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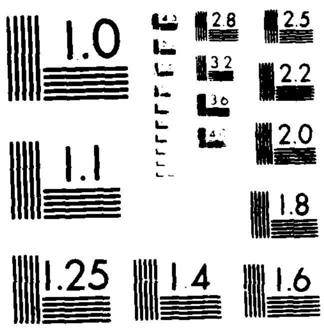

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ANALYSIS OF SOUTH EAST ASIA MAINTENANCE DATA TO DEVELOP A METHOD FOR PREDICTING DEMAND FOR REPARABLE ITEMS

THESIS

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AFIT/GOR/OS/86D-15

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AFIT/GOR/OS/86D-26

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

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Preface

I have attempted to develop a means of evaluating the current methodology for determing the composition of the War Readiness Spares Kits (WRSKs). The current methodology of determining the demand rates for the spares in the WRSK uses failure data from peacetime utilization. This was done by taking actual wartime data and regression analysis to generate demand rates for the spares in the WRSK. The methodology I used shows some promise because the variable that is currently used to detemine demand rates is not the only variable that affects wartime demand rates. Therefore further investigation of what variables do affect demand rates would be benefical if a proper data base were available.

I want to express my thanks to the Lord for his help and guidance in the past year and a half of scholastic endeavour. I especially want to thank my wife Eloise and my son Brian for their patients, understanding, and support; and my daughter Rachelle for her laughter. Lastly, I would like to express my gratitude to Lt Col Rowell, my advisor, and Mr. Rich Lamb, Mathematician at the Human Resources Laboratory, for their help in putting this all together.

Cecil D. Stevens Jr.

LIST OF ACRONYMS

AFLC	--	Air Force Logistics Command
BLSS	--	Base Level Self-Sufficiency Spares
DR	--	demand rate
E(NMC)	--	expectd NMC aircraft
E(SDO)	--	expected parts shortages
FMC	--	fully mission capable
LRU	--	line replaceable unit
MAJCOM	--	Major Command
MEIS	--	Multi-Echelon Inventory System
METRIC	--	Multi-Echelon Technique for Recoverable Spares
NMC	--	not mission capable
PMC	--	partially mission capable
sd	--	standard deviation
SEA	--	South East Asia
SL	--	spares level
SRU	--	shop replaceable unit
WARMIFS	--	Wartime Maintenance Information and Forecasting System
WRM	--	War Reserve Materiel
WRSK	--	War Readiness Spares Kit
$WRSK_c$	--	composite WRSK
$WRSK_g$	--	generated WRSK

Abstract

The War Readiness Spares Kit (WRSK)/Base Level Self-Sufficiency Spares Requirements Computation System ([illegible]) is currently used to compute the demand rates (DRs) and spares levels (SLs) for WRSK line replaceable units (LRUs) from peacetime failures per flying hour. This thesis applied linear regression analysis on C-130 aircraft subsystems data, collected during the South East Asia (SEA) conflict to calculated LRU DRs. The results indicated the reciprocal of flying hours the number of aircraft, and the reciprocal of average sortie length rather than flying hours were better determinants of the C-130 subsystem DRs.

A WRSK was created by apportioning the subsystem DRs to the LRUs under the subsystems. The D029 marginal analysis methodology was applied to refine this WRSK. The final WRSK (WRSK[illegible]), a D029 WRSK, and a WRSK with the DRs from WRSK[illegible] and the SLs of the D029 WRSK were input into the Dyna-METRIC model to evaluate the effect of each WRSK on aircraft availability for a 30 day conflict without resupply of spares.

Dyna-METRIC output indicated the DRs in WRSK[illegible] were greater than those in the D029 WRSK and the SLs in WRSK[illegible] were slightly higher than those in the D029 WRSK. These findings were suspect because the form of the data and the model used to evaluated the performance of the two WRSKs impacted the results. The SEA failure data were aggregated by subsystem:

D029 WRSKs are created from LRU failure data. Dyna-METRIC uses demands per flying hour as an input, but flying hours was not the only significant variable for predicting DRs.

ANALYSIS OF SOUTH EAST ASIA MAINTENANCE DATA TO DEVELOP A METHOD FOR PREDICTING DEMAND FOR REPARABLE ITEMS

I. Introduction

Background

In order for an aircraft to perform its mission all required systems must be functional (3:14). Required systems that are malfunctioning must either be repaired or removed and replaced for an aircraft to remain capable of performing its mission. Trained personnel; proper test equipment, tools, and facilities; and sufficient spares are needed to repair or replace broken systems. According to research done by the McDonnell Douglas Astronautics Corporation spares level have a more significant impact on the operational readiness than manpower and support equipment; although support equipment can regenerate spares to keep aircraft that are not operationally ready because of support at a low level (4:19).

Spares levels are a critical factor for insuring an aircraft's mission capability: therefore, a War Readiness Spares Kit (WRSK) is vital for determining the aircraft's mission capability in combat. WRSK is

> an air transportable package of spares and repair parts required to sustain wartime or contingency operation of a weapon system on a remove and replace concept for a specified period of time pending resupply [4:3,4].

WRSK composition depends on many factors such as configuration, tasking, and initial deployed maintenance capability of the system, but all WRSKs must contain the specified minimum quantities of items to support the Major Command's (MAJCOM's) mission as required in the War Mobilization Plan document. Maintenance data are used to determine the items and specific quantities needed. Peacetime demand data are extrapolated to yield wartime demand and used to estimate WRSK requirements (6:19).

The WRSK items fall into one of two categories: consumable and reparable items. Consumable items are those which fail and are not repaired either because of excessive repair costs or the item cannot be repaired. Examples of consumable items are gun barrels, tires, fuses, and windows. Reparable items are items which can be repaired after they fail. Examples of reparable items are landing gear, radios, inertial navigation systems, and engines. Reparable items are either repaired at the base or depot level depending on the item's complexity.

In order for the Air Force to be capable of fighting future conflicts it must be capable of projecting its force into areas without pre-established supply and equipment until resupply is accomplished or the conflict ends. To meet this requirement the Air Force has developed a concept for keeping War Reserve Materiel (WRM) on hand in case of the need to deploy to such areas where we have no establish resources. WRM is

> the material required in addition to peacetime assets to support planned wartime activities outlined in the Air Force War and Mobilization Plan (6:3).

There are two types of WRM: WRSK and Base Level Self-Sufficiency Spares (BLSS). WRSK is WRM for organizations that will deploy to an area in the vicinity of the conflict and operate from this new location. BLSS is WRM for organizations that will operate in place during wartime (16:7). This thesis effort will only look at WRSK.

To maintain the level of readiness necessary to meet any contingency, WRSK adequacy is evaluated each year for all on line weapons systems or a WRSK is developed for systems entering the inventory. Headquarters (HQ) Air Force Logistics Command (AFLC) has the primary responsibility for Air Force WRSK and BLSS evaluation.

HQ AFLC obtains data on the worldwide demands for spares for all Air Force weapons systems. These demands are inputs for the D029 (WRSK/BLSS Requirements Computation System). The D029 is used yearly to compute the level of spares for each weapon system contingency listing of a WRSK.

> A contingency listing is configured to support wartime/contingency activity at the present time, that is, based on current year WRSK/BLSS authorizations and aircraft configuration, and the line item usage rates being presently experienced (17:14-2).

[illegible] systems are [illegible] down by recoverable line [illegible] WRSK is [illegible] remove and replace operation. No indenture relationships are addressed between LRUs and shop replaceable units (SRUs). All components are treated as LRUs, but in fact an LRU may consist of several SRUs.

D029 uses marginal analysis to compute the level of spares for each WRSK. After the D029 computes the spares level of a WRSK the data are stored in the D040 (WRM List/Requirements and Spares Support System) which passes through the MAJCOMs to the bases and to the D041 (Recoverable Item Consumption Requirements System).

In the D040 consumable items are added to the list generated by the D029. The D040 also serves as a hold file for all spares and the economic order quantity (EOQ) items. EOQ items are calculated at the base level.

The D041 contains the demands for all spares by national stock number, not by weapon system, and is the basis for buy listings.

> A buy listing is configured to support wartime/contingency activity based on the WRSK/BLSS authorizations, aircraft configurations and line item usage rates being projected at the third year forecast period [17:14-42].

A buy listing is an estimate of what spares are needed to meet future demands for new weapons systems or currently deployed systems. The buy kits are compared to those computed by the D029 after the system is operational and data are collected on demand rates for spares (13).

The WRSK's effect on capability is assessed by HQ AFLC with Dyna-METRIC in the Sustainability Assessment Module of the Weapon System Management Information System (16:6).

Dyna-METRIC is an analytical model that simulates the movement of spares in a dynamic wartime situation by looking at the spares stockage levels, the demand for the spares, and the repair capability for spares at the base and depot level (14:8). Dyna-METRIC will be discussed further in Chapter II.

Motivation

The current method used to determine the demand rate for spares takes the total number of failures for a particular part and divides it by the total number of flying hours. This demand rate is adjusted to depict the expected level of activity that would be encountered in a conflict. The calculated demand rate is multiplied by a wartime adjustment factor to translate it from peacetime to wartime demand. This method may not be valid for the following reasons: it assumes there is a linear relationship between wartime activity and peacetime activity; and the demand for spares depends on flying hours only.

The linearity assumption poses a potential problem. First, the data used to calculate the demand rates are based on peacetime activity. War is an unstable and highly dynamic situation and the way aircraft are used in wartime is likely to change from the more stable pattern encountered in peacetime. If wartime demand is obtained from peacetime data, it may not accurately consider how aircraft are utilized in wartime (7:1,2).

Secondly, the assumption that the linear relationship between flying hours and demand completely captures the demand rate for all spares is not true. According to a Rand report, this assumption is not true for all components. Aircraft engine failure rates depend more on the throttle settings or ranges used during the mission and landing gear failure rates depend more on the number of landings than on the flight hours of the aircraft. This demand assumption has resulted in overestimating wartime demand for cargo aircraft components (7:ix).

Are these discrepancies enough to invalidate the current method of calculating WRSK or is this the best we can do since we have no data or not enough data to prove otherwise. One possible test to examine the validity of the current method is to take some demand rates derived from wartime data and compare the performance of a WRSK derived from peacetime data to that derived from wartime data.

Problem Statement

Can we more accurately estimate maintenance demand rates for aircraft reparables during wartime?

The intent of this study is to develop a more realistic relationship for demand which uses not only flight hours but other significant variables to determine more accurately the demand for reparables.

Research Questions. Is the Air Force method of computing demands based upon peacetime flying hours to predict wartime requirements realistic?

Is there a significant difference between predictions of wartime requirements derived from peacetime flying data and estimates based on multiple factors derived from combat experience?

Objectives

There are two objectives of this research. The first is to investigate the variables affecting maintenance demand for reparables using data collected in South East Asia (SEA).

The second objective is to investigate the effect on C-130 availability in a warime scenario of using a WRSK created by the D029 versus one developed using the demand derived from wartime data.

Summary

The Air Force needs the capability to fight conflicts for a sustained period before our support can be provided to the combatants. To do this, weapon systems must have enough spares available to sustain them until the organization can be resupplied. The WRM concept was developed to this end. WRSK, a subset of WRM, was designed to keep deployed weapons systems operational in wartime until resupply can occur.

HQ AFLC is the responsible for WRSK derivation and evaluation in the Air Force. WRSK is calculated in the D029 and passed through the MAJCOMs to the using bases. Inputs for WRSK computation are obtained from worldwide failures of the items and expert observations of the using community through yearly WRSK reviews.

The WRSK's demand rates are calculated by dividing the total number of failures by the total number of flying hours

II. LITERATURE REVIEW

Introduction

The purpose of this literature review is to evaluate the current models which examine spares levels for weapons systems. I will provide a brief description of what the model does and the model's assumptions. Then all models will be evaluated for their applicability to the proposed research. The most appropriate model will be used in this research to compare a WRSK generated by the D029 using peacetime data and a WRSK generated using wartime data.

Models

The following models have been used to evaluate WRSK requirements or to measure the effect of WRSK on aircraft availability:

1. Multi-Echelon Technique for Recoverable Items Control (METRIC).
2. Dynamic Multi-Echelon Technique for Recoverable Items Control (Dyna-METRIC).
3. Weapon System Spares Support Model.
4. Low-density Equipment Algorithm.
5. Analytical Methodology for Predicting Repair Time Distributions.
6. Multi-Echelon Inventory System (MEIS).

METRIC. The Multi-Echelon Technique for Recoverable Items Control (METRIC) model, developed by Close and Gillen in 1969, is an analytic model which determines optimal stock levels for reparable items for a system with a maximum of 20 bases and 1 depot. METRIC does this by minimizing the total number of days all items are backordered at all bases (2:471). METRIC uses a marginal approach to find an optimal solution: it adds that unit of stock which causes the greatest decrease in expected backorders to the system. The model terminates when the user input cost constraint is exceeded or the expected number of backorders is minimized (2:476).

METRIC assumes the following:

1. Demand for each item is logarithmic Poisson and stationary over each demand period.

2. The decision to repair at base or depot level is based on the complexity of the component.

3. Base resupply is not allowed.

4. All components are repairable either at base or depot level.

5. Repairable items do not have the same priority.

6. The depot does not batch items for repair.

7. The demand rate of bases for the same item can be combined to form a composite demand for the item (2:472).

Dyna-METRIC. Dyna-METRIC is an analytic model, developed by Rand Corporation, that predicts the effect of the logistic support process on flying units' capabilities to perform their mission in a dynamic wartime environment. Dyna-METRIC is a modification of METRIC. It is used by HQ AFLC to assess the capability of WRSKs to support war operations. Dyna-METRIC takes aircraft components and forecasts the amount of each component in repair and resupply for a wartime scenario. It is usually run for a 30-day scenario. Dyna-METRIC has the capability to forecast component pipelines, estimate aircraft availability and number of sorties, identify problem parts and suggest cost-effective stock purchases (14:8).

Dyna-METRIC assumes the following:

1. Poisson demand distribution for repair process if mean to variance ratio is 1.00, negative binomial if it is greater than 1.00, and binomial if it is less than 1.00.

2. Failures are not correlated.

3. The repair process time of an item is constant regardless of the number of failed items in the system (14:25,26).

Weapon System Spares Model. The Weapon System Spares model was developed primarily to obtain fast and inexpensive best estimates of how long a conflict can be sustained with a given level of nonconsumable spares. The model was created by Folkerson in 1981. The model estimates the number of days of spares support using the following linear regression equation:

$$y = \alpha + Fx(n)$$

where

y = the total days of spares support

α = the number of war days spares support available from war reserves material

x = the number of planned days of contingency operation

n = the inherent variability due to degradation of actual peacetime support

F = Fp/Fw; the proportion of programmed flying hours in a standard peacetime day to the number of programmed flying hours in a planned war day (8:1,2).

The spares available for the conflict are the war reserve materiel (8:2).

Low-density Equipment Algorithm. The Low-density Equipment Algorithm was developed by Pankonin in 1982 to predict the availability of a weapon system given a specific spares inventory level (12:1,2). The computer algorithm uses a marginal assessment approach to determine the effect of increasing inventory items on system availability. The algorithm deals only with high-reliability, low demand items that possess the following characteristics:

1. Each base supports one end-item and that end-item has no built-in redundancy.

2. All items are equally essential and mission critical.

3. Item demands are independent, with a usage rate at each base of one or less per year (12:99,93).

The inputs required for this algorithm are the yearly demand for each item, the ratio of failed items to items reparable at base level, the repair cycle time, and the order shipping time (12:46).

The Low-density Equipment Algorithm assumes the following:

1. There is no base repair capability; all failures result in a demand on the depot.

2. The item is authorized one unit of base stock; the depot always has stock on hand.

3. The demand for each item is Poisson distributed and varies between one and five units per year (12:58).

Analytical Methodology. The Analytical Methodology was developed by Dietz in 1985. The Analytical Methodology examines the effects of aircraft reliability and maintainability on availability and sortie generation capability in advanced technology (high reliability) aircraft (5:6-1). First, subsystem repair time distributions are obtained by analytically combining each aircraft's subsystem reliability and maintainability characteristics (5:x). Second, an aggregate repair time distribution is formulated as a probabilistic mixture of all the subsystem repair time distributions (5:8-1).

The movement of the aircraft from four states (flying a sortie, being turned, being repaired, and awaiting launch) is modeled as a continuous flow (5:6-3).

The Analytical Methodology assumes the following conditions exist:

1. The probability of failure of any aircraft subsystem is not affected by other subsystem failures.

2. The time between failures of each subsystem is exponentially distributed.

3. Only one subsystem failure occurs before aircraft repair is initiated (5:8-1).

<u>MEIS</u>. MEIS was a research effort produced by Miller in 1985. MEIS is a simulation developed primarily as a tool to investigate the effects of different logistic alternatives on a system consisting of three bases and one centralized repair facility (depot). Two of the bases are operational: one is located in the continental United States (CONUS) and the other is located overseas. The third base is a training base in the CONUS. All aircraft on the bases possess only two

components (A and B). Component A is repairable at the base, as well as, at the depot and component B is only repairable at the depot (10:31,32).

MEIS's measures of effectiveness are as follows:

1. Percent of flights flown - total number of flights flown divided by the total number of flights planned for 365 days.

2. Base supply stockage effectiveness - percent of requisitions filled by supply immediately through base spare stock.

3. Mean backorder days - average number of days a grounded aircraft waits for spares from the supply system.

4. Mean units awaiting depot repair - average number of reparables awaiting entry to depot repair shop.

5. Worker utilization at depot - fraction of the time depot workers are busy (10:54).

Inapplicable Models. All models were evaluated for their usefulness for determining aircraft (C-130) availability in a wartime scenario given the current D029 WRSK levels. All models except Dyna-METRIC were judged inappropriate to accomplish the task.

The METRIC model will not be useful for determining aircraft availability since it was developed to design an optimal WRSK given a monetary constraint or a required minimum aircraft availability. The model chosen must be capable of predicting aircraft availability given the current WRSK levels.

The Weapon System Support Model is not suited for the proposed analysis because it does not measure aircraft availability, but calculates the number of days war reserves material will provide for a wartime scenario.

The Low-density Equipment Algorithm is inappropriate because it does not work for aircraft items with demands greater than one to five per year. Such low demands are not likely for the level of aircraft utilization that will be experienced in a wartime scenario. Also, contrary to the algorithm's assumptions, all demands will be met by the base supply (WRSK) until spares are exhausted. The current concept of WRSK is predicated around this idea.

The Analytical Methodology is also inappropriate because it is designed for aircraft with very high subsystem reliability, such as the advanced technology aircraft. The C-130 is not an advanced technology aircraft. In addition to high reliability, the failure of one C-130 subsystem before another is repaired may be acceptable in wartime.

The Multi-Echelon Inventory System is not appropriate in its present formulation as a solution tool because the number of spares is limited to two and the time period used in the simulation is 365 days. The number of items in the C-130 WRSK is over 100 and the use of two will not accurately portray the entire C-130 maintainability. The period of time the WRSK is expected to be critical is the first 30 days of a war, that is, before pipelines can be set up to provide spares and equipment to the forward units.

Applicable Models. The remaining model, Dyna-METRIC, is suited for the analysis. The time frame for the simulation is 30 days and one of the model's outputs is aircraft availability over this period of time.

The limitations of Dyna-METRIC are as follows:

1. Repair procedures and productivity are unlimited and stationary unless repair capacity is explicitly stated.

2. Forecast sortie rates do not directly reflect flight-line resources and the employment plan.

3. Component failure rates depend only on aircraft flying hours.

4. All aircraft on a base are identical.

5. No items are repaired before the testing is finished.

6. The number of full mission capable aircraft does not affect the component failure rates.

7. All echelons' component repair processes are the same (14:viii).

Relevant Limitations. The assumption that the component failure rate depends only on aircraft flying hours is a significant factor in the problem at hand, since I will examine its validity for predicting demand rates. The assumption that demand depends only on flying hours is not valid for all aircraft items; tire demand depends on the number of landings more than on flying hours. There currently is no way to eliminate this problem because it is an assumption that is the cornerstone of all models. I will allow for this assumption and use the following plan to work around this problem. If the demand for an item is not closely related to the number of flying hours the unit's demand will be coverted to "flying-hour equivalents" by taking the average demand per sortie and average sortie length. This may not be a significant problem if the characteristic of the particular wartime scenario are known in advance. If the demand rate changes over the period of the scenario, it is possible to run the model with the initial demand and then run the second period with the new demand rate (14:34).

Other Limitations. Unconstrained consumption and stationary repair procedures imply there is no change in the repair cycle time of a component when there are more broken components in the system. No change occurs because it is assumed there are ample repair resources to achieve a user specified repair cycle time. Ample repair resources are allowed unless the user specifies a constraint for some of the components (14:32). This consumption assumption may not be valid in a situation when the demand for components and resources is very dynamic, such as a war, but is not a limitation in the problem considered since WRSK is designed on a remove and replace basis: repair is not considered in WRSK development.

The sortie rate of fully mission capable (FMC) aircraft is not constrained by flight-line resources or operational plan because Dyna-METRIC assumes the average FMC aircraft can complete a given number of sorties per day. This assumption may not be valid if flight-line resources are not available to turn aircraft in time or operational plans call for using the available aircraft in ways that preclude efficient use of those flight-line resources (by massing aircraft sorties, for example) (14:33). A method to work around this problem is to use another model to determine the maximum number of sorties sustainable with the given flight-line constraints and operational plan (14:34). This will not be a factor in the analysis planned.

Considering all aircraft identical (having the same components) is valid for the proposed problem since the C-130 is the only aircraft being considered. The occurrence of repair decision and action after testing is complete follows from the model's use of the average repair time as the sole measure of the complete repair process. The repair process consists of a diagnostic period and a physical repair period. The diagnostic period is assumed to be considerably longer than the repair period. If the repair period is longer than the diagnostic period, the number of aircraft awaiting parts is overestimated. To compensate for this overestimation each component and its subcomponents can be treated independently, since finding the failed subcomponent happens approximately the same time as discovering the failed component (14:36,37).

Dyna-METRIC does not adjust component failure rates to reflect previous failures because it assumes some partially mission capable (PMC) aircraft will be used to fly missions if FMC aircraft are not available. The user input sortie rates are therefore used to compute failures. If few PMC aircraft are available to meet sortie demand, the model will initially overestimate sorties and capability. This problem can be handled by iteratively feeding back the number of FMC aircraft sorties as the user input sortie rates (14:38).

The assumption that all echelons' repair times were equal was designed to handle a centralized off-base repair facility for those items not repairable at the base. This final limitation can be eliminated since no repair will be at the base level. No repair will be done at the base level because WRSK is designed primarily on a remove and replace basis.

Summary

The Dyna-METRIC model is the best suited for the task to be undertaken. Its limitations can be overcome or are inapplicable to this research problem. The Multi-Echelon Inventory System could be applicable to the problem if its time frame were changed from 365 days to 30 days and the number of items in the WRSK were increased from two items to the number of items in a conventional C-130 WRSK. The Low-density Equipment Algorithm, METRIC, Weapon System Support Model, and the Analytical Methodology are all not appropriate to answer the research problem posed. The Low-density Equipment Algorithm does not work for aircraft items with demands greater than one to five per year; METRIC designs optimal WRSK given a monetary constraint or a required minimum aircraft availability; the Weapon System Support Model calculates the number of days war reserves material will provide for a wartime scenario; and the

Analytical Methodology is designed for aircraft with very high subsystem reliability, such as the advanced technology aircraft.

Now that a model has been chosen to evaluate the performance of a WSRK a methodology must also be developed to first derive the demand rates from the SEA data and then generate a WRSK from these demand rates. The methodology used to accomplish this task is discussed in the next chapter, as well as, an explanation of the data and its origin.

III. Research Methodology

Introduction

This chapter details the data and methodology used in this research effort. The first topic discussed will be the data's origin and format. This will be followed by an explanation of the methodology used to derive the demand rates (DRs) for each WUC and the methodology used to generate a WRSK.

Data

In 1986 the AF Human Resource Laboratory received maintenance data collected in SEA from the Boeing Aerospace Company. Boeing obtained the data from historic AFR 66-1 maintenance tapes collected by AF maintenance personnel from 1965 until 1975, but the data are not available for this entire period (see Appendix A). The data were purchased from the Boeing Aerospace Company, since the Air Force does not keep more than five continuous years of maintenance data on its aircraft (19:12).

The data were broken down into maintenance action, operations activities, geographic features, and climatic factors (i.e. temperature, humidity, presence of weather phenomena that will affect launch of mission, etc.), by aircraft type and by base on a monthly basis. The data are aggregated by subsystem not LRU/SRUs (see Table I).

Appendix A contains an example of the data format. The focus of this study was the C-130 aircraft data collected in Viet Nam.

Table I

Subsystems in SEA Study

System Number	Subsystem
11	Airframe
12	Interior Fittings
13	Landing Gear
14	Flight Controls
22	Turboprop Power
23	Propulsion*
24	Auxillary Power
32	Hydraulic Prop
41	Environmental Control
42	Electric Power
44	Lighting*
45	Hydraulics
46	Fuel
47	Oxygen
49	Miscellaneous
51	Instruments
52	Autopilot
61	HF Communications
62	VHF Communications
63	UHF Communications
64	Interphone Communications
65	IFF/SIF
66	Emergency Communications
69	Miscellaneous Communications
71	Radio Navigation
72	Radar Navigation

*no data were collected on these subsystems

The SEA maintenance data may be used to develop a methodology for accurately predicting wartime spares requirements through statistical modelling. Past efforts to model wartime spares requirement have relied on the hypothesis that demand is highly correlated only with the number of flying hours and were based upon extrapolation of wartime DRs from exercises or peacetime DRs.

The data can be analyzed with a stepwise linear regression package using BMDP procedures called by the Wartime Maintenance Information and Forecasting System (WARMIFS) (9:11). WARMIFS was developed by the Boeing Aerospace Company. A drawback of the regression package is it only does linear regression. Neither the non-linear regression nor transformations can be used with the WARMIFS regression package. The stepwise approach that was used in the WARMIFS regression model will be used to derive the demand rates for each subsystem and LRU in the WRSK.

Demand Derivation

The approach used to derive the DRs was that of regression analysis. The failures for each subsystem were the dependent variable while the average sortie length, number of sorties, number of landings, and total sortie length were the independent variables. The aptness of the model was checked by looking at plots of the residuals versus all variables and the normality of the residuals were verified with normality plots of the residuals versus the predicted values of the regression model. The "SAS" statistical package was used to perform a multiple linear test on the data with the "proc reg" procedure. "Proc reg" uses the method of least squares to find the linear model that best fits the data. The linear model was of the form

$$y = B_0 + B_1 x_1 + B_2 x_2 + \ldots + B_{p-1} x_{p-1}$$

where

y = the dependent variables

x_i = the independent variables

B_i = the coefficients of the linear regression model

The full model F-statistic value was compared it to the critical value for the given model at a level of significance of 95 percent. The critical value is $F(1-\alpha, p-1, n-p)$ where $1-\alpha$ is the level of significance, p is the number of variables in the model (dependent and independent), and n is the sample size.

The null hypothesis was that all B_i's equal zero and the alternate hypothesis was that not all B_i's equal to zero:

H_0: $B_1 = B_2 = \ldots = B_{p-1} = 0$ (null hypothesis)

H_a: not all $B_i = 0$ (alternate hypothesis)

If the critical value is less than the F-statistic value then the alternate hypothesis cannot be rejected at the given level of significance.

The plots of each independent variable against failures were examined to see if any common non-linear functions (i.e., logarithmic, exponential, quadratic,etc.) could be applied to the independent variable to make the plots more linear. Transformations were applied to those variables which appeared transformable and examined the value of the coefficient of determination (r^2) value to see if the r^2 of the transformed variable was greater than that of the original variable. The coefficient of determination is a measure of how well the variation in the dependent variable is associated with the independent variables (9:97). The values of r^2 range from zero to 1; the closer r^2 is to one the greater the linear association between the independent variables and the dependent variable (9:97).

Again regression analysis was performed on the new (transformed) models using the "proc stepwise" procedure. "Proc stepwise" uses the F-statistic's value to add and remove variables from the model to achieve the model that best represents the data. This is done by checking if the reduced model's F-statistic value is greater than its critical value. For example, if "proc stepwise" has already selected three out of four variables to include in a model it then would examine the model fit if the fourth variable (Z) were added. "Proc stepwise" would test the hypothesis that the model omitting Z is better than the model including Z given the other three variables were already in the model. Any variables left in the final model have B_i's not equal to zero. The variables that were significant with "proc stepwise" were used to calculate the DRs for that subsystem unless they contained dependent variables.

Prior to using these models to calculate the DRs the correlation matrix was examined to determine if all the independent variables were independent of each other. The variables were dependent if the value of the correlation coefficient is close to one. The correlation coefficient ranges from zero to one and All models containing dependent independent variables in it were further investigated to determine which variable to delete from the model. The F-statistic values of the regression models with each of the dependent variables in it were calculated using the "proc reg" procedure. The model with the largest F-statistic value was used to calculate the DR for that subsystem.

WRSK Generation

Because the Boeing data were broken down by subsystem not by LRU, a method to transform the subsystem DRs to LRU DRs. The demand for each LRU was based on the DR derived for its subsystem and the percent of the item in the C-130 WRSK (kit serial number 0C130E0Q1600) obtained from HQ AFLC. For example, assume there are two LRUs (A and B) in a WRSK associated with subsystem X and the quantity of A and B in the WRSK are three and one, respectively. If the DR for subsystem X is 40 per flying hour, then the DR for A is 30 per flying hour (40 x 3/4) and the DR for B is 10 per flying hour (40 x 1/4). This type of calculation was done to determine the DR for each LRU in the D029 WRSK. The LRU DR was then rounded to the nearest integer to determine the number of items to put in my WRSK. The rounded DR, less any available asset from maintenance for the support period, will be the conventional WRSK. No assets are assumed available from maintenance therefore the rounded DR value was the spare level in the conventional kit.

A marginal analysis was then done on the conventional WRSK. Marginal analysis is an iterative process that evaluates how both the expected parts shortages (E(SDO)) and the expected number of not mission capable aircraft (E(NMC)) are reduced for each dollar spent for an additional spare. The goals for E(SDO) and E(NMC) were specified in the WRSK as 0.00 and 2.67, respectively. The marginal analysis was accomplished with a Pascal program (Appendix D) which iteratively added the items to the original kit which provide the greatest reduction of a combination of E(SDO) and E(NMC) aircraft for the dollar spent until the E(SDO) and E(NMC) goals were met. D029 does not use a budgetary constraint for this portion of the analysis.

The D029 assumed all demands follow a Poisson distribution and depend on aircraft flying hours: the DR computed by dividing total failures by total flying hours. But the DR calculated in this research effort are based on regression equations and consider the number of flying hours required for the given scenario. The use of flying hour equivalents is necessary because demands are input into Dyna-METRIC as demands per flying hours. The number of flying hours used are the projected utilization sorties upon which the D029 WRSK was built (1).

The performance of the WRSK generated using the marginal analysis program was compared against the WRSK created by D029 using peacetime demand data extrapolated to wartime.

Comparison

The two WRSKs calculated by the D029 and by the above methodology will be assessed with Dyna-METRIC. Both WSRKs were were input into Dyna-METRIC and ran using a scenario that does not favor either WRSK. The Dyna-METRIC model was run in the full cannibalization mode for this analysis. The availablity of the C-130 will be compared as well as the items in the WRSK that may impact aircraft availability significantly.

Scenario. Forward bases are resupplied by a fleet of 16 C-130s from one base. The C-130s use only WRSK spares for the entire conflict (30 days). The C-130 will fly out to a forward base and back to main base (sortie) with an average sortie length of two hours. This may not be similar to the mission the C-130s currently fly, because they were used as TAC resources in Viet Nam and may not be used by MAC in this method in future wars. The general combat environment was assumed comparable to the level of combat in SEA from 1965 to 1975, but updated to portray present operational, logistical, and technological conditions (9:19). No adjustment factor was used to translate C-130 performance to current time since the C-130 is still in service. No spares for the C-130s will be flown in during the conflict. The aircraft will fly a total of 64 hours per day for the entire conflict. This scenario was reviewed by HQ AFLC/AT (Assessment).

Summary

Data describing failures of items by subsystem were collected by the Boeing Aerospace Company from SEA and put into a data base. The purpose of this data base was to investigate the relationship between failures and other factors such as weather, flying hours, sortie rates, number of landings, etc. Linear regression analysis was performed on the data pertaining to the C-130 aircraft to determine what factors other than flying hours had a significant impact on DRs. The significant variables of this analysis were used to derive the DR for each aircraft subsystem. The DR for the subsystems were apportioned to the LRUs in each subsystem to calculate the DR of each LRU. These LRU DRs were used to stock a conventional WRSK with spares levels equal to the monthly DR for each LRU rounded to the nearest integer. Marginal analysis was performed on the conventional WRSK to find out which items decreased the E(SDO) and E(NMC) aircraft to meet predetermined E(SDO) and E(NMC) goals. This WRSK was compared with a D029 WRSK using the Dyna-METRIC model. A common scenario was used for input into Dyna-METRIC to compare the two WRSKs. Chapter IV contains a discussion of the results of the regression analysis and comparison of the two WRSKs.

IV. Findings

Introduction

The results of the regression analysis, the marginal analysis, and Dyna-METRIC runs are discussed in this chapter. First, the final regression models obtained from the "proc stepwise" procedure are described as well as pertinent statistical data on all models. Second, the results of the marginal analysis performed on the WSRK generated from the regression analysis are identified. Finally the output from the Dyna-METRIC runs is discussed.

Regression Analysis

Initially all bases in Viet Nam that had data available were used in the regression analysis. This resulted in 33 data points from 3 bases (Tan Son Nhut, Cam Ranh Bay, and Da Nang) collected in 1971 and 1972. The F-statistic values for all models were greater than the critical value but the R^2 values (r^2 for multiple regression) indicated that the variation in the number of failures was due more to the error term than to the independent variables used in the models.

Instead of attempting to improve these models by transforming the variables, I examined the effect of the base and year the data were collected on the model by analysis of variance using the "proc glm" procedure. The output from "proc glm" indicated the base had a significant effect on the model's predictive capability. When the means of the number of failures by base were compared using a statistical test for the equivalence of the means (Scheffe test), the means were not equal. The values in the correlation matrix also showed the number of landings, number of sorties, flying hours, and number of aircraft were dependent on each other (see Table II).

Table II

Correlation Matrix (3 Base Model)

	Time	Sort	Sortt	Land	Planes
Time	1.00	-0.18	0.21	-0.18	-0.04
Sort		1.00	-0.91	1.00	0.81
Sortt			1.00	0.91	0.80
Land				1.00	0.80
Planes					1.00

Key: Time = average sortie length (sortt/sort)
Sort = number of sorties
Sortt = total flying hours
Land = number of landings
Planes = number of aircraft

To negate the base affect the data from two bases were deleted from the sample data. The regression analysis was completed with the remaining base (Tan Son Nhut). Table III shows the initial F-statistic values obtained for each subsystem using this base. All regression analysis was done with $\alpha = 0.05$. The critical value for each model was [illegible] is the number of variables in the model [illegible].

Table III

Initial Subsystem F-statistic Values

Subsystem	F-statistic *
Airframe	17.00
Interior Fittings	6.72
Landing Gear	11.85
Flight Controls	12.60
Turboprop Power	12.55
Auxillary Power	8.73
Hydraulic Prop	13.97
Environmental Control	7.59
Electric Power	5.74
Hydraulics	8.85
Fuel	16.44
Oxygen	8.64
Miscellaneous	7.98
Instruments	14.23
Autopilot	14.94
HF Communications	3.67
VHF Communications	5.29
UHF Communications	6.85
Interphone Communications	17.98
IFF/SIF	3.02
Emergency Communications	2.87
Miscellaneous Communications	0.07
Radio Navigation	11.56
Radar Navigation	19.21

* the critical value for all subsystem models was 2.93

The initial single base regression model had five independent variables: flying hours, sorties, average sortie length, aircraft, and landings. All subsystem linear models had F-statistic values that were greater than the critical value except for Emergency Equipment, Miscellaneous Communications, and HF Communications subsystems. The low R^2s of these models also indicated most of the estimation of failures was in the error term and not in the model variables.

The plots of the failures versus the independent variable showed potential transformations for the independent variable were the logarithm, the square root or the reciprocal. The r^2 value of the transformed independent variables were compared to that of the nontransformed independent variable. If a transformed variable had a greater r^2 value than the nontransformed variable it replaced the nontransformed variable in the regression model. In all instances the reciprocal of the number of flight hours and the reciprocal of the average sortie length had greater r^2 values than the number of flight hours and the average sortie length respectively.

The models with the transformed variables were run again using the "proc stepwise" procedure. The models used to calculate the demand rates are listed in Appendix B. The variables present in a majority of the models used were the reciprocal of the number of flight hours, the number of aircraft, and the reciprocal of the average sortie length. The number of landings was only significant in the Landing Gear subsystem model. All models failed to reject the alternate hypothesis (not all B_i's equal zero) except the Miscellaneous Communications subsystem.

The values in the correlation matrix indicated there was a very high correlation (dependence) between the number of sorties and the number of landings (see Table IV). This result was expected since cargo aircraft typically takeoff and land once per sortie. Therefore any regression models in which both landings and sorties were present had to be investigated further to eliminate the least significant variable.

Table IV

Correlation Matrix (1 Base Model)

	T2	Sort	S2	Land	Planes
T2	1.00	0.41	0.28	0.42	0.45
Sort		1.00	-0.71	1.00	0.68
S2			1.00	-0.71	-0.26
Land				1.00	0.67
Planes					1.00

Key: T2 = 1/(average sortie length)
Sort = number of sorties
S2 = 1/(total flying hours)
Land = number of landings
Planes = number of aircraft

Table V depicts the F-statistic and associated critical value for each subsystem as well as the R^2 value and subsystem demand rate calculated from the linear regression model equations. All regression models had F-statistic values greater than the corresponding critical value except the model of the Miscellaneous Communications subsystem. This implies the null hypothesis (all B_i's are equal to zero) cannot be rejected for this subsystems. The mean number of failures were used as an estimate of the demand rate for the Miscellaneous Communications subsystem.

Table V

Final Model

Subsystem	F-statistic	Critical value	R^2
Airframe	45.64	3.49	0.82
Interior Fittings	25.15	3.49	0.75
Landing Gear	26.66	3.13	0.81
Flight Controls	19.74	3.49	0.66
Turboprop Power	68.56	3.13	0.92
Auxillary Power	30.73	3.49	0.75
Hydraulic Prop	46.40	3.13	0.88
Environmental Control	12.57	3.49	0.56
Electric Power	14.79	3.49	0.60
Hydraulics	31.23	3.49	0.76
Fuel	44.70	3.49	0.82
Oxygen	25.77	3.49	0.72
Miscellaneous	19.42	3.49	0.66
Instruments	56.33	3.13	0.90
Autopilot	51.69	3.49	0.84
HF Communications	9.24	3.49	0.48
VHF Communications	13.19	3.49	0.57
UHF Communications	9.45	3.49	0.49
Interphone Communications	25.31	3.49	0.72
IFF/SIF	14.00	4.33	0.40
Emergency Communications	6.62	3.49	0.40
Miscellaneous Communications*	0.07	2.93	0.04
Radio Navigation	28.00	3.49	0.74
Radar Navigation	66.95	3.13	0.91

*failed to reject the null hypothesis (all β_i's equal zero)

The subsystem demand rates were apportioned to the LRU's under each subsystem to derive the LRU demand rates. A conventional WRSK was created by rounding the LRU demand rates to the nearest integer. The subsystem demand rates calculated from the regression equations, for the Airframe and Interior Fittings subsystems were deemed unrealistic because they were much greater than those in the D029 WRSK and due to the nature of the subsystems it is not possible for the demand rates or spares levels to be that high for the few LRUs under these subsystems. The demand rates and spares levels in the D029

WRSK were used instead of the generated demand rates and spares levels. Appendix C contains the subsystem and LRU DRs for the conventional WRSK.

Marginal analysis was performed on this WRSK to achieve predetermined goals for expected shortages (E(SDO)) and not mission capable (E(NMC)) aircraft.

Marginal Analysis Results

The initial run of the marginal analysis program resulted in an E(SDO) and E(NMC) of 0.00 and 2.67, respectively. These values were equal to the goals specified on the D029 WRSK; therefore no changes were made to the conventional WRSK. The conventional WRSK was used as the generated WRSK ($WRSK_g$) and was compared against the D029 WRSK with Dyna-METRIC. The demand per flying hour (DFH) for each LRU was calculated from the monthly DR using the following equation

$$DFH = DR \div (\text{total flying hours} \times \text{quantity per application})$$

The typical demand per flying hour is of the magnitude 10^{-4}. The comparison of the $WRSK_g$ and the D029 WRSK by subsystem revealed the following as far as differences in demand rates (DR) and spares levels (SLs). There is no difference between the DRs and SLs for the Airframe and Interior Fittings subsystems because the D029 WRSK DRs and SLs were used instead of the DRs and SLs calculated from the regression equations. All but four of $WRSK_g$ subsystems had LRU DRs that, on the average, exceeded the LRU DRs in the D029 WRSK. The four subsystems that had LRU DRs that were less than the D029 WRSK LRU DRs were as follows: Hydraulic Propeller, HF Communications, and Miscellaneous Communications. Table VI illustrates the mean and standard deviation (sd) of the difference between $WRSK_a$ LRU DRs and the D029 WRSK LRU DRs by subsystem.

Table VI

Difference Between $WRSK_a$ and D029 WRSK Subsystem DR and SL

Subsystem	Difference DR		Difference SL	
	mean	sd	mean	sd
Airframe	*			
Interior Fittings	*			
Landing Gear	5.67	3.45	0.44	0.87
Flight Controls	4.64	1.91	0.18	0.40
Turboprop Power	3.18	2.67	1.29	0.82
Auxiliary Power	5.14	1.21	0.00	0.53
Hydraulic Prop	-0.40	1.30	-2.47	1.55
Environmental Control	10.24	5.31	1.48	0.98
Electric Power	1.30	1.64	-1.30	0.67
Hydraulics	8.88	6.94	2.88	1.96
Fuel	2.43	4.43	-1.43	0.36
Oxygen	4.67	4.04	-1.67	0.58
Miscellaneous	5.00	2.83	4.50	2.12
Instruments	-0.14	8.50	-2.21	1.37
Autopilot	-1.06	7.24	3.00	1.57
HF Communications	-11.50	10.25	-5.75	4.27
VHF Communications	16.50	2.12	-0.50	0.71
UHF Communications	21.33	16.26	6.00	5.29
Interphone Communications	8.25	3.50	5.00	2.58
IFF/SIF	46.50	16.26	6.00	0.71
Emergency Communications	5.00	0.00	0.00	0.00
Miscellaneous Communications	-2.50	1.00	0.00	0.00
Radio Navigation	7.70	9.42	1.32	1.06
Radar Navigation	[illegible]	[illegible]	[illegible]	[illegible]

* D029 WRSK [illegible]

All but eight of $WRSK_g$ subsystems has LRU DRs that, on the average, exceeded the LRU DRs in the D029 WRSK. The eight subsystems that had LRU DRs that were less than the D029 WRSK LRU DRs were as follows: Hydraulic Propeller, Electrical Power, Fuel, Oxygen, Instruments, Autopilot, HF Communications, and Radar Naviagation. Table VI also illustrates the mean and standard deviation of the difference between $WRSK_g$ LRU SLs and the D029 WRSK LRU SLs by subsystem.

Dyna-METRIC Results.

Initially two Dyna-METRIC runs were made. The first with the D029 WRSK and the second with the WRSK derived from wartime demands and the marginal analysis program. The problem with this approach was it does not provide a valid means of comparing the two WRSKs because the only factor equal in both runs was the scenario: the DRs and SLs were not equal. Therefore, in order to determine which factors were responsible for any difference between the D029 WRSK and the generated WRSK ($WRSK_g$) an additional Dyna-METRIC run was performed. In this third run the demand rates from $WRSK_g$ were used in conjunction with the spares levels used in the D029 WRSK to from a composite WRSK ($WRSK_c$). A fourth run could have been performed with a second composite WRSK, that contained the D029 WRSK DRs and $WRSK_g$ SLs, but because it would have served the same purpose as the third run it was not done.

The E(NMC) that result form the Dyna-METRIC runs with the three WRSKs are listed in Table VII. The D029 WRSK has less NMC aircraft at the end of the conflict than either WRSK or WRSK .

Table VII

Expected Not Mission Capable Aircraft

	WRSK		
Day	D029	WRSK	WRSK
3	1.2	3.1	3.2
10	1.8	3.7	4.8
15	2.7	5.0	6.7
25	5.4	9.1	10.8
30	7.2	11.4	12.7

Summary

When linear regression techniques were used to analyze subsystem demand rates for the three bases, the base where the data were collected affected the capability of the models to estimate the number of failures. To handle this problem only the data from a single base (Tan Son Nhut) were used. The regression models resulting from the single base data were better able to predict the number of failures.

The subsystem demand rates were apportioned to the LRUs under the subsystem to calculate LRU demand rates. The LRU demand rates were rounded to the nearest integer and used as the initial spare level for the conventional WRSK. The DRs calculated for the LRUs under the Airframe and Interior Fittings subsystems were not deemed realistic and disregarded. The D029 WRSK DRs and SLs were used in place of the calculated

DRs and SLs. Marginal analysis was then done on the conventional WRSK to meet a goal of 0.00 for E(SDO) and 2.67 for E(NMC). The calculated E(SDO) and E(NMC) values were equal to the goal values therefore no changes were made to LRU spare levels in the conventional WRSK.

The Dyna-METRIC runs indicated the D029 WRSK had an E(NMC) of 7.2 and WRSK$_G$ had an E(NMC) of 11.4 at the end of 30 days. Because the only factor in the two Dyna-METRIC runs that was the same was the scenario, another run was made using a composite WRSK (WRSK$_C$). WRSK$_C$ consisted of the demand rates from the generated WRSK (WRSK$_G$) and the spares levels from the D029 WRSK. The purpose of the final Dyna-METRIC run was to provide a basis for evaluating the differences between DR and SL of WRSK and the D029 WRSK. The E(NMC) for WRSK$_C$ at the end of the conflict was 12.7. The conclusions drawn from these findings are discussed in the next and final chapter.

V. Conclusions and Recommendations

Introduction

This chapter contains the conclusions drawn from the findings in the previous chapter. The conclusions reached apply to the following aspects of the analysis: regression analysis, marginal analysis, and Dyna-METRIC analysis. The final topic discussed in this chapter are my recommendations.

Regression Analysis

The base where the data were collected had a significant statistical effect on the linear regression model's capability to predict the number of failures based on the number of sorties, average sortie length, total flying hours, number of landings, and number of aircraft. When the data from one base was used to model the number of failures, the effect of the base on the model was not a factor in the regression and the statistical models were significant. The subsystem models resulting from the single base data all rejected the null hypothesis (all B_i's equal zero) except for the Miscellaneous Communciations subsystem model. Therefore, if the data from more than one base are used as a data base for predicting DRs the base effect is likely to affect the statistical test results.

The data collected at a single base were able to [illegible] the demand [illegible] them for several subsystem [illegible]. The following subsystems had models which provides good estimates of the number of failures:

Autopilot, Airframe, Fuel, Instruments, Landing Gear, Hydraulic Propellers, Radar Navigation, and Turbopropeller. The following subsystems had models which were not very good for predicting the number of failures: UHF Communications, Miscellaneous Communications, IFF/SIF, HF Communications, and Emergency Communications. No communications subsystems were modeled well by a linear regression of failures with flying hours, sortie length, average sortie length, landings or aircraft. Therefore, the use of any of the five variables chosen does not accurately measure the DR for any of the communications subsystems.

The use of regression is very time consuming and would require considerable judgement concerning the variables which are significant and the correct model to use. The use of total number of failures divided by the total number of flying hours is simpler to use and the current method for evaluating the WRSK is set up to use the number of demands per flying hour as an input.

WRSK Generation

The DRs calculated for the Airframe and Interior Fittings subsystems were not used because when the subsystem DRs were apportioned to the LRUs to calculate the LRU DRs, the resulting LRU demand rates were much higher. This may be due to there being more items considered under this subsystem then those items listed in the D029 WRSK. Attempting to derive DRs for LRUs when the DRs are collected by subsystem may not work well unless the LRU failures in the subsystem are independent, the number of failures captures the number of LRUs under the subsystem, and the LRUs fail in proportion to their number in the subsystem.

Marginal Analysis

Marginal analysis did not affect the composition of the WRSK because the conventional WRSK created met the predetermined E(SDO) and E(NMC) goals. Marginal analysis is useful if there is a monetary constraint associated with the improvement function. Otherwise you could build a large kit that meets your E(SDO) and E(NMC) goals but is very costly. Marginal analysis also needs to incorporate constraints regarding size and weight to be more realistic. Only a limited amount of equipment and resources can be deployed with an organization. If the spares in the WRSK take up too much space other combat equipment cannot be deployed.

The comparison of WRSK$_a$ and the D029 WRSK subsystem DRs indicated that all WRSK$_a$ subsystems except Hydraulic Propeller, HF Communications, and Miscellaneous Communications had DRs that were equal to or greater than those in the D029 WRSK. The WRSK$_a$ subsystem SLs were equal to or greater than to the D029 WRSK subsystem SLs in all but the Hydraulic Propeller, Electrical Power, Oxygen, Instruments, Autopilot, HF Communications, and Radar Navigation subsystems. This implies the subsystem DRs of WRSK$_a$ are significantly greater than the subsystem DRs of the D029 WRSK while the SLs in the WRSK$_a$ are only slightly greater than the subsystem SLs in the D029 WRSK.

Dyna-METRIC

The factor used to adjust the peacetime DRs to wartime DR cannot be accepted as valid. The estimate of E(SDO) and E(NMC) at the end of 30 days was greater for the D029 WRSK than $WRSK_a$ or the $WRSK_b$. $WRSK_c$ consisted of $WRSK_a$'s demand rates and the D029 WRSK's SLs. $WRSK_a$ and $WRSK_b$ were closer in their performance than the performance of the D029 WRSK. The SLs were the only factor that was different between the $WRSK_a$ and $WRSK_c$. Therefore, the SLs in $WRSK_a$ do a better job of fulfilling the demands incurred during a conflict than the SLs in the D029 WRSK.

The D029 WRSK also performs better than the $WRSK_c$, almost twice as well. The factor that is different between the D029 WRSK and $WRSK_c$ is the DRs. This implies the DRs in $WRSK_c$ are higher than those in the D029 WRSK. Because the DRs in $WRSK_c$ are equivalent to the DRs in $WRSK_a$, the DRs in $WRSK_a$ are greater than those in the D029 WRSK.

For the particular scenario used in this thesis, the DRs are the overriding factor because in both cases when $WRSK_a$'s DRs are used the D029 WRSK does approximately twice as well as the WRSK using $WRSK_a$ DRs. The current methodology's estimate of the LRU DRs is lower than the estimate of LRU DRs using linear regression; although the difference between the two WRSK's LRU SLs are closer though not equal.

Recommendations

Further analysis should be done using LRU DRs derived from wartime data to investigate if the adjustment factor is truly too low. A comparison of the D029 WRSK and WRSK$_4$ indicated the DRs in WRSK$_4$ are greater than those used in the D029 WRSK. But several problem areas make it difficult for these findings to be 100 percent valid. Two of the most significant ones are the method used to evaluate the two WRSKs and the form of the data used.

The Dyna-METRIC model used to evaluate the two WRSKs used demand per flying hour as the input and basis for determining expected not mission capable aircraft. A better means of comparing the two WRSKs would be to develop a model that performed operations and provided outputs similar to those in Dyna-METRIC but determined them by evaluating the factors which are relevant to determining the DRs for the particular LRU. Because no such model exists, another approach to the research problem be to calculate the DRs using the current methodology (D029) but use actual wartime failure data.

The second area of concern was the form of the SEA data. The data were aggregated by subsystem: all LRU failures was assigned to the subsystem the LRU was under. This type of maintenance data is not useful unless you are attempting to define the subsystem DR to evaluate the weapon system reliability. In this case the failure of each LRU will cause the weapon system to be NMC. Dyna-METRIC could then be used [illegible] assessment mode to derive the [illegible] for each subsystem [illegible] model developed by [illegible] could be used to analyze weapon system reliability. Also a marginal analysis was done to achieve the D029 WRSK. The SLs in the D029 WRSK are therefore greater than or equal to those calculated in the conventional D029 WRSK, using the rounded value of the DRs. The fraction of the failures that are caused by a particular LRU may be altered by the change in the spare level that resulted from the marginal analysis.

The above areas of concern had the most impact on the acceptance of the conclusions of this thesis, but there are two other issues that had a lesser impact on the acceptance of the conclusions drawn. These two issues are the use of all the linear regression model to calculate DRs and the scenario chosen.

Not all the regression models used to derive DRs at the subsystem level provide good estimates of the number of failures. Regression models based on the five variables used in this analysis should not be used to derive DRs for communications spares. Based on the regression analysis done in this research effort none of the five independent variables used to predict failures of communications subsystem yielded a good model. If regression analysis is used to model failures in these subsystems, other variables which effect failures must be found and collected.

The final issue is how well can the level of conflict be determined for a future conflict. Although the single scenario used was approved, more Dyna-METRIC runs could have been made at a range of flying hour programs to perform a sensitivity analysis or develop a response surface for the performance of each WRSK over a range of conflict levels. Also, in a real world conflict spares will be made available before the end of the conflict and maintenance capability will also increase the number of spares available by repairing those LRUs that are reparable in the field.

Appendix A

SEA Data

SEA DATA CASE MAP

		MONTH											
YEAR	BASE	J	F	M	A	M	J	J	A	S	O	N	D
1971	CAM RANH BAY	*	*	*	*	*	*	*	*	*	*	*	*
	DA NANG	*	*							*	*	*	
	TAN SON NHUT	*	*	*	*	*	*	*	*	*	*	*	*
1972	CAM RANH BAY	*	*										
	DA NANG				*	*	*						
	TAN SON NHUT	*	*	*	*	*	*	*	*	*	*	*	

* Indicate date were available in this month

F4C AIRCRAFT
SEA COMBAT THEATER
VIETNAM
CAM RANH BAY AIR BASE
JUNE
1966
RECORD TYPE
RECORD TYPE SEQUENCE NUMBER

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AAAB0666 A01          666    4546    2474    2474  73        1.8                       3
AAAB0666 B0101GROUND HANDLING          .0        .0      38.9        .0      .0
AAAB0666 B0202AIRCRAFT CLEANING        .0        .0       4.2        .0      .0
AAAB0666 B0303"LOOK" PHASE OF INS      .0        .0    3090.4        .0      .0
AAAB0666 B0404SPECIAL INSPECTION       .0        .0     626.7        .0      .0
AAAB0666 B0506GROUND SAFETY            .0        .0      18.0        .0      .0
AAAB0666 B0607PREP. MAINT. RECORD      .0        .0        .7        .0      .0
AAAB0666 B0708SPECIAL WEAPON HAND      .0        .0        .4        .0      .0
AAAB0666 B0809SHOP SUPPORT GEN         .0        .0        .2        .0      .0
AAAB0666 B0911AIRFRAME              220.4     258.7    1335.8        .0     1.1
AAAB0666 B1012FSLG COMPARTMENTS     121.0      36.5     419.6        .4      .9
AAAB0666 B1113LANDING GEAR           44.2      72.8     438.2       1.8     3.1
AAAB0666 B1214FLIGHT CONTROLS        31.7      81.4     716.7      80.1     2.0
AAAB0666 B1323TURBO FAN PWR PLTB     22.0      91.9     768.4      10.0     3.3
AAAB0666 B1441AIR COND. ANTI-ICE     14.7      18.5     127.7       1.9      .9
AAAB0666 B1542ELECT POWER SUPPLY      8.8      10.3     106.0       3.0      .2
AAAB0666 B1644LIGHTING SYSTEMS        7.3      17.2      39.7       1.4      .0
AAAB0666 B1745HYD/PNEU PWR SUP       40.9      35.2     216.5       1.8     1.8
AAAB0666 B1846FUEL SYSTEM             8.6      24.2     241.1      32.5     1.8
AAAB0666 B1947OXYGEN SYSTEM           2.8       9.0      21.3       1.2      .2
AAAB0666 B2049MISC UTILITIES          1.8       1.1      14.3        .2      .4
AAAB0666 B2151INSTRUMENTS, GEN        2.4      37.6      76.9        .6      .0
AAAB0666 B2252AUTOPILOT              11.6       9.9     153.7      38.7      .4
AAAB0666 B2361HF COMM SYSTEMS          .0        .2        .2        .0      .0
AAAB0666 B2471RADIO NAVIGATION       15.8      33.7     221.2        .0      .4
AAAB0666 B2572RADAR NAVIGATION         .0       1.1       5.5        .8      .0
AAAB0666 B2673BOMBING NAVIGATION      5.3       5.7      61.9        .0      .0
AAAB0666 B2774FIRE CONTROL           23.8     112.6     484.9       3.1      .0
AAAB0666 B2875WEAPONS DELIVERY       15.0      14.7     150.8      21.4      .2
AAAB0666 B2976ELECT COUNTER MEAS       .0        .6      11.7        .0      .0
AAAB0666 33077PHOTO/RECON              .6       1.5       2.7        .0      .0
AAAB0666 B3191EMERGENCY EQUIP         5.7       2.2       7.0        .0      .0
AAAB0666 B3293DRAG CHUTE EQUIP        2.0      10.3      14.0        .2      .0
AAAB0666 B3396PERSONNEL EQUIP         1.5        .6       2.6        .0      .0
AAAB0666 B3497EXPLOSIVE DEVICES       1.5        .0      17.0        .0      .0
AAAB0666 C0199TOTAL ALL SYSTEMS     609.5     887.8    9435.4     199.2    16.7
AAAB0666 D01 64-0571   8TFW  433TFS   3430  1500 10  13  03   6660601 2155  5
AAAB0666 E01D01 HE3          AAA 5 57MMSH 5
AAAB0666 F01D0111 AIRFRAME WGETC          EXPLOS 4
AAAB0666 G01D01  2 PILOT 09 INJURY 3 NOTSERI 4 PARLN03 ANKLE 04          POWR   5
AAAB0666 G02D01  2 COPILO08 INJURY 3 NOTSERI 4 PARLN03 BACK  14          POWR   5
AAAB0666 H01 00349 64-0658 061466 061566 020266 071166 00260 SHIP     CRASH
AAAB0666 I01PAF MINOR1 5052 04   L12          EMERGENCY LANDING HARD LDG 00000000
AAAB0666 J011018111 AIRFRM13 HARD LDG TOTAL AIRCRAFT    00NONE 0      00      00
AAAB0666 K01 0006  012N 109  SANDCOAST08FINMSAND28COPSE   11 001 038 007 008 100
AAAB0666 L01 102  92  78  74       27  30         7  0  6  1  0  0  5 SSW  6  26
AAAB0666 M01  2.1  2.0   0   0   6   1   0   0  82  57  74  .85   400
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Appendix B

Regression Equations

This Appendix contains the linear regression model equations used to calculate demand rates

β_0 = the intercept value

β_1 = the coefficient of 1/flying hours (1/1920)

β_2 = the coefficient of 1/average sortie length (1/2 hrs)

β_3 = the coefficient of number of sorties (960)

β_4 = the coefficient of number of landings (960)

β_5 = the coefficient of number of aircraft (16)

* indicates demand rates in D029 were used
** indicates the mean of the demands was used

AIRFRAME *

INTERIOR FITTINGS *

LANDING GEAR

β_0 = -98.6
β_2 = 391.5
β_4 = 6.0
β_5 = -0.09

FLIGHT CONTROLS

β_0 = -18.1
β_1 = 0.8
β_5 = 62363.6

TURBO PROP POWER PLANT

β_0 = -120.6
β_2 = 544.7
β_3 = -0.1
β_5 = 7.2

AUXILLARY POWER

β_0 = -38.6
β_1 = 1.2
β_5 = 83621.1

HYDRAULICS PROP

B_0 = -5.5
B_2 = 166.1
B_3 = -0.02

ENVIRONMENTAL CONTROL

B_0 = -34.2
B_1 = 91.6
B_2 = 140754.2

ELECTRICAL POWER SUPPLY

B_0 = -12.6
B_1 = 0.5
B_5 = 42987.7

HYDRAULICS

B_0 = -5.5
B_2 = 166.3
B_3 = -0.02

FUEL

B_0 = -39.6
B_1 = 132966.5
B_5 = 1.3

OXYGEN

B_0 = 1.7
B_2 = 17.5
B_4 = -0.0

MISCELLANEOUS

B_0 = -13.8
B_1 = 38545.7
B_5 = 0.5

INSTRUMENTS

B_0 = -29.5
B_2 = [illegible]
B_3 = -0.04
B_4 = 2.2

AUTOPILOT

B_0 = -82.2
B_1 = 205333.1
B_2 = 2.3

HF COMMUNICATIONS

B_0 = -11.6
B_1 = 223489.9
B_2 = 0.4

VHF COMMUNICATIONS

B_0 = -5.4
B_1 = 15.5
B2 = 19448.2

UHF COMMUNICATIONS

B_0 = -14.8
B_1 = 68943.9
B_2 = 0.9

INTERPHONE

B_0 = -49.7
B_1 = 113170.8
B_2 = 1.9

IFF/SIF

B_0 = 3.4
B_1 = 33771.9

EMERGENCY COMMUNICATIONS

B_0 = -0.18
B_2 = 2.8
B_3 = 0.00

MISCELLANEOUS

β_0 = -13.8
β_1 = 38545.7
β_4 = 0.5

RADIO NAVIGATION

β_0 = -45.9
β_1 = 206713.1
β_2 = 98.7

RADAR NAVIGATION

β_0 = -109.7
β_2 = 483.8
β_3 = -0.1
β_4 = 8.5

Appendix C

WRSK

(*) indicates the demand rates and quantity of the D029 WRS* were used instead of the demand rates calculated with the linear regression model

WUC	SUBSYSTEM	Demand/FH D029/WRS* (10^-4)	qty	qpa	cost	failure rate
11	AIRFRAME					
1129M			2(*)	2	4851.00	28.52
11321			1(*)	1	76421.88	14.26
1142M			1(*)	1	21592.26	14.26
12	INTERIOR FITTINGS					
12616			1(*)	1	617.65	5.03
12618			6(*)	2	11943.88	30.20
12840			11(*)	11	923.90	55.36
13	LANDING GEAR					
1311M		1(6)	2(2)	2	1455.00	2.20
13111		2(6)	1(1)	1	29046.00	1.10
13111		0(1)	1(1)	4	5738.13	1.10
1321F		2(6)	1(1)	1	2935.50	1.10
1342A		6(12)	4(4)	2	2377.29	4.40
1342B		1(1)	1(1)	4	6926.75	1.10
1342C		7(12)	8(9)	4	4921.39	8.81
1342D		5(16)	11(12)	4	275.80	12.11
1343A		0(1)	3(3)	1	2338.10	3.30
1343C		0(1)	1(1)	4	1152.57	1.10
1343F		0(1)	1(1)	4	392.43	1.10
1343G		2(6)	1(1)	1	402.73	1.10
13434		4(11)	2(2)	1	757.05	2.20
13522		9(17)	3(3)	1	660.23	3.30
13712		19(29)	10(11)	2	1557.96	11.01
13711		21(29)	20(22)	4	4341.12	22.02
13721		21(30)	20(22)	4	605.64	22.02
13722		19(29)	10(11)	2	218.36	11.01
14	FLIGHT CONTROLS					
1413K		7(12)	2(2)	1	11994.35	2.31
14141		3(6)	1(1)	1	3327.75	1.16
14233		4(6)	1(1)	1	13338.50	1.16
1424E		10(18)	3(3)	1	5757.70	3.47
14336		2(6)	1(1)	1	914.64	1.16
14341		5(12)	2(2)	1	3166.22	2.31
14414		3(6)	1(1)	1	3914.00	1.16
14411		4(8)	5(6)	4	1564.14	5.76
14412		1(8)	5(6)	4	3242.84	5.78
144[illegible]		2(6)	1(1)	1	705.55	1.16
144[illegible]		2(6)	1(1)	1	1936.46	1.16

22	TURBO PROP	demand	qty	qpa	cost	failure rate
22AAM		3(5)	3(4)	4	1556.04	3.75
22DAA		5(2)	1(1)	4	2160.00	1.25
22DAE		1(2)	2(3)	8	175.29	2.50
[illegible]		3(7)	4(5)	4	2655.30	5.00
22EBA		3(7)	3(4)	4	3045.71	3.75
22EBD		14(16)	10(12)	4	5065.00	12.49
22FAA		10(16)	10(12)	4	2667.70	12.49
22FAC		5(10)	6(8)	4	3709.03	7.50
226BE		13(16)	10(12)	4	3348.00	12.49
226CA		11(20)	12(15)	4	915.67	15.00
226DA		2(11)	6(8)	4	447.85	7.50
22120		1(5)	3(4)	4	1863.14	3.75
2213A		1(3)	2(3)	4	1256.95	2.50
22141		6(13)	8(10)	4	2686.30	10.00
22144		6(7)	4(5)	4	3585.73	5.00
22154		7(7)	1(1)	1	129.00	1.25
22333		2(5)	3(4)	4	2262.08	3.75
2251E		4(7)	4(5)	4	26942.77	5.00
2251F		4(11)	7(9)	4	218.64	8.75
22511		1(2)	1(1)	4	8567.11	1.25
22517		4(3)	2(3)	4	5023.78	2.50
2253A		3(7)	4(5)	4	1686.11	5.00
22532		3(3)	2(3)	4	9865.56	2.50
22533		1(3)	2(3)	4	1796.16	2.50
22534		0(0)	1(1)	4	700.00	1.25
22536		2(10)	6(8)	4	659.20	7.50
22681		1(5)	3(4)	4	1233.44	3.75

24	AUXILLARY POWER					
24AED		21(30)	7(6)	1	2163.00	6.04
2414E		6(13)	3(3)	1	2946.32	2.59
2414K		9(13)	3(3)	1	614.91	2.59
24142		9(13)	3(3)	1	1884.90	2.59
2415E		17(23)	5(4)	1	2410.20	4.32
2421S		9(13)	3(3)	1	49955.00	2.59
24216		9(13)	2(2)	1	3522.60	1.73
243AA		3(9)	2(2)	1	953.78	1.73

32	HYDRAULICS PROP					
3251R		5(4)	6(3)	4	3234.00	3.18
3251S		4(3)	5(3)	4	1115.99	2.65
32517		6(4)	12(6)	8	1254.20	6.36
3251V		5(4)	6(3)	4	4082.92	[illegible]
[illegible]		4(3)	5(3)	4	1230.62	2.65
32511		4(3)	5(3)	4	80134.00	2.65
32520		6(5)	7(4)	4	573.91	3.71
3252E		4(3)	5(3)	4	30165.61	2.65
3252C		5(5)	6(3)	4	3159.00	6.36
3252F		7(6	8(4	4	16792.09	4.24

wuc	demand	qty	qpa	cost	failure rate
32536	26(25)	9(5)	1	8000.00	4.77
[illegible]	2(2)	1(1)	1	1057.26	0.53
32551	0(1)	1(1)	4	4738.00	0.53
325[illegible]	1(2)	3(2)	4	4562.66	1.59
32653	4(3)	5(3)	4	2672.65	2.65
41	**ENVIRONMENTAL CONTROL**				
41114	4(16)	2(3)	1	1980.09	3.02
41121	7(16)	2(3)	1	7016.42	3.02
41125	8(16)	2(3)	1	2090.90	3.02
41141	4(6)	1(2)	1	5671.00	1.51
41142	5(16)	2(5)	1	6751.65	3.02
41212	7(16)	2(3)	1	4603.47	3.02
41221	10(24)	3(5)	1	7975.29	4.54
41223	10(31)	4(6)	1	1914.15	6.04
41224	0(5)	2(3)	1	5118.07	3.02
41226	3(16)	2(3)	1	2290.02	3.02
41251	7(16)	2(3)	1	4599.98	3.02
41252	7(12)	3(3)	1	6773.28	4.54
41311	13(39)	5(8)	1	2331.92	7.65
41321	7(16)	2(5)	1	7364.50	3.02
41322	3(16)	2(3)	1	2435.06	3.02
41322	8(16)	2(3)	1	4986.23	3.02
41421	5(16)	2(3)	1	5027.43	3.02
41421	6(16)	2(3)	1	4808.04	3.02
41422	3(10)	5(6)	4	1753.06	7.56
41424	3(8)	6(9)	6	1970.39	9.07
41532	6(12)	3(3)	2	1824.62	4.54
42	**ELECTRICAL POWER SUPPLY**				
42124	0(3)	1(1)	1	264.90	0.62
42155	1(2)	2(1)	4	3537.00	1.23
4221C	3(2)	3(2)	4	9751.01	1.85
42212	3(3)	4(2)	5	4478.44	2.47
42213	1(3)	4(2)	5	1912.85	2.47
4222B	11(13)	4(2)	1	6712.51	2.47
42225	6(10)	3(2)	1	6281.74	1.85
4226A	7(6)	2(1)	1	1828.00	1.23
4227C	8(10)	3(2)	1	3563.80	1.85
42624	12(13)	4(2)	1	573.14	2.47
45	**HYDRAULICS**				
452A1	2(4)	1(2)	1	3119.87	1.74
452A[illegible]	1(7)	3(5)	4	[illegible]	5.23
453AF	5(5)	1(2)	2	4010.00	1.74
453AA	6(11)	5(9)	4	2683.76	8.72
453A[illegible]	14(36)	4(7)	1	15512.87	6.98
454A2	5(21)	7(12)	7	[illegible]	[illegible]
454A1	2(8)	2(3)	1	[illegible]	[illegible]

wuc		demand	qty	qpa	cost	failure rate
45636		3(12)	9(15)	7	591.20	15.70
46	FUEL					
46211		2(4)	3(3)	4	2663.40	2.73
46213		1(2)	5(5)	10	1233.22	4.54
46215		1(4)	3(3)	4	1689.20	2.73
4623B		8(2)	4(4)	11	847.00	3.63
46236		0(2)	5(5)	15	1400.00	4.54
46314		1(1)	1(1)	8	4500.00	0.91
46321		4(9)	2(2)	1	1224.48	1.82
46611		12(12)	10(9)	4	366.00	9.09
46613		23(38)	8(7)	1	775.19	7.27
46614		3(5)	4(4)	4	1571.00	3.63
46621		6(10)	4(4)	2	2113.56	3.63
46621		3(5)	2(2)	2	2134.16	1.82
46621		4(7)	3(3)	2	2146.52	2.73
46621		4(5)	2(2)	2	2200.06	1.82
47	OXYGEN					
4732F		8(12)	4(2)	1	656.11	2.43
47322		1(10)	3(2)	1	830.18	1.83
47326		15(16	5(3)	1	3051.08	3.04
49	MISCELLANEOUS					
4911E		9(12)	2(5)	2	1292.65	4.79
49128		3(7)	4(10)	5	921.85	9.58
51	INSTRUMENTS					
51111		3(3)	1(1)	1	2060.00	0.61
51113		4(6)	4(2)	2	404.94	2.46
51114K		5(6)	2(1)	1	1802.50	1.23
51136		23(21)	13(8)	2	1416.00	7.99
5114F		4(21)	4(2)	1	685.00	2.46
51143		6(10)	3(2)	1	2902.00	1.84
51145		36(16)	5(3)	1	2089.46	3.07
5182D		1(2)	7(4)	14	633.45	4.30
5182E		4(3)	2(1)	2	3193.00	1.23
51821		3(5)	3(2)	2	3270.25	1.84
51822		17(11)	7(4)	2	6757.00	4.30
51823		22(16)	10(6)	2	8806.50	6.14
51824		6(14)	9(6)	2	1545.00	5.53
51826		13(17)	6(5	2	916.64	4.91
52	AUTOPILOT					
5211M		8(11)	4(2	1	3399.00	2.05
5211N		3(2)	3(2	[illegible]	2165.00	1.56
5211V		14(14)	5(3)	1	6477.00	2.61

wuc		demand	qty	qpa	cost	failure rate
52115		11(8	3(2)	1	8076.29	1.56
52111		4(4)	13(7)	1	19776.00	6.77
52112		14(10	7(4)	1	10830.54	3.65
52113		28(22)	8(4)	1	1116.00	4.17
52115		7(11)	4(2)	1	906.40	2.08
52117		11(14)	5(3)	1	4538.00	2.61
52116		11(14)	6(3)	1	4560.50	3.13
52211		4(4)	3(2)	2	1747.91	1.56
52213		9(11)	8(4)	2	540.00	4.17
52214		6(8)	3(2)	1	414.00	1.56
52215		17(12)	9(5)	2	2469.94	4.69
52216		9(11)	8(4)	2	674.00	4.17
52311		40(14)	10(5)	2	10830.45	5.21
52312		17(14)	10(5)	2	1823.00	5.21
52320		7(12)	9(5)	2	6628.00	4.69
61	HF COMMUNICATIONS					
61122		1(0)	2(1)	2	772.90	0.46
612AE		8(3)	5(1)	2	1391.00	1.16
6121V		22(5)	9(2)	2	12736.98	2.08
61214		24(1)	14(3)	2	4450.63	3.24
62	VHF COMMUNICATION					
62BAD		11(236)	11(10)	2	5981.16	9.84
62BBD		8(26)	3(3)	1	3078.67	2.68
63	UHF COMMUNICATIONS					
63AAA		24(63)	12(24)	2	5043.91	24.11
63FAA		3(21)	4(8)	2	1565.60	8.04
63JAD		3(10)	2(4)	2	2267.03	4.02
64	INTERPHONE					
64211		1(11)	2(4)	2	439.09	4.16
64212		1(5)	6(12)	13	749.70	12.49
64213		7(7)	4(8)	6	254.87	8.33
64216		3(15)	7(15)	5	776.15	14.57
65	IFF/SIF					
65BBD		24(62)	8(12)	1	8771.00	11.97
65EAA		12(47)	6(9)	1	2075.12	6.97
66	EMERGENCY COMMUNICATIONS					
66171		0(5)	1(1)	1	6650.75	1.04

69	MISCELLANEOUS	demand	qty	qpa	cost	failure rate
69211		3(1)	1(1)	1	500.00	0.15
69212		4(1)	1(1)	1	2466.00	0.15

71	RADIO NAVIGATION					
716AA		25(60)	9(12)	1	7066.40	11.50
716AC		8(17)	5(6)	2	1450.49	6.39
71ZAC		10(17)	5(6)	2	11864.57	6.39
71ZBC		4(10)	3(4)	2	1986.93	3.83
71ZDC		3(10)	3(4)	2	947.60	3.83
71111		12(47)	2(3)	2	480.00	2.56
71231		1(7)	1(1)	1	1540.00	1.28
71411		4(10)	3(4)	2	1200.00	3.83
71412		2(13)	4(5)	2	100.50	5.11
71416		3(10)	3(4)	2	361.00	3.83
71417		18(47)	14(18)	2	1560.00	17.89
7111A		5(20)	6(8)	2	65.00	7.67
7111E		6(11)	5(6)	3	544.70	6.39
71112		1(2)	1(1)	3	2576.33	1.28
71115		17(33)	10(13)	2	403.00	12.76
71116		6(23	7(9)	2	170.00	8.94
71231		3(7)	1(1)	1	1540.00	1.28
71512		3(7)	2(3)	2	380.00	2.56
71721		2(10)	3(4)	2	695.30	3.83

72	RADAR NAVIGATION					
720AA		9(10)	3(2)	1	15341.00	1.99
720AC		10(10)	3(2)	1	17835.48	1.99
72CAE		1(3)	1(1)	1	7983.00	0.66
72CAI		5(10)	3(2)	1	4222.69	1.99
72CAL		8(14)	4(3)	1	2675.94	2.66
72CBA		70(66)	19(13)	1	15100.00	12.62
72CCA		30(10)	10(7)	1	53005.00	6.64
72CDC		10(14)	4(3)	1	10292.00	2.66
7215A		27(31)	9(6)	1	12000.00	5.96
7215F		10(10)	3(2)	1	5504.95	1.99
72331		4(10)	3(2)	1	176.70	1.99
72752		38(34)	10(7)	1	13122.00	6.64
72753		38(34)	10(7)	1	38482.00	6.64
72755		38(34)	10(7)	1	34136.00	6.64
72757		38(34)	10(7)	1	1236.00	6.64
72767		13(10)	3(2)	1	[illegible]	1.99
72768		13(10)	3(2)	1	7786.80	1.99
[illegible]		6(14)	4(3)	1	4024.00	2.66
72773		42(38)	11(7)	1	20692.00	[illegible]
72774		42(38)	11(7)	1	[illegible]	[illegible]
72778		17(38)	11(7)	1	19549.00	[illegible]
[illegible]		4(7)	[illegible]	1	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	1	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	1	[illegible]	[illegible]

wuc	demand	qty	qpa	cost	failure rate
728EA	11(14)	4(3)	1	5525.95	2.66
728[illegible]A	10(21)	6(4)	1	4852.33	3.96
728[illegible]A	7(14)	4(3)	2	6833.67	2.66
728[illegible]A	14(14)	5(3)	1	5604.00	3.32
728[illegible]A	46(46)	14(9)	1	28006.34	9.30
728[illegible]A	9(14)	5(3)	2	1446[illegible].20	3.32
728NA	22(34)	10(7)	1	33327.71	6.64
7281[illegible]	9(14)	4(3)	1	5256.85	2.66

Appendix D

Marginal Analysis Program

```
(* this program generates a wrsk using marginal analysis to
optimize the expected shortages and not mission capable
aircraft  *)

program marganalysis(input,output,do29,kit2,kit3);

type
  nsn= record;
    qpa,spare: integer;
    fail,cost: real;
    wuc: array [1..5] of char; (* work unit code *)
    margin: array [1..5] of real; (* marginal value of
              adding on unit of spare to wrsk *)
    pnmc: array [1..2,1..16] of real (* probability of
              having x failures given the number of spares
              and the qpa *)
  end;

  wrskfile= file of nsn;

var
  do29,kit2,kit3: wrskfile;
  item: nsn;


(* calculates lamda to the ith power divided by i factorial
for computation of E(SDO)  *)

function factor(i: integer; fail: real): real;

var
  j: integer;
  k,r: real;

begin
  k= 1.0;
  if i > 0 then
    for j:= 1 to i do
      begin
        r:= j+0.0;
        k:= K*fail/r;
        if k < 0.0001 then
          k:= 0.0
      end;
  factor:= k
end;  (*  factor *)


(* calculates E(SDO) for particlular wrsk item given the
level the spare is currently at *)

function esdo(replace: nsn): real;
```

```
var
  b,i,ue,d,tot: integer;
  iexp,hold,thold,lamda: real;

begin
  ue:= 16;
  thold:= 0.0;
  with replace do
    begin
      tot:= ue*qpa+spare;
      if tot > 40 then
        tot:= 40;
      iexp:= exp(-fail); (* fail is failure rate  *)
      for i:= spare to tot do
        begin
          d:= i-spare:
          lamda:= factor(i,fail);  (* fail to the i power/i
                                                   factorial *)
          hold:= d*lamda; (* x- spare level* poisson *)
          thold:= thold+hold
        end
    end;
  esdo:= thold*iexp
end;  (* procedure esdo  *)


(* calculates E(SDO) for wrsk entire kit , equals sums of
individual spares E(SDO) *)

procedure totsdo(var one: wrskfile; var sdo: real);

var
  replace: nsn;
  psum: real;

begin
  reset(one);
  sdo:= 0.0;
  while not eof(one) do
    begin
      read(one,replace);
      psum:= esdo(replace);
      sdo:= sdo+psum
    end
end;


(* calculates the probabilities of having x failures given
the failure rate of the particular spare *)

procedure poisnmc(var replace: nsn);
```

```
var
  b,i: integer;
  iexp,hold,lamda,thold,dummy: real;

begin
  thold:= 0.056;
  with replace do
    begin
      iexp:= exp(-fail); (* fail is failure rate *)
      for i:= 0 to 15 do
        begin
          if thold < 0.999 then
            begin
              lamda:= factor(i,fail); (* fail to the
                                         i power/i factorial *)
              hold:= lamda*iexp;  (* poisson  *)
              if i=0 then
                pnmc[1,1]:= hold
              else
                pnmc[1,i+1]:= hold+pnmc[1,i];
              thold;+ pnmc[1,i+1]*1000.0
            end  (* if *)
          else
            pnmc[1,i+1]:= 1.00
        end  (* for *)
    end  (* with *)
end;  (* poisnmc  *)


(* calculates the cumulative probability of having x or less
failure for a given failure rate *)

procedure matnmc var replace:nsn);

var
  b,i: integer;

begin
  with replace do
    begin
     for i:= 0 t 15 do
       begin
         b:= qpa*i+spare;
         if b > 16 then
           pnmc[2.i+1:= 1.000
         else if pnmc[1,b] > 0.999 then
           pnmc[2,i+1]:= 1.000
         else
           pnmc[2,i+1]:= pnmc[1,b]
       end  (* for *)
     end  (*  with  *)
 end;  (* matnmc *)
```

```
(* calculates the number of NMC aircraft sustainable for
the given wrsk and failure rate of the item in the wrsk;
multiplies the probability of having NMC aircraft due to
each lru  *)

function totnmc(var one: wrskfile): real;

var
  replace:nsn;
  i: integer;
  a: array [1..2] of real;
  r,r1: real;

begin
  a[2]:= 0.0;
  for  i:= 0 to 15 do
    begin
      a[1]:= 1.0;
      reset(one);
      while not eof(one) do
        begin
          read(one,replace);
          with replace do
            begin
              a[1]:= a[1]*pnmc[2,i+1];
              if a[1] < 0.0001 then
                a[1]:= 0.0
            end (* with  *)
        end;  (* while *)
      a[2]:= a[1]+a[2]
    end;  (* for *)
  totnmc:= 16-a[2]
end;  (*  totnmc  *)


(*  calculates the marginal value of each spare item in the
conventional wrsk file; reads items one at a time and
calculates marginal value *)

procedure calcmarg(var one,two: wrskfile; var replace:nsn;
  a: real);

begin
  reset(one);
  rewrite(two);
  while not eof(one) do
    begin
      read(one,replace);
      with replace do
        begin
          margin[1]:= (margin[3]+margin[5]*a)/cost;
          write(two,replace)
        end  (* with *)
    end  (* while  *)
```

```
end; (* calcmarg *)

(*transfers contents of one file to a second file  *)

procedure transfer (var fromfile,tofile: wrskfile);

var
  part: nsn;

begin
  reset(fromfile);
  rewrite(tofile);
  while not eof(fromfile) do
    begin
      read(fromfile,part);
      write(tofile,part)
    end   (* while  *)
end;  (* transfer  *)


(* finds percent of wrsk items to increment by one  *)

function find1(b:char): real;

var
  a: array [1..6] of real;

begin
  a[1]:=1/4;
  a[2]:=1/8;
  a[3]:=1/16;
  a[4]:=1/32;
  a[5]:=1/64;
  a[6]:=1;
  case b of
    'a': find1:= a[1];
    'b': find1:= a[2];
    'c': find1:= a[3];
    'd': find1:= a[4];
    'e': find1:= a[5];
    'f': find1:= a[6]
  end
end;  (* find1 *)


(*  finds weight and percent of top elements (greatest
increase E(SDO) and E(NMC) function) in wrsk to increase by
one for next iteration *)

procedure find(n,n,c,b,a,r: real; var f1,f2: real;);
```

```
var
  t,u: real;
  alpha: char;
  a: array[1..2,1..6] of real;

begin
  a[1,2]:=  10;  (* weights for expected value function  *)
  a[1,3]:=  25;  (* combination of E(SDO) and E(NMC)*)
  a[1,4]:=  50;
  a[1,5]:=  150;
  a[1,6]:=  500;
  a[2,1]:=  1000;
  a[2,2]:= 1/4;  (* Percent of wrsk to increase spare *)
  a[2,3]:= 1/8;  (* level by one  *)
  a[2,4]:= 1/16;
  a[2,5]:= 1/32;
  a[2,6]:=  1;
  t:= n-b;  (* difference between current E(NMC) and goal *)
  u:= m-c; (* difference between current E(SDO) and goal *)
  if u >= r then
    if t >= s then
      begin
        f1:= a[1,3];
        alpha:= 'a'
      end
    else if (t > s*0.8) then
      begin
        f1:= a[1,2];
        alpha:= 'a'
      end
    else if (t > s*0.6) then
      begin
        f1:= a[1,2];
        alpha:= 'a'
     end
   else if (t > s* 0.4) then
     begin
       f1:= a[1,1];
       alpha:= 'b'
     end
  else if (t > s*0.2) then
    begin
      f1:= a[1,1];
      alpha:= 'b'
    end
  else
    begin
      f1:= a[1.1];
      alpha:= 'b'
    end
  else if u > r*0.8 then
    if t >= s then
      begin
        f1:= a[1,4];
```

```
          alpha:= 'a'
        end
      else if (t > s*0.8) then
        begin
          f1:= a[1,3];
          alpha:= 'a'
        end
      else if (t > s*0.6) then
        begin
          f1:= a[1,2];
          alpha:= 'b'
       end
     else if (t > s* 0.4) then
       begin
         f1:= a[1,2];
         alpha:= 'b'
       end
    else if (t > s*0.2) then
      begin
        f1:= a[1,1];
        alpha:= 'c'
      end
    else
      begin
        f1:= a[1,1];
        alpha:= 'b'
      end
    else if u > r*0.6 then
      begin
        if t >= s then
          begin
            f1:= a[1,5];
            alpha:= 'a'
          end
        else if (t > s*0.8) then
          begin
            f1:= a[1,4];
            alpha:= 'b'
          end
        else if (t > s*0.6) then
          begin
            f1:= a[1,3];
            alpha:= 'b'
         end
       else if (t > s* 0.4) then
         begin
           f1:= a[1,2];
           alpha:= 'c'
         end
      else if (t > s*0.2) then
        begin
          f1:= a[1,1];
          alpha:= 'd'
        end
```

```
else
  begin
    f1:= a[1,1];
    alpha:= 'd'
  end
else if u > r*0.4 then
  begin
    if t >= s then
      begin
      f1:= a[1,5];
      alpha:= 'b'
    end
   else if (t > s*0.8) then
    begin
      f1:= a[1,5];
      alpha:= 'b'
    end
   else if (t > s*0.6) then
    begin
      f1:= a[1,4];
      alpha:= 'c'
  end
  else if (t > s* 0.4) then
   begin
     f1:= a[1,3];
   alpha:= 'c'
  end
 else if (t > s*0.2) then
  begin
    f1:= a[1,1];
    alpha:= 'd'
  end
 else
  begin
    f1:= a[1,1];
    alpha:= 'd'
  end
else if u > r*0.2 then
 begin
   if t >= s then
     begin
       f1:= a[1,5];
       alpha:= 'b'
     end
   else if (t > s*0.8) then
     begin
       f1:= a[1,5];
       alpha:= 'c'
     end
   else if (t > s*0.6) then
     begin
       f1:= a[1,5];
       alpha:= 'd'
    end
```

```
      else if (t > s* 0.4) then
        begin
          f1:= a[1,5];
          alpha:= 'd'
        end
     else if (t > s*0.2) then
       begin
         f1:= a[1,3];
         alpha:= 'e'
       end
     else
       begin
         f1:= a[1,1];
         alpha:= 'f'
       end
  else
     begin
       if t >= s then
          begin
            f1:= a[1,6];
            alpha:= 'c'
          end
        else if (t > s*0.8) then
          begin
            f1:= a[1,6];
            alpha:= 'd'
          end
        else if (t > s*0.6) then
          begin
            f1:= a[1,6];
            alpha:= 'd'
         end
       else if (t > s* 0.4) then
         begin
           f1:= a[1,6];
           alpha:= 'e'
         end
      else if (t > s*0.2) then
        begin
          f1:= a[1,6];
          alpha:= 'f'
        end
      else
        begin
        f1:= a[1,6];
        alpha:= 'f'
        end
    end;
   f2:= find1(alpha);
   if (t < 0.0 ) and (u < 0.0) then
     begin
       f1:= -1.0;
       f2:= -1.0
     end
```

```
end;  (*  find *)


(* finds spare that will provide greatest decrease in
expected value if added to the wrsk *)

procedure findgreat(var kit,extra: wrskfile; replace: nsn);

var
  part: nsn;
  i: integer;

begin
  reset(kit);
  rewrite(extra);
  if not eof(kit) then
    begin
      read(kit,replace);
      part:= replace;
      while not eof(kit) do
        begin
          read (kit,replace);
          if replace.margin[1] > part.margin[1] then
            begin
              write(extra,part);
              part:= replace
            end  (* if  *)
          else
            write(extra,replace)
        end;  (* while  *)
      part.spare:= part.spare+1;
      part.margin[1]:= 0.0;
      write(extra,part);
      transfer(extra,kit)
   end  (*  if not eof  *)
end; (* findgreat  *)


(* finds change in nmc of increasing spare level of one spare
by one for each item in the wrsk on at a time *)

procedure bigexpe(var one,two: wrskfile; var replace: nsn;
  cnt: integer; var delta: real);

var
  i,g: integer;
  chng: real;

begin
  for i:= 1 to cnt do
    begin
      g:= 0;
      reset(one);
      rewrite(two);
```

```
        while not eof(one) do
          begin
            read(one,replace);
            g:= g+1;
            with replace do
              begin  (* increase lru one at a time by one *)
                if i = g then  (* all  other lrus remain at
                                previous level  *)
                  spare:= spare+1;
                write(two,replace)
              end  (*  with *)
          end;  (* while*)
        reset(two);
        rewrite(one);
        g:= 0
        while not eof(two) do
          begin
            g:= g+1;
            read(two,replace);
            matnmc(replace);
            if i = g then
              replace>spare:= replace.spare-1;
            write(one,replace)
          end;  (* while  *)
        g:= 0;
        chng:= totnmc(one);  (* calculates E(NMC) for new
                                kit *)
        reset(one);
        rewrite(one);
        while not eof(one) do
          begin
            read(one,replace);
            g:= g+1;
            if  g = i then
              replace.margin[5]:= delta-chng;
            write(two,replace)
          end;  (* while  *)
      end  (* for *)
  end;  (* bigexpe  *)


  (* performs marginal analysis on wrsk to reach goals  *)

  procedure runmargin(var two,three: wrskfile);

  var
    nm1,sd1,nm,sd: real;
    on: boolean;
    replace: nsn;
    i,p,cnt: integer;
    delta: array [1..3] of real;
    goal: array [1..2] of real;
```

```
begin
  con:= 0;
  reset(two);
  rewrite(three);
  while not eof(two) do
    begin
      read(two,item);  (* matrix of probabilities from which
                          E(NMC) are calculated for current wrsk
                          levels *)
      cnt:= cnt+11;
      matnmc(item);
      write(three,item)
    end;  (*  while  *)
  nm:= totnmc(three);  (*  E(NMC) current spares levels  *)
  totsdo(three,sd);
  writeln('E(NMC)= ',nm:5:3,'E(SDO)= ',sd:5:3);
  writeln('input goal for sdo');
  readln (goal[1]);
  writeln('input goal for nmc');
  readln (goal[2]);
  on:= true;
  transfer(three,two);
  while (nm > goal[2]) or (sd > goal[1]) do
    begin
      totsdo(two,sd);
      reset(two);
      rewrite(three);
      while not eof(two) do
        begin
          read(two,item);
          with item do
            begin
              spare:= spare+1; (*  sdo for wrsk with one
                                   spare increased by one all other
                                   spares at initial levels  *)
              margin[2]:= esdo(item);
              margin[3]:= sd-margin[2];
              spare:= spare-1
            end;  (* with *)
          write(three,item)
        end;  (* while  *)
      reset(three);
      rewrite(two);
      while not eof(three) do
        begin
          read(three,item);
          matnmc(item);
          write(two,item)
        end;   (*  while  *)
      nm:= totnmc(two);
      bigexpe(two,three,item,cnt,nm);
```

```
        if on then
          begin
            one:= false;
            nm1:= nm-goal[2];
            sd1:= sd-goal[1]
          end;  (* if *)
        find(nm,sd,goal[1],goal[2],nm1,sd1,delta[1],delta[2]);
        calcmarg(three,two,item,delta[1]);
        delta[3]:= cnt*delta[2];
        p:= round(delta[3]);
        if p < 1.0 then
          p:= 1;
        for i:= 1 to p do
           findgreat(two,three,item)
      end  (* while  *)
  end;  (* runmargin  *)


  begin   (* main program  *)
    reset(kit2);
    rewrite(kit3);
    while not eof(kit2) do
      begin
        read(kit2,item);
        poisnmc(item);
        write(kit3,item)
      end;  (*  while  *)
    transfer(kit3,kit2);
    runmargin(kit2,kit3,sdo,nmc,item)
  end.
```

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Vita

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Abstract

The War Readiness Spares Kit (WRSK)/Base Level Self-Sufficiency Spares Requirements Computation System (D029) is currently used to compute the demand rates (DRs) and spares levels (SLs) for WRSK line replaceable units (LRUs) from peacetime failures per flying hour. This thesis applied linear regression analysis on C-130 aircraft subsystem data collected during the South East Asia (SEA) conflict to calculate LRU DRs. The results indicated the reciprocal of flying hours, the number of aircraft, and the reciprocal of average sortie length rather than flying hours were better determinants of the C-130 subsystem DRs.

A WRSK was created by apportioning the subsystem DRs to the LRUs under the subsystems. The D029 marginal analysis methodology was applied to refine this WRSK. The final WRSK ($WRSK_m$), a D029 WRSK, and a WRSK with the DRs from $WRSK_m$ and the SLs of the D029 WRSK were input into the Dyna-METRIC model to evaluate the effect of each WRSK on aircraft availability for a 30 day conflict without resupply of spares.

Dyna-METRIC output indicated the DRs in $WRSK_m$ were greater than those in the D029 WRSK and the SLs in $WRSK_m$ were slightly higher than those in the D029 WRSK. These findings were suspect because the form of the data and the model used to evaluate the performance of the two WRSKs impacted the results. The SEA failure data were aggregated by subsystem: D029 WRSKs are created from LRU failure data. Dyna-METRIC uses demands per flying hour as an input, but flying hours was not the only significant variable for predicting DRs.

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