AD-A193 301    COMPUTATION OF ECM (ELECTRONIC COUNTRR-MEASURES) WAR    1/1
              RESERVE MATERIEL SPARE REQUIREMENTS(U) AIR FORCE
              LOGISTICS COMMAND WRIGHT-PATTERSON AFB OH
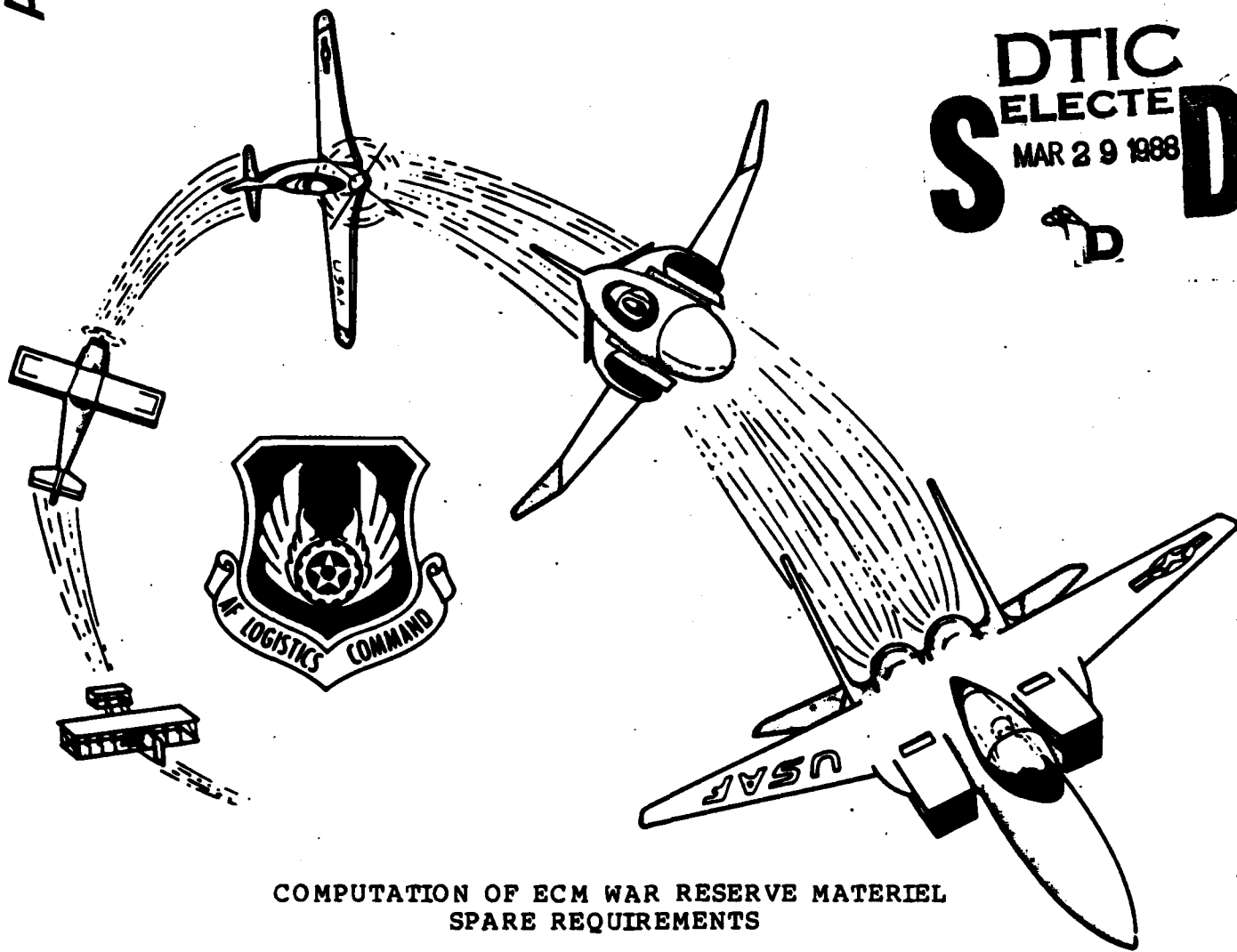UNCLASSIFIED  T J SAKULICH ET AL  NOV 87                F/G 15/5    NL

AD–A193 301

# AIR FORCE LOGISTICS COMMAND

# MATERIEL ANALYSIS



DTIC
SELECTED
MAR 2 9 1988
D

## COMPUTATION OF ECM WAR RESERVE MATERIEL SPARE REQUIREMENTS

Lt Timothy J. Sakulich

HQ AFLC/MMMA
NOVEMBER 1987

Mr George Zeck

88 3 01 033

| Page | Location | Description |
|---|---|---|
| | | |

Page Location　　　　　　　　Description

5　　11 line from bottom　　　change
"...the product TOIMDR WARFAC can be thought of..."
to
"...the product TOIMDR·WARFAC can be thought of..."

11　　example 1, last line　　change
"...quantity is 2.19071/100　　2800　　1 ≅ 61."
to
"...quantity is 2.19071/100 · 2800 · 1 ≅ 61."

13　　example 3, last line　　change
"...quantity is 1.39154/100　　2800　　3 ≅ 117."
to
"...quantity is 1.39154/100 · 2800 · 3 ≅ 117."

B-4　first equation　　change

$$\text{"TOIMDR} = \frac{\text{Total Equipment Demands Expected}}{\text{Total Equipment Wartime Flying Hours}} \quad 100$$

$$= \frac{p \cdot S_w \cdot QPA_w}{FHP_w \cdot QPA_w} \quad 100\text{"}$$

to

$$\text{"TOIMDR} = \frac{\text{Total Equipment Demands Expected}}{\text{Total Equipment Wartime Flying Hours}} \cdot 100$$

$$= \frac{p \cdot S_w \cdot QPA_w}{FHP_w \cdot QPA_w} \cdot 100\text{"}$$

B-4　second to last line　　change

$$\text{"} = p \quad \frac{S_w \cdot 100}{FHP_w \, 100} \cdot FHP_w \cdot QPA_w\text{"}$$

to

$$\text{"} = p \cdot \frac{S_w \cdot 100}{FHP_w \cdot 100} \cdot FHP_w \cdot QPA_w\text{"}$$

| Page Location | Description |
|---|---|
| B-6 last equation | change |

$$\text{'TOIMDR}_w = \mu \quad \frac{OT_w}{FHP_w} = \frac{X^2(1-C;2n_f)}{2T} \cdot \frac{OT_w}{FHP_w} \cdot 100.\text{'}$$

to

$$\text{'TOIMDR}_w = \mu \cdot \frac{OT_w}{FHP_w} = \frac{X^2(1-C;2n_f)}{2T} \cdot \frac{OT_w}{FHP_w} \cdot 100.\text{'}$$

B-10 last equation

change
'E[wartime demands] = TOIMDR$_w$   FHP$_w$   QPA$_w$.'
to
'E[wartime demands] = TOIMDR$_w$ · FHP$_w$ · QPA$_w$.'

B-17 line 12

change
'...formula, $X^2(0.50,2n_f)$ ≅ 2 20 - 0.665 = 39.335, for a relative...'
to
'...formula, $X^2(0.50,2n_f)$ ≅ 2·20 - 0.665 = 39.335, for a relative...'

Computation of ECM War Reserve Materiel

Spares Requirements

Lt Tim Sakulich, HQ AFLC/MMMA

Mr George Zeck, HQ AFLC/MMMR

November 1987

## ABSTRACT

This study demonstrates the conversion of sortie and operating hour failure data into factors compatible with the AFLC requirements system used to compute War Reserve Materiel (WRM) requirements for Electronic Counter-Measures (ECM) spares. The study predicts significant improvements to item and weapon system availability when sortie and operating hour demand rates are used in place of the current flying hour rates.

EXECUTIVE SUMMARY

In this study we address the problem of how to convert sortie and operating hour failure data into factors compatible with the AFLC requirements system in order to improve the computation of Electronic Counter-Measures (ECM) War Reserve Materiel (WRM) requirements. The current system estimates wartime spares requirements using flying hour demand rates and programs. Peacetime flying hour demand rates are transformed into wartime rates using estimated ratios of wartime-to-peacetime ECM usage per flying hour (ECM Factors). This methodology assumes that wartime ECM requirements are best predicted using flying hour programs and that wartime ECM demands are a linear multiple of peacetime demands. Using the results of a recent ECM exercise as evidence, Hq SAC/LGS demonstrated two related shortcomings of the current system.

First, Hq SAC/LGS showed that wartime ECM requirements are not necessarily a linear multiple of peacetime demands. To solve this shortcoming, they proposed that future ECM wartime demand rates be developed directly from data collected during annual war exercises. Second, Hq SAC/LGS showed that sortie and operating hour programs are superior to flying hour programs for predicting ECM demands. They recommended that wartime requirements be estimated using sortie and operating hour demand rates and programs instead of flying hour rates and programs.

Based on these recommendations, Hq AF/LEY tasked the strategic and tactical communities to collect ECM demand data from simulated wartime exercises and to provide Hq AFLC/MMM with rates based on sorties and operating hours. Likewise, Hq AFLC/MMM was tasked to develop procedures to use the sortie and operating hour demand rates and programs to estimate ECM requirements in the War Readiness Spares Kit (WRSK)/Base Level Self-Sufficiency Spares (BLSS) requirements computation system (D029).

Prior to this study, no procedures had been developed to use sortie or operating hour demand data in the WRSK/BLSS computational system. This study developed and verified computational procedures to use such data in that requirements system. The new procedures work. Demand data from wartime exercises is being provided by the MAJCOMs. The WRSK/BLSS computation system is able to use the new sortie and operating hour data to better estimate the wartime requirements for ECM. The more-accurate factors enhance the credibility of the ECM IRM requirement and significantly improve item and weapon system availability.

Due to current system limitations, the new procedures require some manual manipulation of data. In the future, the Weapon System Management Information System (WSMIS) Requirements Execution/Availability Logistics Module (REALM) will automate the new procedures to compute WRSK/BLSS requirements.

# TABLE OF CONTENTS

# CHAPTER 1

## THE PROBLEM

### PROBLEM STATEMENT

The current system for estimating requirements for War Readiness Spares Kits (WRSK) and Base Level Self-Sufficiency Spares (BLSS) assumes that wartime demands are a function of the wartime flying hour program and that wartime demands are a linear multiple of peacetime demands. Using data from a wartime exercise to support their argument, Hq SAC/LGS recently demonstrated the shortcomings of this approach for computing wartime spares requirements for Electronic Countermeasures (ECM) spares. SAC showed that sortie and operating hour programs are more accurate predictors of ECM demands. Hq AF/LEYS tasked Hq AFLC/MMM to compute WRSK/BLSS ECM requirements using the more accurate sortie and operating hour demand data. However, to compute pipeline requirements and to perform an optimal allocation of spares dollars across an entire WRSK/BLSS kit--including ECM spares--using marginal analysis, AFLC's current system requires flying hour rates and programs. The Air Force WRM requirements system needs a way to compute ECM requirements using the sortie and operating hour demand factors and one which preserves the ability to optimally allocate spares dollars.

### OBJECTIVES

The objectives of this study were to:

1.  Determine how to use sortie and operating hour demand rates to develop ECM requirements.

2.  Evaluate the difference in ECM spares cost and availability between using the current flying hour methodology and the new sortie/operating hour methodologies.

3.  Minimize the need to perform computations external to D029.

4.  Minimize the requirement for AFLC data system changes to ensure timely use of more accurate ECM demand data with the least cost.

1

## BACKGROUND

Forecasting War Reserve Materiel (WRM) requirements for electronic countermeasures spares has traditionally been a high-visibility task due to the cost and importance of such equipment. Unit costs for some line replaceable units (LRU's) approach $1 million (the B-1B ALQ-161 Band 8 RF Source, costs nearly $1.3 million). Unfortunately, this forecasting task has proven to be extremely difficult in the past since the USAF has no recent, comprehensive wartime experience from which to predict wartime demand rates. The need for reliable data is accentuated under marginal analysis trade-offs since items with erroneous or inaccurate factors compete unfairly with other items for safety level support dollars, adversely affecting the entire WRM requirement.

Several efforts to improve data collection techniques have also highlighted the need for improved computational methodologies. The current WRSK/BLSS requirements (D029) algorithm transforms a peacetime demand rate based on flying hours to an expected number of wartime demands per flying hour in order to perform marginal analysis tradeoffs. Research indicates that equipment operating hours or aircraft sorties may be a better predictor of ECM demands. [8,9,10,12] Furthermore, Hq SAC/LGS and Hq TAC/LGS, supported by maintenance data and expertise, have shown that some ECM demands are probably a nonlinear function of operating hours: the longer the equipment is fully functioning, the less likely it is to fail. There is currently no explicit way to input operating hour-based or sortie-based demands into the WRSK/BLSS requirements computation system.

In 1984 the Air Force began using an ECM Factor to transform peacetime ECM demand rates into wartime demand rates. This factor tries to account for differences in ECM operating hour usage from peacetime to wartime. Initial use of ECM Factors contributed significantly to a $956 million growth in ECM WRSK requirements from 1984 to 1985. Unfortunately, an abysmal lack of reliable peacetime operating hour data makes it difficult to accurately determine or credibly defend the ECM Factors. Furthermore, the formula for computing the ECM Factors relies on an assumption that demands are a linear function of operating hours. Detailed field maintenance data collected by Hq SAC/LGS under a 1986 test program refuted that assumption for some items and led to an alternative methodology which is described in this report.

Today, MAJCOM's are collecting more accurate usage and field maintenance information during peacetime operations and wartime readiness exercises. Hq TAC has tasked special teams to collect ECM usage and demand data during Green Flag and Red Flag exercises at Nellis AFB. Hq SAC has recently completed the first of a series of their own tests of wartime ECM usage and demands using B-52G aircraft based at Loring AFB and Mather AFB. These MAJCOM data collection programs concentrate on compiling sortie and operating hour usage and demands. The resulting demand factors are representative of wartime conditions, mitigating the nonlinearity issue.

This study shows how to use the new Hq TAC and Hq SAC sortie and operating hour demand data to estimate wartime requirements. We develop an alternative methodology for computing D029 demand factors (using existing data and data available through the Hq TAC and Hq SAC data collection programs) which considers the practical limitations of available data as well as computational efficiency.

## MAJOR ASSUMPTIONS

Four major assumptions affected the course of our analysis. The first two address the validity of using the sortie and operating hour methodologies proposed by Hq SAC/LGS. The third speaks to our expectations of receiving accurate demand data on a regular basis to ensure the new methods remain up-to-date and useful. The final assumption explains why we adapted the new methods for compatibility with the current WRSK/BLSS marginal analysis process as opposed to developing a completely separate computational procedure for ECM requirements.

1. When it is available and reliable, demand data from wartime exercises should be used to predict WRSK/BLSS requirements. In particular, indications of a nonlinear relationship of demands to usage implies that forecasts of wartime demands should be made from data obtained under conditions which most resemble the war scenario, rather from a dissimilar peacetime scenario.

2. The expertise for determining the reliability characteristics of ECM equipment (i.e., whether demands are driven by sorties, flying hours or operating hours) is with Hq TAC and Hq SAC analysts and maintenance personnel. The users have hands-on experience in working with the equipment; they are the source of usage and demand data and are in the best position to "interpret" the raw statistics. Especially at Hq SAC, analysts and maintenance personnel have worked closely together to recommend the best predictors (program elements) of demands on a system-by-system and item-by-item basis.

3. Hq SAC and Hq TAC are willing to make the effort to collect more reliable usage and demand data in order to get a better statement of requirements. As mentioned previously, Hq TAC made a commitment to task special teams at Green Flag and Red Flag exercises to collect more accurate ECM usage and demand data and Hq SAC has already conducted operational tests during which ECM data was carefully recorded. .

4. If possible, D029 should be used to project WRSK/BLSS requirements for ECM, rather than having to externally compute these requirements--it is important to be able to compute marginal analysis tradeoffs among items in order to get the best WRSK/BLSS support per dollar. This must be done with the visibility of an entire WRSK/BLSS kit. Computing individual item requirements external to the system, a process call non-optimization, is inferior since it does not maximize total system performance per dollar.

3

ANALYSIS

## OVERVIEW

The primary purpose of this study was to determine how to compute ECM requirements in D029 using sortie and operating hour demand data provided by Hq SAC/LGS and Hq TAC/LGS. We document our study in five sections. First we describe the Current System programming. Next, we discuss the New Computational Procedures required to use sortie and operating hour demand data. A discussion of AFLC Implementation Issues follows. Finally, we show the Effect on the Requirement of using the new ECM factors and discuss the Current Status of the implementation effort.

In writing up the study results, we experienced a great deal of frustration in trying to keep explanations simple and straightforward while not misrepresenting the flavor, depth and complexity of the problem and its solution. We decided to keep the main body of the report relatively unencumbered by intricate explanations. Instead, the appendices provide the interested reader with more detailed information. Appendix A (A Background of the Current Requirements System for ECM) discusses the past approaches to predicting wartime ECM requirements and the decisions which ultimately led to this study. Appendix B (Revised ECM Methodology) details the mathematical derivations and justifications of the revised demand rate formulas. Such information is, by nature, complex: only the more intrepid readers will want to venture into those appendices.

## CURRENT SYSTEM

The WRSK/BLSS requirements system (D029) computes the requirements for prepositioned materiel intended to support operational requirements for the first 30 days of a war (D-Day to D+30). The two categories of prepositioned requirements are War Readiness Spares Kits (WRSK) and Base Level Self-Sufficiency (BLSS) kits. WRSK must support the full level of wartime operations for units which operate in war at locations other than their normal peacetime bases. BLSS kits are intended to support wartime operations of units which will remain in-place; since such units will have their peacetime spares and maintenance at hand, BLSS is designed to support the difference between war and normal peace operations. WRSK and BLSS kits are "built" and serialized by Mission Design Series (MDS) application and D029 forecasts requirements within each kit by stock number. Requirements for a given kit are based on the Primary Aircraft Authorization (PAA) for the unit the kit is intended to support.

4

## Computation of Daily Demands

The current D029 algorithm requires flying hour demand rates in order to compute expected demands and to determine marginal analysis safety levels. Since actual wartime demand rates are not known, peacetime demand rates by stock number are obtained from the Recoverable Consumption Item Requirements system (D041). Adjustments to individual peacetime demand rates can be negotiated at annual WRSK reviews in order to account for base or weapon system peculiarities. The D029 system does not perform any direct adjustments to the demand rate, thereby assuming that demands are based on flying hours and that demands are linearly proportional to flying hour programs. This is normally appropriate, especially when both peacetime and wartime use of an item is high.

Daily wartime flying hours for the appropriate MDS are also needed, as well as each item's quantity per application (QPA) to that MDS. The expected number of daily wartime demands for each item is then computed by multiplying the item's flying hour demand rate by the number of daily aircraft flying hours and the item QPA. The expected number of daily wartime demands can be expressed mathematically by the following formula:

$$E[DDmd] = \frac{TOIMDR}{100} \cdot WARFAC \cdot DFHP_{MDS} \cdot QPA.$$

where

$TOIMDR$ = total OIM demand rate is units of demands per 100 flying hours,

$WARFAC$ = war adjustment factor (normally set to 1),

$DFHP_{MDS}$ = daily flying hour program for the MDS on which the item is installed,

$QPA$ = item quantity per application for the MDS, and

$E[DDmd]$ = expected (mean) number of daily demands.

(Note that the product TOIMDR WARFAC can be thought of as a wartime demand rate per 100 flying hours.)

For example, if the OIM demand rate for an item is one demand per 100 flying hours in peacetime, WARFAC = 1 (wartime usage per flying hour is expected to be the same as in peacetime), the planned wartime flying hour program for the item's MDS application is 126 hours per day, and QPA = 1, then one would expect 1.26 demands for the item on an average day.

## Pipeline (Conventional) Quantities

Using this basic equation, a pipeline quantity (called the "conventional quantity" in D029) is computed for each item. The conventional quantity is defined as the peak expected Stock Due Out (SDO) quantity during the WRSK/BLSS

5

support period, assuming mean demands per flying hour and no available WRSK/BLSS assets. In other words, the conventional quantity is the "baseline" stock required to fill an item's average pipeline. Theoretically, it is the stock level which has a 50 percent chance of meeting all demands for that item. For example, the WRSK pipeline quantity for remove-and-replace (RR) items is the total accumulated number of demands expected over the first 30 days of the war:

$$E[30 \text{ Days Dmd}] = \frac{\text{TOIMDR}}{100} \cdot \text{WARFAC} \cdot \text{DFHP}_{\text{MDS}} \cdot \text{QPA} \cdot 30 \text{ days}.$$

In the example case of 1.26 expected demands per day, the pipeline quantity is 1.26(30) = 37.8 ≅ 38 (on the average, approximately 38 demands would be expected over 30 days).

Since demands and lead-times are random, safety levels are needed to protect against the uncertainty that demands or lead-times will be greater than expected. Adding safety levels can result in a higher probability of meeting all demands over the WRSK/BLSS support period. But instead of simply increasing the fill rates uniformly for each item, marginal analysis can be used to buy those items which result in the best support of the weapon system per dollar. In order to perform this tradeoff, a consistent statistical model of demands must be applied across all items: D029 uses a statistical distribution, called the Poisson distribution, which is parameterized by the average (mean) daily demand quantity ($E[DDmd]$). This statistical model defines the probability of experiencing a demand given an average number of daily demands.

## Safety Levels

WRSK safety stock is determined through a marginal analysis tradeoff. In the tradeoff, item stock levels are increased according to which items give the best incremental support per dollar. The measure of incremental support has two parts. One part is to minimize the sum of Stock Due Out (SDO) across all items and a second part is to minimize Non Mission Capable due to Supply (NMCS) aircraft to a Direct Support Objective (DSO) target for the flying unit supported by the kit. The DSO is expressed as a percentage of the PAA permitted to be NMCS at the end of the WRSK support period. The final WRSK requirement is defined as the WRSK pipeline quantity plus the safety level. Note that items never receive less than their pipeline quantity.

A fundamental aspect of the marginal analysis tradeoff is the interdependence of demand rates and unit costs across items in the kit. However, all else being equal, the item with the highest demand rate (highest probability of experiencing a demand at a given point in time) will receive the greater amount of stock; all else being equal, the item with the lower unit cost will receive the greater amount of stock. Accurate demand rates and costs are critical in correctly performing this trade-off.

6

For BLSS items, the use of time-phased repair cycles would make a marginal analysis tradeoff quite complicated. Instead, for BLSS items, D029 computes a fixed safety level quantity which is the square root of the BLSS pipeline quantity. Since flying units supported by BLSS will have peacetime stocks on hand, D029 subtracts a POS offset (expected number of peacetime stocks on hand) from the total wartime requirement. The BLSS requirement for a given item is then defined as the BLSS pipeline level plus the safety level minus the POS offset.

## Use of the War Adjustment Factor for ECM

Current policy defines WARFAC equal to one for all items other than ECM spares. In other words, for non-ECM items the wartime demand rate per flying hour is expected to be the same as the peacetime rate. For ECM equipment, WARFAC is equivalent to an ECM FACTOR, defined in [2,3]. The ECM FACTOR is the ratio of wartime ECM operating hours per flying hour to peacetime ECM operating hours per flying hour. ECM operating hours, also called "on-time" or "on-hours", is the amount of time that the ECM equipment is in a power-on status, whether in stand-by, transmit, or receive mode. Mathematically,

$$\text{ECM FACTOR} = \frac{\text{ECM On-time}_w}{\text{TOTFHP}_w} \cdot \frac{\text{TOTFHP}_p}{\text{ECM On-time}_p},$$

$$= \frac{\% \text{ ECM On-time}_w}{\% \text{ ECM On-time}_p},$$

where

TOTFHP   = total accumulated peacetime or wartime item flying hour program, and

ECM On-time = the number of ECM operating hours accumulated over TOTFHP.

The ECM FACTOR estimates wartime flying hour demand rates from peacetime flying hour demand rates using operating hour data. The factor assumes the linearity of demands to operating hours. The ECM FACTOR is normally greater than one, accounting for the fact that peacetime ECM usage is relatively low, while wartime ECM usage is expected to be extensive.

AFM 67-1 tasks MAJCOM operational staffs to provide ECM FACTORS by MDS to Hq USAF for validation (Hq TAC supplies the factors on behalf of the Tactical Air Forces). The ECM FACTORS are to be based on actual peacetime 30-day average flying time versus on-time data and anticipated wartime average flying time versus on-time data from the appropriate War Mobilization Plan (WMP). Maintenance expertise is to be used to ensure ECM FACTORS are realistic adjustments from peace to war. All ECM systems are to be considered and the factors are to be updated annually. Because the ECM FACTORS are specified by ECM system and MDS application, expected daily demands for each ECM item in a given ECM system and WRSK/BLSS kit are adjusted using the same ECM FACTOR. This factor is file maintained into D029 by the appropriate ALC WRSK monitor.

7

# NEW COMPUTATIONAL PROCEDURES

## Test Data from Hq SAC

In the spring of 1986, SAC conducted a 30 day test of operational B052G units which flew sorties with wartime ECM usage profiles. Emphasis was placed on carefully recording actual ECM operating times. The resulting demand data was computed by stock number rather than by ECM system and MDS.

Hq SAC/LGS asserted that the original ECM FACTOR technique would once again cause substantial increases to ECM requirements in the D029 computation. Using their test results as evidence of the non-linearity of demands to operating hour usage, they felt that such increases were not realistic. Hq SAC/LGSMO in the keynote briefing (SAC Electronic Countermeasures Meeting, 24-25 Nov 1986) illustrated this with the ALQ-117 system. Using the computed D029 WRSK requirements for FY85 as a baseline, and using 1986 on-time and demand data to compute new ECM FACTORS, they estimated a 6-fold increase in the computed ALQ-117 requirement. Based on the actual demands experienced during their test, they estimated only a 1 percent increase in the requirement and felt this was more realistic. [12] The conclusion: The current ECM FACTOR methodology incorrectly states WRSK requirements for some ECM items due to the non-linearity of demands to usage.

After reviewing the items on which demand data had been collected, considering the use of the equipment and the available data, SAC analysts and maintenance personnel recommended that future ECM WRSK requirements be determined using sortie and operating hour demand rates, and that these rates be based on data collected during simulated wartime exercises. Using data from their 30-day test, Hq SAC/LGS demonstrated the development of such sortie and operating hour rates.

In the cases where multiple demands had occurred during the ECM test, a demand rate directly based on equipment operating hours was recommended. For each of these items an average operating hour demand rate was computed by dividing the number of demands by the total operating hours for the ECM system. When demands had occurred but item operating hour usage was low, SAC analysts and maintenance experts concluded that sortie-based demand rates were more statistically reliable than demand rates based on operating hours. For those items which normally experience peacetime demands but did not fail during the test period, the analysts showed how to develop credible sortie demand rates.

Hq SAC/LGS recommended that future estimates of wartime ECM spares requirements be developed directly from data collected during simulated wartime exercises instead of using an ECM Factor to transform peacetime demand data. They asserted that this not only results in a lower pipeline ECM requirement

8

but is also more credible than the ECM Factor approach. Hq SAC/LGS also recommended that future wartime spares estimates be based on sortie and operating hour usage instead of flying hour programs. Hq USAF and Hq AFLC reviewed SAC/LGS's recommendations and agreed that this approach, since it was based on more realistic usage and is more credible for predicting expected wartime demands for ECM items.

A drawback to using sortie and operating hour rates is their incompatibility with current system inputs. The D029 system can only use flying hour demand rates to compute pipeline quantities (expected demands) and to perform marginal analysis trade-offs. However, our analysis shows that sortie and operating hour demand data can be converted into factors which are compatible with D029 logic to compute pipeline kit quantities and valid for performing the marginal analysis trade-offs.

In addition to the above recommendations, SAC analysts suggested that reliability and statistical theory should be used to compute confidence intervals on the values of the sortie and operating hour demand rates in order to account for uncertainty. SAC adjusted all of the rates to their 90 percent upper confidence limits. The final demand rates recommended to Hq USAF and Hq AFLC were the 90 percent upper confidence limits on the average demand rates. However, use in D029 marginal analysis of demand rates based on 90 percent upper confidence limits would be like adding explicit safety levels on top of implicit safety levels. In addition, such implicit safety levels increases costs without considering which items give the best weapon system support per dollar. We will show the increased costs of using the 90 percent rates at the end of this chapter.


## Revised Computational Approach

Using reliability theory and statistical analysis we proved that sortie and operating hour demand data from simulated wartime exercises can be converted into demand rates that D029 can use. Whether an item has sortie-based or operating hour-based demands, we can determine a wartime demand rate based on flying hours that is valid for computing safety levels using marginal analysis.

The following sections describe how to adjust item demand data from test results or war exercises into D029 inputs (detailed derivations and rigorous proofs of validity are provided in Appendix B). The gist of the mathematics is to convert demands based on sorties or operating hours into demands per flying hour. Thus the formulas that follow convert the SAC demand estimates into demands per flying hour, thereby "tricking" the D029 system to use more accurate demand estimates. The first section describes how to convert demands per sortie into equivalent demands per flying hour. Following that, we show how to convert demands per operating hour into equivalent demands per flying hour. If the reader is not interested in the mathematics, skip this section and continue with the discussion of AFLC Implementation Issues.

9

## Flying Hour Demand Rates for Demands Based on Sorties

Obviously, for demands which are a function of sorties, we require an estimate of wartime sorties $S_w$. An estimate of wartime flying hours $FHP_w$ is also required in the conversion to a flying hour demand rate.

For items whose demands are best predicted by aircraft sortie rates, and at least one failure for the item is observed during data collection, a TOIMDR based on flying hours can be determined by first computing the demands per sortie and then multiplying by the average sorties per flying hour. The result is a rate in units of demands per flying hour which is valid for any war scenario where the average flying hours per sortie is equal to $SFH_w$. This equation follows:

$$TOIMDR_w = \frac{n_f}{N} \cdot \frac{S_w}{FHP_w} \cdot 100,$$

where

$n_f$ = Number of equipment demands observed during the data collection period,

$N$ = Number of equipment sorties (aircraft sorties multiplied by QPA) during the data collection period,

$FHP_w$ = Planned wartime aircraft flying hours (first 30 days),

$S_w$ = Planned wartime aircraft sorties (first 30 days), and

$TOIMDR_w$ = Expected wartime demands per 100 flying hours.

Example 1

Flying Hour Demand Rates for Observed Demands Based on Sorties


ECM System: ALT-32 system
NSN:        5865-00-758-4479EW
QPA:        1

There were 103 equipment sorties in the SAC test, and 9 demands observed. If a total of 2800 wartime flying hours and 702 aircraft sorties are planned, then

$n_E$    = 9 demands
$N$      = 103 equipment sorties
$S_w$    = 702 sorties
$FIP_w$  = 2800 hours

$TOIMDR_w$ = (9/103) (702/2800) 100 = 2.19071 demands per 100 flying hours.

The 30-day pipeline quantity is 2.19071/100   2800   1 ≈ 61.


When demands are believed to be a statistical function of sorties but no demands are observed in the test sample, a TOIMDR based on flying hours can still be computed by first computing the demands per sortie and then dividing by the average flying hours per sortie. In this case we use a statistical model to estimate a nonzero demand rate per·sortie.

For example, suppose an item has a low average demand rate such as one demand per two hundred sorties (0.005 demands per sortie). It is possible that no demands will occur for the item in one sortie, ten sorties or even two hundred sorties of a test program. The expected number of demands for this item after one hundred sorties is "one-half of a demand" (0.005 demands per sortie times 100 sorties equals 0.5 expected demands). "One-half of a demand" translates to a fifty percent chance that no demands will occur and an equal chance that at least one demand will occur after one hundred sorties. If we conducted several tests, each consisting of one hundred sorties, no demands would be observed for fifty percent of the tests.

Given this, suppose the failure rate is not known already and that no demands occur for the item during a test program of one hundred sorties. There exists some non-zero demand rate that will result in this outcome (i.e., zero demands) fifty percent of the time for one hundred sorties. Our statistical model allows us to estimate that rate.

11

15

So, when no demands are observed, we estimated a demand rate based on the probability of observing no demands fifty percent of the time for the given number of sorties in the test program. Once again, the final rate is in units of demands per flying hour which is valid for any war scenario with $S_w$ sorties and $FHP_w$ flying hours. The resulting equation is slightly more complicated than the previous formula and is written as follows:

$$TOIMDR_w = (1 - 0.5^{1/N}) \cdot \frac{S_w}{FHP_w} \cdot 100.$$

### Example 2

Flying Hour Demand Rates for Demands Based on Sorties
(when no demands are observed)

ECM System:  ALQ-122 system
NSN:         5865-01-125-3823EW
QPA:         1

There were 103 equipment sorties in the SAC test, and 0 demands observed. If a total of 2800 aircraft wartime flying hours and 702 aircraft sorties are planned, then

N      = 103 equipment sorties
$S_w$  = 702 sorties
$FHP_w$ = 2800 hours

$$TOIMDR_w = (1-0.5^{1/103}) \cdot (702/2800) \cdot 100 = 0.16185 \text{ demands per 100 flying hours.}$$

The 30-day pipeline quantity is $0.16185/100 \cdot 2800 \cdot 1 \cong 5$.

## Flying Hour Demand Rates for Demands Based on Operating Hours

When demands are best predicted by system operating hours, computation of a wartime TOIMDR is also somewhat more complicated than the first case. Basically, a demand rate per operating hour is computed and this is multiplied by the operating hours per flying hour. Use of standard reliability theory in this case necessitates a slight adjustment to the demand rate per operating hour to account for an inherent bias of using finite sample sizes. The final demand rate is expressed by the following equation:

$$TOIMDR_w = \frac{(n_f - 0.3325)}{T} \cdot \frac{OT_w}{FHP_w} \cdot 100,$$

where

$T$ = total equipment operating time during the data collection period,

$OT_w$ = the number of wartime aircraft flying hours during which the ECM equipment will be operated (ECM on-time for the first 30 days), and

$FHP_w$ = Planned aircraft wartime flying hours (first 30 days).

Appendix B discusses the origin of the expression $(n_f - 0.3325)$. Basically, it adjusts the demand data to an average, unbiased demand rate using an approximation to a statistical distribution from standard reliability theory.

### Example 3

Flying Hour Demand Rates for Observed Demands Based on Operating Hours

ECM System:  ALQ-155 system

NSN:        5865-01-070-0271EW
QPA:        3

In the SAC test, this ECM equipment was operated for a total of 814.2 hours.
20 demands occurred. If a total of 2800 wartime flying hours are planned, during which the ECM will be operated for 1613 hours, then

$n_f$ = 20 demands
$T$ = 814.2 operating hours
$OT_w$ = 1613 hours
$FHP_w$ = 2800 hours
$(n_f - 0.3325)$ = 19.6675

$TOIMDR_w$ = (19.6675/814.2) (1613/2800) 100 = 1.39154 demands per 100 flying hours.

The 30-day pipeline quantity is 1.39154/100    2800    3 = 117.

When demands are believed to be a statistical function of operating hours but no demands are observed in the test sample, we can still estimate a non-zero TOIMDR based on flying hours. There was little MAJCOM interest in considering this situation, and the theory is somewhat involved. We do not document it in this chapter but include the derivation and resulting formula in Appendix B.

14

## Overview

The overall implementation goal is to use sortie and operating hour demand data, collected during simulated war exercises, to determine WRSK/BLSS requirements for ECM. For near-term implementation, MAJCOM personnel must convert the sortie and operating hour demand data into flying hour demand rates for input into D029. Long-term implementation consists of automating the conversion to flying hour rates so MAJCOM sortie and operating hour demands can be directly input to the computation system.

## Near-Term Issues

Near-term alternatives for implementing the new wartime demand computation methods are limited to using the current D029 data elements and formula for demands. The number of expected demands for an item in D029 is a function of the data elements TOIMDR, ECM FACTOR (WARFAC), FHP, and QPA. The flying hour program (FHP) is a fixed quantity for an entire WRSK/BLSS kit and the quantity per application (QPA) is already defined for each item. On-line D029 file-maintenance can be performed to adjust the data elements TOIMDR and ECM FACTOR. For WRSK kits, the simplest way to implement the new methodology is to set TOIMDR to the computed wartime demand rate $TOIMDR_w$ (as defined in the previous section) and set ECM FACTOR equal to one. This solution is acceptable for WRSK kit computations--since it is not necessary to compute a POS offset in such cases-- and clearly causes D029 to predict the "correct" number of wartime demands.

For BLSS kits, the POS offset must be computed, and therefore TOIMDR must be set to the peacetime demand rate $TOIMDR_p$ (obtained directly from D041 or negotiated during WRSK/BLSS reviews). In order to compute the "correct" number of expected wartime demands, the ECM FACTOR must be defined as

$$\text{WARFAC} = \text{ECM FACTOR} = \frac{TOIMDR_w}{TOIMDR_p}.$$

where $TOIMDR_w$ is the wartime demand rate computed using the new sortie/operating hour methodology and $TOIMDR_p$ is the peacetime demand rate (in units of demands per 100 flying hours). To see that this solution is correct, refer to Appendix B.

In summary, valid wartime flying hour demand rates can be computed from sortie or operating hour failure data. For immediate implementation, the D029 data elements TOIMDR and ECM FACTOR (WARFAC) can be externally computed and file maintained so that D029 will compute the correct WRSK/BLSS requirement. Using the new methodology to compute average demand rates the D029 marginal analysis algorithm will give the best mission support per dollar across the entire WRSK kit. This procedure requires no system changes to D029.

15

## Future Issues

A disadvantage of the near-term implementation is that TOIMDR and ECM FACTOR (WARFAC) must be externally computed and file-maintained into the D029 system. Even if the current system were enhanced to maintain separate peacetime and wartime demand rates, the current system will be limited to using flying hour programs to compute demands.

An ideal implementation for the wartime requirements system would include wartime usage programs other than flying hours (e.g., sorties and operating hours) and allow for demand rates based these alternative program elements. A preprocessor could perform any conversions necessary to allow marginal analysis tradeoffs among items having demand rates based on dissimilar programs. (For example, sortie-based and operating hour-based rates could be converted by the preprocessor to flying hour rates using the formulas derived in this report.) Also, to eliminate any need for a wartime adjustment factor, the system database could explicitly include both peacetime and wartime demand rates. Unlike the current system--where the wartime rate must be inferred from a product of data elements (the peacetime rate and the war adjustment factor)--this would allow peacetime or wartime rate to be adjusted directly and independently. The functional description for the Weapon System Management Information System (WSMIS)-Requirements Execution Availability Logistics Module (REALM), which is scheduled to replace D029, should be revised to include sortie and operating hour programs and demand rates based on these program elements.

## THE EFFECT ON THE REQUIREMENT

We used D029 to compute B052G and B052H WRSK requirements first with the old ECM FACTOR methodology and then again with the new sortie/operating hour-based demand rates for the 43 ECM items identified in the Hq SAC test program. The dollar costs shown in Table 2-1 are for FY88 WRSK programming kits (kits used for budget planning purposes).

COMPARISON OF COSTS
(Millions of $'s)

|  | CURRENT SYSTEM | NEW METHODOLOGY |
|---|---|---|
| B052G (ENTIRE KIT) | $360.3 | $373.9 |
| B052G (43 ITEMS ONLY) | $105.1 | $137.8 |
| B052H (ENTIRE KIT) | $481.7 | $464.6 |
| B052H (43 ITEMS ONLY) | $119.5 | $118.2 |

TABLE 2-1

To achieve the D029 SDO and NMCS goals, a B052G WRSK kit costs approximately $360 million using the current system (i.e., the ECM FACTOR approach) and nearly $374 million (a 3.8 percent increase) using the new methodology to estimate demand rates. The B052G kit requirements increase from $105 to nearly $138 million for the 43 ECM items involved in the SAC test (the unit cost of these items ranged from $640 to $107,000). On the other hand, the B052H kit cost is 3.6 percent ($17.2 million) lower using the new methodology. For the current authorization of four B052G WRSK kits and two B052H WRSK kits, the total cost increases by less than 1 percent (from $2.405 billion to $2.425 billion) using the new methodology.

As a further comparison, we assessed the stock levels generated by D029 under the old and new methodologies. In accordance with Hq SAC/LGS' original assertion, we assumed that the sortie-based and operating hour-based demand rates, as opposed to the old ECM FACTORed demand rates, are better estimates of the true demand rates for the 43 ECM items. When we assessed the levels, the ECM FACTOR methodology resulted in 484 expected backorders over a 30-day flying program for the B052G, and 273 backorders for the B052H. The new methodology resulted in only 4 backorders for the B052G and 2 for the B052H. At basically the same cost, the new methodology significantly reduces backorders.

17

We grouped the 43 items of the SAC test into their respective ECM systems in order to estimate the _system_ availabilities. Table 2-2 compares the predicted availabilities.

## COMPARISON OF SYSTEM AVAILABILITIES

### AVAILABILITY

| B052G WRSK KIT | CURRENT SYSTEM | NEW METHODOLOGY |
|---|---|---|
| ALQ-117 (7 items) | 0 % | 86.3% |
| ALQ-153 (16 items) | 0 % | 33.1% |
| ALT-16 (3 items) | 0 % | 98.9% |
| ALT-32 (5 items) | 0 % | 99.3% |
| ALQ-122 (4 items) | 19.3% | 99.3% |
| CHAFF (5 items) | 100.0% | 49.1% |
| FLARE (3 items) | 100.0% | 91.3% |

| B052H WRSK KIT | | |
|---|---|---|
| ALQ-117 (7 items) | 0 % | 91.0% |
| ALQ-153 (16 items) | 0 % | 52.8% |
| ALT-16 (3 items) | 62.7% | 99.2% |
| ALT-32 (5 items) | 0 % | 99.5% |
| ALQ-122 (4 items) | 65.8% | 99.4% |
| CHAFF (5 items) | 100.0% | 90.8% |
| FLARE (3 items) | 100.0% | 96.5% |

TABLE 2-2

Under the current system methodology, D029 grossly understocked some items, resulting in such low item availabilities that the assessed system availability was negligible. At the same time, D029 generated unnecessarily high stock levels for other items. In other words, the old methodology caused D029 to stock the wrong quantities. Using the new methodology, however, D029 buys a better mix of stock levels, resulting in much higher system availabilities.

Earlier, we discussed Hq SAC/LGS' recommendation to use rates based on 90 percent confidence estimates and indicated that using such rates would include safety levels as part of the pipeline. We computed the pipeline quantities using the new methodology outlined in this chapter and then again using SAC's 90 percent rates. The results are shown in Table 2-3.

COMPARISON OF PIPELINE COSTS
(Millions of $'s)

| | NEW METHODOLOGY | SAC 90% RATES |
|---|---|---|
| B052G (43 ITEMS ONLY) | $119.9 | $137 |
| B052H (43 ITEMS ONLY) | $100.6 | $114 |

TABLE 2-3

Using the new methodology, the predicted pipeline values for the 43 ECM items are $119.9 million for the B052G and $100.6 million for the B052H. Using SAC's 90 percent rates to compute pipelines, costs increase to $137 million and $114 million, respectively. Considering the current authorization of four B052G kits and two B052H kits, use of the 90 percent rates to compute expected demands would have increased pipeline requirements by nearly $95 million. In fact, the cost to stock the 90 percent pipeline quantities (e.g., $137 million for each B052G WRSK) would be nearly as much as the entire safety level costs using the new methodology ($137.8 million--from Table 2-1). This increase in the pipeline cost would not be based on an optimal allocation of dollars to maximize kit support. Furthermore, D029 would have added its own safety levels to these increased pipeline quantities, raising the kit costs even more.

19

## CURRENT IMPLEMENTATION STATUS

### The MAJCOMs

In accordance with the Hq AF/LEYS tasking, the MAJCOMs are continuing to collect more accurate sortie and operating hour usage and demand data from wartime readiness exercises. As we mentioned earlier, Hq TAC has tasked special teams to collect this data during Green Flag and Red Flag exercises. At the World-Wide ECM Conference in May 1987, Hq TAC/LGS projected having initial results for some tactical weapon systems by December 1987. Hq SAC is undertaking follow-on data collection efforts similar to their 1986 test program but on an expanded set of ECM subsystems.

Hq SAC/LGS has converted the sortie and operating hour rates from their 43-item test into flying hour rates using the procedures outlined in this chapter and has provided the new factors to ALC WRSK/BLSS monitors. The other MAJCOMs have been asked to follow suit as they collect and validate their own factors.

### AFLC

ALC WRSK/BLSS monitors have file-maintained the new demand factors provided by Hq SAC/LGS into the D029 computation system. As of March 1987 these factors have been used to determine WRSK/BLSS requirements for SAC ECM systems. The WRSK/BLSS monitors have been instructed to file-maintain additional factors as they are made available by the other MAJCOMs.

20

Blank

25
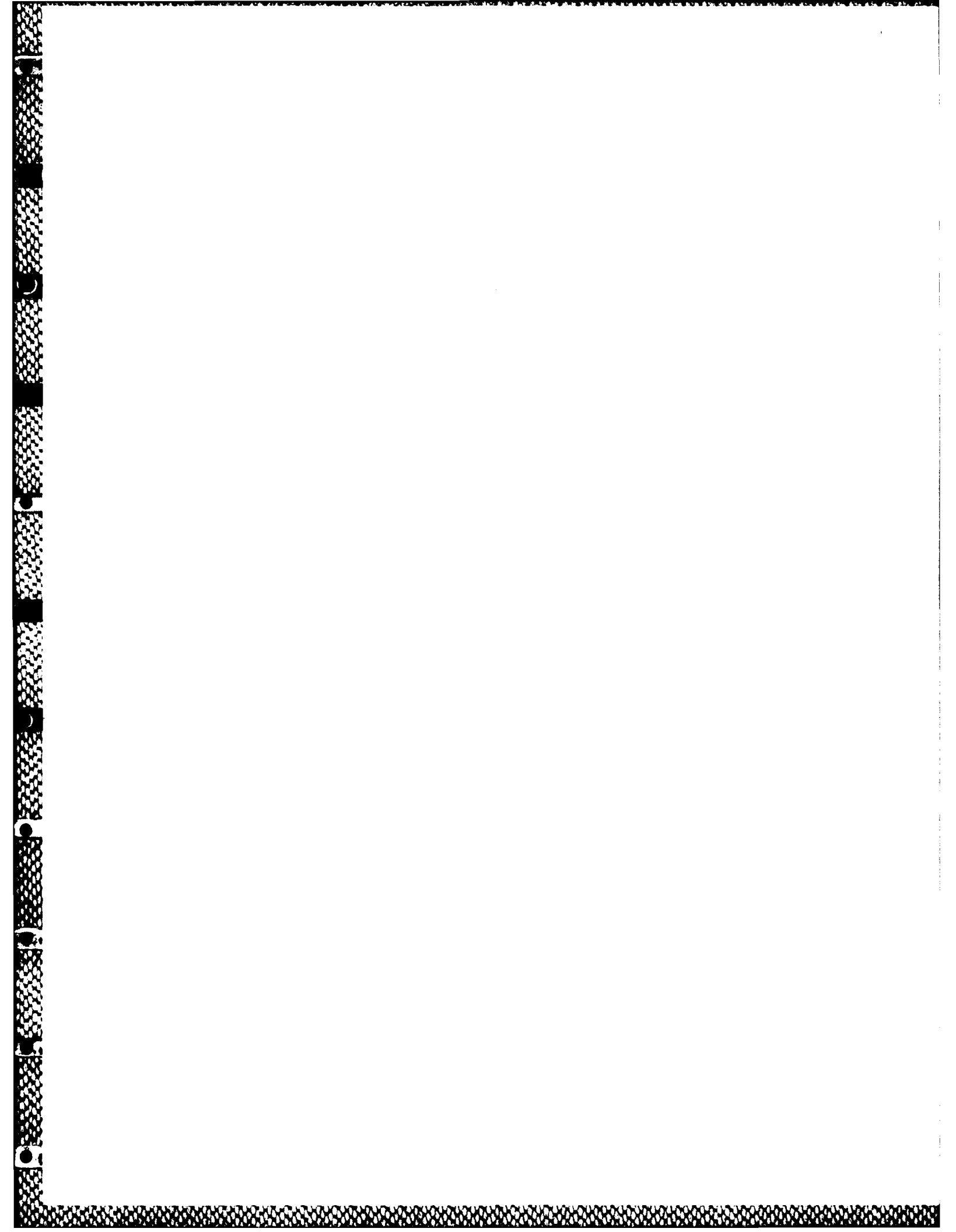
# CHAPTER 3

## CONCLUSIONS AND RECOMMENDATIONS

### CONCLUSIONS

1. For many ECM items, sortie and operating hour demand data provide a more accurate estimate of the requirement than flying hour data.

2. The current WRSK/BLSS requirements system only accepts demand rates based on flying hour programs.

3. Sortie and operating hour demand data can be converted into factors which War Requirements Computation System (D029) can use to compute pipeline WRSK/BLSS quantities, fixed safety levels for BLSS, and marginal analysis safety levels for WRSK.

4. D029 can use the converted demand rates to achieve optimal safety levels.

5. Under the old ECM FACTOR methodology, D029 grossly understocked some items, resulting in such low item availabilities that the assessed system availability was negligible. Use of the new methodology costs about the same but significantly improves ECM system and weapon system availability.

6. Use of Hq SAC/LGS' original demand rates based on 90 percent upper confidence limits overstates pipeline requirements by $95 million and would increase safety level requirements even more.

7. Immediate implementation in D029 will require external computation of the data elements TOIMDR and ECM FACTOR (WARFAC) using the formulas outlined in Chapter 2.

8. WSMIS/REALM should provide the capability to directly input, maintain and use sortie and operating hour demand rates.

### RECOMMENDATIONS

1. Change policy to authorize the new methodology for computing ECM wartime demand rates as an alternative to the former ECM FACTOR methodology. (OPR: Hq USAF/LEYS)

2. In the near term, MAJCOM's should use the new methodology to convert sortie and operating hour demand data into wartime flying hour demand rates by NSN, and provide this data to the appropriate ALC WRSK monitor. (OPR: each MAJCOM)

3. Task ALC WRSK monitors to file maintain the MAJCOM-provided demand data (TOIMDR and WARFAC) into D029 by stock number during the August update cycle. D029 processing then continues as usual. (OPR: Hq AFLC/MMMR)

4.    Incorporate into the WSMIS/REALM functional description the ability to explicitly specify demand rates based on sorties or operating hours and use these rates to compute WRSK/BLSS requirements.    (OPR: Hq AFLC/MMM)

# REFERENCES

1. "B-52 ECM Spares for War Readiness Spares Kit (WRSK)," 14 July 1986 Draft Staff Summary, Hq SAC/DOJA, Offut AFB, NE.

2. Department of the Air Force. Management and Computation of War Reserve Materiel (WRM). AFLCR 57-18. Wright-Patterson AFB: HQ AFLC, 21 April 1986.

3. Department of the Air Force. USAF Supply Manual. AFM 67-1, Volume 1, Part One, Chapter 14. Washington, D.C.: HQ USAF, 10 June 1985.

4. "Electronic Warfare Spares Requirement," 16 September 1986 briefing by Hq TAC/LGSWA during Electronic Warfare Spares Conference, 16-17 September 1986, Hq TAC/LGS, Langley AFB, VA.

5. "The EW Story," briefing given by WR-ALC/MMR during World-Wide ECM Conference, 5-6 May 1987, WR-ALC/MMR, Warner Robins AFB, GA.

6. "Forecasting Wartime Demands for Aircraft Electronic Countermeasure (ECM) Equipment," briefing dated 17 September 1986 by Perceptronics, Inc under AFHRL contract F33615-84-C-0071.

7. Minutes of Electronic Countermeasures (ECM) Factors Senior Level Review, 4 October 1984, WR-ALC/MMR, Warner Robins AFB, GA. Hq AFLC/MMMRR, 25 February 1985.

8. Minutes of Electronic Warfare Spares Conference, 16-17 September 1986, Hq TAC/LGS, Langley AFB, VA. Hq TAC/LGS, 30 September 1986.

9. Personal notes from Electronic Warfare Spares Conference, 16-17 September 1986, Hq TAC/LGS Langley AFB, VA. Hq TAC/LGS, 30 September 1986.

10. Personal notes from SAC ECM Meeting, 24-25 November 1986, Hq SAC/LGS Offut AFB, NE.

11. "Request for Senior Level Review," 9 July 1984 letter from Hq USAF/LEY to Hq TAC/LG and Hq AFLC/MM.

12. "SAC Electronic Countermeasures (ECM) Meeting," 17 November 1986 briefing by Hq SAC/LGSMO during SAC Electronic Countermeasures (ECM) Meeting, 24-25 November 1986, Hq SAC/LGS, Offut AFB, NE.

13. "Statistical Analysis of ECM Failure Data," 24 November 1986 briefing by Hq SAC/NR during SAC Electronic Countermeasures (ECM) Meeting, 24-25 November 1986, Hq SAC/LGS, Offut AFB, NE.

# GLOSSARY

Apportionment Year - the first full year of the D041 requirements computation.

Base Level Self-Sufficiency (BLSS) - WRM spares and repair parts intended for use as base support for units that plan to operate in place during wartime, considering the available maintenance capability.

Base Repair Rate (BRR) - that portion of the TOIMDR which base level maintenance can repair.

Bernoulli Trial - a statistical event which can have one of two possible outcomes.

Binomial Distribution - a statistical distribution describing the outcome of a series of identical Bernoulli trials.

Budget Year - the second full year of the D041 requirements computation. Also known as the War Year.

Chi-Square Distribution - a distribution describing a sampling statistic for the mean of the exponential distribution.

Confidence Limit - a statistical level of certainty in the outcome of a probabilistic event.

Conventional Quantity - the stock level of an item required if demands were to occur at exactly the average rate.

Current Year - the remainder of the current fiscal year in the D041 requirements computation.

D-Day - the first day of the war.

D029 - WRSK/BLSS Requirements Computation System.

D040 - War Readiness Lists/Requirements and Initial Spare Support Lists.

D041 - Recoverable Consumption Item Requirements System.

Daily Demand Rate (DDR) - the expected (mean) number of demands per day.

Demand on Supply - a failure which requires replacement from off-the-shelf stock.

Direct Support Objective (DSO) - a target NMCS rate used in D029.

ECM Factor - a ratio used to adjust peacetime demand rates to wartime demand rates.

Equipment Flying Hours - the number of hours accumulated across all installed units.

24

Equipment Sorties - the number of sorties accumulated across all installed units.

Exponential Distribution - a standard failure/reliability distribution.

Failure - the event where a component is no longer functioning within acceptable limits.

Fiscal Year - currently the period between 1 October thru 30 September.

Flying Hour Program (FHP) - number of hours flown by a unit in a specified time period (e.g., DFHP--Daily Flying Hour Program--is the number of flying hours accumulated by one unit in one day).

Marginal Analysis (MA) - an optimization technique in which spare parts are iteratively added to a requirement in order of greatest increase in support per dollar until the desired level of support is achieved.

Non-Optimized - the case where a requirement quantity is file maintained into D029 (e.g., D029 does not compute the requirement).

Not Mission Capable Supply (NMCS) - a situation in which a weapon system or end item can't perform any of its assigned wartime mission due to lack of parts.

Operate Time - the amount of time that equipment is switched on and fully functioning.

Other War Reserve Materiel (OWRM) - that portion of the requirement designed to support demands when POS and WRSK/BLSS have been exhausted. This quantity in on hand at D-Day, and supports the war effort until production from industry and resupply from repair can satisfy the war requirement.

Peacetime Operating Stocks (POS) - the quantity of spares required to support flying in peacetime.

POS Offset - the Peacetime Operating Stock offset is the quantity expected to be on hand at a BLSS supported unit when hostilities break out; computed from peacetime base repair rate (BRR).

Poisson Distribution - a statistical distribution often used to describe demands on supply.

Primary Aircraft Authorization (PAA) - the number of aircraft in a unit supported by WRSK or BLSS.

Prepositioned - WRM support of D-Day thru D+30.

Prestocked - WRM support of D+30 thru D+365.

Quantity Per Application (QPA) - the number of units of an item which are installed on one weapon system or end item.

Quarter - one of the following "90-day" periods: 1 Oct - 31 Dec, 1 Jan - 31 Mar, 1 Apr - 30 Jun, or 1 Jul - 30 Sep.

Remove and Replace (RR) - item is not repaired during WRSK support period.

Remove, Repair, and Replace (RRR) - item is repaired during WRSK support period.

Safety Level (S/L) - additional level over and above the conventional quantity. The safety level provides spares for those items which experience a greater than average failure rate.

Serviceable - a recoverable item considered to be fully operational.

Stock Due Out (SDO) - a situation in which a demand is generated and there are no spares available to replace the failed item.

Tactical Air Forces - the combined fleet of TAC, PACAF, USAFE, and AAC aircraft.

Total Organizational and Intermediate Demand Rate (TOIMDR) - average rate of demands an item experiences expressed in demands per 100 flying hours.

Unit Cost - the acquisition cost of one unit of a particular item.

Unserviceable - an item not considered to be fully functional.

Usage Program - a quantity of which demands are a statistical function.

War Mobilization Plan (WMP) - A document outlining various aspects of wartime operations, including expected aircraft flying hours and sortie generation rates.

War Readiness Spares Kit (WRSK) - an air transportable package of WRM spares, repair parts and related maintenance supplies required to support planned or contingency operations of a weapon or support system for a specified period of time pending resupply.

War Reserve Materiel (WRM) - that materiel required in addition to peacetime assets, to support the planned wartime activities reflected in the USAF war and mobilization plan (WMP).

War Year - the second full year (Budget Year) of the D041 requirements computation.

Wartime Usage Factor (WARFAC) - ratio of expected usage per flying hour in war to usage per flying hour in peacetime.

APPENDIX A

A BACKGROUND OF THE

CURRENT REQUIREMENTS SYSTEM

FOR ECM

Appendix A

A BACKGROUND OF THE CURRENT REQUIREMENTS SYSTEM FOR ECM

## Overview

Chapter 2 of the main report outlines the basics of the current system for computing ECM wartime spares requirements. In limiting the discussion in the main report, we exluded a great deal of background materiel. There is currently no single source which details the historical background of the ECM spares computation process (available sources of information consist of numerous letters and messages). So that other researchers/decision makers are not burdened by having to reconstruct this history, we assimilate much of it here. Besides, it never hurts to know where we've been and where we are.

In this appendix we first review the original capabilities of D029 to project wartime demands. Then we motivate the development of the current ECM Factor approach, which was to improve the D029 computation for ECM spares. Finally, we outline the MAJCOM test data collection program and the discussions which led to the new approach outlined in the main report.

## ORIGINAL D029 FORMULA FOR DAILY DEMANDS

When first implemented, D029 did not include the war adjustment factor (WARFAC). Every item was treated identically within the computation system—the system "assumed" that demands were direct, linear function of the flying hours. This original equation for the expected number of daily demands looked like this (the subscripts p and w denote peacetime and wartime, respectively):

$$E[DDmd] = \frac{TOIMDR_p}{100} \cdot DFHP_{MDS,w} \cdot QPA_w.$$

where

$TOIMDR$ = total OIM demand rate is units of demands per 100 flying hours,

$DFHP_{MDS}$ = daily flying hour program for the MDS on which the item is installed,

$QPA$ = item quantity per application for the MDS, and

$E[DDmd]$ = expected (mean) number of daily demands.

As we stated in the main report, the current system does include the additional factor WARFAC, but current policy sets WARFAC equal to one for non-ECM items. With this value of WARFAC, the current system formula for expected demands is still equivalent to the above formula.


## Non-optimization

To handle special cases--for example, demands for items such as the A-10 gun platform are not flying hour based--the system provided (and still provides) the capability to directly specify the requirements for an item in the computation. This is called a non-optimized (NOP) requirement since the it is not to based on marginal analysis. This option is used for items whose demands are not believed to be flying hour based or when the use of peacetime demand data is questioned. The decision to NOP an item is jointly made by the Item Manager (IM), System Program Manager (SPM), and the using command (MAJCOM). Developing requirements for such items is a completely manual and intensive process. Normally, information such as MICAP data is used to develop stock levels. As many as 35 to 40 percent of the items in some WRSK/BLSS kits are currently NOP items. (Also, MAC performs independent forecasts to determine their WRSK/BLSS requirements so this data is input as NOP requirements to D029.) The resulting requirements for such items are file maintained into D029 along with a NOP reason code from [3].


## Factor Reviews

In order to ensure the validity and credibility of WRSK/BLSS requirements, annual WRSK/BLSS Reviews are held for each weapon system at the managing Air Logistics Centers (ALC's). At each review, technicians evaluate item maintenance concepts (whether a kit item should be designated RR--remove and replace--or RRR--remove, repair, and replace), and other stock number data such as the daily demand rate, the base repair rate, the work unit code (WUC), and QPA. Demand data for ECM is thoroughly scrutinized due to the high value of ECM requirements.


### Development of the ECM Factors Approach


The D029 system normally considers all demands (except NOP quantities) to be a linear function of flying hours. It is here that problems arise with computing an ECM requirement in D029 since ECM demands are a function of several factors:


TYPE I:     equipment flying hours (failures due to mechanical shock, vibration, and other maintenance),

TYPE II:    equipment sorties,

TYPE 111:    equipment switching (failures due to power surges, and physical switching on/off, switching between transmit and receive), and

TYPE IV:    equipment operating time (failures which are due to electronic component fatigue or malfunction). This is believed to be the dominant mode of failure for ECM.

The situation is complicated slightly because reliability failures do not always translate into demands on the supply system. Quick-turn repairs can be performed on some equipment between sorties and these failures do not require stock to be obtained "off the shelf". The simplifying assumption is often made that demands on supply are proportional to reliability-based failure modes. This is essentially the reason why flying hours can often be used as a predictor of demands.

It is not the mere potential for several different ECM failure modes which causes a peacetime flying hour demand rate to be a poor candidate to predict wartime demands. In fact, when total operating hour usage and equipment switching is always proportional to total equipment flying hours (i.e., that ECM usage per flying hour was relatively constant) then a flying hour-based demand rate could implicitly account for TYPE III and TYPE IV demands. When sorties are proportional to flying hours, a flying hour-based demand rate could implicitly account for TYPE II demands. The original D029 logic is quite reasonable for predicting demands in this case.

On the other hand, if the expected wartime scenario calls for much greater ECM usage per flying hour than in peacetime then ECM usage per flying hour will not be constant from peace to war and a strict flying hour-based peacetime demand rate is likely to be a poor predictor of wartime demands in this case. For example, suppose that ECM failures are a linear function of operating hours (the TYPE IV failure mode is dominant). Suppose 5 failures are observed over 100 peacetime flying hours, during which the ECM equipment was operated for 50 hours. If the wartime program is 80 flying hours and ECM operate time is still 50 hours one would still expect 5 wartime failures. However, using a demand rate per flying hour, only 4 (= 80/100 · 5) wartime failures would be predicted. If the peacetime ECM operating time had been 25 hours then the demand rate per flying hour would predict only half of the expected wartime failures.

Not surprisingly, peacetime and wartime ECM usage are indeed expected to be very different. Peacetime ECM use is quite limited due to FCC regulations and the desire to limit the data our adversaries can obtain on the capabilities of the systems. On the other hand, wartime usage is obviously expected to be extensive. These facts suggested that D029's use of the peacetime demand rate was resulting in understated requirements for ECM spares.

In lieu of a computational alternative in D029, ECM requirements were NOP'ed using the best judgement (educated guesses and "gut feel") of WRSK review participants. Unfortunately this approach had its problems as well. Discounting the peacetime data did not leave much to go on--the USAF has not fought any recent conflicts which could be used as alternative data sources.

The resulting NOP requirements were difficult to defend during audit and operational scrutiny. [11] Furthermore, it was felt that these estimates were still understating the true requirement. Finally, by estimating requirements on a item-by-item basis externally to D029, no return-on-investment trade-off was possible to ensure the best weapon system support per dollar.

Implementation of the ECM Factor

In 1983 Hq USAF/LEYS directed the implementation of the ECM FACTOR, an adjustment ratio relating wartime to peacetime ECM usage. The idea was to keep the basic D029 methodology intact while accounting for differences between peace and war usage. Under the revised system, peacetime flying hour demand rates--necessary to calculate the POS offset in the BLSS computation--would still be obtained from D041; adjusted wartime ECM demand rates would be computed in D029 using the ECM war adjustment factor. The ECM FACTOR was defined as follows:

$$\text{ECM FACTOR} = \frac{\text{ECM On-time}_w}{\text{TOTFHP}_w} \cdot \frac{\text{TOTFHP}_p}{\text{ECM On-time}_p} \, ,$$

$$= \frac{\% \text{ ECM On-time}_w}{\% \text{ ECM On-time}_p} \, ,$$

where

TOTFHP = total accumulated peacetime or wartime item flying hour program, and

ECM On-time = the number of ECM operating hours accumulated over TOTFHP.

The ECM FACTOR converts peacetime flying hour demand rates to wartime flying hour demand rates by assuming that demands are actually a linear function of ECM operating hours. Substituting the ECM FACTOR into the daily demand formula,

$$E[DDmd] = \frac{\text{TOIMDR}_p}{100} \cdot \text{ECMFACTOR} \cdot \text{DFHP}_{MDS,w} \cdot \text{QPA}_w.$$

But

$$\text{TOIMDR}_p = \frac{\text{Demands}_p}{\text{TOTFHP}_p} \cdot 100,$$

and

$$\text{TOTFHP}_w = \text{DFHP}_w \cdot 30 \text{ days}$$

and

$$\text{ECM FACTOR} = \frac{\text{ECM On-hours}_w}{\text{TOTFHP}_w} \cdot \frac{\text{TOTFHP}_p}{\text{ECM On-hours}_p} \cdot$$

By holding the programs for peace and war constant throughout the computation (i.e., assume the same peacetime flying hours were used in the computation of both the demand rate and the ECM factor and assume that the wartime flying hours used to develop the ECM factor are applied to the computation of E[DDmd] for war) we see that

$$E[DDmd] = \text{Demands}_p \cdot \frac{\text{ECM On-hours}_w}{\text{ECM On-hours}_p} \cdot$$

This is basically the adjustment to peacetime demand data that was sought. Hq AFLC/MMMR wrote the program specifications to implement this new methodology in D029. In order to minimize programming effort and because of the potential to use this methodology for other items, the actual change to D029 allows a war adjustment factor, defined as

$$\text{WARFAC} = \frac{\text{Demand Rate}_w}{\text{Demand Rate}_p} ,$$

to be specified for any item. The daily demand formula was redefined:

$$E[DDmd] = \frac{\text{TOIMDR}_p}{100} \cdot \text{WARFAC} \cdot \text{DFHP}_{MDS,w} \cdot \text{QPA}_w.$$

Current policy defines WARFAC equal to one for all items other than ECM spares. For ECM equipment, WARFAC is equivalent to the ECM FACTOR. This factor is file maintained into D029 by the appropriate ALC WRSK monitor, and is fed back to the Recoverable Consumption Item Requirements System (D041) as the OWRM WAR ADJUSTMENT FACTOR.

As stated in Chapter 2, MAJCOM operational staffs are tasked to provide ECM FACTORS by MDS to Hq USAF for validation. Maintenance expertise is to be used to ensure ECM FACTORS are realistic adjustments from peace to war. Because the ECM FACTORS are specified by ECM system and MDS application, expected daily demands for each ECM stock number for a given ECM system in a given WRSK/BLSS kit are adjusted using the same ECM FACTOR. A reference table of past ECM FACTORS is provided in Attachment 1 to this appendix.

## 1984 Senior Level Review

Initial use of the ECM FACTOR methodology in D029 for a limited number of weapon systems resulted in dramatic increases in WRSK/BLSS ECM requirements. The March 1984 requirements computation reflected a $230 million growth in WRSK/BLSS. By March 1985, the ECM factor was in use for all weapon systems and accounted for the majority of a $956 million WRSK/BLSS increase. [5] Because of such increases, Hq USAF/LEY directed Hq TAC/LG and Hq AFLC/MM to conduct a senior-level review of the entire methodology. [11]   The purposes of the review were to validate the ECM computation methodology, determine if the ECM FACTORS were accurate, determine if the projected requirements were valid and determine how to defend them.

The review was conducted in October 1984. [7]   During the review, participants reexamined the old methodology (the computation without the ECM FACTORS) and confirmed that this obsolete methodology was understating the true requirement for many items. On the other hand, though the new methodology appeared sound and most of the factors appeared reasonable, it seemed to overstate the requirement for some items. In particular, the review group concluded that the factors for the ALQ-119 POD, ALQ-131 POD and ALE-40 chaff dispenser seemed unplausibly high: low peacetime usage resulted in factors of more than 25 for some MDS applications (which would increase item demand rates by 25 times).

The review brought out many issues concerning data accuracy, validity and application. A representative from Hq TAC/DOF felt that the TAF MAJCOMs did not realize the impacts of correctly/incorrectly estimating the ECM FACTORS. The discussions clarified several data collection issues so that all players would be operating from the same set of assumptions. The participants recommended that Hq USAF/LEY provide explicit instuctions to all MAJCOMs on the development of the ECM FACTORS, stressing the importance of providing accurate estimates of peacetime ECM usage--a critical part of the ECM FACTOR.

The group also emphasized the need .to consider individual ECM system peculiarities (e.g., transmitters versus receivers) when developing the ECM factors and agreed that the MAJCOMs should develop ECM factors for transmitters (which operate only part of the time) separately from receivers (which operate continuously). Equipment Specialists at Warner-Robins ALC--the ECM technology repair center--were tasked to identify the applicable stock numbers.

The MAJCOMs also questioned the linearity of failures (operating hour based or not) from peacetime to wartime, a fundamental assumption even in the revised D029 computation.

A-6

FAILURE RATE
(failures per
operating hour)

Linear Rate ——————
Nonlinear Rate ————

Peacetime
Operating
Hours

Wartime
Operating
Hours

OPERATING
HOURS
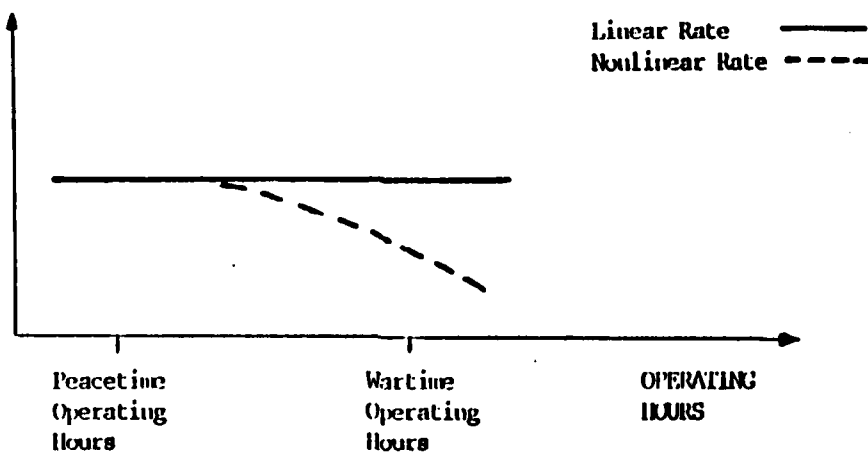
Figure A-1a.  Linear versus nonlinear failure rate

EXPECTED
NUMBER OF
FAILURES

Linear Rate ——————
Nonlinear Rate ————

Peacetime
Operating
Hours

Wartime
Operating
Hours

OPERATING
HOURS
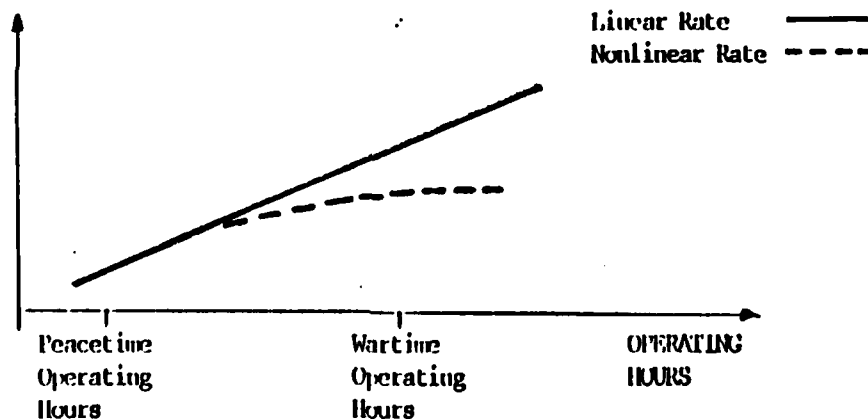
Figure A-1b.  Linear versus nonlinear failures

Since wartime ECM usage is expected to be quite high relative to peacetime, the validity of such an assumption is crucial to developing realistic requirements.  However, no alternative was offered to the use of the ECM FACTOR methodology.  A suggestion was made during the review to collect data under simulated wartime conditions in a controlled or desolate environment (to prevent the equipment from jamming commercial and military radar and communications).

A-7

Such a data collection effort for one ECM system (the F-16 ALQ-119 POD) had already been contracted out by WR-ALC/MMRRS.

Significant results of the review: Hq AFLC requested a reexamination of the peacetime usage data, Hq TAC/DOF and Hq SAC/DOR revised and validated their ECM FACTORS and Hq USAF/LEYS approved the revised rates. The new ECM FACTORS were provided to the ALC's and corrective procedures to improve and standardize the collection of ECM usage data were adopted in October 1984.

TAC Data Collection Program

In September of 1986, Hq TAC held a conference to discuss their progress on the ECM WRSK/BLSS issue. Participants from Hq USAF, Hq TAC/LG, Hq SAC/LG and Hq AFLC/MM examined data collection and validation problems.

TAC/LGS presented the results of a recent 30-day data collection test concerning ECM usage for combat coded aircraft carrying ECM. ECM pod failure data was not included; data was collected only for system control boxes (LRU's). The findings of the test were significant. The manual data collection effort, mainly consisting of pilot interviews, resulted in erroneous data, since tracking ECM usage was competing with other aspects of the missions flown. Also, peacetime ECM usage varied widely among different flying units; but in developing past ECM FACTORs on behalf of the TAF, Hq TAC/DOF had been giving equal weight to individual factors from USAFE, TAC, PACAF and AAC. TAC/LGS was to review the appropriateness of this approach.

Also at the conference, representatives from Perceptronics, Inc, briefed the results of a study under contract from the Air Force Human Resources Laboratory (HRL). Their study found evidence that average ECM demand rates decreased as the ECM usage increased, once again bringing the linearity of demands to operating hours into question. The study also determined that wartime usage and demands for ECM items could best be estimated by using data from operational exercises. [6]

After some discussion, the group recommended that special teams be tasked to collect ECM data at Green Flag, Red Flag and the Electronic Warfare Evaluation Program (EWEP). The group emphasized the need to collect of more accurate ECM usage data from an environment representative of wartime conditions and the need to collect more reliable operating hour failure data. One potential problem was identified: since operational units are assessed on overall performance at such exercises, advance maintenance performed on tested systems may result in biased demand data.

## SAC Data Collection Program

In spring of 1986, Hq SAC conducted a testing program to improve demand data collection. The 30 day test was of operational B-52G units which flew sorties with wartime ECM usage profiles and included careful recording of actual ECM operate times. Only those demands which would have resulted in WRSK/BLSS demands were included (e.g., certain on-aircraft repairs were not counted) through careful recording and filtering of failure data. The resulting demand data was established by individual stock number rather than by ECM system and MDS. The test was conducted by both northern (Loring AFB) and southern (Mather AFB) units and the data was aggregated.

Based on their test results Hq SAC/LGS recommended alternatives to using the current D029 ECM FACTOR methodology. As we discussed in the main report, SAC showed that sortie and operating hour demand rates are more accurate than flying hour rates for estimating wartime ECM spares requirements. The problem that motivated this study was that the current system (D029) requires flying hour rates--it cannot directly use sortie and operating hour rates.

Attachment 1 to Appendix A

HISTORICAL ECM FACTORS

The following tables show the ECM Factors which have been provided by Hq USAF/LEY to Hq AFLC/MMM for use in the D029 computation. These factors represent the planned percent on-time for war divided by the estimated percent on-time during peace. The large variations in some of the factors is caused primarily by 1) low peacetime usage of ECM and 2) changing estimates of this usage on the part of the MAJCOMs. For example, consider the case when the estimate of peacetime on-time increases from 1 percent to 2 percent. Though this change is small in absolute terms, it causes the ECM Factor to double, merely because an estimated value changed. The wide fluctuations in actual ECM Factors pointed to the need to better validate peacetime on-time data and the need to develop a better method for predicting wartime demands. Sources are noted below.

## TABLE A-1

## ECM FACTORS FOR TACTICAL AIR FORCE AIRCRAFT

| MDS | ECM System | 1984[a] | 1985[b] | 1985[c] | 1986[d] |
|-----|-----------|---------|---------|---------|---------|
| A-7 | ALE-40 | 37.01 | 4.00 | 20.00 | 20.00 |
| " | ALQ-119 | 18.52 | 4.00 | 16.67 | 14.28 |
| " | ALR-46 | 2.00 | 2.00 | - | 2.00 |
| A-10 | ALE-40 | 37.01 | 37.01 | 33.33 | 9.80 |
| " | ALQ-119 | 18.52 | 18.52 | 16.67 | 4.85 |
| " | ALQ-131 | 18.52 | 18.52 | 16.67 | 4.85 |
| " | ALR-46 | 2.44 | 2.44 | - | 2.36 |
| " | ALR-69 | 2.44 | 2.44 | - | 2.36 |
| " | ALR-74 | 2.44 | - | - | - |
| F-4C/D | ALE-40 | 2.38 | 4.00 | 14.28 | 14.28 |
| " | ALQ-101 | - | 4.00 | - | - |
| " | ALQ-119 | - | 4.00 | 20.00 | 20.00 |
| " | ALR-46 | - | 4.00 | - | 2.00 |
| " | ALR-69 | - | 2.00 | - | 2.00 |
| F-4E | ALE-40 | 14.28 | 14.28 | 14.28 | 7.69 |
| " | ALQ-119 | 9.09 | 9.09 | 9.09 | 9.09 |
| " | ALQ-131 | 14.28 | 14.28 | 12.50 | 4.55 |
| " | ALR-46 | 1.66 | 1.66 | - | 1.64 |
| " | ALR-69 | - | - | - | 1.64 |
| " | ALR-74 | 1.67 | - | - | - |
| F-4G | ALE-40 | 7.14 | 7.14 | 7.14 | 17.70 |
| " | ALQ-119 | 4.00 | 4.00 | 9.09 | 9.01 |
| " | ALQ-131 | 4.00 | 4.00 | 4.17 | 4.12 |
| " | APR-38 | 2.00 | .2.00 | - | 2.00 |

| MDS | ECM System | 1984[a] | 1985[b] | 1985[c] | 1986[d] |
|---|---|---|---|---|---|
| RF-4C | ALQ-101 | – | 1.08 | – | – |
| " | ALQ-119 | 1.08 | 1.08 | 1.08 | 1.30 |
| " | ALQ-125 | 2.00 | 2.00 | – | – |
| " | ALQ-131 | 1.08 | 1.08 | 1.08 | 1.30 |
| " | ALR-46 | 1.00 | 1.00 | – | 1.00 |
| " | ALR-74 | 1.00 | – | – | – |
| F-15D | ALQ-119 | 23.80 | 23.80 | – | – |
| " | ALQ-128 | 3.44 | 3.44 | – | 3.83 |
| " | ALQ-131 | 11.90 | 11.90 | 12.50 | 12.50 |
| " | ALQ-135 | 2.00 | 2.00 | – | 2.17 |
| " | ALR-50 | 1.06 | 1.06 | – | – |
| " | ALR-56 | 1.06 | 1.06 | – | 1.18 |
| F-16 | ALE-40 | 14.28 | 14.28 | 14.28 | 7.69 |
| " | ALQ-119 | 25.00 | 25.00 | 10.10 | 4.30 |
| " | ALQ-131 | 12.20 | – | 12.20 | 4.30 |
| " | ALR-69 | 1.01 | 1.01 | – | 1.16 |
| F-111D/E | ALQ-94 | 8.33 | – | – | 3.33 |
| " | ALR-62 | 2.38 | 2.38 | – | 2.35 |
| " | ALQ-119 | 8.33 | – | 10.00 | 3.33 |
| F-111F | ALQ-94 | 8.33 | – | – | 3.23 |
| " | ALQ-131 | 8.33 | – | 10.00 | 3.23 |
| " | ALR-62 | 2.38 | 2.38 | – | 2.44 |
| EF-111A | ALQ-94 | 8.33 | 8.33 | – | – |
| " | ALQ-99 | 1.01 | 1.01 | 3.00 | 3.40 |
| " | ALQ-119 | 8.33 | 8.33 | – | – |
| " | ALQ-137 | 3.00 | . – | – | – |
| HH-53 | ALR-46 | – | 1.00 | – | – |
| " | ALR-69 | – | 1.00 | – | – |
| OV-10A | ALR-46 | 1.15 | – | – | – |

[a]  Hq USAF/LEYS 051634Z Aug 83 message; Hq TAC 272110Z May 83 message; Hq AFLC/MMM 0918042 Apr 84 message.
[b]  Hq USAF/LEYS 221740Z Oct 84 message.
[c]  Hq USAF/LEYS 042115Z Jan 85 message.
[d]  Hq USAF/LEY 161510Z Dec 85 message.

TABLE A-2

ECM FACTORS FOR STRATEGIC AIR COMMAND AIRCRAFT

| MDS | ECM System | 1984[a] | 1985[a] | 1986[a,b] |
|------|-----------|---------|---------|-----------|
| B-52 | ALE-20 | 17.20 | 17.20 | 24.33 |
| " | ALE-24 | 28.66 | 28.66 | - |
| " | ALQ-117 | 3.33 | 3.33 | 17.29 |
| " | ALQ-122 | 1.01 | 1.01 | 38.88 |
| " | ALQ-153 | 8.60 | 8.60 | 3.65 |
| " | ALQ-155 | 1.87 | 1.87 | 9.25 |
| " | ALQ-172 | 3.33 | 3.33 | - |
| " | ALR-20A | 1.11 | 1.11 | 1.09 |
| " | ALR-46 | 1.11 | 1.11 | 0.99 |
| " | ALT-16 | 10.00 | 10.00 | 46.93 |
| " | ALT-32 | 10.00 | 10.00 | 131.40 |

[a] Hq USAF/LEYS 012043Z Oct 84 message; "Electronic Countermeasures (ECM) Meeting", briefing given 24 Nov 1986 at Hq SAC/LG; Hq USAF/LEY 161510Z Dec 85 message.

[b] 1986 ECM factors were not validated. Alternate test data was used instead.

APPENDIX B

REVISED ECM METHODOLOGY

# Appendix B

## REVISED ECM METHODOLOGY

As discussed in the main report, Hq SAC showed that use of sortie-based and operating hour-based demand data from carefully monitored wartime exercises could result in a more accurate and credible ECM requirement. However, in order to use such data in the current WRSK/BLSS requirements system (D029) some data conversions are required. In the following sections we derive those conversion formulas and show that the resulting factors are compatible with both the basic D029 demand computation and with the D029 algorithm used to perform marginal analysis tradeoffs. This discussion is admittedly tedious, but it provides rigorous proof that the conversions are valid.

For reference, the basic D029 equation for expected demands appears below, along with the corresponding definitions for each data element.

$$E[Dmd] = \frac{TOIMDR}{100} \cdot WARFAC \cdot FHP_{MDS} \cdot QPA.$$

| | | |
|---|---|---|
| TOIMDR | = | total OIM demand rate is units of demands per 100 flying hours, |
| WARFAC | = | the war adjustment factor, |
| $FHP_{MDS}$ | = | flying hour program for the MDS on which the item is installed, |
| QPA | = | item quantity per application for the MDS, and |
| E[Dmd] | = | expected (mean) number of demands. |

Our discussion is divided into five major sections. The first two sections are devoted to the situation where at least one demand is recorded during a test. After discussing the cases where demands are a function of sorties, we consider demands as a function of operating hours. The next two sections describe the more difficult cases where no demands are recorded during a test. Again, we discuss sortie-based demand rates first, followed by an examination of demands as a function on operating hours. Finally, the last section summarizes and discusses how to implement the new wartime demand rates using the current D029 data elements.

## Some Definitions

We assume that WRSK demands are equivalent to equipment demands and we use the terms demand and failure interchangeably. Failures rectified by immediate on-aircraft repairs are not included since such activity does not result in a withdrawal from WRSK/BLSS stock.

Also in the following discussion, the term equipment flying hours refers to the number of hours accumulated across all installed units of a given item: Equipment flying hours is equal to the number of aircraft flying hours multiplied by the item quantity per application (QPA). Likewise, equipment sorties refers to the number of sorties accumulated across all installed units of a given item: Equipment sorties equals the aircraft sorties multiplied by the item QPA.

## CASE 1: DEMANDS BASED STRICTLY ON SORTIES
## WHEN AT LEAST ONE DEMAND HAS OCCURRED

In this first case, the probability of ECM demand p is independent of equipment operate time--the number of ECM demands is a statistical function of the number of equipment sorties flown. For a given ECM system in the SAC test, all sorties are approximately identical with respect to the flying hours and ECM operate time. Since the number of demands cannot be greater than the number of equipment sorties, the series of test sorties for a given system can be thought of as a series of Bernoulli trials with some probability of ECM demand during a given equipment sortie:

Bernoulli trial = One equipment sortie of flying time h and ECM operate time of t,

$N$ = Number of equipment sorties,

$n_f$ = Number of equipment demands observed, and

$p$ = Probability that an ECM demand will occur during a random equipment sortie $(0 \leq p \leq 1)$

$$= \frac{n_f}{N} .$$

The binomial distribution describes the probability of observing a given number of ECM demands x for a given number of equipment sorties N with a probability of ECM demand p during a random equipment sortie:

$$f(x|N,p) = \binom{N}{x} p^x (1-p)^{N-x}, \qquad x=0,1,2,\ldots,N,$$

where the average number of demands is expressed by

$$E[demands] = N \cdot p.$$

B-2

Example:
$$p = 0.1$$
$$N = 10 \text{ trials}$$

$$P(0|N,p) = \binom{N}{0} p^0 (1-p)^N = (1-p)^N = 0.3486784$$

That is, in a set of 10 equipment sorties with a 10 percent chance of ECM demand during a random equipment sortie, nearly 35 percent of the time no demands would be observed.

The cumulative binomial distribution gives the probability of observing no more than x ECM demands for a given number of equipment sorties N with a probability of ECM demand p during a random equipment sortie:

$$F(x|N,p) = \sum_{i=0}^{x} \binom{N}{i} p^i (1-p)^{N-i}.$$

The cumulative binomial distribution can be used to determine a safety level since it is theoretically possible to determine the value of one of the variables x, N, p, or $F(x|N,p)$ when the values of the remaining three are known. An appropriate and intuitive approach is to select a safety level confidence C, $0 \leq C \leq 1$, and compute the safety level x such that $C = F(x|S_w \, QPA_w, p)$. The resulting value of x is the safety stock required to be 100 C percent confident that there will be enough stock to cover the demands over a wartime program of $S_w$ aircraft sorties. The value of x can be determined by enumerating the values of $F(x|S_w \, QPA_w, p)$ for x = 0, 1, 2, etc., until $F(x|S_w \, QPA_w, p) \geq C$.

This safety level model, though completely sound from the theoretical standpoint, requires data elements and computational logic which are very different from the structure of the current D029 system. However, D029 uses the Poisson distribution in marginal analysis. This distribution, with mean $S_w \, p$, is an approximation of the binomial distribution when $S_w$ (the number of wartime sorties) gets large and p (the probability of demand during a random sortie) gets small. Under these conditions the Poisson distribution has the same expected value and approximately the same "shape" as the binomial distribution (Attachment 1 to this appendix contains a comparison of the Poisson to the binomial distribution for realistic values of $S_w$ and p and shows it to be an excellent approximation).

The conditions on p and $S_w$ do hold: p is relatively small in the test data and $S_w$ is relatively large in the wartime scenario. Therefore, given the correct expected value (i.e., average number of demands), the D029 Poisson distribution will closely approximate the theoretical binomial demand distribution and therefore D029 marginal analysis will be consistent with the theoretically pure safety level model. So that D029 does compute the correct expected value, we need an appropriate wartime flying hour demand rate. The expected wartime demand rate per 100 flying hours is

$$\text{TOIMDR}_w = \frac{\text{Total Equipment Demands Expected}}{\text{Total Equipment Wartime Flying Hours}} \quad 100$$

$$= \frac{p \cdot S_w \cdot QPA_w}{FHP_w \quad QPA_w} \quad 100$$

$$= p \cdot \frac{S_w}{FHP_w} \cdot 100,$$

$$= \frac{n_f}{N} \cdot \frac{S_w}{FHP_w} \cdot 100,$$

where

$FHP_w$ = wartime flying hour program (first 30 days),

$S_w$ = wartime sorties (first 30 days), and

$\text{TOIMDR}_w$ = demand rate per 100 flying hours.

Notice that the aircraft flying hours and sorties are necessary ingredients to this computation. The expected number of demands for a given number of wartime flying hours $FHP_w$ consisting of $S_w$ sorties is

$$E[\text{30 Day Dmd}] = \frac{\text{TOIMDR}_w}{100} \cdot FHP_w \cdot QPA_w$$

$$= p \quad \frac{S_w \cdot 100}{FHP_w \quad 100} \cdot FHP_w \cdot QPA_w$$

$$= (S_w \cdot QPA_w) \cdot p,$$

B-4

which is the expected number of demands based on the original binomial probability distribution. This shows the basic D029 methodology can be used to compute the exact same expected number of demands (pipeline quantity) which was obtained using the original binomial formulation of the problem.

We illustrate the conversion from sortie based demands (with at least one observed demand) to a flying hour demand rate using Example 1 from the main report.

Example:

ALT-32 system        NSN 5865-00-758-4479EW

103 equipment sorties in the SAC test

9 demands observed

$QPA_w = 1$

$p = 9/103 = 0.0873786$

$FHP_w = 2800$ flying hours

$S_w = 702$ sorties over 30 days

$TOIMDR_w = 0.0873786 \cdot (702/2800) \cdot 100$
$= 2.19071$ demands per 100 flying hours

Total expected demands in 30 days

$E[30 \text{ Day Dmd}] = 2.19071/100 \cdot 2800 \cdot 1$
$\cong 61.3$ demands

$= p \cdot 702.$

We emphasize that the value of the $TOIMDR_w$ is dependent on the number of wartime sorties and flying hours. These values must be consistent with the WMP data used in D029. If changes to the wartime scenario cause the ratio of sorties to flying hours to change, then the value of $TOIMDR_w$ must be recomputed even if p, the probability of demand per sortie, is unchanged.

## CASE 2: DEMANDS BASED ON OPERATING TIME
## WHEN AT LEAST ONE DEMAND HAS OCCURRED

In this second case, where demands are observed for an ECM stock number and demands are believed to be based on operating time, a mean demand rate per operating hour is estimated. The collected data from the SAC test includes for each ECM item the number of demands observed $n_f$ and the number of operating hours up to the observation of each demand $t_1, \ldots, t_N$. The standard estimate of the true mean operating hour demand rate u given such data is the total number of demands divided by the total operating time:

$$\hat{u} = \frac{n_f}{t_1 + t_2 + \ldots + t_{nf}} = \frac{n_f}{T}.$$

If the mean time between demands is exponentially distributed (a valid assumption under reliability theory) then this estimate of the mean demand rate is biased. The bias becomes less significant as the observed sample size N increases. The sample size of the SAC test data is small and the bias in the estimate $\hat{u}$ of u could be large; however, confidence intervals on the true value of u can be developed by noting that the sampling statistic $2n_f/\hat{u}$ follows a chi-square distribution (denoted by $X^2$) with $2n_f$ degrees of freedom. The upper 100C percent confidence limit $\tilde{u}$ on the true value of u is then

$$\tilde{u} = \frac{X^2(1-C;2n_f)\hat{u}}{2n_f} = \frac{X^2(1-C;2n_f)}{2T}.$$

The 50 percent (C=0.50) confidence limit represents the average or expected demand rate per operating hour. To be 90 percent confident that the true demand rate is less than or equal to the computed value of $\tilde{u}$, given $n_f$ demands in T equipment operating hours, one would compute u using C=0.90. This demand rate is biased on the high side and would cause a marginal analysis routine to add safety levels on top of the implicit safety level already contained in the demand rate.

Because of the linearity/nonlinearity issue, this estimated mean demand rate per operating hour is valid only if the ECM equipment on time averages t hours per sortie. The value of $\tilde{u}$ is converted over to a wartime demand rate per 100 flying hours ($TOIMDR_w$) by multiplying by the portion of the aircraft wartime flying hours during which the ECM equipment will be operated.

$$TOIMDR_w = \tilde{u} \quad \frac{OT_w}{FHP_w} = \frac{X^2(1-C;2n_f)}{2T} \cdot \frac{OT_w}{FHP_w} \cdot 100.$$

where

$OT_w$ = the total number of aircraft flying hours the ECM equipment will be operated (first 30 days), and

$FHP_w$ = the wartime aircraft flying hours during which ECM will be used (first 30 days).

When demands are a function of operating hours, use of the Poisson distribution to perform D029 marginal analysis is completely sound since the Poisson distribution actually represents the "arrival rate" of demands when the mean time between demands is exponentially distributed (as previously assumed).

B-6

Therefore, we need only compute the average demand rate, which is determined at the 50 percent (C=0.50) confidence limit.

In this case, the previous equation is simplified by using the approximation $X^2(0.50; 2n_F) \cong 2n_F - 0.665$ (see Attachment 2 to this appendix). Substituting this into the equation gives the appropriate demand rate per 100 flying hours:

$$\text{TOIMDR}_w = \tilde{u} \cdot \frac{\text{OT}_w}{\text{FHP}_w} = \frac{(n_F - 0.3325)}{T} \cdot \frac{\text{OT}_w}{\text{FHP}_w} \cdot 100.$$

This value of $\text{TOIMDR}_w$ is valid in the case where the average wartime operating hours per sortie is approximately the same as the average test operating hours per sortie (small deviations are allowable when adjusting for WMP changes). In this sense, $\text{TOIMDR}_w$ is a point estimate of the average demand rate for a given scenario. This implicitly requires that the ECM test be performed in as realistic a setting as possible. When the ratio of $\text{OT}_w$ to $\text{FHP}_w$ changes, $\text{TOIMDR}_w$ must be recomputed.

We again illustrate the conversion with process with an example (in this case, Example 3 from the main report).

Example:

> ALQ-155 system       NSN 5865-01-070-0271EW
> 814.2 equipment operating hours in the SAC test
> 20 demands observed
> $\text{QPA}_w = 3$
> $\text{FHP}_w = 2800$ flying hours
> $\text{OT}_w = 1613$ hours

> $\text{TOIMDR}_w = (19.6675/814.2) \cdot (1613/2800) \cdot 100$
>            $= 1.39154$ demands per 100 flying hours

Total expected demands in 30 days

E[30 Day Dmd] = 1.39154/100 $\cdot$ 2800 $\cdot$ 3 $\cong$ 117.


## ITEMS EXPERIENCING NO DEMANDS:
## DERIVING A NONZERO DEMAND RATE

Certain ECM stock numbers did not experience any demands during the SAC test. A traditional computation of TOIMDR would result in a zero demand rate. The Poisson demand distribution for these items would then have a mean and variance of zero, and these stock numbers would compute a zero WRSK requirement. This is unacceptable, since peacetime demands for these items do occur. An alternate

provides credible demand rates but still uses data gathered from the ECM test period.

There are two ways to handle the case where no demands are observed during ECM operational testing: 1) nonoptimization and 2) conversion to a D029 TOIMDR.

## Nonoptimization

In this case, D029 does not compute the WRSK requirements for these items. The requirements are negotiated by item and the quantities are file maintained into D029. This requires intense involvement by MAJCOM and AFLC experts on ECM usage and demand experience and risks too much subjectivity.

## Determining a Demand Distribution

It is still possible to determine a nonzero demand rate by again considering the test sorties as a series of Bernoulli trials. Since $n_f = 0$ in this case, the value of p, if computed as before, would be zero. However, it is possible that no demands would be observed in a series of Bernoulli trials even when p is positive.

Example:
$$p = 0.1$$
$$N = 10 \text{ trials}$$

$$P(0|N,p) = \binom{N}{0} p^0 (1-p)^N = (1-p)^N = 0.3486784$$

That is, in a set of 10 sorties with a 10 percent chance of ECM demand during a random equipment sortie, nearly 35 percent of the time no demands would be observed.

This fact provides a way to use the binomial distribution in reverse to provide an estimate of an appropriate value of p. With the binomial distribution, it is possible to determine the value of one of the variables x, N, p, or $F(x|N,p)$ when the values of the remaining three are known. In the SAC test only two are known: N and x=0. This leaves the variables p and $F(x|N,p)$. Aside from eliminating the need to use this distribution in the first place, an arbitrary choice for p would be difficult to defend. Judgmental estimates could be used to select a value of p, but a more appropriate and intuitive approach is to develop a judgmental estimate of confidence that the test results are representative of what would be expected on the average for the same conditions. Under this approach, instead of specifying an explicit value of p, "experts" specify a percent confidence (100·C) that the normal outcome for N equipment sorties is more than x ECM demands. For x=0, the value of p is such that

$$1-C = \binom{N}{0} p^0 (1-p)^{N-0} = (1-p)^N.$$

Solving for p gives

$$p = (1-(1-C)^{1/N}).$$

The resulting value of p is the probability of ECM demand per equipment sortie such that N equipment sorties of flying time h and ECM operate time t will result in 0 demands $100 \cdot (1-C)$ percent of the time and more than 0 demands $100 \cdot C$ percent of the time.

This relationship can be used to provide an implicit "safety level" against the possibility of skewed test results. For example, to estimate a 90 percent upper confidence probability of demand based on having zero demands in N equipment sorties, one would compute p using C=0.90 (10 percent or 100-90 percent confidence in the test results). On the other hand, to compute D029 marginal analysis safety levels on top of a 90 percent upper confidence limit demand rate has the conceptual disadvantage of adding an explicit safety level to an implicit safety level. Therefore, to perform a valid marginal analysis tradeoff, the 50 percent (C=0.50) confidence limit is required:

$$p = (1-0.50^{1/N}).$$

We illustrate the computation of a demand probability using this approach. This is not yet the flying hour demand rate which we ultimately desire—the final flying hour demand rate will be derived in the next section. The following example is based on Example 2 from the main report.

Example:
        ALQ-122 system        NSN 5865-01-125-3823EW
        103 equipment sorties in the SAC test
        0 demands observed
        C = 0.50   (to get an "average" demand rate)

$$p = (1 - 0.50^{1/103}) = 0.006707$$

Notice that $P(0|103,0.006707) = 0.50$. In other words, 50 percent of the time, no ECM demands would be observed after 103 sorties when the probability of ECM demand on a random sortie is 0.006707.

The previous section has described a statistical model of ECM test results for the case when no demands are observed and a means to determine a demand probability distribution based on the number of test sorties flown. We now turn to the question of how to convert this statistical model into a flying hour demand rate. To do this, a fundamental question must be raised: Is the

true ECM demand mode one based on the number of equipment sorties flown or by the amount of time the equipment was operated per sortie?

## CASE 3: DEMANDS BASED ON SORTIES
## WHEN NO DEMANDS HAVE OCCURRED

In this case the probability of ECM demand p is independent of equipment operate time and the number of ECM demands is a statistical function of the number of equipment sorties flown. The "sortie based" methodology described for the case when demands were observed can also be applied to this situation:

$$TOIMDR_w = \frac{\text{Total Equipment Demands Expected}}{\text{Total Equipment Wartime Flying Hours}} \cdot 100$$

$$= \frac{p \cdot S_w \cdot QPA_w}{FHP_w \quad QPA_w} \cdot 100$$

$$= p \cdot \frac{S_w}{FHP_w} \cdot 100,$$

$$= (1-0.5^{1/N}) \cdot \frac{S_w}{FHP_w} \cdot 100,$$

where

$FHP_w$ = wartime flying hour program (first 30 days),

$S_w$ = wartime sorties (first 30 days), and

$TOIMDR_w$ = demand rate per 100 flying hours.

The result is the desired average flying hour demand rate. As before, the average aircraft flying hours per sortie $SFH_w$ is a necessary ingredient to this computation. The expected number of demands for a given number of total aircraft wartime flying hours $FHP_w$ consisting of $S_w$ sorties is

E[wartime demands] = $TOIMDR_w$ $FHP_w$ $QPA_w$.

To show the complete conversion to a flying hour demand rate, we use Example 2 from the main report.

B-10

Example:

ALQ-122 system       NSN 5865-01-125-3823EW
103 equipment sorties in the SAC test
0 demands observed
C = 0.50   (to get an "average" demand rate)

$S_w$ = 702 sorties
$FHP_w$ = 2800 hours
$QPA_w$ = 1

Then $TOIMDR_w$ = $(1-0.5^{1/103})\cdot(702/2800)\cdot 100$
                      = $0.006707\cdot(702/2800)\cdot 100$
                      = 0.16815 demands per 100 flying hours

E[demands] = 0.16815/100 $\cdot$ 2800 $\cdot$ 1 $\cong$ 4.7 demands

Note that this gives the same answer as if we had computed the expected number of demands using the original binomial distribution:

E[demands] = $S_w\cdot$ p = 702 $\cdot$ 0.06707 $\cong$ 4.7.

Once again, we emphasize that the value of the $TOIMDR_w$ is dependent on the number of wartime sorties and aircraft flying hours. If changes to the wartime scenario cause the ratio $S_w/FHP_w$ to change, the value of $TOIMDR_w$ must be recomputed even if p, the probability of demand per equipment sortie, is unchanged.


## CASE 4: DEMANDS BASED ON OPERATE TIME
## WHEN NO DEMANDS HAVE OCCURRED


In this last case, the demands are a function of operating time and the test results can be thought of as N estimates of the demand rate per operating hour $\hat{u}$; in this case $\hat{u}=0$. However, there is still a way to compute a nonzero TOIMDR using the probability of ECM demand per equipment sortie p developed above, but considering that fact that p is a function of operate time t per equipment sortie. We make the important assumption that the test of t operating hours per equipment sortie is representative of the wartime scenario. We also assume a reliability function which is exponentially distributed.

Let u be the demand rate per ECM operating hour and t be the ECM operating hours per equipment sortie. Then the probability of observing a demand in t operating hours is 1-exp(-u$\cdot$t). Since every sortie is assumed identical, t is a constant and this implies that


p = 1-exp(-u$\cdot$t).

Solving for the demand rate ,

$$u = \frac{- \ln (1-p)}{t}.$$

In other words, u is the mean demand rate of an exponential demand distribution such that the probability of observing a demand during an equipment sortie consisting of t ECM operating hours is p.

In the case where zero demands are observed, the definition of p can be used to simplify this equation. Since every sortie is assumed identical, let T = N t.

$$u = \frac{- \ln (1-p)}{t} = \frac{- \ln (1- (1-(1-C)^{1/N}))}{t}$$

$$= \frac{- 1/N \cdot \ln (1-C)}{t} = \frac{\ln (1/(1-C))}{N \cdot t}$$

$$= \frac{\ln (1/(1-C))}{T}.$$

We once again illustrate by way of example. This example does not appear in the main report.

Example:

ALQ-122 system        NSN 5865-01-125-3823EW
103 equipment sorties in the SAC test
325.6 equipment operating hours in the SAC test
0 demands observed
C = 0.50   (to get an "average" demand rate)

u = -ln(1/0.5)/(325.6) = 0.002129 demands per operating hour.

Note that the probability of ECM demand in 325.6/103 = 3.16 operating hours is the same the probability of demand per sortie estimated earlier for this item:

1 - exp(-0.002129·3.16) = 0.06707 = p.

u is a point estimate for a fixed value of t and N. The computation of this estimate must be based on the actual test conditions since we have made the assumption that p is dependent on t. u is still valid for small deviations from the test sortie conditions (e.g., slightly different ECM operate times). To

convert to an average wartime $TOIMDR_w$ based on aircraft wartime flying hours, $C=0.50$. Also the ECM operate time and aircraft wartime flying hours is required. The desired average demand rate per 100 flying hours is

$$TOIMDR_w = u \cdot \frac{OT_w}{FHP_w} \cdot 100 = \frac{\ln (1/0.50)}{T} \cdot \frac{OT_w}{FHP_w} \cdot 100$$

$$= \frac{\ln (2)}{T} \cdot \frac{OT_w}{FHP_w} \cdot 100.$$

Example:
ALQ-122 system      NSN 5865-01-125-3823EW
325.6 equipment operating hours in the SAC test
0 demands observed

$OT_w$ = 1613 operating hours
$FHP_w$ = 2800 flying hours

$TOIMDR_w = (\ln(2)/325.6) \cdot (1613/2800) \cdot 100$
           $= 0.12264$ demands per 100 flying hours.


Once again, the value of $TOIMDR_w$ is dependent on the wartime scenario. If the scenario changes with slight changes in the ECM operate time per sortie, the old value of u is valid, but the ratio $OT_w/FHP_w$ has changed and $TOIMDR_w$ must be recomputed. If the operating hours per sortie in the new scenario is radically different from the conditions of the test, then the test results may no longer be applicable and the value of   must be rejected. This would force the collection of new test data under conditions representative of the revised wartime scenario.

B-13

## Attachment 1 to Appendix B

## COMPARISON OF POISSON AND BINOMIAL DISTRIBUTIONS

In our analysis we claim that the Poisson distribution can be used in place of the binomial distribution for sortie-based demands. Many statistical text books show that the Poisson distribution can be derived from the binomial distribution with mean Np by holding Np constant and letting N while p 0. Even when these conditions are approximately true--when N is large and p is small--the cumulative Poisson distribution can be used to approximate the cumulative binomial distribution for the purpose of computing confidence levels. Under such conditions the two distributions not only have the same expected value, Np, but the "shapes" of the distributions are nearly the same.

In this study the value of p is determined from the test demand data and is the probability of demand during a random sortie. As discussed in Chapter 2 of the main report, SAC recommended a sortie-based demand rate for an item when no demands were recorded over the test or when demands had occurred but equipment operating hours was too low to provide a statistically reliable operating-hour demand rate. In these cases, p was usually less than 0.05 and the largest value of p turned out to be 0.10 (i.e., less than 1 demand per 10 sorties).

The value of N is determined from the wartime scenario and represents the number of wartime sorties to be flown over the 30-day WRSK support period. N is a relatively large number--for a 24 PAA squadron, even two sorties per aircraft per day would result in 48 sorties per day and 1440 sorties over 30 days.

Let C = confidence levels (that demands will not exceed a specified quantity),

   N = the number of Bernoulli trials (i.e., number of sorties),

   p = probability of demand during a Bernoulli trial (i.e., the probability that the item will fail during a random sortie),

   $u = Np$
     = mean of the binomial and Poisson distributions
     = expected quantity,

   $x_B$ =   the lowest value of x such that the cumulative binomial distribution $F_B(x|N,p) \geq C$ (the amount of stock required to be 100·C percent confident that demands will not exceed stock),

   $x_P$ =   the lowest value of x such that the cumulative Poisson distribution $F_P(x|u) \geq C$ (the amount of stock required to be 100·C percent confident that demands will not exceed stock).

As stated above, when N is large and p relatively small, $x_p \approx x_B$. Tables B-1, B-2, and B-3 compare the values of $x_B$ and $x_p$ for two values of N, various values of p, and for reasonable confidence levels.

For example, suppose an item has a probability of demand of 0.1 (1 per 10 sorties) and that 48 sorties are planned (a relatively low value of N for the 30-day WRSK support period). Suppose the goal is to be 85 percent confident that on-hand stocks will be sufficient to cover the demands generated by the 48 sorties. Table B-1 shows that the binomial and the Poisson models both predict that there is at least an 85 percent chance that the number of demands will not exceed 7. Therefore, the stock level for 85 percent confidence is 7 in both cases.

From the following tables, it should be clear that the two distributions begin to differ significantly only when the probability of demand is rather high (e.g., more than a 25 percent chance of demand per sortie) and the number of sorties is relatively small. For our purposes the number of ECM demands is relatively small and the number of sorties relatively large. So, for the wartime scenario and test conditions the Poisson distribution is an excellent proxy for the binomial distribution.

TABLE B-1

COMPARISON OF BINOMIAL AND POISSON DISTRIBUTIONS
FOR N=48 AND u = Np

| Confidence Level | p=0.010 | | p=0.025 | | p=0.050 | | p=0.100 | | p=0.200 | | p=0.250 | | p=0.500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $x_p$ | $x_B$ | $x_p$ | $x_B$ | $x_p$ | $x_B$ | $x_p$ | $x_B$ | $x_p$ | $x_B$ | $x_p$ | $x_B$ | $x_p$ | $x_B$ |
| 60.0 % | 1 | 1 | 1 | 1 | 3 | 3 | 5 | 5 | 10 | 10 | 13 | 13 | 25 | 25 |
| 75.0 % | 2 | 2 | 2 | 2 | 4 | 4 | 6 | 6 | 12 | 11 | 14 | 14 | 27 | 26 |
| 85.0 % | 3 | 3 | 3 | 3 | 5 | 5 | 7 | 7 | 13 | 12 | 16 | 15 | 29 | 28 |
| 90.0 % | 4 | 4 | 4 | 4 | 6 | 6 | 8 | 8 | 14 | 13 | 17 | 16 | 30 | 29 |
| 92.5 % | 5 | 5 | 5 | 5 | 7 | 7 | 9 | 9 | 15 | 14 | 18 | 17 | 31 | 30 |
| 95.0 % | 6 | 6 | 6 | 6 | 8 | 8 | 10 | 10 | 16 | 15 | 19 | 18 | 32 | 31 |
| 97.5 % | 7 | 7 | 7 | 7 | 9 | 9 | 11 | 11 | 17 | 16 | 20 | 19 | 34 | 32 |
| 99.0 % | 8 | 8 | 8 | 8 | 10 | 10 | 12 | 12 | 18 | 17 | 21 | 20 | 36 | 33 |
| 99.5 % | 9 | 9 | 9 | 9 | 11 | 11 | 13 | 13 | 19 | 18 | 22 | 21 | 38 | 34 |
| 99.9 % | 10 | 10 | 10 | 10 | 12 | 12 | 14 | 14 | 20 | 19 | 24 | 22 | 40 | 35 |

# TABLE B-2

## COMPARISON OF BINOMIAL AND POISSON DISTRIBUTIONS
## FOR N=480 AND u = Np

| Confidence Level | p = 0.010 | | p = 0.025 | | p = 0.050 | | p = 0.100 | | p = 0.150 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $x_P$ | $x_B$ | $x_P$ | $x_B$ | $x_P$ | $x_B$ | $x_P$ | $x_B$ | $x_P$ | $x_B$ |
| 60.0 % | 5 | 5 | 13 | 13 | 25 | 25 | 50 | 50 | 74 | 74 |
| 75.0 % | 6 | 6 | 14 | 14 | 27 | 27 | 53 | 52 | 78 | 77 |
| 85.0 % | 7 | 7 | 16 | 16 | 29 | 39 | 55 | 55 | 81 | 80 |
| 90.0 % | 8 | 8 | 17 | 17 | 30 | 30 | 57 | 57 | 83 | 82 |
| 92.5 % | 9 | 9 | 18 | 18 | 31 | 31 | 58 | 58 | 84 | 83 |
| 95.0 % | 10 | 10 | 19 | 19 | 32 | 32 | 60 | 59 | 86 | 85 |
| 97.5 % | 11 | 11 | 20 | 20 | 34 | 34 | 62 | 61 | 89 | 88 |
| 99.0 % | 12 | 12 | 21 | 21 | 36 | 36 | 65 | 64 | 92 | 91 |
| 99.5 % | 13 | 13 | 22 | 22 | 38 | 37 | 67 | 66 | 95 | 93 |
| 99.9 % | 14 | 14 | 24 | 24 | 40 | 40 | 71 | 69 | 100 | 97 |

# TABLE B-3

## COMPARISON OF BINOMIAL AND POISSON DISTRIBUTIONS
## FOR N=720 AND u = Np

| Confidence Level | p = 0.010 | | p = 0.025 | | p = 0.050 | | p = 0.100 | | p = 0.150 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $x_P$ | $x_B$ | $x_P$ | $x_B$ | $x_P$ | $x_B$ | $x_P$ | $x_B$ | $x_P$ | $x_B$ |
| 60.0 % | 8 | 8 | 19 | 19 | 37 | 37 | 74 | 74 | 110 | 110 |
| 75.0 % | 9 | 9 | 21 | 21 | 40 | 40 | 78 | 77 | 115 | 114 |
| 85.0 % | 10 | 10 | 22 | 22 | 42 | 42 | 81 | 80 | 119 | 118 |
| 90.0 % | 11 | 11 | 24 | 23 | 44 | 44 | 83 | 82 | 121 | 120 |
| 92.5 % | 12 | 12 | 25 | 24 | 45 | 45 | 84 | 84 | 123 | 122 |
| 95.0 % | 13 | 13 | 26 | 25 | 46 | 46 | 86 | 85 | 125 | 124 |
| 97.5 % | 14 | 14 | 27 | 27 | 48 | 48 | 89 | 88 | 128 | 127 |
| 99.0 % | 15 | 15 | 29 | 28 | 51 | 50 | 92 | 91 | 133 | 131 |
| 99.5 % | 16 | 16 | 30 | 20 | 52 | 52 | 95 | 93 | 136 | 133 |
| 99.9 % | 17 | 17 | 32 | 32 | 56 | 55 | 100 | 98 | 141 | 139 |

## CHI-SQUARE VALUES[*]

In our analysis we required the 50 percent confidence point of the $X^2$ distribution in order to compute demand rates for demands based on operating hours. Selected values of $X^2(0.50, 2n_f)$ are listed in the following table ($n_f$ represents the number of demands). An excellent approximation to these values is

$$X^2(0.50, 2n_f) \approx 2n_f - 0.665.$$

The percent error in this approximation is only 4 percent when the number of demands equals one and is negligible for all $n_f$ greater than 3. Such an approximation is reasonable since $n_f$ will be greater than one.

In Example 3 of the main body of this report, $n_f$ had a value of 20. Using Table B-4, the appropriate value of $X^2(0.50, 2n_f)$ is 39.34. Using the approximation formula, $X^2(0.50, 2n_f) \cong 2 \cdot 20 - 0.665 = 39.335$, for a relative error of less than 0.013 percent.

### TABLE B-4

### VALUES OF $X^2(0.50, 2n_f)$

| $n_f$ | $X^2(0.50, 2n_f)$ | $n_f$ | $X^2(0.50, 2n_f)$ |
|-------|-------------------|-------|-------------------|
| 1 | 1.39 | 12 | 23.34 |
| 2 | 3.36 | 13 | 25.34 |
| 3 | 5.35 | 14 | 27.34 |
| 4 | 7.34 | 15 | 29.34 |
| 5 | 9.34 | 20 | 39.34 |
| 6 | 11.34 | 25 | 49.33 |
| 7 | 13.34 | 30 | 59.33 |
| 8 | 15.34 | 35 | 69.33 |
| 9 | 17.34 | 40 | 79.33 |
| 10 | 19.34 | 45 | 89.33 |
| 11 | 21.34 | 50 | 99.33 |

[*] Adapted from William W. Hines and Douglas C. Montgomery, _Probability and Statistics in Engineering and Management Science, 2nd Ed._ (John Wiley & Sons: New York), 1980.

END

Date

FILM

DTIC

7 — 85