarify the terms used in this research, a list of definitions is provided in Appendix A.

II. Background and Literature Review

Chapter Overview

This chapter addresses five main areas. First, a justification for the research. Second, a background on the PoAF constraints, and their impact on the management of a weapon system. Third, an overview of the importance of logistics support. Fourth, the aspects to consider when introducing a weapon system, including a look at international logistics. Finally, the use of computer models as a management tool for logistics support management is evaluated. The background exposed in this chapter is the result of a literature research.

Reason for Research

The Portuguese Air Force (PoAF) is planning to buy the F-16 weapon system. Financial constraints and technical limitations suggest changes in PoAF logistic support.

The PoAF normally performs all levels of maintenance, required for the systems it operates, within the country. The introduction of smaller, more complex weapon systems, with costlier support does not allow this option for the F-16. This is mainly for economic reasons. The result is that maintenance capability will be limited within the country.

PoAF Constraints

Portugal is a relatively small country, and the PoAF reflects this. Current manning for the entire PoAF is approximately 11,100 (15:275). PoAF's financial resources are scarce and are not expected to grow in the future. The U.S. provides part of the financing for the F-16 interceptor aircraft program (3:51). This is due as part of the payment for the ". . . use of the Lajes air base in the Azores" (17:276). However, on several occasions in recent years, these levels of assistance provided by the U.S. have been lower than the agreed upon between the two countries (4:22). This makes the financial aspects of acquisition and support of the weapon system a constant concern for the weapon system managers.

Logistics Support

Logistics support dictates weapon system availability. The availability of fuel, spare parts, and munitions determines the capacity of an aircraft to perform its mission. If no spare parts are available when demanded, the aircraft may not be able to fly the next mission. This means ". . . what the logistics system provides in terms of both the types and quantities of resources determines the nature of the capability for individual aircraft, individual wings, and the entire theater" (18:21).

Modern weapon systems are increasing in complexity. These systems require costly logistics support (21:13). There are some indicators of this cost and of its impact. In one study, the United States Air Force (USAF) ". . . found that parts failures accounted for 75% of support equipment costs in aircraft procurement accounts and at least 20% of the Air Force budget" (13:5). An aerospace company official, referring to the costs for a life cycle of 20 years, states:

> Acquisition represents approximately 40 percent of total costs, operations and logistics support more than 50 percent, and upgrades and other items, the remainder. (15:13)

Estimated costs for aircraft support found in research done by the U.S. Army are similar (16:5). A close look at the logistics support costs reveals that they account for more than 25% of the total life cycle cost (16:9).

The share of the support costs is proportional to, and increases with, the life cycle of the weapon system. The acquisition cost is a fixed amount and its percentage of total costs decreases as life cycle increases.

Logistics for a Weapon System

The introduction of a weapon system into the inventory requires careful planning. Logistics support requires particular attention. Logistic support includes a broad array of areas, and it can be compared to an iceberg. The aircraft on the flight line, ready to operate, is just the tip of the iceberg. For a weapon system like the F-16, 29 different areas within logistics are recognized. Examples of these areas are: spares, technical data, support equipment, management services, training, overhaul and repair. All of these areas are interrelated and fundamental to the support of the aircraft (11:100-101).

Logistics Support For The F-16. One of the initial USAF requirements for the F-16 demanded improved supportability, as compared to then current weapon systems. The designer and manufacturer did include it from the beginning. "The original F-16 contract, let in 1975, included logistic support award fee provisions; the criterion for eligibility was reduction of actual F-16 support costs below very challenging targets" (14:8).

Some of the general aspects of this supportability are: ". . . improved engine removal, improved maintenance access, built-in performance indicators, extensive use of existing hardware," and ". . . maintaining a good margin for cooling of electronic equipment" (22:6). Additional details of these design features are available in another source (14:9).

However, in spite of these design concerns, or as a result of them, the F-16 is a complex aircraft. The avionics area is a clear example of this complexity.

> . . .General Dynamics personnel performed a trade study to determine the most cost-effective design configuration for the avionics intermediate shop. After doing

> economical analyses of 101 candidate aircraft line-replaceable units, study personnel designated the majority for depot repair with no intermediate-level test requirement. Due to the cost of the added number of unit spares required to support depot repair, they concluded that acquisition of an intermediate shop would in fact be more economical for 32 of the units. These 32 units, plus four safety-of-flight units, were selected for test by the intermediate shop. (14:11)

The F-16 weapon system maintenance concept is organized in three maintenance levels: Organizational, Intermediate and Depot. The aircraft itself has no scheduled depot maintenance. Some of the repairable items, like the engine, have scheduled maintenance.

International Logistics. International logistics can be defined as "the negotiating, planning, and implementation of supporting logistics arrangements between nations, their forces and agencies" (8:362). In this study, it relates to the relations between the U.S. and other countries operating the same weapon system. Different countries have different approach to logistic support. Local conditions often dictate peculiar alternatives to support problems. Both the U.S. military, and civilian contractors, recognize this problem. "We could simply provide the country the same decisions that we have made for ourselves, but this might cause a degradation of overall logistics support" (11:102).

A major U.S. contractor, tasked to set up an avionics depot in a foreign country, drew the following conclusions from its experience:

> The concepts for repair of complicated and expensive avionics components in the United States Armed

> Services do not always satisfy the requirements for maintenance support for smaller countries.
>
> Countries that need to improve or replace obsolete inventories often are faced with the difficult task of choosing how these new articles are to be supported. Careful decisions for this support must be made based on the various criteria, ground rules and considerations. These criteria include degree of self-sufficiency, the country's avionics inventory, needs and resources. (7:33)

Another author further supports this argument. He stresses that the maintenance concept must be ". . . clearly understood and defined. . . ." and "is particularly important since the maintenance concept often forms the baseline for the determination of other logistic support requirements" (23:21).

A case study on the delivery of F-16s to one country illustrates the relationship between international logistics and F-16 support. Problem areas include supply system interface with the USAF and the definition of spare parts and support equipment needs (20:21).

<u>Manpower</u>. Manpower is the working force that operates the resources available for maintenance support. Its availability dictates the capability to operate the support equipment. Manpower options may also be different from country to country. There are differences between the USAF and PoAF operation. The USAF predominantly uses two shifts per day for maintenance activities. The definition and reason for this type of operation is:

> A maintenance operation concentrating the maintenance effort into two work shifts daily, thereby eliminating the need for all but a token force during the third shift. The concept provides for the alignment of

> operations requirements with maintenance capability and affords the best use of maintenance resources. The aircraft and maintenance schedule is the key to this system, and it must provide for an even flow of maintenance support within the two shifts. (8:718)

The PoAF uses only one 8-hour period per day. Another aspect to note within this area is personnel availability levels. External factors may impose some constraints on the manning levels. These constraints can be temporary or can affect the manning levels for a long period. Examples of constraints are a reduction in force, or a lack of skilled workforce.

Use of Computer Models

Computer models simulate "real world" situations and thus support decision making. To assist logistics management of weapon systems there are various computer models available. Some are directed at the supply area, focusing on the availability of spare parts.

Dyna-METRIC. A model currently used is the Dyna-METRIC model. For this model, an aircraft is just a collection of spare parts, each of which is fundamental for the mission. After each mission, the parts that failed need replacement. "The operational mission is considered only to the extent that it requires numbers of aircraft and causes items to fail" (10:22). This model only addresses the spare parts problem, and their availability to complete an aircraft.

Aircraft Availability Model. Another supply model is the Aircraft Availability Model (AAM). "Rather than focusing on fill rates, AAM acquires parts and measures performance against the ability of the supply system to provide operational aircraft" (19:36). By definition, "An available aircraft is one that is not awaiting a resupply action" (19:36). Thus this model only covers the supply side of the requirements.

These two models have limitations on the capability to simulate and relate the different logistics areas. Other models exist for extended simulation of broader logistic systems.

TSAR Model. One such model is the Theater Simulation of Airbase Resources (TSAR), which has a wide range of capabilities and has the capability to cover other areas.

> The TSAR . . . model simulates a system of interdependent theater airbases, supported by shipments from the continental United States (CONUS) and by intratheater transportation, communication, and resource management systems. By capturing the interdependencies among 11 classes of resources, the simulation permits decisionmakers to examine the implications of many possible improvements in terms of their effects upon the sortie generation capabilities of a system of airbases. (9:1)

With TSAR, it is possible to simulate a broad range of options, or improvements, for a given theater.

> By comparing how such improvements affect the system's capabilities for generating effective combat sorties, TSAR can assess new passive defenses, new maintenance doctrine, dispersed aircraft operating locations, modified manning levels, enhanced cross-training, increased stock levels for parts and equipment, and many others, as well as several concepts for theater wide resource management. (9:2)

Thus, one important aspect of this model is its capability to handle the relationships between the different logistics support areas within a theater. Following the definition of a theater setting, or settings, simulations are run to gather data and analyze the outcome. The output of the simulations give managers a chance to compare the impact of alternative courses of action. Due to this capability, it is possible to simulate:

1. A single base operation. Used to evaluate the capability of a stand alone base and its support of scheduled requirements.

2. The interaction of several bases to include an intermediate repair facility or a depot, for example.

3. The interface with the external environment. This allows one to evaluate the interface and response capability of a theater and its out-of-the-theater support capability.

Computer simulation models are used to observe the behavior of a system, and infer the effects of changes in the variables under observation. This technique is used as a tool to assist management, since experimentation with the system is not possible or practical (6:587). In this study, the system is the maintenance support for the F-16 weapon system.

The USAF uses the TSAR model to study and simulate airbase capability in terms of aircraft sorties. This model is used to simulate a broad range of logistic relationships. The main aspect that differentiates this from other models, is the capability to simulate logistic dependencies within a theater, or between the theater and the environment.

Conclusion

Logistics and maintenance support are important aspects to address when introducing a new weapon system in another country. Local conditions may impose constraints leading to different solutions from the USAF ones. Thus, it is important to evaluate the different solutions' impact on the future weapon system support.

The use of a computer model allows one to simulate different scenarios based on the expected constraints. The results of the simulations give a basis to compare and assess different solutions. The TSAR model is used to simulate an operational theater response within a given scenario. The next chapter describes the methodology used in this study, to evaluate the outcomes of different scenarios expected on the implementation of PoAF's F-16.

III. Methodology

Chapter Overview

This chapter covers the methodology used in the application of this model. First, an overview of the particular method is presented. Second, a description is given on how the TSAR model is used in this study. In the third part the different scenarios are presented. Where applicable, an explanation is provided on the assumptions made to build the scenarios. A fourth area covers the variables involved in the simulation and the considerations and assumptions made on their implementation. This chapter ends with the description on the methodology used to analyze the results.

Particular Method

This research addresses a theater that includes an operating airbase and a repair facility. This facility is considered only to have intermediate repair capability, for the purpose of this study. The results of different TSAR computer simulations are the basis to answer the investigative questions. These simulations are set according to different possible scenarios of PoAF logistics support. The basic analysis steps are the evaluation of the model, the creation of the possible scenarios to run the models, the output and measurement variables, the simulation runs, and the comparison of the results.

Use of TSAR

The model used is the Theater Simulation of Airbase Resources (TSAR). The simulations use archival data from the United States Air Force (USAF) F-16 data base. The scenarios were created by adapting the model and input data to the PoAF situation. Data were adapted in several ways. One was the comparison of PoAF and USAF maintenance concepts and practices on different weapon systems operated by both services. Examples are the A-7, the T-38, and the C-130. Where applicable, this comparison is the basis for the definition of the scenarios. Another source was the information available from the discussion between the PoAF and the USAF on the planned purchase of the aircraft. Information required to specify the scenarios was obtained through contact with PoAF F-16 representatives in the negotiations with USAF.

Although the TSAR model can take into consideration the costs of parts, this area is not addressed in this study. The costs of parts and support equipment are important through the life cycle of the weapon system. However, the goal of this study is not a cost analysis of the support provided. The study is done with a fixed set of spare parts and support equipment. The quantities of each of these categories are set as constants, and used throughout the simulations with no changes. The variable factors are the location of the support equipment and the quantities and work shifts of the maintenance personnel.

Since TSAR is a Monte Carlo discrete-event simulation model (9:1), it is important to guarantee that the simulations are comparable. In this study, the seed of the random number generator used is always the same. This means that there is consistency in the results, and any differences across scenarios are not due merely to differences in random number streams.

Scenarios

Several scenarios are used to simulate various alternatives for PoAF. These scenarios are based on the information available on PoAF plans for the F-16. This information includes the planned quantities of support equipment in the engine and avionics area. It further includes the planned quantity of spare parts (reparables) supported in those two areas. These quantities of resources are constant across the different scenarios.

The maintenance management policies were considered when building the scenarios. One question in this area is whether to have two or three levels of maintenance. The USAF currently operates under a three level maintenance concept for the F-16, and the PoAF is planning to follow the same concept.

Another concern is the use of manpower. The PoAF uses a one shift working day, as opposed to USAF's 2 shift working day. Another aspect in this area is the operation with a reduced workforce, at 80% of its desired level. This reduction may be due to external constraints, or the effect of sharing part of the workforce with other weapon systems. This is applicable especially in the back shops. The effect of both of these aspects is assessed in this study.

Finally, the operational requirements are based on PoAF's planned use of this weapon system. For planning purposes, this value is 22.5 flying hours per aircraft per month.

The baseline under study is the influence of the logistic maintenance support for 30 days of the weapon system operation. This period has no peculiarities and represents a regular month of operations, at the planned sortie rate.

The basic scenarios are:

1. (Baseline). All the intermediate maintenance for the engine and avionics systems is performed on base. Depot maintenance for both systems is performed at a depot facility out of the country.

2. The intermediate maintenance for avionics is performed on base. The intermediate maintenance for engines is performed at PoAF depot facility in another location. The depot maintenance for engines and avionics is done out of the country.

3. Intermediate maintenance for engines is done on the base. The intermediate maintenance for avionics is performed at the PoAF depot facility. Avionics maintenance not already accounted for, and engine depot maintenance is done out of the country.

4. Intermediate maintenance for engines and avionics is done at the intermediate repair facility. The depot maintenance for engines and avionics is done out of the country.

Table 1 depicts the scenarios that are simulated, analyzed, and compared in this study. The letters represent the different scenarios under analysis. They range from one extreme being with the support the closest to operations, on base, to the other extreme the furthest from operations. Scenario A, the baseline scenario, has intermediate avionics and engine maintenance on base, working two shifts at 100% manning. At the other extreme, Scenario P represents both those levels at the CIRF, working one shift at only 80% manning level.

TABLE 1

SCENARIOS OF MAINTENANCE SUPPORT

Shifts	Manning (%)	Location				Shop
		Base	Base	CIRF	CIRF	Avionics (AIS)
		Base	CIRF	Base	CIRF	Engine
2	100	A	E	I	M	
2	80	B	F	J	N	
1	100	C	G	K	O	
1	80	D	H	L	P	

For these different scenarios the manning level is also changed. In particular, the effects of one or two shifts a day, especially in the engine and avionics facility is tested. The desired levels were established based on USAF experience with the weapon system, and are reflected in the weapon system database. Level of manning is the other aspect simulated. The difference in availability of repair resources is thus influenced by the manning and staffing of the shops.

In order to have more insight about the maintenance support capability, some other scenarios are run. The changes are in the spare parts levels and number of aircraft to operate. Scenario A1 has the initial stock of spare parts available increased, with the safety factors in computing their levels doubled. In Scenario ARED the number of aircraft is 12, and in Scenario AINC the number of aircraft is 24. The results of these scenarios are compared to the baseline Scenario A.

Variables

The goal is to analyze the effect of logistic support on the operations, with the emphasis on the influence of the unscheduled maintenance. The control variables are defined according to the scenarios under test. They represent measurable components of logistics support. The planned independent variables are level of spare parts, location and availability of support equipment, and manpower requirements. In addition, transportation times or spare parts turnaround times will also influence the outcome.

The main dependent variable is the number of sorties flown in a given period. This variable measures the capability of the logistic system to support the operational requirements. This is also a measure that, after validation, can translate the results to the "real world".

The planned effort for the POAF fleet is 22.5 flying hours per aircraft per month. This value is considered in the model's scheduled sorties. Furthermore, no more than 8 aircraft are scheduled to fly at the same time, and the weekly flying schedule is similar across the period of the simulation. Mission configuration is air defense because it will be the primary mission for this weapon system. Weapon loading is simulated, and the consumption of munitions is set to a low rate, to include training and other non-war operation.

After each aircraft returns from a mission, the need for maintenance is generated based on the probability that the task is necessary (9:43). The USAF database provided data for the required maintenance tasks. The need for unscheduled maintenance is based on the probability specified for that task. This probability was already in the model, and is based in the USAF data for the aircraft. The maintenance tasks are performed according to the established procedures and using the available equipment. Aircraft Battle Damage Repair (ABDR) is not simulated.

One assumption made in this study is that the manpower and support equipment entered in the simulation are dedicated to the F-16 maintenance. The identified resources are used exclusively in to support this weapon system.

Throughout the various scenarios (A-P), the set of spare parts and support equipment is kept constant. This represents a fixed amount of resources in the theater. The variation between scenarios is on the location of spare parts and support equipment. At the operational base, when a part is found not reparable this station (NRTS), it is sent to the CIRF. This facility has its NRTS rates also defined. If the part is also NRTS at the CIRF, then it is shipped outside the theater. The only scenarios not using this path are the ones where the base has all the intermediate maintenance capability; for these scenarios, NRTS parts are shipped directly from the base to the depot outside the theater. Cannibalization is authorized, according to the definition provided.

Areas not related to direct logistic support are not used as variables for the different scenarios. Consequently the values remain constant, and are entered where that information is necessary. The following are some of these areas.

Air traffic control (ATC) is not simulated. Traffic delays, or other forms of ATC interference, do not enter as variables. The number of aircrews is constant (30), and is considered always available.

Base facilities as runway, taxiway, and buildings are also not entered as variables. In addition, civil engineering activities, such as repair and construction do not enter as variables.

Fuel and armament supplies are made available in sufficient quantities so that they do not influence the outcome.

The Centralized Intermediate Repair Facility (CIRF) is located in country, and the delay in repair is entered as 30 days. This includes administrative time, transportation time, and repair time. The goal is not to penalize the external repair by this practice; rather the goal is to show how this increased time for repair can impact the availability of parts, and therefore aircraft availability. External considerations may lead to the location of the intermediate maintenance capability at the CIRF. Some of these considerations, not entered in this study, are a larger, or more experienced pool of manpower to select the working force from, or being closer to more available supporting areas.

The Turn Around Time (TAT), for the parts Not Repairable at this Station (NRTS) is set to 180 days. In this study the meaning of NRTS is in fact that there is no in-country repair capability, or theater capability.

The model uses 18 aircraft as available at any given time to operate. The two remaining aircraft for the total of 20 are put aside to account for planned actions such as

Phase inspections, time change items, field training, and similar scheduled actions.

Simulation Runs

The scenarios define the conditions for the simulation runs. The outputs of these simulations are statistically compared against each other, thus allowing the comparison of results. The number of sorties flown in each scenario is the variable to evaluate the scenarios.

More specifically, the results are evaluated on the requirement of an average of 300 sorties a month. Then, they are compared against the result of the baseline Scenario A. The baseline is built with the 18 aircraft flying at a rate of 22.5 hours per aircraft per month, with all the intermediate maintenance for engine and avionics on base. Furthermore, the manning of the shops is scheduled for two shifts a day. The different alternatives are variations of this basic scenario which then are compared.

One important aspect in the use of simulation for this type of study is the starting or initialization conditions. In this study, at the start of the simulation all aircraft are ready, the spare parts are all in theater, and the spare parts pipeline is empty. Both personnel and support equipment are fully available. These conditions can cause some problems on the results of the simulation. The simulation of a system running for a period of time is influenced by the starting conditions. As one author points out, "simply stated, the problem is that it takes some time for the simulation to overcome the artificiality introduced by the abrupt beginning of the operation" (5:48). Thus the time covered by the simulation runs is important to allow stabilization of the system and decrease the effect of the initial bias. There are several methods to eliminate the initialization bias (1:430). One is to collect data from the actual system to specify the initial conditions (1:430). Since the system under study is a new one, no data are available to establish the initial conditions. Another method is to run the simulation for a period of time, and divide the run into two parts: the initialization phase up to time t_0, where data are not collected, and a second period where the data are collected (1:430). This allows the system to stabilize in a steady state condition, with some aircraft requiring maintenance due to operations, and spare parts going through the logistics pipeline. To obtain data on the system several replications are required and data are deleted in each run corresponding to the initial phase. Another method deals with this problem by making one long run. This long run is then divided into batches and the data of each batch are used in the analysis. There is no easy way to define the batch size, but it is recommended to have a small number of batches, of the longest possible length (1:440). In this study, the duration of the flight missions is 80 minutes, the repair tasks take hours or days to accomplish, and the repair cycle out of the base is one month. Thus, it is important to address and define the initialization period, and the length of the runs. In this study the adopted method is to have several runs of one year duration, rather than a very long run.

The goal of this study is the supportability of one fleet with a given amount of in-theater resources. One aspect worth mentioning is the behavior of the system in the period just after startup versus a steady state, which means a constant and stable flow of reparables to and from the theater, and within the theater.

In a scenario of theater isolation from external resources for a period of time the behavior of the system is, in fact, that corresponding to starting conditions. This situation may develop when extraneous conditions (political, economical, geographical, or other) dictate the isolation of the theater and interrupt the flow of spares to tthe theater. The resources on hand, within theater, are the only ones available. In this situation it is important to assess how the system performs.

The comparison between the results of the different scenarios is done with the use of statistical techniques. The result of the baseline scenario is compared with each of the others (one at a time) to test the null hypothesis that a higher number of sorties are generated. This test is done using a t-test of small sample size (2:431). The number of trials for each scenario is always less than 30. This implies a small sample statistics analysis. To perform this test, a complementary test is necessary. This is an F-test, the null hypothesis being the sample variances of the two samples being compared are equal (2:445). The t-test is only possible if the null hypothesis of the F-test is not rejected. In the situations where the t-test cannot be used, the confidence intervals for the mean sorties generated for the scenarios are compared (2:392).

Where applicable, for lack of statistical data or other reason, the comparison between scenarios is also performed with the results of one trial. This means a more qualitative type of analysis, with the underlying assumption that the trial under observation is a typical result of the simulation of the corresponding scenario.

This chapter exposed the basic methodology to perform the study. The assumptions made to define the scenarios were explained. Some of the issues on using the simulation techniques were also addressed. In the next chapter the results of the simulation runs are analyzed in light of the methodology exposed here. Some conclusions are drawn in line with the assumptions and considerations presented in this chapter.

IV. Analysis of Results

Overview

This chapter presents the results of the simulation runs. First, it provides an overall analysis of those results. Second, the different scenarios are compared with the baseline, and between themselves. At the end, a comparison with other scenarios is provided. These comparisons cover a period of 30 days. Third, a comparison of results for a 60-day period is provided.

Overall Analysis

During the execution of the simulation runs some unexpected limitations were met. The problems met in simulating periods of more than 60 days prevented the researcher from executing the planned long runs in order to evaluate the system under study in a steady state condition. Limitation on the time available to perform the study prevented the solution of the problems encountered. Thus the longest periods of time under analysis are 60-day periods. This time period is long, but not long enough to provide the expected behavior of the system in a steady state. The values of the cycle time for the reparables are on the order of one month; therefore a 60-day period can shadow the effect of this cycle time, and only show the starting reaction of the system. The benefit of the analysis of these results is similar to the one peresented for the 30-day period. The analysis of the results for this period is presented in the second part of this chapter.

The first analysis of results covers a 30-day period. This analysis is provided to cover the situation were the theater is isolated from outside sources. The resources on hand are the only ones available. The analysis shows the predicted behavior of the system in this situation.

Analysis of 30 Day Period

The results of the simulation runs show the number of sorties generated within the scenarios defined. The mean and standard deviation of the sorties generated are presented in Table 2. They are presented by scenario for a period of 30 days, and the result of 20 trials, under the same constraints of number of spare parts and in-theater support equipment.

An evaluation of the results shows that none of the scenarios meets the requirement of three hundred sorties a month. The values of sorties generated under the conditions simulated is close to 2/3 of the target value. Notice that this does not mean that it cannot be achieved under these conditions. This only means that under the constraints and assumptions made, the 300 sortie requirement probably would not be met. These constraints and assumptions as well as the differences between each scenario are described in the Methodology chapter.

The other aspect to notice is a consistency in the number of sorties generated across the scenarios. The values do not change significantly across the different conditions.

TABLE 2

RESULTS FROM THE SIMULATION RUNS

SCENARIO	Average Sorties	Standard Deviation
A	189.4	30.4
B	156.9	30.8
C	188.7	41.2
D	197.0	33.3
E	201.6	40.6
F	167.9	39.1
G	175.6	31.4
H	178.4	36.1
I	198.1	37.1
J	175.5	32.5
K	191.5	41.7
L	199.1	25.4
M	184.4	42.1
N	169.1	33.3
O	187.5	32.1
P	174.3	28.6

Scenario Comparison

A t-test for small samples is used to compare the average sorties generated in each scenario against the baseline scenario A. This test is used because there are 20 trials for each scenario. The assumptions for the use of this test are:

1. Both sample populations have relative frequencies that are approximately normal.

2. The population variances are equal (tested with the F-test).

3. The samples are independent (2:434).

It is assumed that the distributions are normal distributed. The third assumption is verified because of the nature of the simulations, since each scenario runs for 20 trials. Since each run is based on an independent random number stream, the results of the runs can be considered independent. The test for equal variances is done with an F-test. The null hypothesis H_0 is the variances of the baseline and of the other scenarios are equal, and the alternative hypothesis H_a is they are different. Therefore, this is a two tail test. The test is conducted at a 95% confidence level.

$$H_0:(\sigma_1)^2=(\sigma_2)^2 \tag{1}$$

$$H_a:(\sigma_1)^2\neq(\sigma_2)^2 \quad (2)$$

The test statistic is

$$F=\frac{LSV}{SSV} \quad (3)$$

where LSV is the larger sample variance and SSV is the smaller sample variance. The decision rule is to reject if

$$F>F_{(\alpha/2)} \quad (4)$$

The sample size for both samples is n=20 (for 20 trials). Thus, the degrees of freedom are n-1=19 (2:445). In this case

$$F_{(\alpha/2)}=2.53 \quad (5)$$

The results, shown in Table 3, fail to reject the hypothesis that the variances are equal, thus allowing the application of the t-test to compare the averages of the scenarios. In the t-test, the null hypothesis H_0 is the means of the samples are equal, and the alternative hypothesis H_a is the other scenarios have the same mean as the baseline scenario A. The test is also conducted at a 95% confidence level.

$$H_0:\mu_1=\mu_2 \quad (6)$$

$$H_a:\mu_1 \neq \mu_2 \qquad (7)$$

The test statistic is

$$t=\frac{\bar{x}_1-\bar{x}_2}{\sqrt{(s_p)^2\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \qquad (8)$$

In this equation x_i bar is the scenario mean and n=20.

TABLE 3

RESULTS OF THE F-TEST AND t-TEST

Scenario	Average Sorties	Standard Deviation	F-test	t-test
A	189.4	30.4		
B	156.9	30.8	1.03	3.359
C	188.7	41.2	1.84	0.061
D	197.0	33.3	1.20	-0.754
E	201.6	40.6	1.78	-1.076
F	167.9	39.1	1.66	1.941
G	175.6	31.4	1.07	1.412
H	178.4	36.1	1.41	1.042
I	198.1	37.1	1.49	-0.811
J	175.5	32.5	1.14	1.397
K	191.5	41.7	1.88	-0.182
L	199.1	25.4	1.43	-1.095
M	184.4	42.1	1.92	0.431
N	169.1	33.3	1.20	2.013
O	187.5	32.1	1.11	0.192
P	174.3	28.6	1.13	1.618

The value of s_p is given by the following equation

$$s_p^2=\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{n_1+n_2-2} \tag{9}$$

where s_i is the standard deviation for each sample. The decision rule for this test is to reject if

$$t<-t_{a/2} \vee t>t_{a/2} \tag{10}$$

This is a two-tail test, and the tabulated t-value,for n-1 degrees of freedom is (2:343)

$$t_{a/2}=2.093 \tag{11}$$

The results of the t-test, also presented in Table 3, show that only Scenario B has a mean different from Scenario A. In this case it is smaller than the Scenario A. In all the other cases the t-test fails to reject the null hypothesis of the means being similar. This means that the values are close to each other, not that they are actually the same. This also suggests that the level of support is similar across the scenarios. The small-sample confidence intervals of the means are given in Table 4.

A 95% confidence interval is also used in this case. The following equation is used to find the Upper Limit (UL) and the Lower Limit (LL) of the confidence interval.

$$\bar{x} \pm t_{a/2}\left(\frac{s}{\sqrt{n}}\right) \tag{12}$$

In this equation s is the sample standard deviation, t is the value given above, and n=20 (2:392).

TABLE 4

CONFIDENCE INTERVALS FOR THE MEAN

Scenario	Average Sorties	Standard Deviation	Confid.	Interval
			UL	LL
A	189.4	30.4	203.63	175.17
B	156.9	30.8	171.31	142.49
C	188.7	41.2	207.98	169.42
D	197.7	33.3	212.58	181.42
E	201.6	40.6	220.6	182.6
F	167.9	39.1	186.2	149.6
G	175.6	31.4	190.3	160.9
H	178.4	36.1	195.3	161.5
I	198.1	37.1	215.46	180.74
J	175.5	32.5	190.71	160.29
K	191.5	41.7	211.02	171.98
L	199.1	25.4	210.99	187.21
M	184.4	42.1	204.10	164.70
N	169.1	33.3	184.68	153.52
O	187.5	32.1	202.52	172.48
P	174.3	28.6	187.69	160.91

The graphical representation of the confidence intervals is presented in Appendix C.

Comparison Across Scenarios

Comparisons across the various scenarios are made based on the average sorties generated for each of them. Tables 5 and 6 provide an easier comparison of the results.

TABLE 5

SCENARIOS

Shifts/ Manning	Maintenance in CIRF			
	NONE	ENG	AIS	BOTH
2/100%	A	E	I	M
2/ 80%	B	F	J	N
1/100%	C	G	K	O
1/ 80%	D	H	L	P

TABLE 6

MEAN OF EACH SCENARIO

Shifts/ Manning	Maintenance in CIRF			
	NONE	ENG	AIS	BOTH
2/100%	189	201	198	184
2/80%	157	168	176	169
1/100%	189	176	192	188
1/80%	197	178	199	174

The scenarios in the first column have all the intermediate maintenance done at the base. In the second column the engine intermediate maintenance is performed at the CIRF. In the third column the AIS, used to perform avionics intermediate maintenance, is located at the CIRF. In the last column both of these intermediate levels are performed at the CIRF.

Table 6 provides the values of the mean number of sorties flown, with the same arrangement as the scenarios, for easier use and reference. Notice that the comparison cannot be done only using the mean, but with confidence intervals. These should be used for a more detailed examination.

Horizontal Comparison. Horizontal comparison is the comparison for the scenarios with different location of intermediate repair capability, at the same level of manning and the same working schedule. For instance, compare scenarios A, E, I, M. For easier visualization of the confidence intervals, refer to Appendix D.

On performing this comparison, the values show that the number of sorties is relatively constant. The slightly higher values are found for the scenarios where the AIS is located at the CIRF. This means that the constraints imposed are not limited to the AIS work. The effect of increased distance and consequent increase in turn-around-time, does not affect the overall result. However, notice that the difference from this type of scenario to the other type of scenarios is small.

The four horizontal comparisons--(A, E, I, M), (B, F, J, N), (C, G, K, O) and (D, H, L, P)-- also show that all of the confidence intervals overlap, as can be seen in Appendix

D. Therefore, the conclusion is that there is no significant difference between the number of sorties generated due to location of support.

Vertical Comparison. The vertical comparison is the comparison between the scenarios with the different levels of manning, and different scheduling. The location of the intermediate maintenance capability is constant across these scenarios. The comparison is done across the scenarios, for example A, B, C, D.

Comparing the results, the visible difference is on Scenario B where the average sorties flown is lower than in the others. This is applicable to the other scenarios with 80% manning on two shifts. In this simulation, the quantity of each personnel type per shop was equally divided between the two shifts. This result may indicate that the dispersion of personnel on two shifts, is not beneficial. Notice that this is only as far as unscheduled maintenance is concerned. The scenarios with only one shift have similar results as with 100% manning and two shifts. This shows the need to concentrate the available manpower resources in the flying period, even when the manning is at reduced levels. In the simulation runs the flights are randomly generated within a period defined from 0800 to 1600 hours each day. This also corresponds to the working day period for one shift, and thus the small differences in results.

The results shown in Appendix D, show that the confidence intervals overlap, as with in the Horizontal comparison. The conclusion is that there is no significant difference between the scenarios due to the change in manning, except for the Scenario B.

Average Daily Sortie Comparison

Appendix B shows the data on the average daily sorties flown, by scenario. A graphic representation is also included to assist the comparison. This evaluation shows three areas within the 30-day period, for all the scenarios. Up to the 13th day the values are close to the required mean, 10 sorties per day. Then, they sharply decrease for some days. In the last segment, they stabilize at a very low value between 0 and 1.

This behavior gives some indications of the system reaction. In the beginning of the period all the resources are fully available. The number of sorties generated through the period is not guaranteed to stay at the desired level. The period in the middle is the area to pay attention. Increasing the unscheduled maintenance manpower level may be feasible, with surplus manpower in scheduled maintenance. However, an increase in the other resources, such as support equipment or spares, is not as feasible. Thus, these results show a flying rate of sorties only two-thirds of the desired value.

The last third of the period is close to zero. This result is due to the lack of spares available at the base, since the ones that failed and found NRTS are sent elsewhere for repair. In addition, no repaired parts have arrived yet at the base , to replace the ones that failed. Therefore, there are not enough parts to generate sorties.

Other Comparisons

Some other simulation runs were performed in search for additional data on the behavior of the basic setup. For easier comparison they were assigned different names from the basic simulation. Scenario A1 is similar to Scenario A but the spare parts level is increased, with the safety factors in computing their levels doubled. Although not a true variable in this simulation, the number of aircraft was also changed in two other simulations. The constraints and assumptions are similar to Scenario A. In Scenario ARED the number of aircraft is 12 and in Scenario AINC the number of aircraft is 24.

To compare these different scenarios with Scenario A the same statistical tests are used. These comparisons are conducted against A because that is the basic scenario to test. The results are presented in Table 7.

The results show that the difference in capability depends on the number of aircraft available to operate (ARED and AINC), more than it depends on the level of spare parts available (A1). The comparison of the daily sorties is presented in Appendix D. The values stay closer to the desired levels of 10 sorties per day for scenario AINC, with more aircraft available.

TABLE 7

TEST STATISTICS SCENARIOS A1, ARED, AINC

Scenario	Average Sorties	Standard Deviation	F-test	t-test
A	189.4	30.4		
A1	204.8	35.2	1.34	-1.481
ARED	128.3	27.3	1.24	6.688
AINC	242.7	21.4	2.02	-6.412

Analysis of 60-Day Period

The average daily sorties flown in 60 days for each scenario is presented in Table 9. These results are the average daily sorties for one trial only. These results were obtained under the considerations mentioned in the beginning of this chapter.

The comparison between the scenarios is made on a qualitative basis, since there is no ground for statistical comparison. The values presented are assumed to be representative of the behavior of the scenario. The statistical meaning is not the same, but there is no evidence that these results do not represent that behavior.

TABLE 8

SCENARIOS

Shifts & Manning	Maintenance in CIRF			
	NONE	ENG	AIS	BOTH
2/100%	A	E	I	M
2/80%	B	F	J	N
1/100%	C	G	K	O
1/100%	D	H	L	P

TABLE 9

AVERAGE DAILY SORTIES FLOWN IN 60 DAYS

Shifts & Manning	Maintenance in CIRF			
	NONE	ENG	AIS	BOTH
2/100%	4.72	3.38	4.15	3.90
2/80%	4.57	3.02	4.67	2.97
1/100%	3.78	3.78	3.20	2.06
1/100%	4.23	2.75	4.03	2.28

The demanded average number of sorties is 10 per day. The results show that this average is not met, and the highest average value is close to half of that number. In general, the values show a decline in the average number of sorties, from Scenario A to Scenario P.

The results are provided in Appendix E. Tables present the values of the daily sorties, by the average of two consecutive days, for an easier presentation. In addition, a graphic presentation is also provided. The trend of the results is comparable to the results for the 30 day period. The values show the average number of sorties is not met. In this period of simulation, the values are close to the average for a longer period. The reason is, in this case, the test equipment for ECM was increased to 2 units. With this database, the sorties flown per day, are closer to the average demand, for a longer period.

The comparison across the scenarios, using the daily sorties generated, shows the number of sorties generated is closer to the sortie demand. The scenarios with all the support in the base, A through D, sustain a level of sorties close to the demand for a longer period. The decline in sorties is gradual, starting around day 22 and reaches very low levels around day 34. After day 34 the level stays very low. In the set of all support on base, Scenario A is the one with higher values.

In Scenarios E through H, the sorties are close to the demand up to day 20, and then there is a steep fall to day 24. After this day the values are close to zero. This shows the influence of the engine area, located in the CIRF.

In scenarios I through L the number of sorties stays close to the demanded number up to day 20. After this day, a fall occurs up to day 28, and then the number is very low, close to zero. There is some parallelism with the previous set of scenarios, with the engine maintenance in the CIRF.

Scenarios M through P show the influence of both areas located at the CIRF. The values are close to the demand for the first 22 days and then thre is a gradual in the values, up to day 30. The values stay close to zero for the rest of the period. These scenarios show that the support capacity, on base, sustains the level of demand for the first 22 days, if the spare parts are all on base.

The vertical comparison between the scenarios shows that the difference in manning is not very important. The values of sorties does not change significantly with changes in manning, for the same type of in-base support. Note that these results are only from one trial. The comparison does not have the statistical value of the simulation of 30 days period, but the results are parallel.

The results for the 60-day period are influenced by the startup conditions, and by the periods of time involved in the repair cycle. These periods are on the order of 30 days. The results are also show the influence of the depot level maintenance on the availability of aircraft. Sorties cannot be generated because there are no aircraft available.

The horizontal comparison across the scenarios does not show significant differences between them. The values do not show clear trends or differences among the scenarios that point to relationships with the variables simulated in this study.

The overall analysis of the results shows that sortie generation is close to zero after day 30. This is common to all the scenarios. It also shows the influence of the NRTS rates. With the ones used in the database, and the levels of spare parts defined, the flight activity ceases after day 30 for all scenarios. Lower NRTS rates would require less dependency on out of station repair, and thus more flights available.

Final Remarks

The problems found in running the simulations limit the scope of analysis of the results. However, the results of these simulations do not show an important difference due to a change in only one of the variables, location or manning level. They indicate that the overall support level is dependent on all the factors involved, manpower, support equipment, and spare parts. Notice that these remarks are applicable within the scope of this study, only unscheduled maintenance.

V. Conclusions

Introduction

The goal of this study was to evaluate the capacity to generate a desired level of sorties with a specific level of in-theater resources available. The theater is defined with one operational base and a Centralized Intermediate Repair Facility (CIRF). The focus of the study was on the repairable items, in particular the engine and the avionics areas. These are two of the most important areas for the effective mission accomplishment of the F-16 weapon system.

Maintenance support levels, as part of the overall logistic support determines the availability of a weapon system. In the introduction phase of a new weapon system, the maintenance and logistic support areas require particular attention. In the international logistics arena this is particularly important, since local conditions may impose different solutions than the ones planned for the USAF. This study focus on the evaluation of different allocation and availability of some of the important resources. These resources are manning, support equipment and spares levels. To perform the evaluation of the different alternatives, a simulation of the theater itself and of the different solutions was performed, using the TSAR simulation model. The resource values were defined for the different simulations. Sixteen scenarios were defined and compared. The differences in the 16 scenarios were the location of support equipment and the levels and scheduling of manpower. These were the variables under control. The level of spare parts was kept constant in these 16 scenarios.

Two periods of time were used in the simulations. The 30-day and 60-day periods were used for different reasons. The first was used to analyze the theater behavior in a sitution of isolation from external sources. The available resources dictate the capacity to fly. The 60-day period was used to represent a longer period. The initial intent was to extend this period for 360 days. This would allow the analysis of the long term behavior of the theater. However, limitations on the simulation program did not allow such analysis. The 60-day period still illustrates the expected behavior of the system, although it does not show the steady state condition, with the return of the reparables from external repair facilities.

Analysis of the Results

The analysis of the results of the simulation runs gives a basis to compare and contrast the consequences of each scenario. The results show the effect of the resources simulated here in the unscheduled maintenance. They show that the level of maintenance support entered in this study is insufficient to sustain the desired level of sortie generation for a short period of time, in conditions of isolation from external sources. In addition, they show that the capacity to generate sorties is relatively constant across the 16 different scenarios. The level of in-theater support level determines the capacity to generate sorties, within the theater defined in this study, and for the periods considered and simulated here.

Other simulations were run with variations in aircraft number, spare parts level and period of simulation. Their results sustain the conclusion that an in-theater set of resources supports a relatively constant level of sorties, under the defined conditions.

These results do not show that the level of required sorties is not achievable. They just show that, under the conditions defined in this study, the unscheduled maintenance would limit the sortie generation to 2/3 of the desired level for a 30-day period, and less than 50% for a 60-day period.

The values on personnel and equipment need also to be accounted for in the scheduled maintenance requirements. In this simulation the personnel are only used for unscheduled maintenance. Thus, not all of the planned personnel on the various shops are fully assigned to perform the tasks. The sporadic availability of personnel assigned to scheduled maintenance may be used to reinforce the unscheduled maintenance. These results can be used to support the decisions on the solution to the F-16 maintenance support options.

Further Research

There is opportunity to expand this study and to perform complementary studies. The first logical step is to perform the simulations for an extentend period of time, for example one year. This is conditiond by the capacity of the program to handle this period of time. Another area to expand this analysis is the introduction of the scheduled maintenance requirements. This requires the availability of a task database for this area of maintenance.

Another area is the integration of another weapon system, collocated in the same base and sharing part of the support facilities. This includes the intermediate level shops such as engine, avionics, non-destructive inspections, and other support shops that are shared among different weapon systems. Yet another area to expand is the effect of dispersion of aircraft to forward locations where limited resources available.

This study also illustrates TSAR's capability to simulate a theater logistics support resources, without attack simulation. This can be extended to allow the study of other features in the logistics arena, such as the two levels of maintenance concept, or the maintenance cross-support between bases. The model has such capabilities, and can be useful to evaluate the consequences of different support policy decisions.

Appendix A: Definition of Terms

Availability. Availability is a measure of the degree to which an item, or equipment, is in operable and committable state when required to perform its mission (8:81).

Avionics. Avionics is the equipment that uses the application of electronics to aviation (8:83). In this study, this includes equipment such as radar, communication and navigation equipment, or other such application of avionics in aviation.

Cannibalization. Cannibalization is the authorized removal of specific components from one equipment end-item for installation on another equipment end item to meet priority requirements, with the obligation to replace the removed item (8:107).

Capability. Capability is the power or capacity to do a particular thing, arising from a feature, condition, faculty, ability, or the like (8:108).

Centralized Intermediate Repair Facility. Centralized Intermediate Repair Facility (CIRF), refers to a facility that performs the Intermediate maintenance of systems or items operated on different bases.

Depot Level Maintenance. Depot level maintenance is the maintenance performed on material requiring major overhaul or a complete rebuild of parts, assemblies, subassemblies, and end items, including the manufacture of parts, modification, testing, and reclamation as required (8:215).

Intermediate Level Maintenance. Intermediate level maintenance is the maintenance that is normally the responsibility of,and performed by, designated maintenance activities for direct support of using organizations (8:361).

Life Cycle. The total life span of an end item commencing with the implementation and operational phase up to its removal from the DOD inventory, or in the inventories of Security Assistance Program countries (8:390).

Logistics. Logistics is defined as a system established to create and sustain military capability (21:13).

Logistics support. Logistics support is defined as the supply and maintenance of material essential to proper operation of a system in the force (8:402). For the purpose of this research this definition is addressed as the required support for the F-16, with particular focus on the Intermediate and Depot levels of maintenance.

Maintenance. Maintenance is defined as all actions necessary for retaining material in or restoring it to a serviceable condition (8:407).

Maintenance Task. Maintenance task refers to any action necessary to preclude the occurrence of a malfunction or restore the equipment to a satisfactory working condition (8:416).

Organizational Maintenance. Organizational maintenance is the level of maintenance that is the responsibility of and performed by a using organization on its assigned equipment. Examples of the maintenance tasks at this level are lubricating, servicing, lubricating, adjusting, and replacement of parts, minor assemblies, and subassemblies (8:417).

Repair Cycle. Repair cycle is the period that elapses from the time the item is removed in reparable condition , to the time it is returned to stock in serviceable condition (8:579).

Scheduled Maintenance. Scheduled maintenance is the known or predicted tasks that are planned for accomplishment in an equipment. The tasks include inspection, servicing, completion of modifications, and correction of known discrepancies (8:610).

Support Equipment. In this study, support equipment is equivalent to Aerospace Ground Equipment (AGE). This is all the equipment required on the ground to make a weapon system, subsystem or end-item of equipment operational in its intended environment. This includes all the equipment required, for instance, to install, inspect,test, adjust, calibrate, measure, service,repair, overhaul, maintain or operate, the whole system or any of its components (8:28).

Supportability. Supportability is the characteristic of material that quantifies its ability to adapt to changing supply and maintenance concepts (8:674).

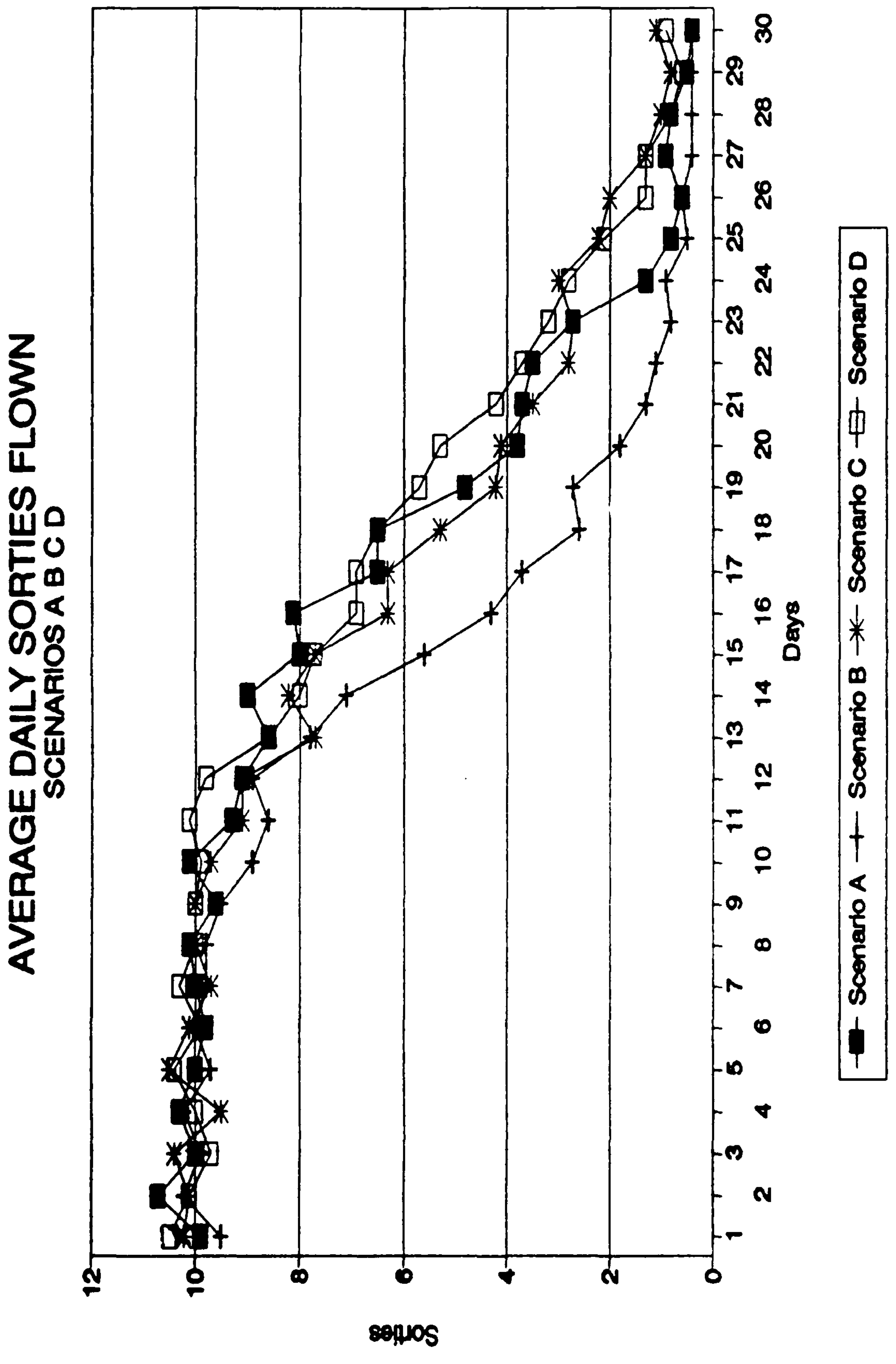
Unscheduled Maintenance. Unscheduled maintenance is the unplanned tasks that require prompt action, to restore equipment serviceability (8:726).

Weapon System. Weapon system can be defined as a weapon and those components required for its operation. It is an agglomerate of equipments, skills and techniques that usually has an aerospace vehicle as its major operational element. The complete weapon system includes all related facilities, equipment, material, services, and personnel required for the effective operation of that aerospace vehicle (8:741).

Appendix B: Average Daily Sorties for the Basic Scenarios

AVERAGE DAILY SORTIES FLOWN

	SCENARIO			
DAY	A	B	C	D
1	9.9	9.5	10.2	10.5
2	10.7	10.2	10.1	10.1
3	10.0	9.9	10.4	9.7
4	10.3	10.2	9.5	10.0
5	10.0	9.7	10.5	10.4
6	9.8	10.0	10.1	9.9
7	10.0	9.8	9.7	10.3
8	10.1	9.8	10.0	10.0
9	9.6	9.5	10.0	10.0
10	10.1	8.9	9.7	9.9
11	9.3	8.6	9.1	10.1
12	9.1	8.9	9.1	9.8
13	8.6	7.8	7.7	8.6
14	9.0	7.1	8.2	8.0
15	8.0	5.6	7.7	7.7
16	8.1	4.3	6.3	6.9
17	6.5	3.7	6.3	6.9
18	6.5	2.6	5.3	6.5
19	4.8	2.7	4.2	5.7
20	3.8	1.8	4.1	5.3
21	3.7	1.3	3.5	4.2
22	3.5	1.1	2.8	3.7
23	2.7	0.8	2.7	3.2
24	1.3	0.9	3.0	2.8
25	0.8	0.5	2.2	2.1
26	0.6	0.6	2.0	1.3
27	0.9	0.4	1.3	1.3
28	0.8	0.4	1.0	0.8
29	0.5	0.4	0.8	0.6
30	0.4	0.4	1.1	0.9


AVERAGE DAILY SORTIES FLOWN
SCENARIOS A B C D
Sorties
0
2
4
6
8
10
12
Days
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
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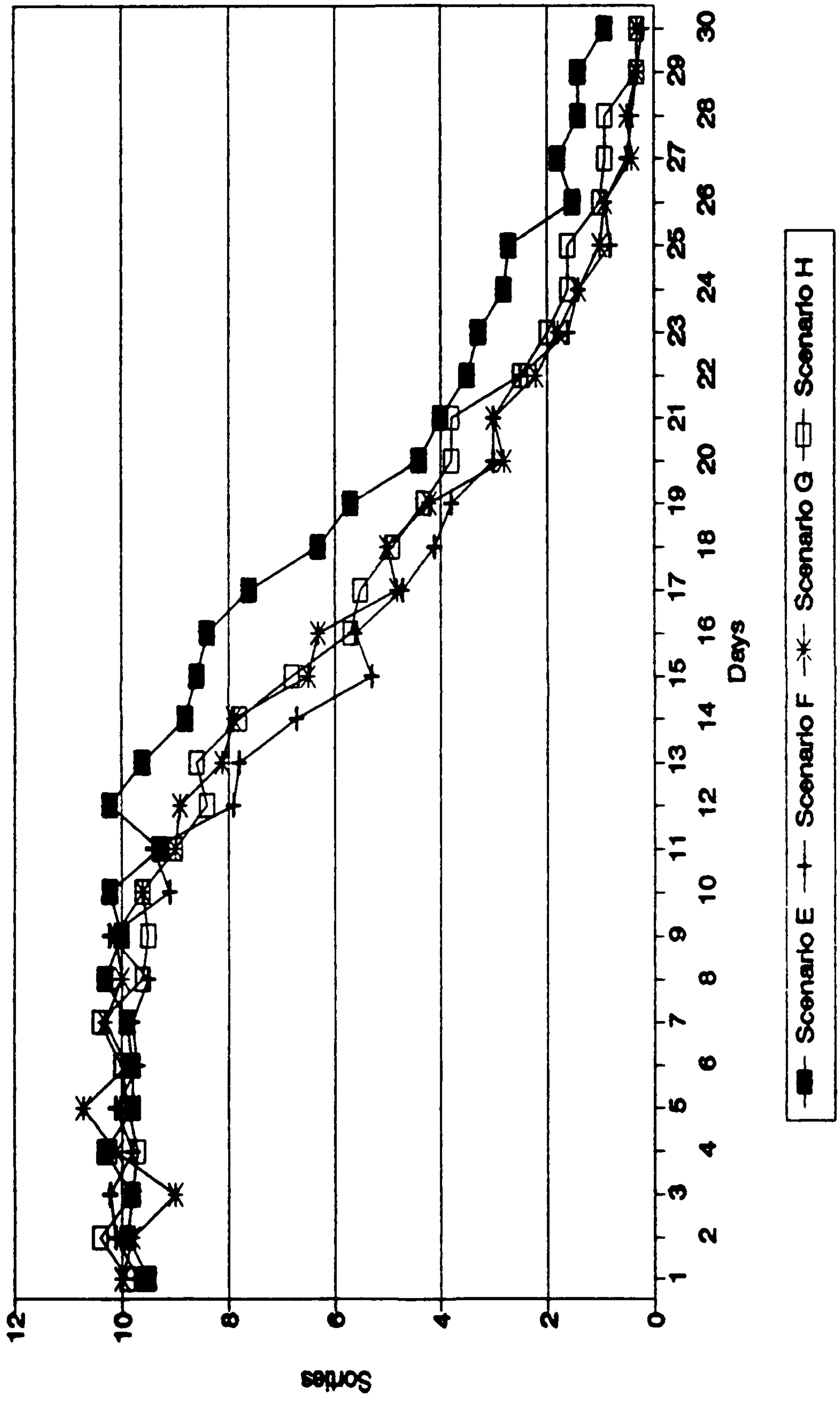
19
20
21
22
23
24
25
26
27
28
29
30
Scenario A
Scenario B
Scenario C
Scenario D

AVERAGE DAILY SORTIES FLOWN

	SCENARIO			
DAY	E	F	G	H
1	9.5	9.7	10.0	9.9
2	9.9	10.1	9.8	10.4
3	9.8	10.2	9.0	9.8
4	10.3	9.8	10.1	9.7
5	9.8	10.1	10.7	9.9
6	9.8	9.7	9.9	10.0
7	9.9	9.8	10.3	10.4
8	10.3	9.5	10.0	9.6
9	10.0	10.2	10.1	9.5
10	10.2	9.1	9.6	9.6
11	9.3	9.4	9.0	9.0
12	10.2	7.9	8.9	8.4
13	9.6	7.8	8.1	8.6
14	8.8	6.7	7.9	7.8
15	8.6	5.3	6.5	6.8
16	8.4	5.6	6.3	5.7
17	7.6	4.7	4.8	5.5
18	6.3	4.1	5.0	4.9
19	5.7	3.8	4.2	4.3
20	4.4	3.0	2.8	3.8
21	4.0	3.0	3.0	3.8
22	3.5	2.5	2.2	2.5
23	3.3	1.6	1.8	2.0
24	2.8	1.4	1.4	1.6
25	2.7	0.8	1.0	1.6
26	1.5	0.9	0.9	1.0
27	1.8	0.5	0.4	0.9
28	1.4	0.4	0.5	0.9
29	1.4	0.3	0.3	0.3
30	0.9	0.2	0.3	0.3

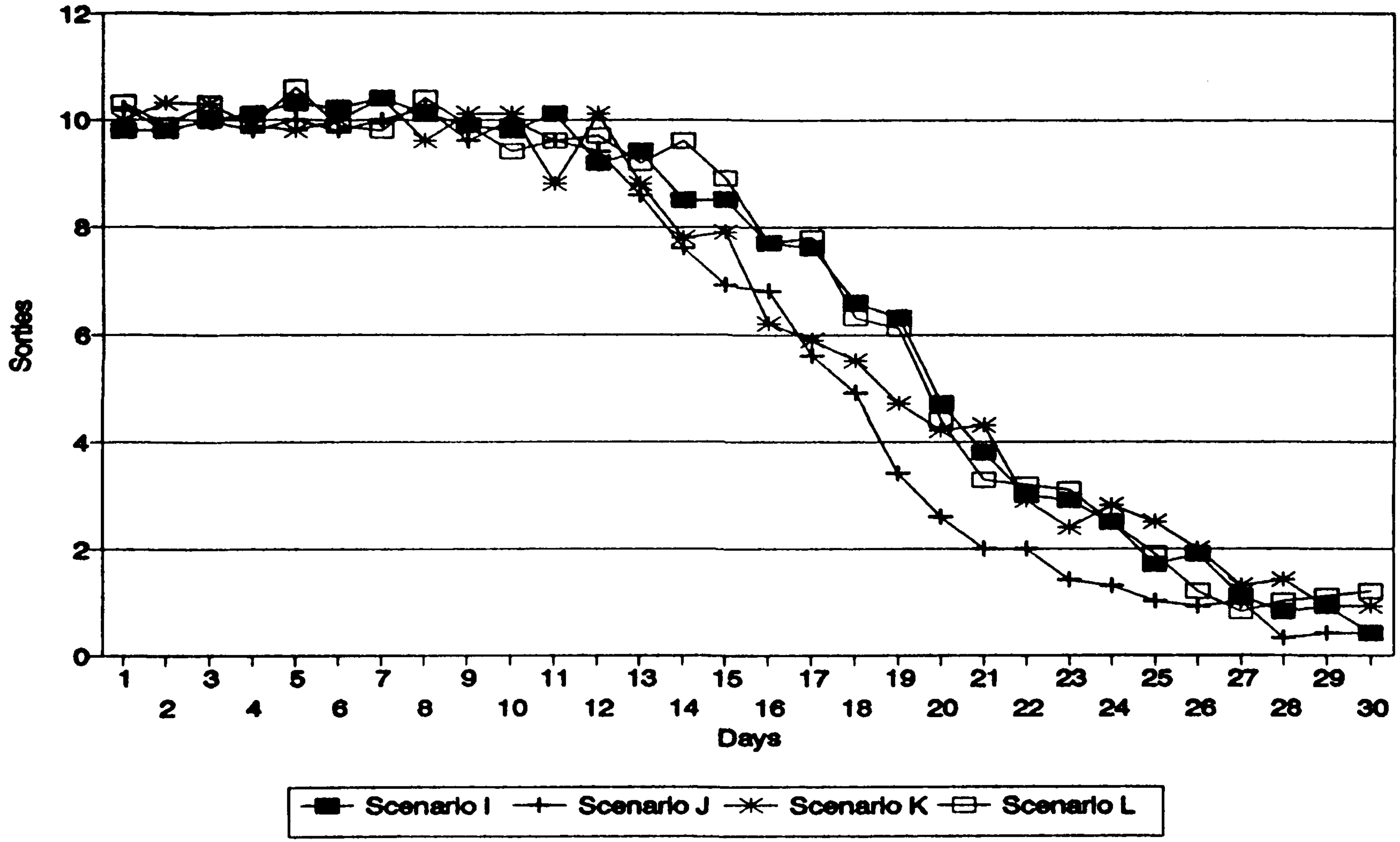
AVERAGE DAILY SORTIES FLOWN
SCENARIOS E F G H



AVERAGE DAILY SORTIES FLOWN

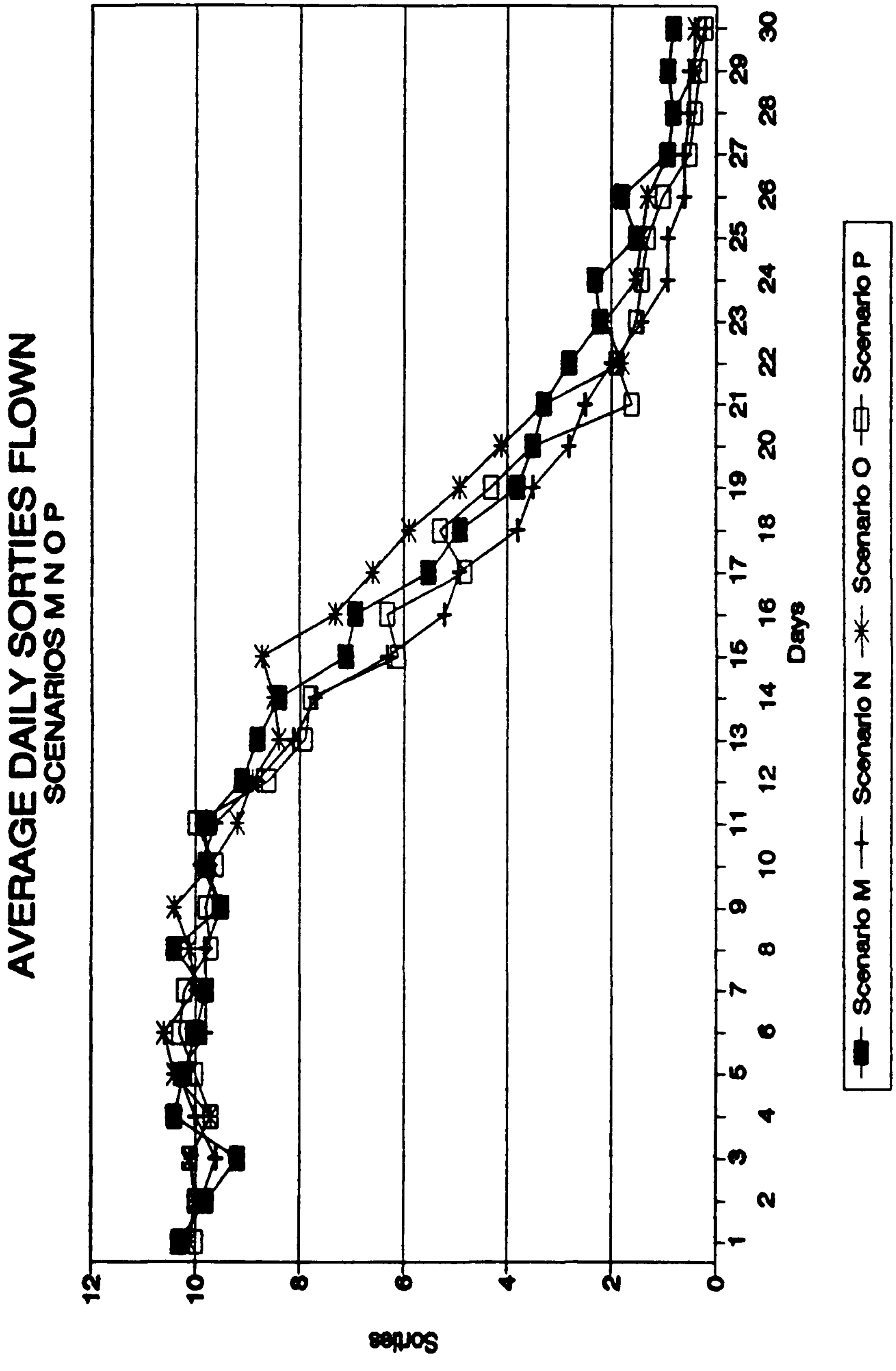
	SCENARIO			
DAY	I	J	K	L
1	9.8	10.2	10.0	10.3
2	9.8	9.8	10.3	9.9
3	10.0	10.0	10.3	10.3
4	10.1	9.8	9.9	9.9
5	10.3	10.0	9.8	10.6
6	10.2	9.8	10.0	9.9
7	10.4	10.0	10.4	9.8
8	10.1	10.2	9.6	10.4
9	9.9	9.6	10.1	9.9
10	9.8	10.0	10.1	9.4
11	10.1	9.6	8.8	9.6
12	9.2	9.4	10.1	9.7
13	9.4	8.6	8.8	9.2
14	8.5	7.6	7.8	9.6
15	8.5	6.9	7.9	8.9
16	7.7	6.8	6.2	7.7
17	7.6	5.6	5.9	7.8
18	6.6	4.9	5.5	6.3
19	6.3	3.4	4.7	6.1
20	4.7	2.6	4.2	4.4
21	3.8	2.0	4.3	3.3
22	3.0	2.0	2.9	3.2
23	2.9	1.4	2.4	3.1
24	2.5	1.3	2.8	2.5
25	1.7	1.0	2.5	1.9
26	1.9	0.9	2.0	1.2
27	1.1	1.0	1.3	0.8
28	0.8	0.3	1.4	1.0
29	0.9	0.4	0.9	1.1
30	0.4	0.4	0.9	1.2

AVERAGE DAILY SORTIES FLOWN
SCENARIOS I J K L



AVERAGE DAILY SORTIES FLOWN

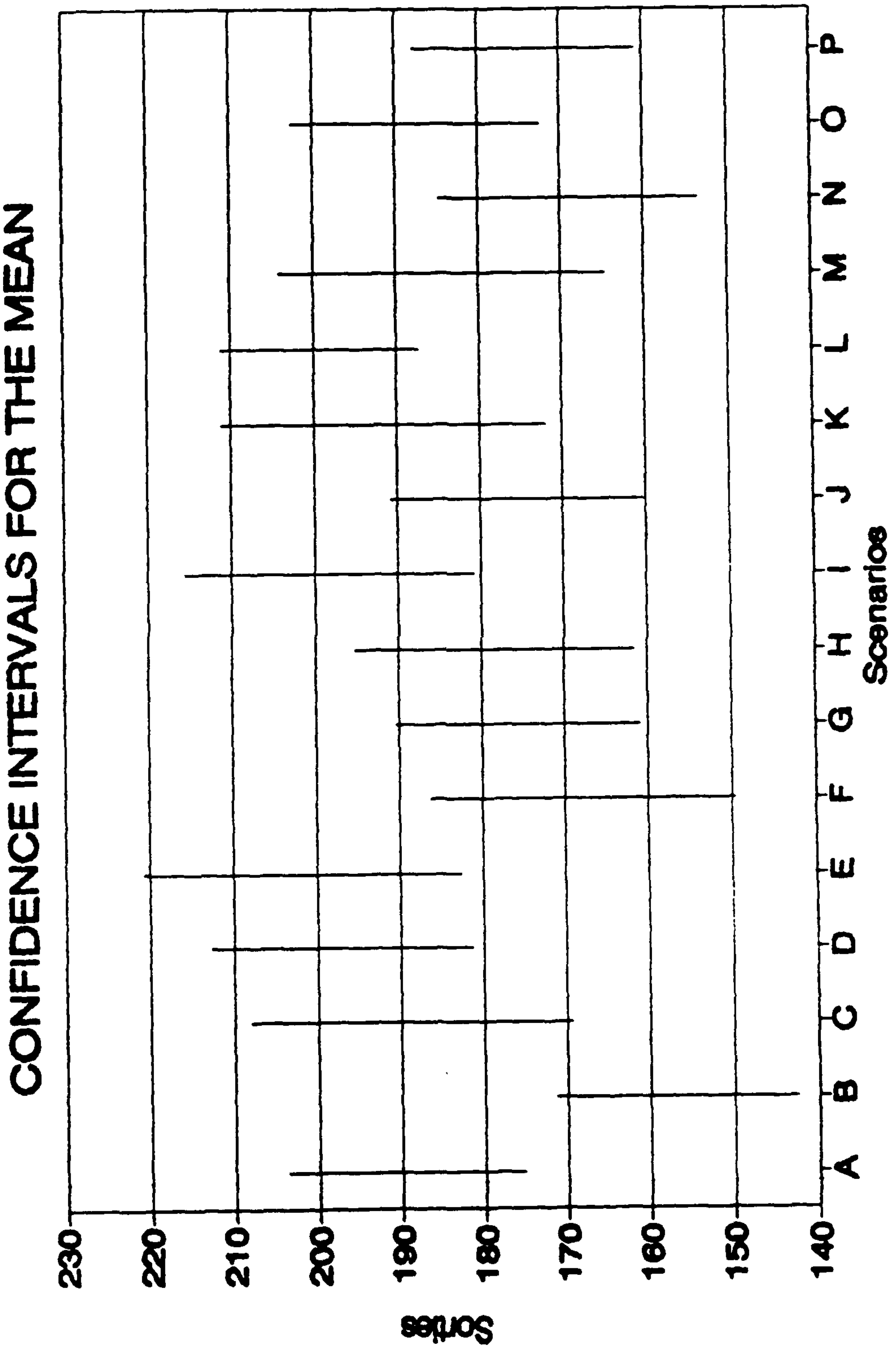
	SCENARIO			
DAY	M	N	O	P
1	10.3	10.2	10.1	10.0
2	9.8	9.9	10.0	10.0
3	9.2	9.6	10.1	10.1
4	10.4	10.0	9.7	9.7
5	10.2	10.3	10.4	10.0
6	10.0	9.8	10.6	10.3
7	9.8	9.8	10.0	10.2
8	10.4	9.8	10.1	9.7
9	9.5	9.5	10.4	9.8
10	9.8	9.9	9.7	9.6
11	9.8	9.6	9.2	10.0
12	9.1	8.8	8.9	8.6
13	8.8	8.1	8.4	7.9
14	8.4	7.7	8.5	7.8
15	7.1	6.3	8.7	6.1
16	6.9	5.2	7.3	6.3
17	5.5	4.9	6.6	4.8
18	4.9	3.8	5.9	5.3
19	3.8	3.5	4.9	4.3
20	3.5	2.8	4.1	3.5
21	3.3	2.5	3.3	1.6
22	2.8	2.0	1.8	1.9
23	2.2	1.4	2.1	1.5
24	2.3	0.9	1.5	1.4
25	1.5	0.9	1.4	1.3
26	1.8	0.6	1.3	1.0
27	0.9	0.6	0.9	0.5
28	0.8	0.5	0.8	0.4
29	0.9	0.5	0.4	0.3
30	0.8	0.2	0.4	0.2



AVERAGE DAILY SORTIES FLOWN

SCENARIOS M N O P

Appendix C: Graphical Representation of Confidence Intervals

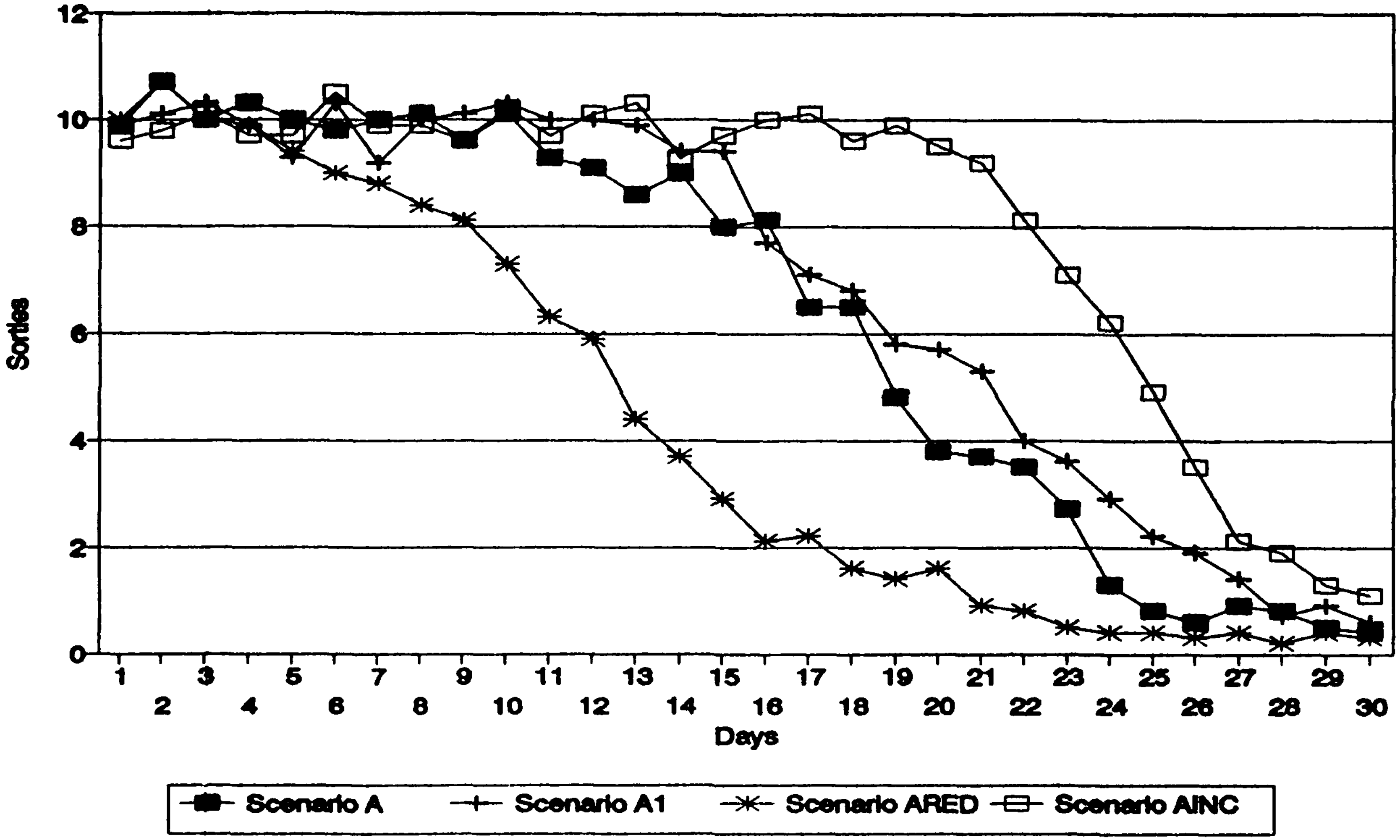


Appendix D: Average Daily Sorties for Scenarios A, A1, ARED, AINC

AVERAGE DAILY SORTIES FLOWN

	SCENARIO			
DAY	A	A1	ARED	AINC
1	9.9	9.9	10.0	9.6
2	10.7	10.1	10.7	9.8
3	10.0	10.3	10.0	10.1
4	10.3	9.9	9.9	9.7
5	10.0	9.3	9.4	9.7
6	9.8	10.3	9.0	10.5
7	10.0	9.2	8.8	9.9
8	10.1	10.0	8.4	9.9
9	9.6	10.1	8.1	9.6
10	10.1	10.3	7.3	10.2
11	9.3	10.0	6.3	9.7
12	9.1	10.0	5.9	10.1
13	8.6	9.9	4.4	10.3
14	9.0	9.4	3.7	9.3
15	8.0	9.4	2.9	9.7
16	8.1	7.7	2.1	10.0
17	6.5	7.1	2.2	10.1
18	6.5	6.8	1.6	9.6
19	4.8	5.8	1.4	9.9
20	3.8	5.7	1.6	9.5
21	3.7	5.3	0.9	9.2
22	3.5	4.0	0.8	8.1
23	2.7	3.6	0.5	7.1
24	1.3	2.9	0.4	6.2
25	0.8	2.2	0.4	4.9
26	0.6	1.9	0.3	3.5
27	0.9	1.4	0.4	2.1
28	0.8	0.7	0.2	1.9
29	0.5	0.9	0.4	1.3
30	0.4	0.6	0.3	1.1

AVERAGE DAILY SORTIES FLOWN
SCENARIOS A A1 ARED and AINC

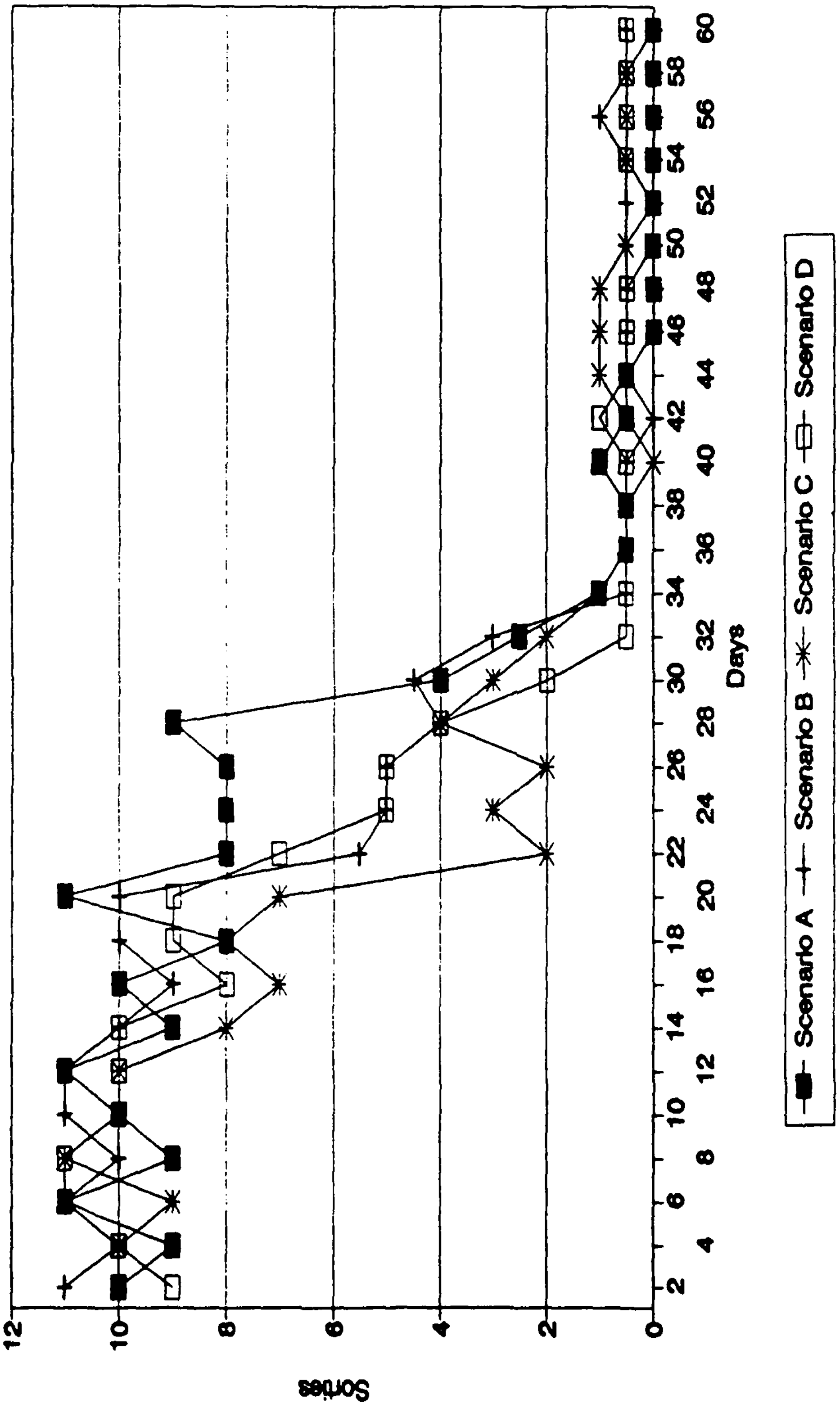


Appendix E: Results of Simulation of 60 Days

SORTIES FLOWN
(Average of Two Days)

	SCENARIO			
DAY	A	B	C	D
2	10.0	11.0	10.0	9.0
4	9.0	10.0	10.0	10.0
6	11.0	11.0	9.0	11.0
8	9.0	10.0	11.0	11.0
10	10.0	11.0	10.0	10.0
12	11.0	11.0	10.0	10.0
14	9.0	10.0	8.0	10.0
16	10.0	9.0	7.0	8.0
18	8.0	10.0	8.0	9.0
20	11.0	10.0	7.0	9.0
22	8.0	5.5	2.0	7.0
24	8.0	5.0	3.0	5.0
26	8.0	5.0	2.0	5.0
28	9.0	4.0	4.0	4.0
30	4.0	4.5	3.0	2.0
32	2.5	3.0	2.0	0.5
34	1.0	0.5	1.0	0.5
36	0.5	0.5	0.5	0.5
38	0.5	0.5	0.5	0.5
40	1.0	0.5	0.0	0.5
42	0.5	0.0	0.5	1.0
44	0.5	0.5	1.0	0.5
46	0.0	0.5	1.0	0.5
48	0.0	0.5	1.0	0.5
50	0.0	0.5	0.5	0.0
52	0.0	0.5	0.0	0.0
54	0.0	0.5	0.5	0.5
56	0.0	1.0	0.5	0.5
58	0.0	0.5	0.5	0.5
60	0.0	0.5	0.0	0.5

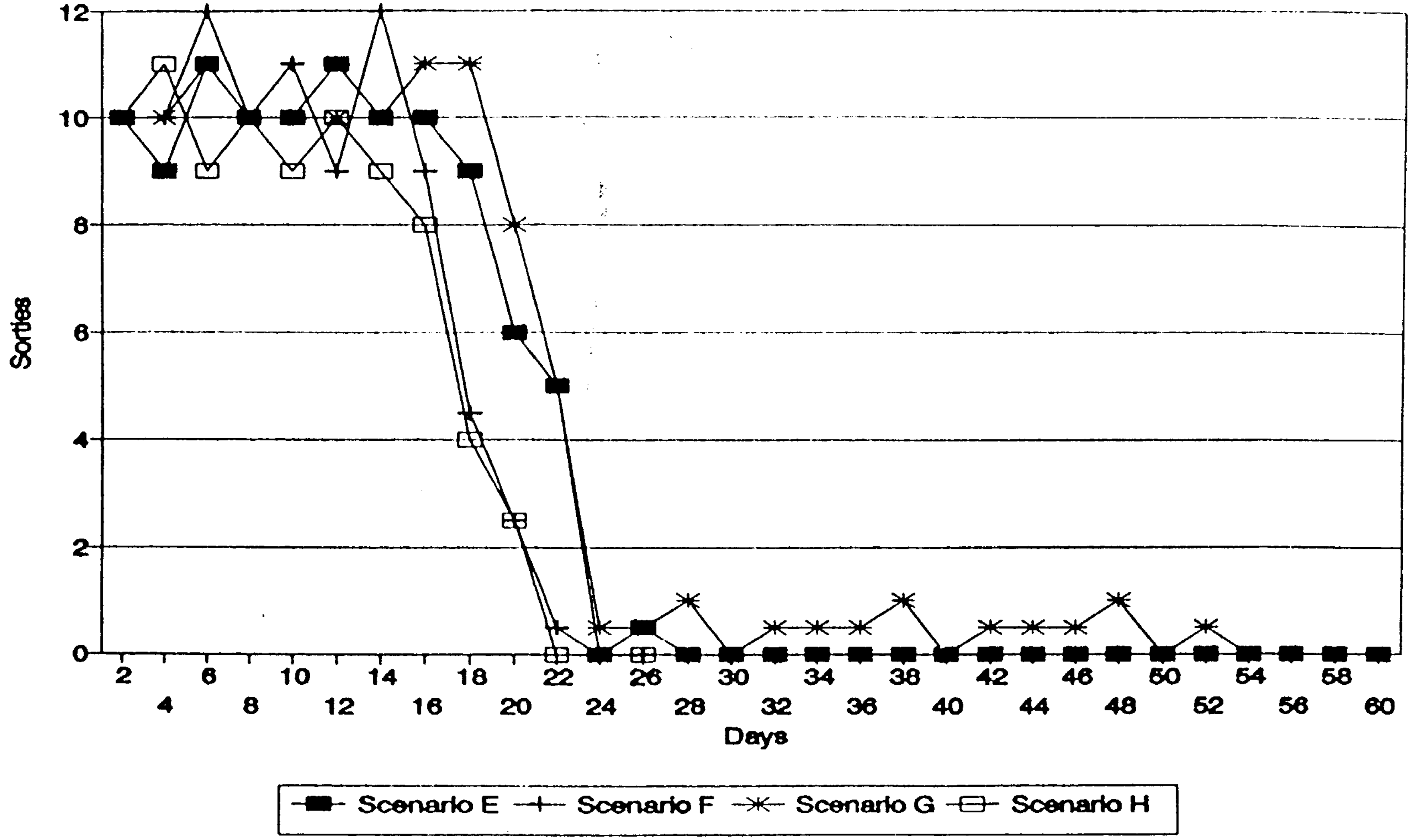
DAILY SORTIES FLOWN
SCENARIOS A B C D



SORTIES FLOWN
(Average of Two Days)

	SCENARIO			
DAY	E	F	G	H
2	10.0	10.0	10.0	10.0
4	9.0	10.0	10.0	11.0
6	11.0	12.0	11.0	9.0
8	10.0	10.0	10.0	10.0
10	10.0	11.0	10.0	9.0
12	11.0	9.0	10.0	10.0
14	10.0	12.0	10.0	9.0
16	10.0	9.0	11.0	8.0
18	9.0	4.5	11.0	4.0
20	6.0	2.5	8.0	2.5
22	5.0	0.5	5.0	0.0
24	0.0	0.0	0.5	0.0
26	0.5	0.0	0.5	0.0
28	0.0	0.0	1.0	0.0
30	0.0	0.0	0.0	0.0
32	0.0	0.0	0.5	0.0
34	0.0	0.0	0.5	0.0
36	0.0	0.0	0.5	0.0
38	0.0	0.0	1.0	0.0
40	0.0	0.0	0.0	0.0
42	0.0	0.0	0.5	0.0
44	0.0	0.0	0.5	0.0
46	0.0	0.0	0.5	0.0
48	0.0	0.0	1.0	0.0
50	0.0	0.0	0.0	0.0
52	0.0	0.0	0.5	0.0
54	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0
58	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0

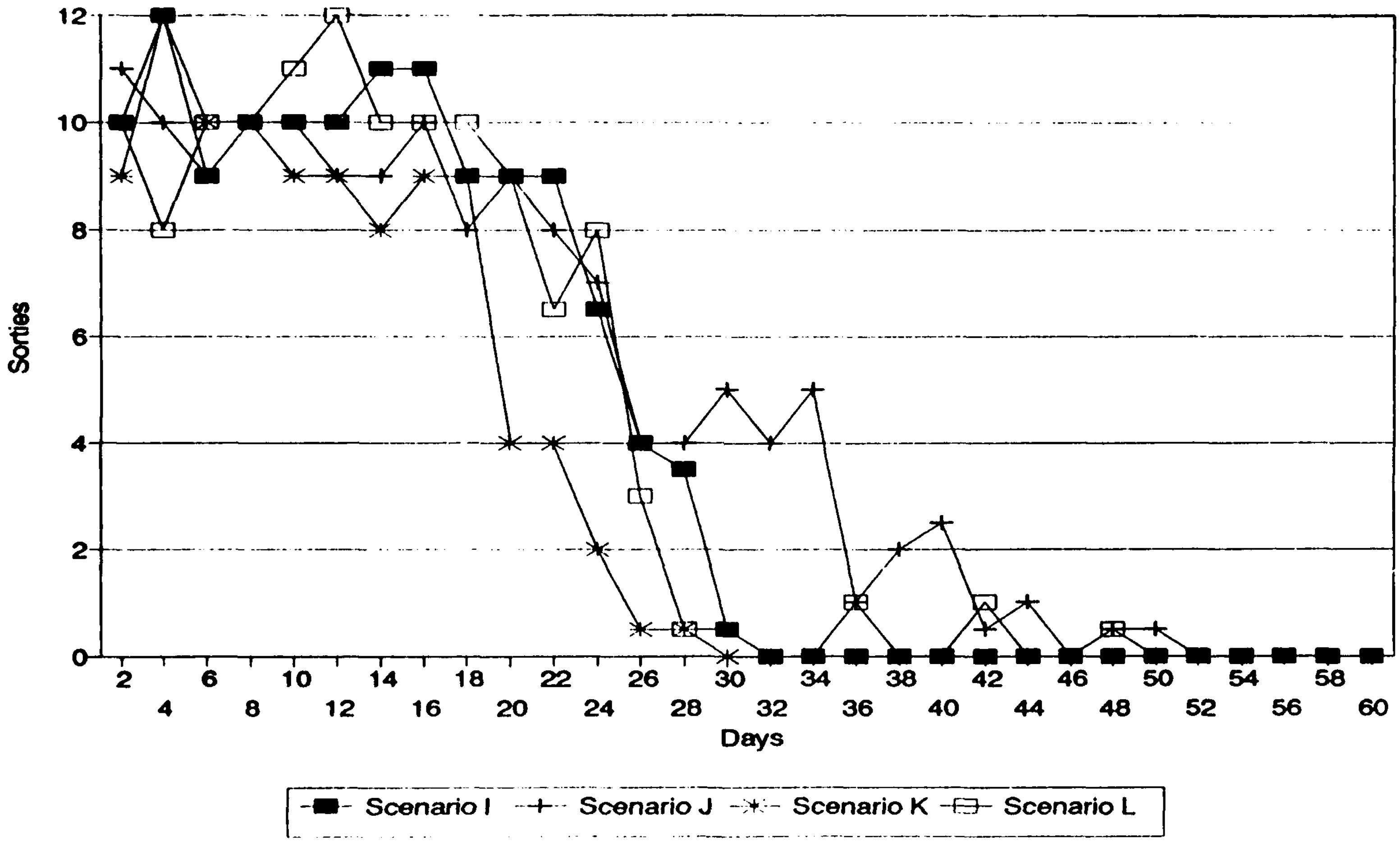
DAILY SORTIES FLOWN
SCENARIOS E F G H



SORTIES FLOWN
(Average of Two Days)

DAY	I	J	K	L
2	10.0	11.0	9.0	10.0
4	12.0	10.0	12.0	8.0
6	9.0	9.0	10.0	10.0
8	10.0	10.0	10.0	10.0
10	10.0	10.0	9.0	11.0
12	10.0	9.0	9.0	12.0
14	11.0	9.0	8.0	10.0
16	11.0	10.0	9.0	10.0
18	9.0	8.0	9.0	10.0
20	9.0	9.0	4.0	9.0
22	9.0	8.0	4.0	6.5
24	6.5	7.0	2.0	8.0
26	4.0	4.0	0.5	3.0
28	3.5	4.0	0.5	0.5
30	0.5	5.0	0.0	0.5
32	0.0	4.0	0.0	0.0
34	0.0	5.0	0.0	0.0
36	0.0	1.0	0.0	1.0
38	0.0	2.0	0.0	0.0
40	0.0	2.5	0.0	0.0
42	0.0	0.5	0.0	1.0
44	0.0	1.0	0.0	0.0
46	0.0	0.0	0.0	0.0
48	0.0	0.5	0.0	0.5
50	0.0	0.5	0.0	0.0
52	0.0	0.0	0.0	0.0
54	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0
58	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0

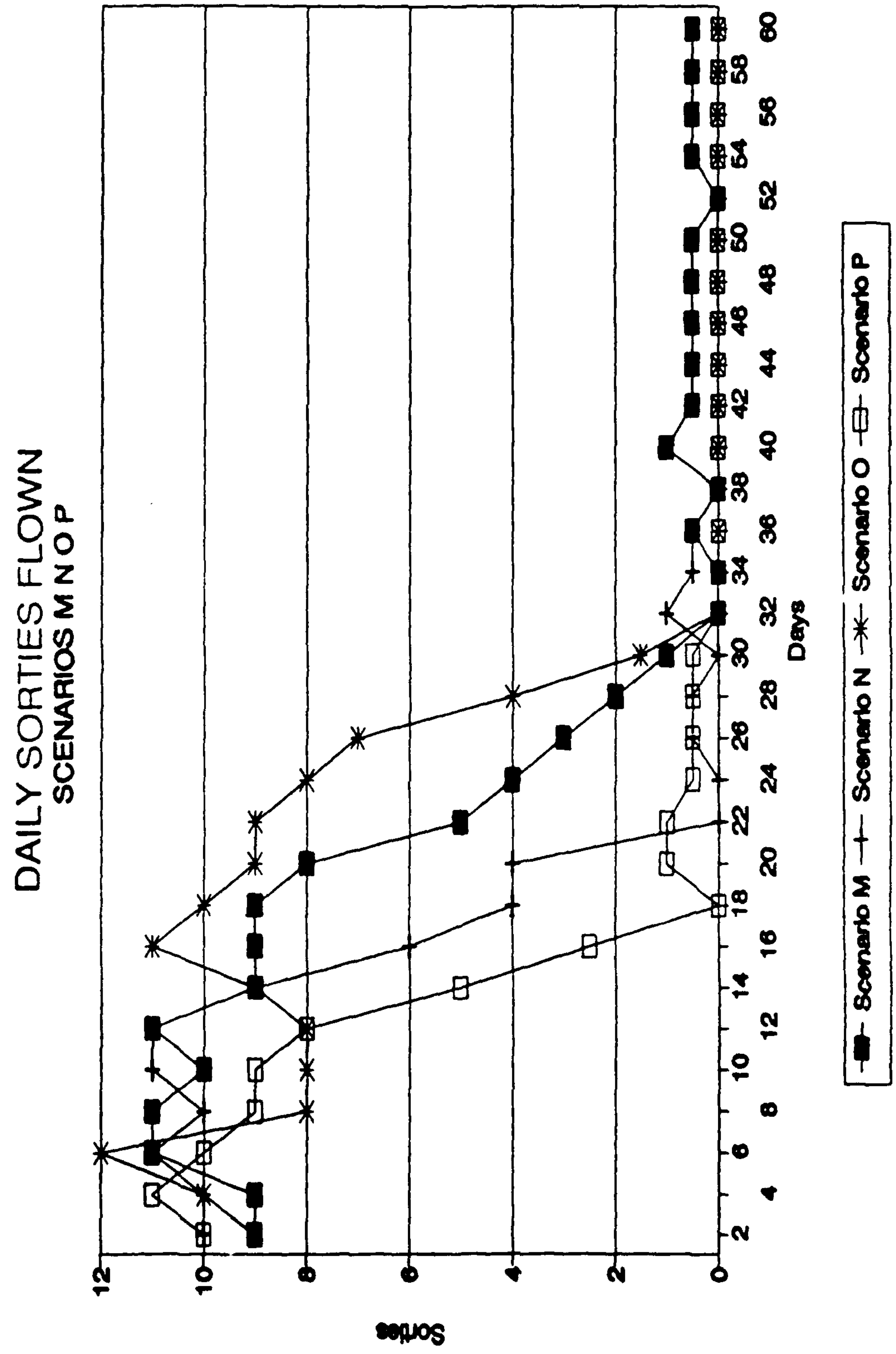
DAILY SORTIES FLOWN
SCENARIOS I J K L



SORTIES FLOWN

(Average of Two Days)

	SCENARIO			
DAY	M	N	O	P
2	9.0	10.0	9.0	10.0
4	9.0	10.0	10.0	11.0
6	11.0	11.0	12.0	10.0
8	11.0	10.0	8.0	9.0
10	10.0	11.0	8.0	9.0
12	11.0	11.0	8.0	8.0
14	9.0	9.0	9.0	5.0
16	9.0	6.0	11.0	2.5
18	9.0	4.0	10.0	0.0
20	8.0	4.0	9.0	1.0
22	5.0	0.0	9.0	1.0
24	4.0	0.0	8.0	0.5
26	3.0	0.5	7.0	0.5
28	2.0	0.5	4.0	0.5
30	1.0	0.0	1.5	0.5
32	0.0	1.0	0.0	0.0
34	0.0	0.5	0.0	0.0
36	0.5	0.5	0.0	0.0
38	0.0	0.0	0.0	0.0
40	1.0	0.0	0.0	0.0
42	0.5	0.0	0.0	0.0
44	0.5	0.0	0.0	0.0
46	0.5	0.0	0.0	0.0
48	0.5	0.0	0.0	0.0
50	0.5	0.0	0.0	0.0
52	0.0	0.0	0.0	0.0
54	0.5	0.0	0.0	0.0
56	0.5	0.0	0.0	0.0
58	0.5	0.0	0.0	0.0
60	0.5	0.0	0.0	0.0


DAILY SORTIES FLOWN
SCENARIOS M N O P
Sorties
0
2
4
6
8
10
12
Days
2
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6
8
10
12
14
16
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20
22
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Scenario M
Scenario N
Scenario O
Scenario P

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Vita

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13. ABSTRACT *(Maximum 200 words)*

The purpose of this study was to evaluate the capacity to generate a desired level of sorties of the F-16 weapon system. This capacity depends on the maintenance concept and structure, that defines a specific level of in-theater resources available. The theater is intended to reflect Portuguese Air Force logistics planned for the F-16, with one operational base and a possible Centralized Intermediate Repair Facility, not co-located.

The TSAR simulation program and one USAF database were used to perform the evaluation of the different alternatives. Sixteen scenarios were defined and compared. The study focused on the unscheduled maintenance tasks and repairable items, in particular the engine and the avionics areas. The responses under evaluation were manning, support equipment and spares levels. The variables were the location of support equipment and the levels and scheduling of manpower.

Limitations on handling the TSAR program restricted the amount of data used in the analysis. However, the results show that the level of maintenance support defined in this study is insufficient to sustain the desired level of sorties, with little difference across the different scenarios. Data gathered covered only the short term (30 to 60 days) capability to support operations.

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