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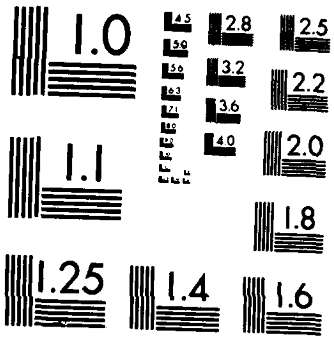

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ANALYSIS OF A STOCHASTIC MODEL TO DETERMINE FAILURE RATES FOR COMMUNICATION-ELECTRONIC SYSTEMS

THESIS

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THESIS

Presented to the Faculty of the School of Logistics

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Thomas M. Skowronek, B.S.

Captain, USAF

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Thomas M. Skowronek

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ABSTRACT

Work accomplished by Headquarters Air Force Logistics Command (AFLC) demonstrates a need to consider both "on-time" and "off-time" failures when computing communication-electronic spares requirements. However, AFLC has been unable to verify and validate a method that would integrate both failure types into a single requirements algorithm. This thesis attempts to verify and validate a method which integrates the two distributions.

On-time failures are derived through a stochastic growth process, where expected on-failures are divided by expected off-failures, then multiplied by both an initial off-failure rate and power-ups. The initial off-failure rate equals expected off-failures divided by average power-ups attempted. Off-failures occur through unsuccessful attempts to power-up a system.

The resultant total failure rate equals the cross product of the two failure functions, and is a failure plane instead of a line. If a linear rate is required, then the sum of the two failures could also be distributed over either on-hours or power-ups to arrive at a requirement.

ANALYSIS OF A STOCHASTIC MODEL TO DETERMINE FAILURE RATES FOR COMMUNICATION-ELECTRONIC SYSTEMS

I. Introduction

Background

The Air Force wartime mission is "to-fly-and-fight" with modern weapon systems. In order to meet this mission, the Air Force must provide adequate support. Computer based management systems aid the process of providing logistics support. The object of these computer-based systems is to effectively manage and assess the supply and maintenance support of weapon systems.

An integral part of the Air Force mission is the support provided by command, control, and communication (C3) systems. Without C3 support, the ability "to-fly-and-fight" would be jeopardized. At present, the Air Force maintains little if any computer-based information to compute wartime spares requirements for C3 systems. However, the Air Force Logistics Command (AFLC) is interested in using a computerized method to determine C3 systems support requirements. The Air Force has computer capability to calculate C3 system support requirements; however, a question exists on how to calculate component failure rates, an essential element for input into any model.

Specific Problem

A small but important element of C3 is mobile communications-electronic (CE) systems. The initial support required to maintain the serviceability of mobile CE systems during the early days of war is provided by war reserve spares kits (WRSKs) (3:14-4). At present, WRSK levels for mobile CE systems are not computed by a computer model. Instead, a meeting is held once a year between the users and the suppliers where they analyze data from past years and offer personal input to arrive at the WRSK levels (3:14-34).

A computerized model offers an alternative method for determining WRSK requirements. However, the main obstacle in implementing a computer model is deciding how to determine component failure rates. After much research and discussion with HQ AFLC, a failure rate based on a dual distribution seems to be a realistic approach to solving how the total failure rate should be calculated. Once the total failure rate is calculated, a computerized model can offer an effective and efficient alternative to the present method of computing WRSK requirements.

Research Questions

At present, component failure rates are determined through dividing total failures by operating time. However, AFLC feels this method may not necessarily compute accurate rates due to the unique operating environment of mobile CE systems (10). At times they are in transit, moving to and from new operating locations; at other times, they are stationary, performing their mission. This unique operating environment suggests two failure rate categories exist.

The first category, operating failures, occur and are detected when the equipment is operating. The second category, non-operating failures, occur when equipment is idle, but are detected when the equipment is powered-up. For clarification, an operating failure is defined as any failure that occurs after the equipment is powered-up and is on-line performing its designated function. A non-operating failure is any failure that is detected during equipment power-up in which the equipment does not come on-line. These non-operating failures are a combination of failures that occur during system power-down, while the system is dormant, or when the system is powered-up. Thus, there exists the possibility of having two unique failure rate distributions which may produce one total failure rate.

Given this scenario, this research attempts to answer these questions:

1. Is it possible to derive a methodology for calculating a total failure rate for mobile CE system components using on-time and off-time failures? In order to calculate this total failure rate, both failure rate distributions must be found, and once found, mathematically combined to calculate a total failure rate.

2. Once the methodology for calculating a total failure rate is produced, can the model be verified and validated using empirical data?

3. Depending on the answers to these questions, determine is it possible to use the validated dual distribution failure rate and calculate a 30 day WRSK requirement using an existing requirements computation model?

Justification

This thesis will develop a methodology for calculating a realistic total failure rate for mobile CE system components. Once developed, the total failure rate will accurately determine WRSK requirements to support mobile CE systems.

Scope and Limitations of Research

This research could extend across many different equipment systems, analyze many types of data, and use different computer models in calculating a total failure rate; however, some limitations needed to be applied. First, the task of computing requirements for an entire system is outside the scope of this thesis. Thus, this research limits the number of end items assessed to five. Five end items, common CE system items used throughout different MAJCOMs, were initially selected for analysis. The five end items selected were:

1. AN/TPS-43E Radar Set
2. A/E 24U-8 Power Plant
3. AN/TRC-97A Radio Set
4. AN/TSC-53 Communications Central
5. AN/TSC-60 HF Communications Van

The serviceability of these end items contribute the most to the availability of any mobile CE system.

The second limitation within this research is the exclusive concentration on mobile CE systems. These systems operate in a unique environment in which they are frequently powered-up and down. This is an ideal environment to conduct research for determining operating and non-operating failure rates.

The third limitation focuses on the two types of failures. Operating failures are straight forward; however, the non-operating failures need clarification. As stated earlier, non-operating failures are detected during equipment power-up. These failures are a combination of three specific types. First there are dormant failures, or failures occurring when the equipment is not operating, which includes failures occurring while the unit is moving from one location to another. Secondly, there are those failures which occur during a power-down phase. Finally, there are power-up failures caused by electrical surges in the equipment. Any of these three categories, will only be discovered when the system is going through a power-up cycle

(1: Sec IV, 12). Therefore, although non-operating failures could include three separate failure rates, for simplicity, they are all combined into one rate based on power-up cycles.

In this research, the terms non-operating failures, off-time failures, and off-failures all refer to the same phenomena. The terms operating failures, on-time failures, and on-failures are also used interchangeably.

Finally, this thesis focuses on determining a failure rate, and thus does not discuss maintenance contributions to requirements. The key to requirements computation in a cyclic environment is determining a true failure rate. Failures, regardless of their cause, will all receive identical repair. Therefore, the issue is to determine a failure function, and not compute repairs.

II. Literature Review

Overview

AFLC wants to computerize the mobile CE WRSK requirements computation model. In order to use a computer model, a total failure rate is required. Over the past few years, AFLC, Air Force Communications Command (AFCC), and various researchers associated with the CE WRSK requirements problem, have been seeking an appropriate method for determining component failure rates.

This chapter provides an expanded background on the problem of computing failure rates. The chapter starts with justification for why a computational method is required, followed by recent research into the problem. The chapter concludes with a discussion of a model which incorporates a dual distribution failure rate.

Supply Policy

Air Force Manual 67-1, Volume 1, Part One, Chapter 14 states the USAF policy and procedures for managing War Reserve Material (WRM). This chapter states WRSK quantities are computed using the WRSK optimization system in the DØ29, or the conventional method. It further states both methods use negotiation, and DØ41 (Recoverable Consumption Item Requirements System) usage data as the WRSK baseline (3: Chp XIV, 26).

DØ29 and conventional methods are more than adequate for aircraft weapon systems. However, since relevant data for CE components is not tracked in the DØ29, these methods are inadequate for CE WRSK requirements computation. Thus, WRSK requirements determination for non-aircraft systems becomes the responsibility of the system or subsystem program manager (3: Chp XIV, 18). It is their responsibility to review current requirements once a year to insure all the data are correct. AFM 67-1 further states that until an automated method is developed, CE WRSK quantities will be determined at the annual review using negotiation between the using commands and the system or subsystem program manager (3: Chp XIV, 34).

This unresolved problem has been highlighted as an area of concern at the Annual Chapter 14 Update and Validation Conference since 1979. These conferences address the topic: "Standard Methodology for Computing Non-Aircraft Spares for WRSK." At the 1985 conference, it was mentioned that during the 1979 Chapter 14 Working Group meeting, HQ USAF/LEYS recognized the need for a standard computational methodology to compute non-aircraft WRSK requirements. HQ AFLC/LORR was tasked to submit a contract study proposal to HQ AFLC/XR for approval. HQ AFLC/XR subsequently approved the study proposal and a contract was let in October 1982. The firm receiving the contract was Tractell Inc., Dayton, Ohio. This was the initial research undertaken to develop a WRSK requirements model. The results were received in 1983, and are discussed below.

Tractell Inc. Report

Tractell Inc., Dayton, Ohio, published a report for AFLC in 1983 which attempted to develop a method to compute WRSK requirements for CE end items. In their research they found that the information required to calculate a total failure rate was unavailable in the required form. Similarly, they found other anomalies inherent in mobile CE systems. They reiterated the fact that mobile CE systems could possibly be dormant for extended time periods, and on the other hand, cycled many times in a short time period. These characteristics were known to occur throughout the mobile CE environment. Likewise, they observed failures during the operating, non-operating, and power-up phases. Given these observations, they suggested a formula for a total failure rate.

Working with the Tractell results, AFLC developed their own model to compute CE WRSK requirements. In order to calculate a total failure rate, AFLC made a few assumptions. First of all, they grouped the power-up failures and the operating failures into a single operating failure category (11:2). Secondly, failures occurring during power-down phase and/or failures occurring while not in operation were grouped into a non-operating category (11:2). All failures were then distributed over time to calculate a total failure rate. AFLC concluded that operating failures were different from non-operating failures, and were in fact mutually exclusive events. (Operating failures equaled FRop, and non-operating failures equaled 1-FRop (11:4)). This relationship between operating and non-operating failures was AFLC's conclusion on how to determine a total failure rate.

Their results were met with mixed emotions. Tractell and AFLC believed the results were valid; however, AFCC and researchers at the Air Force Institute of Technology disagreed. AFCC said the report did not provide anything not already known and if this was a viable method, they would have been using it for years (14). The inability to find an appropriate method prompted an assistant professor of inventory management at the Air Force Institute of Technology to pursue the problem. The following section gives the background and an outline of the AFIT research analysis.

AFIT Research

During 1983 and 1984, two students at the Air Force Institute of Technology, Captains Richard D. Mabe and Robert O. Ormston, published, A Dyna-METRIC Analysis of Support for Mobile Tactical Radar Units in Europe. In their thesis, they adapted the Dyna-METRIC model to assess logistic support requirements for mobile tactical radar units. Their success at adapting the Dyna-METRIC model hinged on their ability to work around seven key assumptions drawn from Hillestad's 1980 description of the model mathematics. Once they worked around these assumptions, and using a failure rate of failures over on-hours, they adapted the model to mobile CE systems. In their results, they concluded the Dyna-METRIC model was a useful tool in assessing mobile CE system requirements (10:72).

AFLC challenged Mabe and Ormston's results, because of the failure rate they used. Captain Mabe, with AFLC support, undertook an informal evaluation of the AFLC method derived from the Tractell report. He used data collected from the U-1050 II computer at Sembach AB Base Supply, which he had used to validate his thesis in 1984. He compared the results using failures over time with the AFLC method results, and recorded his findings in a letter to AFLC/MMMR in 1985. A summary of his conclusions on the validity of the AFLC model follows:

1. As the ratio of non-operating failures to operating failures increased, the spares requirement and the total failure rate both decreased. This was not desired. At best, both the requirement and rate should have remained constant, because total failures remained constant.

2. As a result of these decreasing values, when the non-operating failures were greater than 50% of total

failures, the part requirement became zero. Also, when the non-operating failures equaled the operating failures, no matter the total number, the spares requirement was always one. These two observations were also not desired (11:4).

In his final recommendation to AFLC/MMMR, Captain Mabe suggested the new methodology be abandoned since the results produced were not consistent or accurate (11:4). AFLC/MMMR agreed with this suggestion, which left the total failure rate computation methodology still unresolved.

However, the observations and recommendation of Captain Mabe heightened interest into how to compute a total failure rate using two failure rate distributions. The remaining sections in this chapter address the problems of on-time and off-time failures in calculating failure rates.

Literature on Non-Operating Failures

Although non-operating failures are known to occur, there are not many formal written reports on the subject. The two reports that follow are a good summation of the published literature. One report describes off-time failures and the other non-operating failures. Both terms are interchangeable and relate to failures that occur when the system is not operating. These two reports highlight the fact there is some quantifiable non-operating failure rate which impacts the total failure rate.

Martin Marietta. Martin Marietta has conducted several research projects on power on-off cycling effects on electronic equipment and part reliability. In one such study published in 1973, they concluded that equipment cycling can have adverse effects on component reliability (1: Sec II, 10). They pursued this concept and compared the effects of cycling and normal operation to the dormancy state.

Dormancy. Martin Marietta defined dormancy as:

> The state wherein a device or equipment is connected to a system in the normal operational configuration, and experiences below normal operational and environmental stresses for prolonged periods (up to five years or more) before being used in a mission. (1: Sec III, 1)

In their research, using military standard parts and high reliability part classes, they discovered 251 failures during 259 billion part hours of dormancy (1: Sec III, 7). In these 259 billion part hours, fifteen different items, (i.e., capacitors, resistors, transistors) were used to determine average failure rates. There was a wide variation between items, so to list all the rates would be very tedious and unwarranted. However, they concluded that dormancy failures do occur (1: Sec III, 39).

Power On-Off Cycling Effects. Martin Marietta, (1: Sec IV, 1) defined a power on-off cycle as:

> That state during which an electronic system goes from the zero or near zero (dormant) electrical activation level to its normal system activation level (turn on) plus that state during which it returns to zero or near zero or vise versa.

In their research, they conducted about 697 million power on-off cycles to calculate failure rates (1: Sec IV, 7).

Conclusions. Martin Marietta found that:

> A single power on-off cycle, to thermal equilibrium for about three hours and back to room ambient temperature at about 25 degrees Celsius, is between 165 to 375 (or an average of about 270 times) more stressful or effective in detecting failures than one hour of dormant time. It also appears an energized hour is about 40 to 100 times more stressful or effective in detecting failures than one hour of dormant time. (1: Sec IV, 12)

Another interesting finding within this report was that cycling (going from dormant to energized and back) is about five times more stressful than the sustained energized state (1: Sec IV, 12). This report also stated the USAF, NASA, RCA, and IBM have all conducted studies on the on-off power cycling effects and concluded the cycling effects do contribute to the overall failure rate. Further, the IBM studies highlighted the fact that when all failures are attributed to operating time, the operating failure rate is misleading (1: Sec IV, 15-17).

In the final analysis, "opens", (broken paths restricting current flow), caused 90% of the failures. The opens can be attributed to the continuous expansion and contraction caused by the energizing/de-energizing of the systems (1: Sec VI, 7). Martin Marietta's bottom line conclusion was power on-off cycling can have a definite adverse effect upon electronic equipment reliability (1: Sec VI, 5).

Hughes Aircraft Company. In a more recent report, Hughes Aircraft Company undertook the task of assessing the non-operating failure rate for avionics equipment. Within their assessment, they concentrated on the mean time between failures (MTBF). They, like Martin Marietta, found some interesting results. In their conclusions, they stated if the non-operating failures were not incorporated into the reliability modeling techniques, the overall mission reliability could be seriously misleading (9:xii).

Non-Operating Failures. Non-operating failures in the Hughes report refers to any failure occurring while the equipment is not operating. It does not single out power on-off failures, but instead includes them into the larger category of non-operating failures. Calculating failure rates based on the total failures (regardless of when they were discovered) divided by operating time does not separate the failures into any specific categories. Over time, this then lowers the assessed MTBF as compared to the operating MTBF (9: Sec I, 3).

The Hughes report estimates only a small fraction of the total failures may be non-operating, approximately 5%; however, the equipment spends more time in a non-operating condition which in the end impacts the overall failure rate (9: Sec I, 3). They concluded that if non-operating failures were excluded from the MTBF rate, the MTBF could double (9: Sec I, 3). Further, they estimated that the non-operating failures contribute between 10 and 30 percent of the total failures (9: Sec VI, 1).

The Martin Marietta and Hughes Aircraft Company reports are two of the most current reports undertaken for the Air Force which reveal some startling facts concerning non-operating failures. To disregard these findings when determining a total failure rate for mobile CE systems could lead to inaccurate estimates of WRSK requirements.

Development of an Alternate Model

The literature previously discussed emphasizes the fact that non-operating failures contribute in part to the total failure rate, and should be considered when building a model to determine spares requirements. Similarly, AFLC is interested in automating the process to compute CE spares requirements to include considering both on-time and off-time failures. The next chapter describes a model adapted to incorporate both the on-time and off-time failures of mobile CE systems.

III. Model Building and Testing

Overview

This chapter discusses how a stochastic growth model was adapted for use in the mobile communications-electronic (CE) environment to answer Research Questions #1 and #2. It starts with a brief historical description of two earlier models: the standard supply model the Air Force uses to compute aircraft requirements, and a model developed by AFLC to calculate CE requirements. It then describes the derivation of a stochastic model of mutation and growth as an answer to the research questions. The chapter concludes with a discussion of the verification and validation process for the stochastic model.

History

Standard Calculation. The standard method to calculate component failure rates is to add all failures (no matter when they occurred) and then divide them by the total operating time. This produces a linear relationship between failures and operating time. Appendix A contains the equations used to calculate this failure rate. A graphical representation is presented in figure 1. This failure rate is then used in a War Readiness Material (WRM) requirements computation model, like the D029 used in aircraft systems, to determine spares requirements. The D029 model is very useful and has served aircraft systems extremely well over

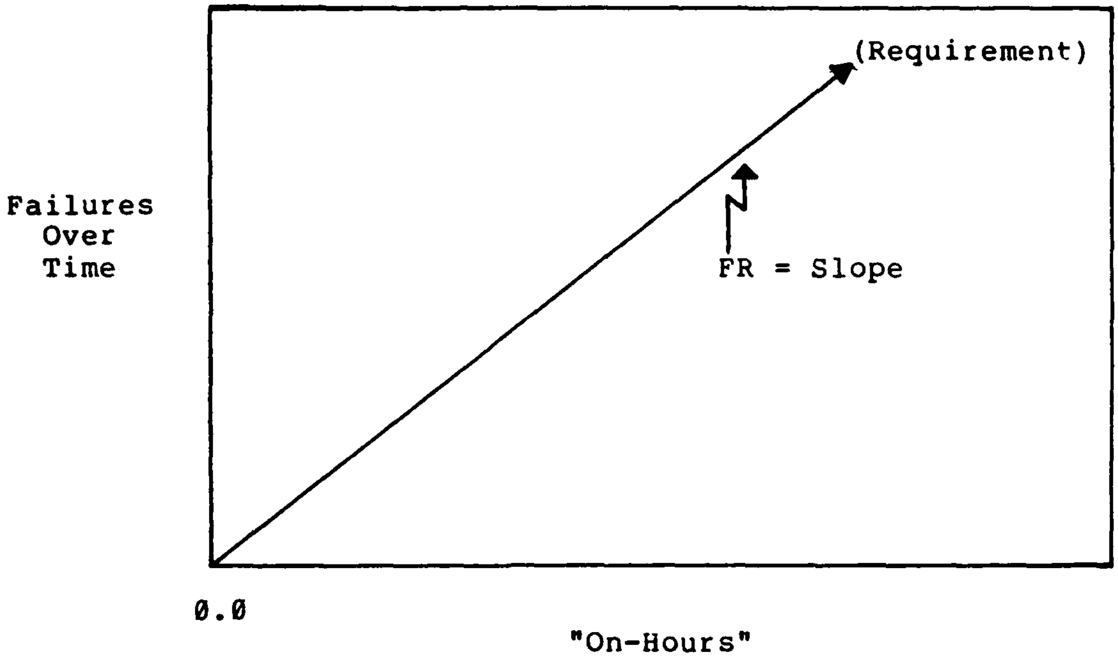


Figure 1. Failures Over Time Verses On-Hours

the years. On the other hand, mobile CE systems have neither an automated WRM requirements computation model nor an accurate method to calculate the failure rate. This research will hopefully change that.

AFLC/MMMR Proposal. The initial undertaking to develop a WRM requirements computation model was based on work accomplished by Jones and associates at Tractell Inc., Dayton, Ohio. AFLC/MMMR used the Tractell report to create a possible model. In their model, MMMR assumed there were two failure rate distributions: one for on-time failures and one for off-time failures. Their method, evaluated by Captain Mabe, using validated data collected for his research from Sembach AB, Germany did not successfully compute requirements for the off-time distributions.

MMMR made the critical assumption that the on-time and off-time distributions were mutually exclusive. This meant only the on-time parameters were computed, then the off-time parameters were derived from the on-time. Figure 2 shows the "Assumed Requirement" (total failures divided by the operating time) emanating from the origin, where the slope of the requirements line is equal to the failure rate. The

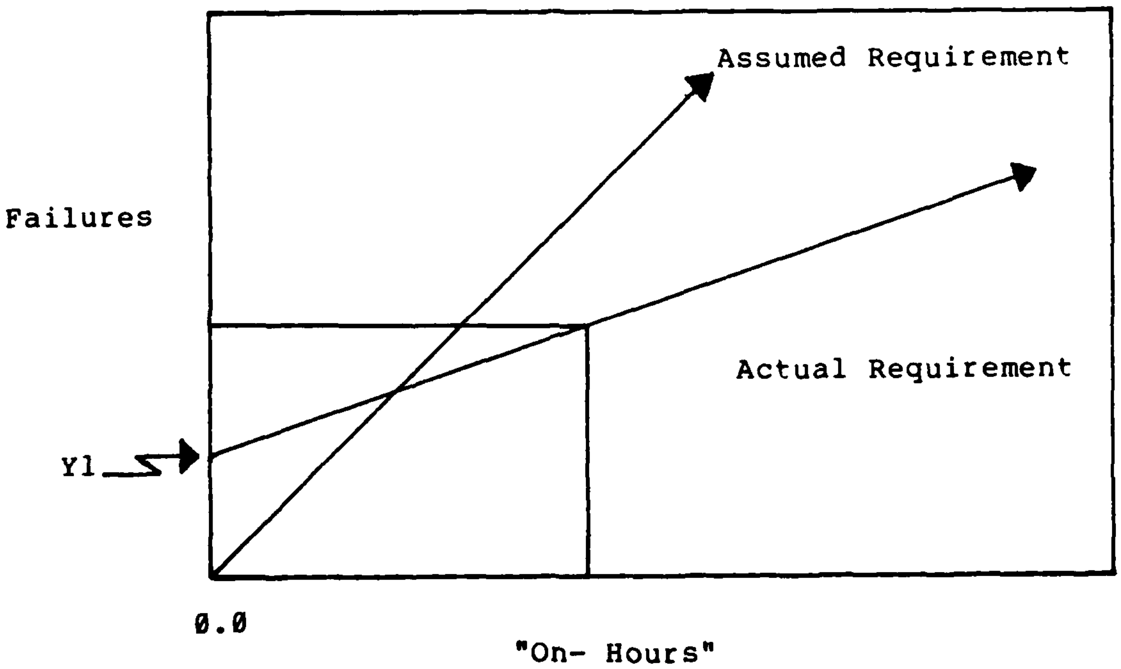


Figure 2. Tractell Inc. Proposal

"Actual Requirement" in figure 2 represents both on-time failures and off-time failures. The y-intercept equals initial off-time failures at system start-up, and the slope of the Actual Requirements line is a function of both on and off-time failures. Given the on-time and off-time distributions are mutually exclusive, and considering 24 hours in a day; then the equation for the Actual Requirements line equals $mx - n(24 - x)$, where (m) is the on-time failure rate, and (n) is the off-time failure rate.

This method, however, did not work, as seen in figure 3. Figure 3 shows that if all failures were off-time failures, then the requirement computed to zero. The problem with this method was assuming on-time and

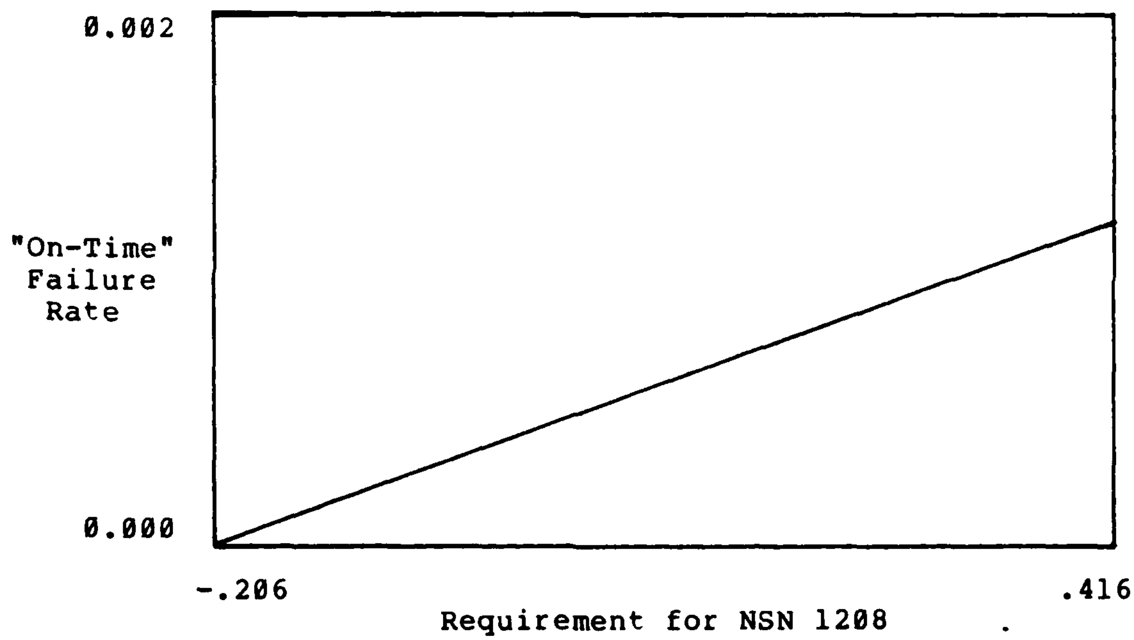


Figure 3. MMMR/Tractell Inc. Computation Results

off-time failures were mutually exclusive. The operating parameters and equations used to calculate the values for figure 3 are contained in Appendix B. Given these results, MMMR still did not have a working computational model.

However, the research validated a need to consider both on-time and off-time failures in the computational methodology.

Initial AFIT Proposal. The analysis and conclusions drawn from the MMMR proposal led to the suggestion that the total failure rate might be a combination of two independent distributions: a Poisson distribution for the on-time failures and a Bernoulli distribution for the off-time failures (5: Sec V, 6; 2:34). The on-time failure rate was a function of on-time failures divided by the on-time program. Figure 4 depicts this relationship where the slope (ml) of the requirements line equals the on-time failure rate (FR_{on}), $Y1 = m1t + b$, and FR_{on} = (Y1)/(on-time program) . Similarly, the off-time failure rate was a

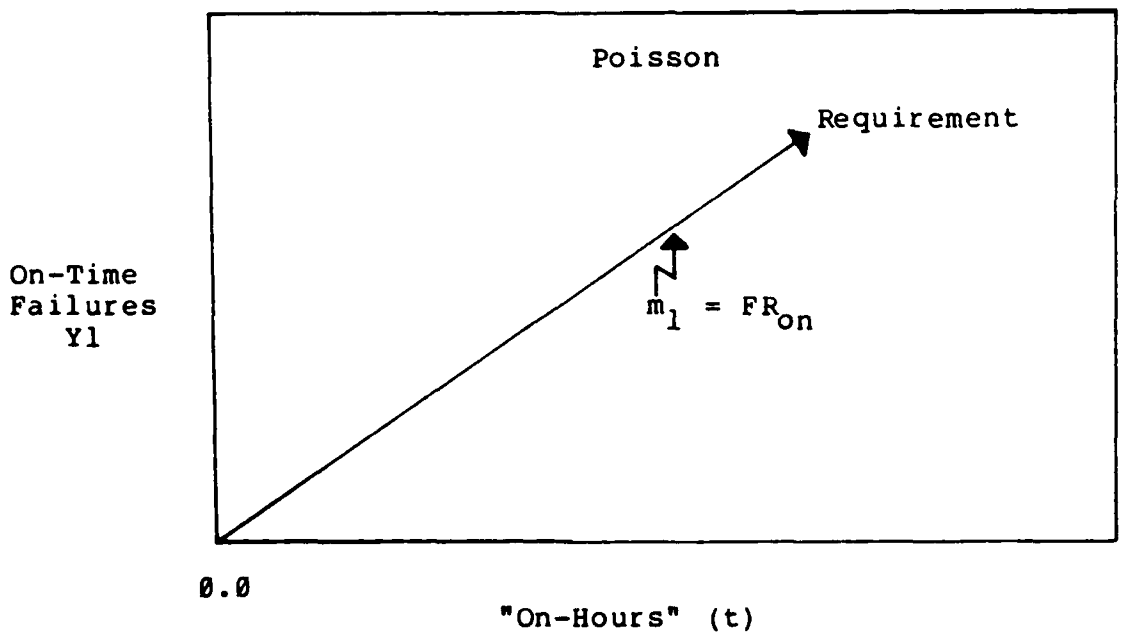


Figure 4. On-Time Failures (Poisson)

function of the off-time failures divided by the number of power-ups (or cycles) in a given program. Figure 5 represents this relationship, where the slope of the requirements line (m_2) equals the off-time failure rate, $Y2 = m_2 c + b$, and $FR_{off} = (Y2)/(\text{power-up program})$. The number of off-time failures occurring at system start-up in both distributions is 'b'. Separating the failures into

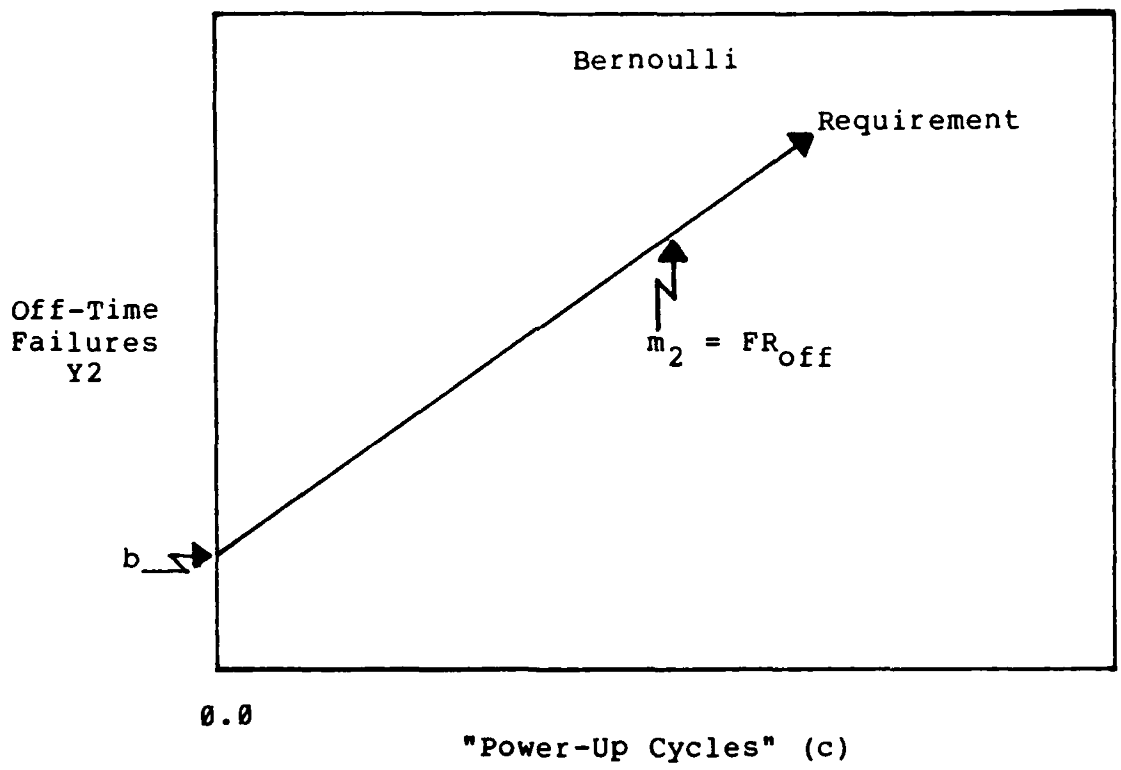


Figure 5. Off-Time Failures (Bernoulli)

independent distributions, then summing their resultant independent requirements verified the possibility of a model solution. When all failures were off-time failures, there still existed a requirement for spares greater than zero. Figure 6 shows the dual distribution method results, based on the same data used to compute figure 3. As can be seen, at '0' on-time failures, there is a requirement for 0.24 spares experiencing off-time failures. Although this method appeared to work, the requirement was the sum of each separately computed distribution. A single failure rate was still needed to answer Research Question #1. This rate appeared to be a convolution of a Poisson and Bernoulli distribution. Attempts to find such a convolution were abandoned in favor of a model not requiring the assumptions of a convolution.

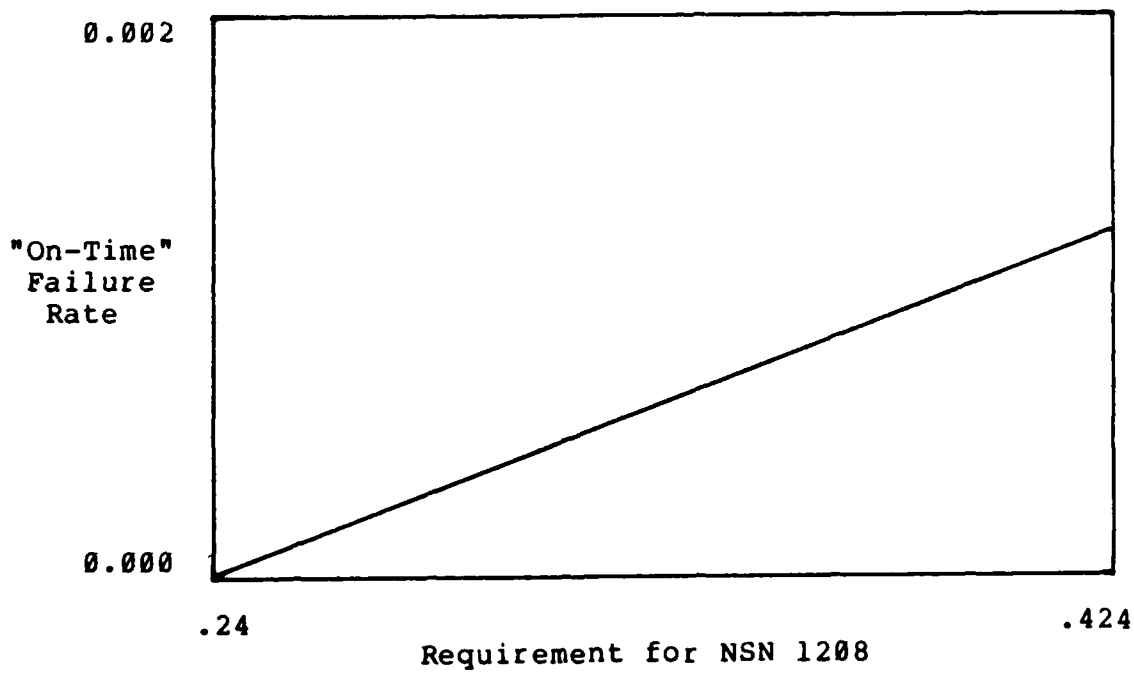


Figure 6. Dual Distribution Method Results

Solution Model for CE Failures

Overview. Attempts to discover the convolution of a Poisson and a Bernoulli distribution and thus answer Research Question #1, were frustrated by the assumptions made to avoid tedious mathematics. Lt Col Carl Talbott, of the Air Force Institute of Technology, suggested the author try a multivariate Poisson model, where the combined renewal function for failures depends on time and cycles (see figure 7). Essentially the failures would occur on a plane that included both an off-time failure rate and an on-time failure rate. Figure 7 shows such a plane. To solve

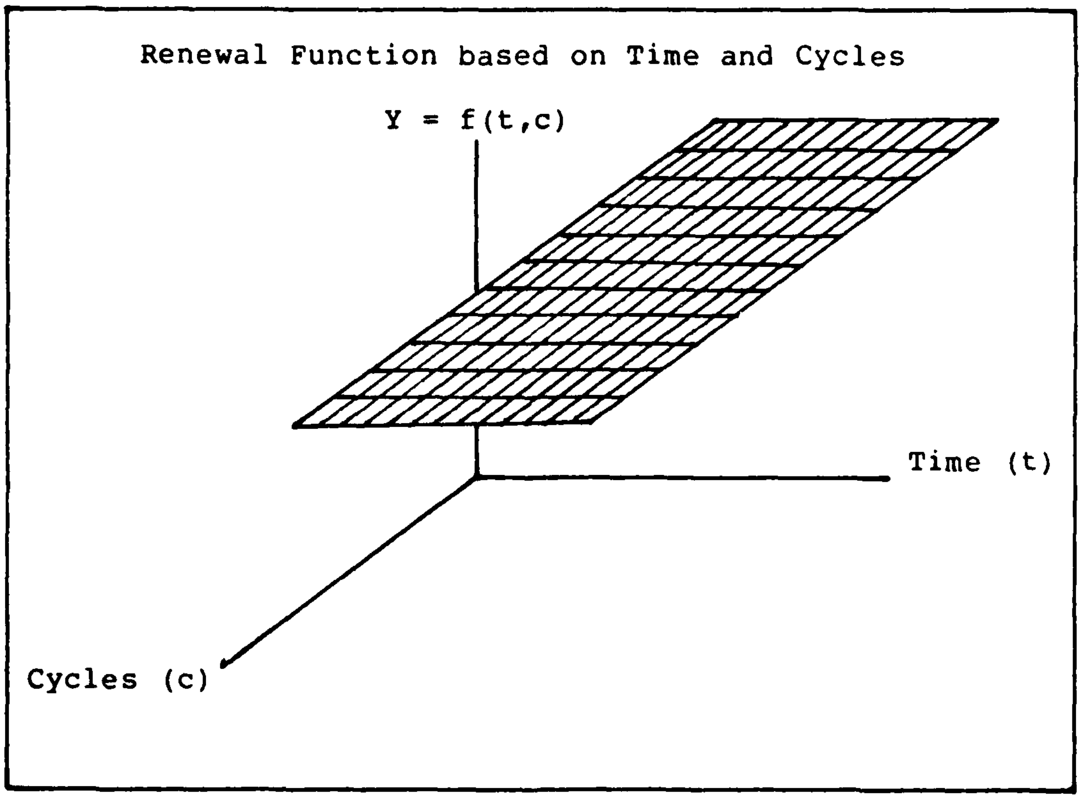


Figure 7. Structural Diagram of the Failure Plane

for failures requires a formula for the plane and a resultant failure rate. This section discusses the solution.

Assumptions. First, if a single failure rate exists, it approximates a Poisson distribution with a parameter value equal to Lambda. This requires Lambda to be a function of both time and cycles. Second, the MTBF is approximately equal to one divided by Lambda, where Lambda equals the failure density on the plane of cycles and time. This implies an exponential MTBF. These assumptions are made for ease in the initial calculations. There is also the potential to use a failure rate which has approximately a negative binomial distribution with parameter values equal to (p,q) as a compound of the Poisson, if and only if variability of demand divided by mean demand is greater than one on the failure plane. However, only the Poisson solution will be developed.

Solving the Plane. See figure 8. In order to solve the plane, let (A) be a point on the "on-failure" function with coordinates $(X_a, 0, Z_a)$. Let (B) be a point on the "off-failure" function with coordinates $(0, Y_b, Z_b)$, and let (P) be a common point to both functions which represents some initial off-time failures at t_0. The solution is found by taking the cross product of $\overrightarrow{PA}$ and $\overrightarrow{PB}$ times a point on either function $[|\overrightarrow{PA} \times \overrightarrow{PB}| * (\overrightarrow{PA} \text{ or } \overrightarrow{PB})]$ to yield a formula

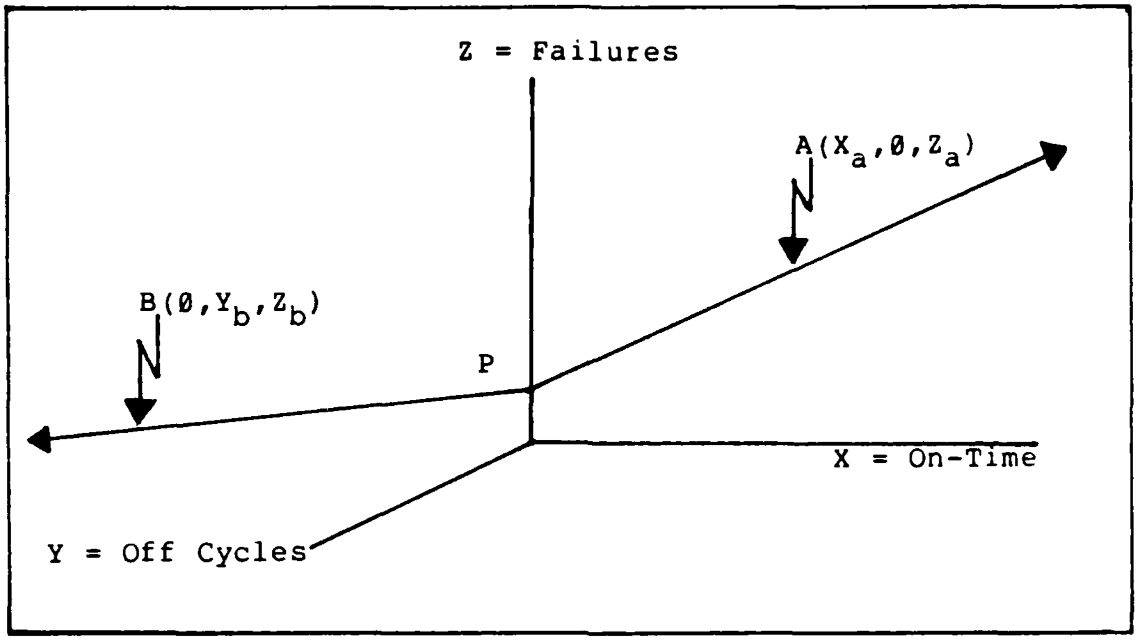


Figure 8. Common Plane to On-Time/Off-Time Failure Function

for the plane common to $\overrightarrow{PA}$ and $\overrightarrow{PB}$. Note: $|\overrightarrow{PA} \times \overrightarrow{PB}|$ is a vector orthagonal to $\overrightarrow{PA}$, $\overrightarrow{PB}$, and to the solution plane.

Solving the above cross product involves a matrix solution described by Swokowski (13:539):

Given:

	i	j	k
A	X_a	Ø	Z_a
B	Ø	Y_b	Z_b

Then:

$$|\overrightarrow{PA} \times \overrightarrow{PB}| = \begin{vmatrix} \emptyset & Z_a \\ Y_b & Z_b \end{vmatrix} i - \begin{vmatrix} X_a & Z_a \\ \emptyset & Z_b \end{vmatrix} j + \begin{vmatrix} X_a & \emptyset \\ \emptyset & Y_b \end{vmatrix} k$$

$$= -Y_b Z_a(i) - X_a Z_b(j) + X_a Y_b(k)$$

And:

$$|\overrightarrow{PA} \times \overrightarrow{PB}| * (\overrightarrow{PA}) = 0$$ (Note: Solution is identical for $|\overrightarrow{PA} \times \overrightarrow{PB}| * (\overrightarrow{PB})$.)

Or:

$$0 = -Y_b Z_a (X-X_a) - X_a Z_b (Y-0) + X_a Y_b (Z-Z_a)$$

$$0 = -Y_b Z_a (X) + Y_b X_a Z_a - X_a Z_b (Y) + X_a Y_b (Z) - X_a Y_b Z_a$$

$$0 = -Y_b Z_a (X) - X_a Z_b (Y) + X_a Y_b (Z)$$

which is the formula for a plane as desired. This then reduces to:

$$Z = \frac{Y_b Z_a (X) + X_a Z_b (Y)}{X_a Y_b}$$

$$Z = \frac{Y_b Z_a (X)}{X_a Y_b} + \frac{X_a Z_b (Y)}{X_a Y_b}$$

$$Z = \frac{Z_a}{X_a} (X) + \frac{Z_b}{Y_b} (Y) \qquad (1)$$

which allows us to solve for total failures as a function of time and cycles.

Values can be attached to equation (1) by letting:

Z_a = Expected on-time failures,

X_a = On-time hours in current period,

X = Transition on-time hours in next period,

Z_b = Expected off-time failures,

Y_b = Off-time cycles in current period,

Y = Transition off-time cycles in next period.

We also assume the ratios (Z_a/X_a) and (Z_b/Y_b) do not change in (X) and (Y) respectively. (Z) then becomes the expected failures in the next period of time, based on current observations for time and cycles.

In fact, the 'Z' location on the plane has meaning consistent with the solution, and representative of expected failures, or density (Lambda) of the Poisson distribution solved for cycles and time. (Z) occurs on a plane common to $\overrightarrow{PA}$ and $\overrightarrow{PB}$, at the intersection of the first moments of the on-time and off-time failure functions. Statistically, this first moment defines the "mean" of the combined cycles/hours distribution at a point $(\overline{X},\overline{Y},Z)$ on the plane.

The coordinates of (Z) are found by solving the coordinates of the $(\overline{X})$ and $(\overline{Y})$ moments, or (Z) is located at $(\overline{X},\overline{Y})$, where:

$$\overline{X} = \frac{\sum_{i=1}^{n} M_i X_i}{M}$$

Then:

$$M\overline{X} = \sum_{i=1}^{n} M_i X_i$$

$M\overline{X} = M_y$, (The $(\overline{X})$ moment, or the points on (X) away from the (Y) axis.)

And:

$$\overline{Y} = \frac{\sum_{i=1}^{n} M_i Y_i}{M}$$

Then:

$$M\overline{Y} = \sum_{i=1}^{n} M_i Y_i$$

$M\overline{Y} = M_x$, (The $(\overline{Y})$ moment, or the points on $(\overline{Y})$ away from the (X) axis.)

'M' in either case is the density, or failures per hour and cycles for $(\overline{X})$ and $(\overline{Y})$ respectively.

Lets call the point $(\overline{X},\overline{Y},Z)$ on the plane common to $(X_a,0,Z_a)$ and $(0,Y_b,Z_b)$ point 'C' (see figure 9). 'C' exists along a vector from P, or is the vector $\overrightarrow{PC}$, where $\overrightarrow{PC} = \overrightarrow{PA} + \overrightarrow{PB}$. Remembering:

$$M_x = M\overline{Y} = (Z_b/Y_b) * Y$$

and:

$$M_y = M\overline{X} = (Z_a/X_a) * X$$

Then given:

$$\overrightarrow{PC} = \overrightarrow{PA} + \overrightarrow{PB} \quad \text{and} \quad Z \text{ at } (M_x,M_y) = \overrightarrow{PC}$$

then:

$$Z = (Z_a/X_a) * \overline{X} + (Z_b/Y_b) * \overline{Y}$$

which is also the formula for our plane. Thus, (Z) is the expected failures on the plane, existing at the first moment of the on-time and off-time failure rates.

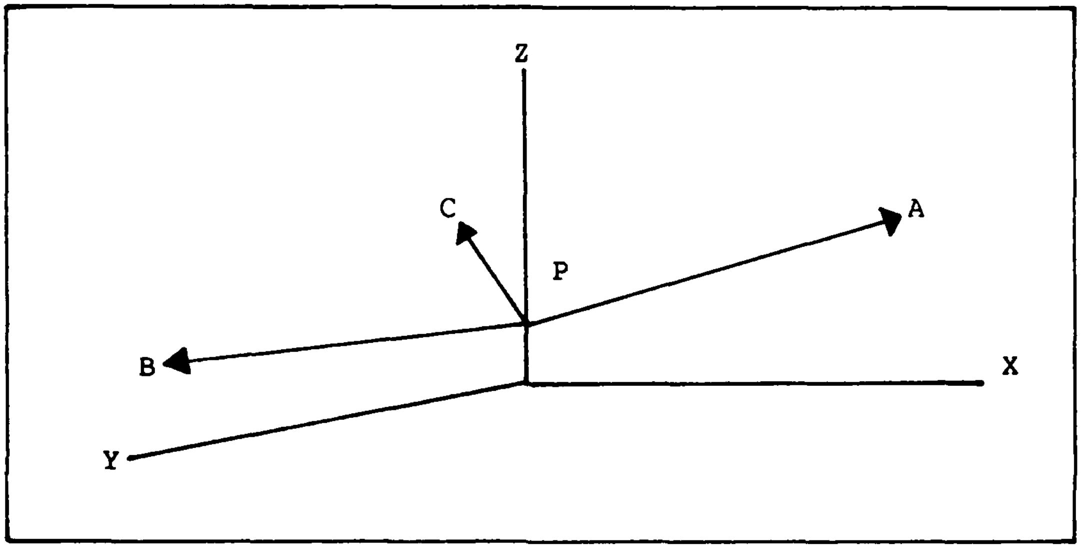


Figure 9. Point 'C' on a Plane Common to PA and PB

Note how the formula for (Z) resembles the initial AFIT solution, where the requirement was the sum of two independent linear processes. However, (Z) is now a point on a 3D plane common to two processes, which is the resultant of the single failure process described by the plane.

The next section describes how the two types of failures can be "growing" simultaneously, and yielding a common number of total failures.

Simultaneous Growth of On and Off Failures. Karlin (1966) discusses a multivariate Poisson process used to forecast the simultaneous growth of normal and mutant organisms in a microbiological test. The derivation of Karlin's model parallels the CE environment where on-time (mutant) failures occur following an initial ($N_{\emptyset}$) number of off-time (normal) failures. During the program period, both normals and mutants increase at predictable rates. In a specified time period, it is possible to determine the total population of both, and when added together yield a spares requirement. Before discussing the process for failures, Karlin's model for organisms will be presented and discussed.

According to Karlin (8:19), mutant growth follows a Markov branching process. He explains:

> A Markov process is a process with the property that, given the value X(t), the values X(s) ((s) greater than (t)), do not depend on the values of X(u) ((u) less than (t)); that is, the probability of any particular future behavior of the process, when its present state is known exactly, is not altered by additional knowledge concerning its past behavior.

Further, it is assumed, according to the Markov process, all mutant and normal births act independently of one another, and produce a random number of further births (8:36). Thus, the Markov branch continues to grow, until the end of the observation period (8:37).

In order for a stochastic growth model using mutation to hold true, it must also follow the growth law described by the Yule process (8:347). The Yule process is one example of a pure birth process. The process starts with (N) normals at time $t_\emptyset$. Normals "grow" at the rate Ne^t and produce mutants. Mutants then become a percent of normals represented by (p), where p = mutants/normals . Thus, based on the Yule process, the probability of a birth at a given time is directly proportional to the population size (8:177-178). This condition must hold in order to adapt the stochastic growth model using mutation to a mobile CE environment.

A pure birth process is defined as a Markov process satisfying the Poisson postulates. The Yule process is a Markov process (8:177), and therefore must also satisfy the Poisson postulates. The Poisson postulates state that, given a sequence of positive numbers, $\{\lambda_k\}$;

then:

1. $P\{X(t+h) - X(t) = 1 \text{ , given } X(t) = k\}$
$$= \lambda_k h + o_{1,k}(h)$$

2. $P\{X(t+h) - X(t) = \emptyset \text{ , given } X(t) = k\}$
$$= 1 - \lambda_k h + o_{2,k}(h)$$

3. $X(\emptyset) = \emptyset$,

4. $P\{X(t+h) - X(t) < \emptyset \text{ , given } X(t) = k\} = \emptyset \quad (k \geq \emptyset)$

The above postulates translated into words mean the following. Postulate 1 is the probability of at least one event happening in the very small increment (t+h) (8:14). Postulate 2 is the probability of two or more events happening in time (t+h). This postulate is essential, in order to exclude simultaneous occurrence of two or more events (8:14). Karlin states postulate 3 is given for convenience only, and says it implies a number of births in a given time period and not the population size. Postulate 4 states, the probability of having a decreasing change, equals zero. Or in other words, it implies that the process is a birth process and not a death process.

Given that the birth model follows a Yule process, and the Poisson postulates hold, then:

$$\text{Probability}\begin{pmatrix}\text{normals will mutate in} \\ \text{small interval } [t,t+h] \\ \text{given some initial} \\ \text{normals occur.}\end{pmatrix} = ph + o(h)$$

The normals and mutants now "grow" at separate rates. Since individuals behave independently, (i.e., mutants and normals):

$$P(\text{formation of mutants in } [t,t+h]) = pNe^{t}h + o(h)$$

which equals pNe^{t} as (h) approaches zero in $[0,t]$.

This is a non-homogeneous Poisson process with intensity function, $\lambda(t) = pNe^{t}$, where (p), the ratio of mutants to normals, and (N), the initial number of normals, are constant, and e^t varies in [0,t].

This defines an initial nonhomogeneous Poisson growth process. The next section discusses the relationship of this proposed model to a mobile CE environment.

Environment. Up to this point, the model derivation concentrated on Karlin's approach as it related to the microbiological environment. The CE environment is quite different than the microbiological environment; however, the basic concepts of on-time/off-time failures and mutant/normal offspring parallel one another in a realistic fashion. In this section, the Yule process will be adapted to fit the CE environment.

The objective of the proposed model is to compute CE WRSK requirements for a specific program period, based on the on-time and off-time phenomena. Figure 10 shows a diagram of the program period.

The cycle begins from dormancy, and at the moment the end item is powered-up (t_0), it assumes some inherent off-time failures (N_0) occur. These failures result from three things:

1. Power surges through the end item when it was powered-off.

2. Mechanical jostling of the system while powered-off (a very real occurrence in CE systems subject to deployments).

3. And power surges in the end item at the moment the end item was powered-up.

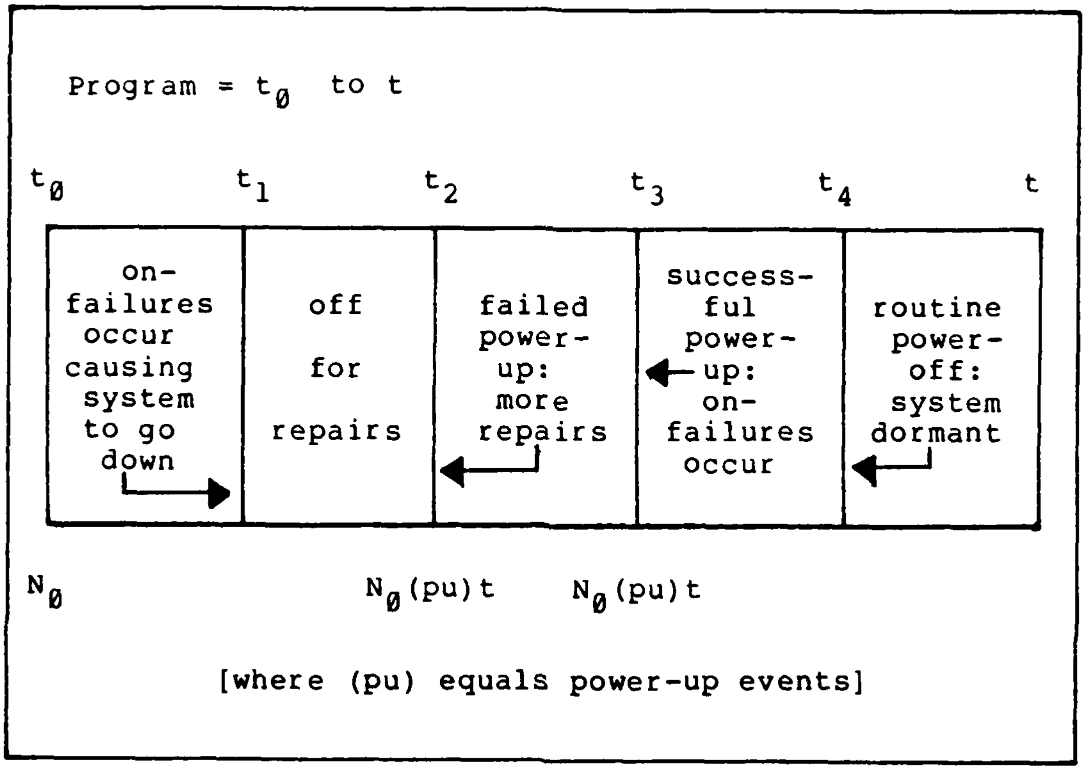


Figure 10. Failure Environment for CE System Components

(N_0) is in reality the Bernoulli probability of failure during cycle-up.

In contrast, on-time failures are those occurring after the system has successfully cycled-up and is in a state capable of, or actually performing its mission. These on-failures may, or may not cause the system to stop operating. In figure 10, an on-time failure caused the system to go down at t_1, and a cycle-up failure caused the system to go down at t_2. If on-time failures cause the system to go down, then additional off-time failures could occur at the next power-up cycle $[N_\emptyset(pu)t]$. Essentially, this implies off-time and on-time failures can be simultaneously generated during the same program period.

However, the cause of failures is operating time for on-time events, and power-up cycles for off-time events. Therefore they are not mutually exclusive distributions, even though both occur with time.

Assumptions. In order to fit the Yule process to tne CE environment, the following additional assumptions were made:

1. Off-time failures are the same as normal offspring.
2. On-time failures are the same as mutants.
3. The ratio (p), on-time failures/off-time failures is reasonably constant in $[\emptyset,t]$.
4. The Poisson postulates hold for the CE environment.
5. Off-time failures grow at a deterministic rate through the program period, based on the number of power-up cycles attempted in the period $[N_\emptyset(pu)t]$.
6. There is a reasonably constant failure rate for the on-time failures (at least during the program period).

Derivation. To discuss the derivation and solution, the following terms are introduced:

$$N_\emptyset = \frac{\text{Expected(off-failures in } [\emptyset,t])}{\text{Average Number of Power-Ups}}$$

(pu) = Expected(power-up cycles) in $[\emptyset, t]$

$$p = \frac{\text{Expected(on-failures in } [\emptyset,t])}{\text{Expected(off-failures in } [\emptyset,t])}$$

t = time in the program period (Note: the entire period is defined as $[t_\emptyset$ to $t]$.)

On Program = on-hours/item * QPA *items

Off Program = power-up cycles/item * items * QPA

QPA = Quantity per Application (or total number of a single NSN on the item)

Given these definitions and assumptions, then the following relationships occur:

$$P\begin{pmatrix}\text{off-time failures will "mutate",} \\ \text{(i.e., become on-time failures)} \\ \text{in } [t,t+h]\end{pmatrix} = ph + o(h)$$

and,

$$P\begin{pmatrix}\text{on-time failures "growing"} \\ \text{in } [t,t+h]\end{pmatrix} = pN_\emptyset(pu)t\ h + o(h)$$

then: as (h) approaches zero

$$P(\text{on-time failures "growing"}) = pN_\emptyset(pu)t$$

This is a nonhomogeneous Poisson process with intensity $\lambda(t) = pN_\emptyset(pu)t$. These are <u>imputed</u> on-time failures in $[\emptyset,t]$ based on cycles and time, where (p) and $(N_\emptyset)$ are constant and $(pu)t$ varies over $[\emptyset,t]$.

This pure birth model describes how on and off-time values can grow simultaneously. In fact, the value $pN_{\emptyset}(pu)t$ is actually the number of on-time failures that occur in $[\emptyset,t]$, given $(N_{\emptyset})$ and (p) are reasonably constant. This assumption will be carefully validated before recommending adoption of the failure model.

Interim Summary

To this point, we have discussed the historical development of a CE system failure model. A model, using the cross product of the on-time and off-time rates to form a failure plane seems to best fit the environment presented. This model requires values for expected on-time and expected off-time failures occurring in $[\emptyset,t]$.

The last section discussed how on and off-failures can grow simultaneously, and produce total failures. In fact, using Karlin's model as an explanation yields a possible value for expected on-failures, given there were $(N_{\emptyset})$ existing off-failures at $t_{\emptyset}$.

The model then that best mixes on-time and off-time failures to compute requirements is shown in equation (1). The values shown on pages 27 and 28 can be used to solve the model, except now $Z_a = pN_{\emptyset}(pu)t$.

This model essentially answers Research Question #1. However, verification and validation of the model need to occur before using it to compute requirements. The next portion of this chapter discusses verification and validation.

Verification and Validation

Overview. Two parts of the model needed verification. First, the Karlin model to compute expected on-time failures needed verification to determine if it would yield realistic results. Then, the failures derived by summing expected on-failures over hours with expected off-failures over cycles needed to be compared to the failures derived from other methods to verify the logic of the entire model.

A spreadsheet program in the AFIT computer system, Multi-Plan, was used to verify and validate the model. Data collected from mobile CE units was used to compare the stochastic model (Equation #1 page 27) to two other models: the present method (total failures divided by operating time), and a method calculated by summing on-time and off-time failures, then dividing by off-time cycles.

Data Collection. At present, failure data based on off-time failures is not tracked and subsequently not stored anywhere. Thus, empirical data from the field was required. The author attempted to collect five data elements from CE units:

1. The number of cycles attempted per day per item.
2. The result of each attempt.

3. National Stock Numbers (NSN) causing failed attempts.

4. The total item on-hours each day.

5. Number of failures occurring during the on-hours.

To facilitate the data collection, a data form (Appendix C) was developed. Headquarters Tactical Air Command/LGSW is currently using the form, and coordinating data collection. They distributed the data forms to their mobile CE units, who in turn completed the forms and returned them to AFIT/LSG. The data collection system was set-up to collect information on the following systems:

1. AN/TPS-43E Radar Set
2. A/E 24U-8 Power Plant
3. AN/TRC-97A Radio Set
4. AN/TSC-53 Communications Central
5. AN/TSC-60 HF Communications Van

In the initial plan, after the data forms were received from the units, the information was to be separated by NSN into the five data categories, and total values calculated for input into the model just described. From these calculated values, a total failure rate was to be calculated which in turn was to be used to determine CE system requirements. The data collection was the most significant hurdle impacting verification and validation of the proposed stochastic model.

Stochastic Model Verification. However, data from TAC was not received in time to verify the stochastic model, so data used by Mabe and Ormston (1984) was adapted for the verification. The verification attempted to establish the accuracy and sensitivity of the model logic. Multi-Plan was used to make the computations quickly, and to organize the results in a tabular form.

The spreadsheet layout developed to verify the logic of the stochastic model consisted of 13 columns and 63 rows. The 63 rows were separated into nine distinct sections each containing seven entries. Within each section, the seven entries represented hypothetical on-time to off-time failure relationships. Appendix D contains the spreadsheet formulas used to carry-out the verification. The thirteen columns on the spreadsheet refer to, or define the following:

1. The NSN of the item (last 4).

2. Total number of failures.

3. Expected on-time failures. For verification purposes, expected on-time failures were a percent of total failures. The values used in each section were: 90%, 85%, 75%, 50%, 25%, 15%, 10%.

4. Expected off-time failures. Again, for verification purposes, off-time failures were a percent of total failures. The values equaled one minus the percent on-time failures.

5. On-program hours. The on-program hours were calculated by assuming there were twelve radar units, each operating an average of eight hours per day, twenty days per month, for six months.

6. Off-program cycles. The off-program cycles were calculated by assuming there were twelve radar units, each powering-up twice per day, twenty days per month, for six months.

7. Expected on-time failures divided by expected off-time failures. This is the ratio (p) discussed earlier.

8. Expected off-time failures per power-up, or (N_0) as described above. This is calculated by dividing expected off-time failures by average cycles. These average cycles were independent of [0,t] and reflected the average attempts over several intervals.

9. Power-ups attempted in the time interval [0,t], or the value (pu)t.

10. Imputed on-time failures, [pN_0(pu)t].

11. Failure rate calculated by adding expected off-time failures and imputed on-time failures, then dividing this sum by total cycles in the time interval [0,t].

12. Stochastic model failure "rate". This was calculated by adding imputed on-time failures divided by on-time, to off-time failures divided by off-cycles in the time interval [0,t]. This assumes these two rates were independently and identically distributed when [pN_0(pu)t]

was used to compute on-failures, and their sum would predict the behavior of (Z).

13. Failure rate calculated by taking total failures divided by operating time.

The 13 X 63 spreadsheet matrix was separated into three major sections, each containing 21 rows. Within each major section, there were three subsections, each containing seven rows. Each seven row subsection was the basic building block upon which all other subsections were built. An outline of the Multi-Plan spreadsheet is shown in figure 11.

In all of the seven row subsections, certain rows were allowed to vary while all other rows were held constant. For example, in the first seven rows, expected on-time failures and expected off-time failures were varied by the ratios discussed earlier. By varying on time and off-time failures, the value 'p' varied as well. The resultant failure rates could then be analyzed, to check the logic and the dynamic effects of the model as 'p' varied.

In the second set of seven rows, all rows and columns contained the same values as the first set of seven rows except power-ups attempted in [0,t], the value '(pu)t', was allowed to vary. As seen in Appendix D, this represents a change from 2000 to 2500. By keeping the first two sets of seven rows the same, except for (pu)t, the effects of (pu)t could be analyzed between sets.

Row One Row Two Row Three Row Four Row Five Row Six Row Seven	Subsection One	
Row One Row Two Row Three Row Four Row Five Row Six Row Seven	Subsection Two	Major Section One
Row One Row Two Row Three Row Four Row Five Row Six Row Seven	Subsection Three	

This arrangement of a major section containing three subsections which in turn contain seven rows is repeated two more times for major sections two and three.

Figure 11. Outline of Multi-Plan Spreadsheet

The third set of seven rows followed the logic of the second set, except again, the '(pu)t' value was allowed to change. The results of this change could then be compared to the first two sets. This completed the analysis of the first major section of 21 rows.

The 21 rows of the second and third major sections were then put through the same tests as the first major section except total failures were allowed to change. In the verification, the first 21 rows had total failures always equaling 37. The second 21 rows had 10 total failures, and the last 21 rows had 2. Thus, the effects of varying total failures could be analyzed with respect to the first part of the file.

Expected Results. If the logic of the stochastic model was correct, and the model adequately adjusted to the dynamic CE environment, then the following results were expected:

1. As power-ups increased over time, then imputed on-time failures should have increased, thus (Z) should have also increased.

2. As more and more off-time failures occurred, the stochastic model failure rate should have increased. The rates of total failures over time and/or cycles should have stayed constant, since those methods did not consider where failures occurred.

3. Based on result 2, the stochastic model should have captured the dynamics of a mobile CE environment better than either the standard method, or the method which related the failure rate just to off-time cycles.

4. The results should have held for $p \geq 1$, $p \leq 1$, and $p = 1$.

Actual results appear in Appendix E, and will be discussed in Chapter 4.

Once the expected results were produced, empirical data from the field was then used to validate the model.

Validation. The validation phase of this research used empirical data collected from TAC and AFCC mobile CE units. The data was sorted by NSN, on-time and off-time failures, then on-program time (hours), and off-program cycles were calculated. Once this information was sorted, it was then input into the Multi-Plan spreadsheet to determine component failure rates. The spreadsheet format was identical to the one used to verify the model. This allowed for comparing the stochastic model to the other two using actual data.

This validation required two steps. First, the failure rates and programs were determined. Then, each model was used to forecast a requirement for the same period as the empirical data. These forecast values were compared to the actual numbers of failures occurring in the data set. The goal was to determine which forecast would most accurately predict the total failures that actually occurred. Results are given and discussed in Chapter 4.

The forecast required the author to determine failure rate increments for consuming resources. For example, either cycles, or operating hours, or a combination of both multiplied by the failure rate determines resources consumed. These increments were required for input into a requirements model. Once these increments were calculated, the model could then compute requirements.

However, the stochastic model presented in Equation (1) does not have a single failure rate or failure increment, because it is a plane which slopes in two directions. Therefore, summing $pN_{\emptyset}(pu)t$ over hours with expected off-time failures over cycles to yield a single failure "rate" proved to be an incorrect method of computing a failure rate, as will be seen with validation results in Chapter 4.

Computing Requirements

Research Question #3 asked if a model could be developed, verified, and validated, could it then be used to compute a 3Ø day WRSK requirement for a CE system? Unfortunately, the author ran out of time to complete this portion. Research Question #3 will be completed as follow-on research to this thesis.

IV. Results and Analysis

Overview

This chapter presents the results and analysis from the verification and validation phases discussed in Chapter 3. It starts with a review of the methodology for calculating total failure rates using on-time and off-time failures. It continues with the verification results using hypothetical ratios of on-time to off-time failures.

Empirical data from the field, as discussed in Chapter 3, was then to be used to validate the model; however, the data collection was insufficient to obtain any significant results prior to 1 September 1985. Data continues to arrive from Tactical Air Command mobile communication squadrons, and will be used in a follow-up study.

An alternative data source to complete model validation was provided through the 2nd Combat Information Systems Group (CISG) at Patrick AFB, Florida. Maintenance personnel provided critical stock numbers, subject to off-time failures, for review. Demand data was then obtained from base supply; however, a problem existed since the demand data was not separated into on-time and off-time failures. As a partial solution, maintenance experts attending a world wide AN/TPN-19 Conference at Patrick AFB recommended to the author realistic off-time failure levels as a percentage of total failures. While this weakened the validation, it did provide a workable solution to compute (p), the ratio of on-time failures to off-time failures.

The verification results presented here were also presented at the 54th Military Operations Research Symposium, (MORS) 26 June 1986, at Fort McNair, Washington D.C. The MORS presentation, presented to the Reliability, Maintainability, and Logistics Working Group described the model history, development, and verification process. The presentation met favorable review by the working group participants.

Stochastic Model Development (Research Question #1)

The first objective of this thesis was to develop a model for calculating a total failure rate for mobile CE system components using on-time and off-time failures. Implicit in this objective was the question as to whether on-time and off-time failures actually occurred. As reported in Chapter 2, Martin Marietta and the Hughes Aircraft Company proved, in fact, that there does exist both on-time and independent off-time failures.

With that conclusion, Chapter 3 presented the methodology for calculating a total failure rate using on-time and off-time failures. This methodology, although derived from a very unique environment, combined both on-time and off-time failure rate distributions using a compound stochastic process. The model developed was then used to calculate total failures, or (Z).

In the model, total failures (Z) were computed by taking the sum of the on-failure rate times on-hours, plus the off-failure rate times off-cycles. The formula appears on page 27. To ensure a compatible growth of failures in the interval [0,t], on-time failures were imputed as a percentage of off-time failures, given that an initial number of off-time failures occurred. The final model then appears as:

$$Z = \frac{pN_{\emptyset}(pu)t}{X_a}(\overline{X}) + \frac{Z_b}{Y_b}(\overline{Y}) \qquad (2)$$

Once this model was developed, the second objective was to use the model to verify and validate the dual distribution failure rate.

Results of the Verification Process (Research Question #2)

Overview. The verification process was separated into two steps. The first step was to verify the performance of the imputed on-failure equation using a Multi-Plan spreadsheet. Step two was to verify the performance of the total failure model, Equation (2). Step two also used Multi-Plan, and was accomplished by assuming a comparative "rate" and not computing a "full" Z value to represent the behavior of Equation (2). This rate was the sum of on-time and off-time failure rates, or $[pN_{\emptyset}(pu)t]/X_a + Z_b/Yb$.

The ability of the stochastic growth model to determine total failures was verified using hypothetical ratios for initial on-time to off-time failures. The ratio (p) was then calculated, and used in the model to further calculate on-time failure rates. Table I shows the hypothetical ratios. Using the values for (p), a stochastic model total failure rate was calculated by summing off-time failures over cycles with imputed on-time failures over time. This

TABLE I

CALCULATION OF (p)

TOTAL FAILURES (X)	PERCENT OF ON-TIME FAILURES	PERCENT OF OFF-TIME FAILURES	VALUE FOR (p)
(X)	.90(X)	.10(X)	9.0000
(X)	.85(X)	.15(X)	5.6667
(X)	.75(X)	.25(X)	3.0000
(X)	.50(X)	.50(X)	1.0000
(X)	.25(X)	.75(X)	0.3333
(X)	.15(X)	.85(X)	0.1765
(X)	.10(X)	.90(X)	0.1111

summation assumed the two rates were identically and independently distributed, which in reality they were not! Therefore, this summation provided only a comparison failure rate which emulated the performance of the equation. This rate was then compared to the standard supply method (all failures divided by operating hours), and a third method of all failures divided by on-cycles. The analysis of the results showed the stochastic model varied as (p) varied. The results were very similar to what had been anticipated. Specific results are presented below.

The Effects of Power-Ups. The mathematical development of the stochastic model implied that as attempted power-ups increased, so should imputed on-time failures, or $[pN_0(pu)t]$. In the verification process, power-ups attempted were allowed to increase from 2000 to 2500 to 3000, and the corresponding imputed failures *did* increase. Results are presented in Appendix E; however, Table II below shows an extraction. Thus, it did not matter what value for (p) was used. If total failures were constant, then as the number of attempted power-ups increased, corresponding imputed on-time failures increased. Conversely, as the number of power-ups decreased, so did the number of imputed on-time failures.

The Effects on Total Failure Rates as (p) Varied. The ratio (p), on-time failures to off-time failures, had a significant impact on total failure rates. Analysis of the results showed that as (p) decreased, (i.e., more off-time failures occurred than on-time failures), the comparative total failure rate from the stochastic model increased. This is in sharp contrast to the constant total failure rate derived by distributing all failures over hours. Distributing all failures over cycles also produced a changing rate; however, it discounted time and therefore

TABLE II

THE EFFECTS ON THE IMPUTED
FAILURES AS POWER-UPS ATTEMPTED CHANGED

For (p) = 9 , and Total Failures = 37

Power-Ups Attempted	Imputed On-Time Failures
2000	26.6400
2500	33.3000
3000	39.9600

For (p) = 5.6667 , and Total Failures = 37

Power-Ups Attempted	Imputed On-Time Failures
2000	25.1600
2500	31.4500
3000	37.7400

For (p) = 0.1765 , and Total Failures = 37

Power-Ups Attempted	Imputed On-Time Failures
2000	4.4400
2500	5.5500
3000	6.6600

skewed the rate in favor of cycles. Table III shows the results of using 37 total failures while varying (p). For more results, refer to Appendix E.

From the results observed in Table III, total failure rates calculated with the stochastic model depended upon (p). The ratio (p) does occur in mobile CE environments subject to cycling, and therefore fits the model to the dynamic CE environment better than assuming all failures

TABLE III

COMPARISON OF THE TOTAL FAILURE RATE AS (p) VARIED

(p)	Stochastic Model Failure Rate	All Failures Over Hours	All Failures Over Cycles
9.0000	0.0036	0.0032	0.0105
5.6667	0.0041	0.0032	0.0107
3.0000	0.0051	0.0032	0.0109
1.0000	0.0077	0.0032	0.0116
0.3333	0.0103	0.0032	0.0122
0.1765	0.0113	0.0032	0.0125
0.1111	0.0119	0.0032	0.0126

occur over time. This ability to capture off-time values distinguishes the stochastic model from the other two models depicted in Table III. However, the equation remains as to whether or not (p) is constant for any interval [0,t].

Analyzing the other two methods, while keeping in mind the dynamic CE environment, shows their weaknesses. For example, the standard supply method (failures over time) computes a failure rate which is constant, no matter when failures occur. The literature review highlighted the fact that non-operating failures impact failure rates and should be included in the model. However, the standard supply method does not make this distinction. On the other hand, the method using cycles to calculate failure rates did not include operating time. Thus, where it corrects one deficiency, it did not address the other.

Values which (p) can hold. Analysis of the results from Appendix D shows that (p) can take on any positive value, ($0 \leq (p) \leq \infty$), and still produce realistic results. The values for (p), as presented in Table I, are not necessarily the only possible values. As stated earlier, (p) is dependent on the ratio of on-time to off-time failures. In the verification phase, various ratios were used to show how they might occur in reality. These various ratios were then used to show how failure rates would change. Thus, in reality, for a given component, one and only one (p) value should occur, (i.e., the ratio of on-time to off-time failures is constant). If this ratio is not constant, the proposed model may not produce tractable results.

Results of the Validation Process (Research Question #2)

Overview. The validation process was also separated into two steps. The first step was to compute total failure rates for components using empirical data from the field. Once these rates were calculated, step two used the results to forecast requirements under a variety of conditions.

The validation process was designed to use three to six months data from mobile CE environments. However, a complete data set was not received in time to adequately validate the model. The information is arriving, and will be used to further validate the model at a later date. Therefore, the demand data from the 2nd Combat Information System Group at Patrick AFB was used. The 2nd CISG provided failure data for thirteen components over twelve months, but it was not divided into on-time and off-time failures. Therefore, values for (p) were derived from estimates on the percentage of off-time failures to total failures. These estimates were provided by maintenance experts and equipment specialists attending a TPN-19 Radar Conference at Patrick AFB. While using these expert derived values over empirical data weakened the validation, it did allow the author to complete the process with favorable results.

The data used to validate the model was taken from the Patrick AFB supply computer on 16 July 1986, and contained component demands for twelve months (July 1985 through June 1986). Table IV contains the expert estimate for percent off-time failure, as well as total failures. (p) was computed by:

$$(p) = \frac{\text{Total Failures} - [\text{Percent Off-Time Failures} * \text{Total Failures}]}{[\text{Percent Off-Time Failures} * \text{Total Failures}]} \quad (3)$$

The first six components in the table are from the AN/TPN-19 radar and the next seven are from the AN/MPN-14 radar.

The <u>Multi-Plan</u> spreadsheet used to validate the model was the same spreadsheet used in the verification process,

TABLE IV
PATRICK AFB SUPPLY DATA
FOR VARIOUS COMPONENTS OVER TWELVE
MONTHS WITH PERCENT OFF-TIME FAILURE
VALUES ESTIMATED USING EXPERT EXPERIENCE

	NOMENCLATURE	NSN	PERCENT OF OFF-TIME FAILURES	TOTAL FAILURES
1.	Deflection Amplifier	5895-00-871-8172	85%	14
2.	Azimuth Encoder	5895-00-576-4882	15%	3
3.	Display Power Supply	5895-00-500-8473	90%	11
4.	Transmitter Radiation Frequency Head	5895-00-763-6246	05%	8
5.	Receiver Radiation Frequency Head	5895-00-857-9908	05%	4
6.	Receiver Module (RML)	5895-00-499-8044	50%	6
7.	Thyratron	5960-00-542-7181	80%	9
8.	Magnetron	5960-00-896-9116	05%	1
9.	Servo Variable Resistor Assembly	5895-00-217-7019ZK	80%	2
10.	Canceller, Staggered	5895-00-228-5267ZK	80%	5
11.	Receiver Transmitter Group	5895-00-500-8386ZK	80%	9

TABLE IV CONTINUED

PATRICK AFB SUPPLY DATA
FOR VARIOUS COMPONENTS OVER TWELVE
MONTHS WITH PERCENT OFF-TIME FAILURE
VALUES ESTIMATED USING EXPERT EXPERIENCE

	NOMENCLATURE	NSN	PERCENT OF OFF-TIME FAILURES	TOTAL FAILURES
12.	Receiver Assembly	5895-00-150-8716ZK	80%	7
13.	Transmitter Assembly	5895-00-150-8707ZK	80%	8

except a few operating parameters were changed. These changes were made based on the CE environment at Patrick AFB. The parameters used in the model are the same as those presented in Chapter 3 except for the following changes:

1. The expected on-time and off-time failures are estimates based on expert user experience.

2. The on-program time in [0,t] was computed using:

   a. One quantity per application.

   b. Seven operating hours per day.

   c. Nineteen operating days per month.

   d. A twelve month time period.

3. The off-program cycles were computed using:

   a. One quantity per application.

   b. One cycle per day.

   c. Nineteen operating days per month.

   d. A twelve month time period.

4. When computing expected off-time failures per power-up cycle ($N_\emptyset$), average cycles equaled 228, (nineteen days per month multiplied by twelve months).

5. Power-ups attempted in [Ø,t] were computed using:

   a. One quantity per application.

   b. One cycle per day.

   c. Nineteen operating days per month.

   d. A twelve month time period.

For a complete listing of the Multi-Plan equations used in validation, see Appendix F.

Results for Computing a Failure Rate (Validation Step #1). The results obtained were all favorable and desirable. The major observation was the significant impact on-time and off-time failures had on the failure rate. The failure rate which distributed all failures over operating hours was significantly lower than the failure rate which distributed all failures over cycle-ups. On the other hand, the stochastic model failure "rate" fell between the two, which was expected. (Remember this stochastic rate is for comparison only and does not actually exist.) Appendix G contains validation results; however, Table V is an extract to show the failure rate comparisons. A minor observation taken from these results shows the stochastic model failure rate had an affinity toward the standard supply method when percent off-time failures were low and conversely, an affinity toward the failure rate using cycles when percent

TABLE V

COMPARISON BETWEEN THE CALCULATED FAILURE RATES

NSN	PERCENT OFF-TIME FAILURES	FAILURES OVER CYCLES ONLY	STOCHASTIC MODEL FAILURE RATE	FAILURES OVER HOURS ONLY
8172	85%	0.0614	0.0535	0.0088
4882	15%	0.0132	0.0036	0.0019
8473	90%	0.0482	0.0441	0.0069
6246	05%	0.0351	0.0065	0.0050
8044	50%	0.0263	0.0150	0.0036
7181	80%	0.0395	0.0327	0.0056

off-time failures were high. This is a logical and desirable occurrence as well, considering how the failure rates were calculated. The stochastic model failure rate depends on the ratio of on-time to off-time failures, and is a more realistic value because it captures both time and cycles. However, the stochastic rate is strictly a comparison value which emulated performance of the model. Total failures actually result from the sum of the independent on-time and off-time failure rates multiplied by hours and cycles respectively.

For the most part, the estimated (p) values had a range of five or ten percentage points. In the analysis, the lowest value was always used as shown in Table V. However, for a few components, the entire range was used and the results analyzed. When the entire range was analyzed, the expected results were similar to the verification results. Table VI is an extract from Appendix H containing the failure rate sensitivity results. The results show the dynamic effects of the stochastic model failure rate compared to the other two. As the number of expected off-time failures increased, so did the stochastic model failure rate. This is a logical and desirable occurrence.

TABLE VI

SENSITIVITY ANALYSIS FOR NSN 8172

NSN	PERCENT OFF-TIME FAILURES	FAILURES OVER CYCLES ONLY	STOCHASTIC MODEL FAILURE RATE	FAILURES OVER HOURS ONLY
8172	85%	0.0614	0.0535	0.0088
8172	86%	0.0614	0.0540	0.0088
8172	87%	0.0614	0.0546	0.0088
8172	88%	0.0614	0.0551	0.0088
8172	89%	0.0614	0.0556	0.0088
8172	90%	0.0614	0.0561	0.0088

<u>Forecasting Requirements</u> (<u>Validation Step #2</u>). All models were used to forecast a one year requirement under various conditions. The data supplied from Patrick AFB was used as a baseline. The total failure rates distributed

over just time and just cycles for three components from Table V (8172, 6246, and 8044) were used to make a forecast. Results for these two methods were compared to (Z) computed by the stochastic model.

The forecast conditions simulated what may happen in a dynamic wartime environment. The forecasting conditions started with the initial Patrick AFB data, where one unit operated 19 days/month for 12 months. These values were changed to one unit operating 30 days/month for 12 months. At the same time, the initial conditions stated that a unit was powered-up once per day and operated on the average seven hours per day. In the dynamic wartime environment, operating hours and cycles were allowed to change. Table VII shows these changes. These changes are hypothetical

TABLE VII

FORECASTING REQUIREMENT CHANGES

(NORMAL ENVIRONMENT)		(WARTIME ENVIRONMENT)	
HOURS	CYCLES	HOURS	CYCLES
1596 (1*7*19*12)	228 (1*1*19*12)	8640 (1*24*30*12)	1 (1*1)
1596 (1*7*19*12)	228 (1*1*19*12)	4320 (1*12*30*12)	720 (1*2*30*12)
1596 (1*7*19*12)	228 (1*1*19*12)	4320 (1*12*30*12)	1440 (1*4*30*12)
1596 (1*7*19*12)	228 (1*1*19*12)	4320 (1*12*30*12)	2880 (1*8*30*12)

values, similar to what might be expected to happen in a wartime environment. The objective here was to hold constant the environmental values, (i.e., operating parameters, the ratio (p), and ($N_{\emptyset}$)), and analyze how different failure models adapted to these operational changes.

Forecasting Results. Table VIII presents total failures for one year based on three different forecasting models. These values were extracted from the Multi-Plan spreadsheet, Appendix H. Various ratios of hours and cycles (as discussed above) were used. These computed values were component requirements needed to support a unit in a dynamic wartime environment without maintenance. The results show:

1. When computing total failures using only hours, total failures calculated were incorrect, because Lambda #3 (from Appendix G) was too high. Total failures were calculated by multiplying Lambda #3 by forecasted on-hours. This method erroneously distributed too many failures over on-hours for each of the four ratios in Table VIII. It considered all failures as on-hour failures when in fact only a percentage of the total were on-time failures.

2. Analyzing total failures using only cycles also showed total failures were incorrect because Lambda #1 was too high. These total failures were calculated by multiplying Lambda #1 by new power-up cycles. This method erroneously distributed all failures over power-up cycles.

TABLE VIII

COMPARING FORECASTED
REQUIREMENTS FROM THREE DIFFERENT MODELS

NSN	HOURS	CYCLES	FAILURES USING ONLY CYCLES	FAILURES USING A DUAL RATE (Z)	FAILURES USING ONLY HOURS
8172					
	8640	1	0.0614	11.4206	75.7895
	4320	720	44.2105	43.2632	37.8947
	4320	1440	88.4211	80.8421	37.8947
	4320	2880	176.8421	156.0000	37.8947
6246					
	8640	1	0.0351	41.1446	43.3083
	4320	720	25.2632	21.8346	21.6541
	4320	1440	50.5263	23.0977	21.6541
	4320	2880	101.0526	25.6241	21.6541
8044					
	8640	1	0.0623	16.2538	32.4812
	4320	720	18.9474	17.5940	16.2406
	4320	1440	37.8947	27.0677	16.2406
	4320	2880	75.7895	46.0150	16.2406

3. The 'Z' value in Table VIII is an accurate assessment of true requirements. It shows the impact of increasing cycles and decreasing on-hours spread over cycles and on-hours respectively.

Table VIII also shows that when failures were distributed over on-hours only, as on-hours decreased, so did the number of failures. These were logical results explainable by how the values were calculated. However, shortening hours and increasing cycles actually increased the total failures occurring.

The value 'Z' again had an affinity towards the method using only on-hours when the (p) ratio was large. Likewise, when the (p) ratio was small, the affinity was toward the method using only cycles. Both of these results were desirable and logical, and in fact shows (Z) is able to capture the effects of both environments, and treat them equally in the model.

Summary

Verification of the model shows it captured the dynamics of a CE environment. As cycles increased, so did imputed on-time failures. As (p) changed, the corresponding stochastic failure rate changed as well in the desired direction. Finally, the results were consistent for any positive 'p' value, which means neither on-time nor off-time failures dominated the results, but had equal impact.

Validation of the results against empirical values was weakened by a lack of data. Values for (p) were derived from estimates by maintenance experts and equipment specialists. Even though the model behaved well, calculated 'p' values would have made a stronger validation.

V. Conclusions and Recommendations

Overview

This chapter presents the conclusions to the research questions addressed in Chapter 1, as achieved by the literature review and model building in Chapters 2 and 3. The chapter concludes with final recommendations concerning adapting a stochastic model.

Summary of Research Effort

The Air Force mission is "to-fly-and fight" with modern weapon systems. In order to meet this mission, the Air Force must provide adequate support through command, control, and communication (C3) systems. An important element of C3, is mobile communication and electronic (CE) systems. Mobile CE systems depend upon war reserve spares kits (WRSKs) to maintain their serviceability during the early days of war. Therefore, correct WRSK levels are crucial in maintaining the support mobile CE systems provide. At present, WRSK levels are determined through manual analysis of data from past years and personal user input.

A computerized model offers a better alternative for determining WRSK requirements. However, to implement a computerized model, an accurate failure rate is required. After much research and discussion with HQ AFLC, a failure rate based on on-time and off-time failures seems to be a realistic approach.

This thesis sought to improve WRSK requirements determination by answering three research questions: 1) Do on-time and off-time failures occur, and if they do, can they be used to calculate a total failure rate? 2) If a model exists to calculate a total failure rate, can it be verified and validated? 3) If the model is verified and validated, can WRSK requirements be determined using a requirements computation model such as the D029, Mod-METRIC, or Dyna-METRIC?

The literature review documented work by Martin Marietta and Hughes Aircraft, who both agreed that total failures are a combination of on-time failures and off-time failures. These facts answered the first part of Research Question #1. In Chapter 3, a three-dimensional Poisson model, with stochastic growth properties was built and adapted to fit the CE environment. The model was then used to answer Research Question #2.

The first part of Research Question #2 was answered through the verification of the stochastic growth properties of the model. Using hypothetical values, model logic and performance were tested for accuracy. Results from a <u>Multi-Plan</u> program verified the model. The validation process then used empirical field data to calculate total failure rates for specific components. Once these failure rates were computed, requirements for one year were forecast. This validation was weakened by using expert opinion in lieu of empirical data. However, the validation process proved that a stochastic growth model, which uses both cycles and hours, better estimates real world CE conditions than a model which distributes all failures over just time.

Conclusions

Dual Distribution Failure Rate (Research Question #1). Based on research Martin Marietta and Hughes Aircraft have accomplished, and understanding the dynamic environment mobile CE systems operate in, mobile CE systems have both on-time and off-time failures. Therefore, to calculate *failure rates based on only operating time,* will under estimate the true failure rate. Thus, mobile CE systems should include on-time and off-time failures distributed over on-hours and power-up cycles respectively.

A three-dimensional model was developed to treat both on-time and off-time failures. Essentially, failures occur on a plane that includes both an on-time failure rate (Z_a/X_a) and an off-time failure rate (Z_b/Y_b). The formula for the plane is:

$$Z = (Z_a/X_a)(X) + (Z_b/Y_b)(Y)$$

where:

Z_a = Expected on-time failures,

X_a = On-time hours in current period,

X = Transition on-time hours in next period,

Z_b = Expected off-time failures,

Y_b = Off-time cycles in current period, and

Y = Transition off-time cycles in next period.

The value 'Z' is expected total failures in the next period of time, based on current observations for time and cycles. In fact, the 'Z' location on the plane is the density (Lambda) of a Poisson distribution solved for time and cycles. The probability for values other than (Z) are distributed according to the histogram in figure 12.

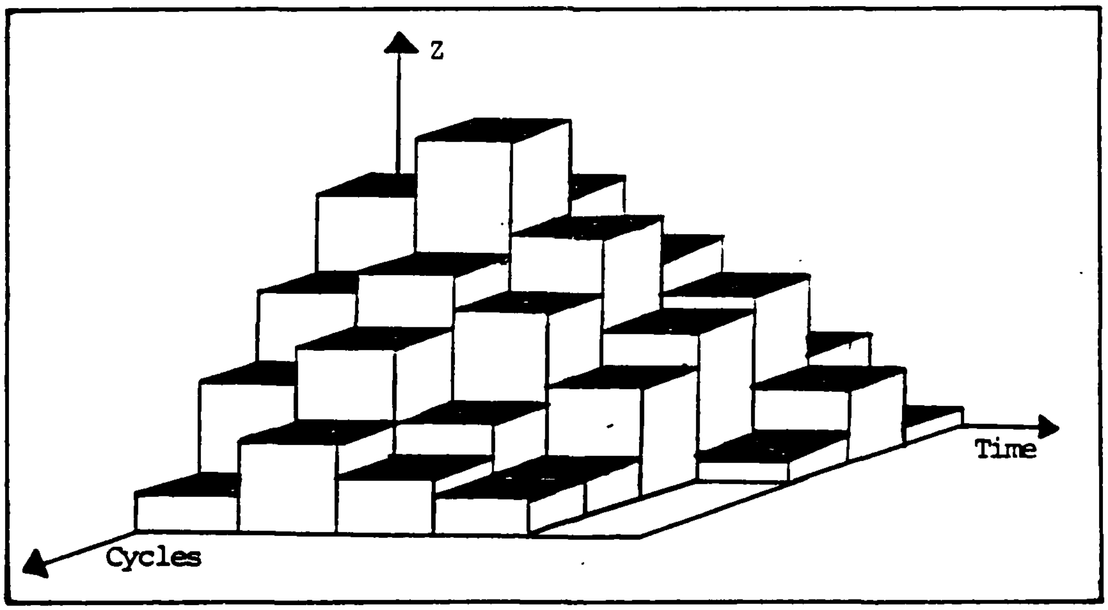


Figure 12. Three-Dimensional Poisson Distribution

Figure 12 depicts a three-dimensional Poisson distribution, and pictorially describes what is occurring in the dynamic mobile CE environment. In figure 12, failures occur over time along the X-axis and over cycles along the Y-axis. The resultant failure plane experiences various failure probabilities. The histogram describes the probability density function (pdf) as it relates to both time and cycles for the plane.

Once the above relationship was found, the model then needed to simultaneously forecast on-time and off-time failures. Using a multivariate Poisson process discussed by Karlin (1966), an appropriate model was found that described simutaneous growth. By relating mutant organisms to on-time failures and normal organisms to off-time failures, and stating mutants grow according to a pure birth process, the conclusion is made that on-time and off-time failures occur simultaneously, and on-time failures are an imputed percentage of off-time failures, given that an initial density of off-time failures occurred.

Verification and Validation (Research Question #2). The failure model developed to answer Research Question #1 calculated a total failure rate based on summing on-time failures over on-hours and off-time failures over cycles. This assumed the two rates were identically and independently distributed, which in reality they were not. Therefore, this summation provided only a comparative "rate" that emulated the performance of (Z).

However, this comparative "rate" produced some interesting results. As the number of power-up cycles increased, so did the number of imputed on-time failures. Thus, power-up cycles and imputed on-time failures were directly proportional. On the other hand, as the ratio (p), on-time failures to off-time failures increased, the stochastic model failure rate decreased. Here, the ratio (p) and the failure rate were inversely proportional. These results lend credibility to a significant conclusion: the stochastic model adapts more realistically to mobile CE environments, because it changes with the dynamics of the environment.

Data obtained from Patrick AFB was used to validate the model. However, this data lacked individually recorded on-time and off-time failures required to calculate failure rates. Instead, the ratio (p) was derived from values provided by maintenance experts and equipment specialists for percent of off-time failures to total failures. Although these expert derived values weakened the validation, favorable results were obtained.

In the validation phase, the following conclusions were made. The value 'Z' is more realistic because it captures effects of both time and power-up cycles. The model using total failures over time produced an overly high failure rate, because all failures, no matter when they occurred, were distributed over operating hours. Correspondingly, the model distributing total failures over just power-up cycles also produced an overly high failure rate, because all failures were distributed over cycles.

The validation phase continued by forecasting requirements for one year using all three methods. While keeping the ratio (p) and the value (N_0) constant, properties consistent with mobile CE environments, the forecasts were analyzed. Based on similar arguments discussed in the preceding paragraph, the stochastic model produced more realistic forecasts when compared to the other two models. The mix between on-hours and power-up cycles makes it the best device for a requirements computation model.

Adapting a Stochastic Model Failure Rate to a Requirements Computation Model (Research Question #3)

The final research question was hopefully to adapt the model developed in the research to a requirements computation model, and forecast a 30 day WRSK requirement. Due to the fact that insufficient data was collected in time to make a strong validation, as well as the complications in arriving at values for a requirements computation model, a 30 day WRSK requirement was not accomplished.

Recommendation. It is recommended that an AFIT graduate student follow-up this research to include calculating a 30 day WRSK requirement using a requirements computation model. The data which is now arriving from TAC should be incorporated into the stochastic model. Each month of data could be used to forecast the expected failures for the next month. Comparing the forecast failures with the actual failures would make a stronger validation. This process could continue with each month of new data until a full validation was complete.

Final Recommendations

Mobile CE environments are very unique. Movement from one location to another is a common occurrence with frequent power-ups and downs. The dynamic characteristics of the stochastic model make it a much more realistic model when compared to others. The stochastic model should be adapted to calculate mobile CE system component failure rates.

This thesis is one research effort showing that on-time and off-time failures actually occur and impact total failure rates. AFLC, in conjunction with Sacramento ALC, needs to establish a data collection system to track and store on-time failures with on-time hours, and off-time failures with power-up cycles. Only then could any dual distribution failure rate model be used to calculate requirements.

As mentioned under the conclusions for Research Question #3, continued validation of the stochastic model is required. Continued support from TAC is recommended to make a strong validation.

With data presently arriving from TAC, further research by an AFIT graduate student is recommended. It is recommended that besides further validating the model, research should continue to develop a requirements computation model similar to Dyna-METRIC or METRIC, only using on-time and off-time failures to forecast a 30 day WRSK requirement. Research should also continue and expand into other systems which operate in a similar environment. Likely candidates are: aircraft avionics, radios, or possibly mobile missile systems.

Appendix A: Standard Supply Computation

Steps	Explanation
1.	Determine the number of demands per part over an operating interval.
2.	Determine the total number of operating hours over which the above demands were generated. This is subjective, based on:

[Total days - down days (weekends and holidays)] * [average number of operating hours per unit per day] * [average number of units operational each day] = total operational hours.

3. Compute the meantime between demands (MTBD) for each part:

$$\text{MTBF} = \frac{\begin{array}{c}\text{total operational} \\ \text{hours (step 2)}\end{array} * \begin{array}{c}\text{quantity per end item} \\ \text{of the part (QPA)}\end{array}}{\text{total demands for the part (step 1)}}$$

4. Compute the demands per flying hour (operational hour) for each part:

$$\text{D/FH} = \frac{1}{\text{MTBD}}$$

Appendix B: Tractell Inc./MMMR Equations

Definitions:

F(op) = Number of Operating Failures

F(non-op) = Number of Non-Operating Failures

P = Program in Equipment Months over which Failures are Collected

ODP = One Day Peace Program in Hours

D(p) = Peacetime Duty Cycle (On-Time)

FR(op) = Operating Failure Rate

FR(non-op) = Non-Operating Failure Rate

PAA = Primary Aircraft Authorized

Equations:

$$D(p) = \frac{\text{ODP (ON-Time)}}{24 * \text{Number of units Supported}}$$

$$FR(op) = \frac{F(op)}{D(p) * 720 * P}$$

$$FR(non\text{-}op) = \frac{F(non\text{-}op)}{[1-D(p)] * 720 * P}$$

Requirement = (Operating Failure Rate * Daily War Program * QPA) + (Non-Operating Rate * [(24 hours * PAA) - Daily War Program] * QPA)

Appendix C: Data Form

DATA FORM

DATE: ______________.

1. NOMENCLATURE OF END ITEM: ______________________________.

2. NUMBER OF CYCLE ATTEMPTS PER DAY: (Cross-out a number after each attempt is made. If more than 10, add in numbers.)

1 2 3 4 5 6 7 8 9 10

3. RESULT OF EACH ATTEMPT: (Record any failure, i.e., critical or non-critical. Circle SUCCESS or FAILURE. Add more if required.)

1. SUCCESS or FAILURE	2. SUCCESS or FAILURE
3. SUCCESS or FAILURE	4. SUCCESS or FAILURE
5. SUCCESS or FAILURE	6. SUCCESS or FAILURE
7. SUCCESS or FAILURE	8. SUCCESS or FAILURE
8. SUCCESS or FAILURE	10. SUCCESS or FAILURE

4. NSN CAUSING FAILED ATTEMPT (OR NONE): 1. ______________.

2. ______________ 3. ______________ 4. ______________.

5. ______________ 6. ______________ 7. ______________.

8. ______________ 9. ______________ 10. ______________.

NOTE: 2, 3, and 4 above refer to non-operating failures only.

FOR OPERATING FAILURES:

1. TOTAL NUMBER OF OPERATING FAILURES FOR TODAY: __________.

2. NSN OF PART (SUBASSY OR LRU) THAT FAILED (FOR EACH OPERATING FAILURE). ______________________________.

3. TOTAL "ON-HOURS" FOR EACH DAY: (I.E., HOURS OPERATED AFTER SUCCESSFUL POWER-UP TODAY): ______________________.

When determining NSN's, use the NSN for the assembly or subassembly (LRU) containing the failed component. Examples: Governor, SF-6 tank, RT-1168, or item that would normally be in WRSK

Appendix D: Multi-Plan Spreadsheet Verification Formulas

Column Number

1. National Stock Number: Alpha Character

2. Total Failures in [0,t]: Value

3. Expected On-Time Failures in [0,t]:

   a. 0.9 * Total Failures
   b. 0.85 * Total Failures
   c. 0.75 * Total Failures
   d. 0.5 * Total Failures
   e. 0.25 * Total Failures
   f. 0.15 * Total Failures
   g. 0.1 * Total Failures

4. Expected Off-Time Failures in [0,t]:

   a. 0.1 * Total Failures
   b. 0.15 * Total Failures
   c. 0.25 * Total Failures
   d. 0.5 * Total Failures
   e. 0.75 * Total Failures
   f. 0.85 * Total Failures
   g. 0.9 * Total Failures

5. "On-Program" in [0,t] (unit hours):

   (12 radar units * 8 hours/day
   * 6 days/week * 20 days/month)

6. "Off-Program" in [0,t] (power-up cycles):

   (12 radar units * 2 cycles/day
   * 6 days/week * 20 days/month)

7. Expected On-Time Failures Divided by Expected Off-Time Failures, Ratio (p):

   (Expected on-failures/expected off-failures)

8. Expected Off-Time Failures Divided by Power-Up Cycles ($N_{\emptyset}$):

(Expected off-failures/average power-ups)

9. Power-Ups Attempted in [0,t], "(pu)t": Value

10. Imputed On-Time Failures, "$pN_{\emptyset}$(pu)t":

{(Expected on-time failures/expected off-time failures) * (expected off-time failures/power-up cycles) * (power-ups attempted in [0,t])}

or

Column 7 times, column 8 times, column 9

11. Lambda Cyclic, Imputed On-Time Failures Plus Expected Off-Time Failures Divided by Off-Time.

[(Imputed on-time failures + expected off-time failures)/(off-time)]

12. Lambda Cyclic, Imputed On-time Failures Divided by On-Time, Plus Off-Time Failures Divided by Off-Time:

[(Imputed on-time failures/on-time) + (off-time failures/off-time)]

or

[(Column 10/column 5) + (column 4/column 6)]

13. Lambda Normal, Total Failures Divided by On-Time:

(Total failures/on-time)

Appendix E: Multi-Plan Spreadsheet Verification Results

NATIONAL STOCK NUMBER	TOTAL FAILURES IN [0,t]	EXPECTED ON-FAILURES IN [0,t]	EXPECTED OFF-FAILURES IN [0,t]	ON PROGRAM IN [0,t] (Unit-Hours)
		(Varying Ratios From 0.9 to .1)		
1208	37.0000	33.3000	3.7000	11520.0000
1208	37.0000	31.4500	5.5500	11520.0000
1208	37.0000	27.7500	9.2500	11520.0000
1208	37.0000	18.5000	18.5000	11520.0000
1208	37.0000	9.2500	27.7500	11520.0000
1208	37.0000	5.5500	31.4500	11520.0000
1208	37.0000	3.7000	33.3000	11520.0000
1208	37.0000	33.3000	3.7000	11520.0000
1208	37.0000	31.4500	5.5500	11520.0000
1208	37.0000	27.7500	9.2500	11520.0000
1208	37.0000	18.5000	18.5000	11520.0000
1208	37.0000	9.2500	27.7500	11520.0000
1208	37.0000	5.5500	31.4500	11520.0000
1208	37.0000	3.7000	33.3000	11520.0000
1208	37.0000	33.3000	3.7000	11520.0000
1208	37.0000	31.4500	5.5500	11520.0000
1208	37.0000	27.7500	9.2500	11520.0000
1208	37.0000	18.5000	18.5000	11520.0000
1208	37.0000	9.2500	27.7500	11520.0000
1208	37.0000	5.5500	31.4500	11520.0000
1208	37.0000	3.7000	33.3000	11520.0000
1208	10.0000	9.0000	1.0000	11520.0000
1208	10.0000	8.5000	1.5000	11520.0000
1208	10.0000	7.5000	2.5000	11520.0000
1208	10.0000	5.0000	5.0000	11520.0000
1208	10.0000	2.5000	7.5000	11520.0000
1208	10.0000	1.5000	8.5000	11520.0000
1208	10.0000	1.0000	9.0000	11520.0000
1208	10.0000	9.0000	1.0000	11520.0000
1208	10.0000	8.5000	1.5000	11520.0000
1208	10.0000	7.5000	2.5000	11520.0000
1208	10.0000	5.0000	5.0000	11520.0000
1208	10.0000	2.5000	7.5000	11520.0000
1208	10.0000	1.5000	8.5000	11520.0000
1208	10.0000	1.0000	9.0000	11520.0000

1208	10.0000	9.0000	1.0000	11520.0000
1208	10.0000	8.5000	1.5000	11520.0000
1208	10.0000	7.5000	2.5000	11520.0000
1208	10.0000	5.0000	5.0000	11520.0000
1208	10.0000	2.5000	7.5000	11520.0000
1208	10.0000	1.5000	8.5000	11520.0000
1208	10.0000	1.0000	9.0000	11520.0000
1208	2.0000	1.8000	0.2000	11520.0000
1208	2.0000	1.7000	0.3000	11520.0000
1208	2.0000	1.5000	0.5000	11520.0000
1208	2.0000	1.0000	1.0000	11520.0000
1208	2.0000	0.5000	1.5000	11520.0000
1208	2.0000	0.3000	1.7000	11520.0000
1208	2.0000	0.2000	1.8000	11520.0000
1208	2.0000	1.8000	0.2000	11520.0000
1208	2.0000	1.7000	0.3000	11520.0000
1208	2.0000	1.5000	0.5000	11520.0000
1208	2.0000	1.0000	1.0000	11520.0000
1208	2.0000	0.5000	1.5000	11520.0000
1208	2.0000	0.3000	1.7000	11520.0000
1208	2.0000	0.2000	1.8000	11520.0000
1208	2.0000	1.8000	0.2000	11520.0000
1208	2.0000	1.7000	0.3000	11520.0000
1208	2.0000	1.5000	0.5000	11520.0000
1208	2.0000	1.0000	1.0000	11520.0000
1208	2.0000	0.5000	1.5000	11520.0000
1208	2.0000	0.3000	1.7000	11520.0000
1208	2.0000	0.2000	1.8000	11520.0000

OFF PROGRAM IN [0,t] (Pwr-Up Cycles)	EXPECTED ON FAILS OVER EXPECTED OFF FAILURES (The Ratio 'p')	EXPECTED OFF-TIME FAILURES PER POWER -UP CYCLE (No) =E(off)/Avg Cycles	POWER-UPS ATTEMPTED IN [0,t] (pu)t
2880.0000	9.0000	0.0015	2000.00
2880.0000	5.6667	0.0022	2000.00
2880.0000	3.0000	0.0037	2000.00
2880.0000	1.0000	0.0074	2000.00
2880.0000	0.3333	0.0111	2000.00
2880.0000	0.1765	0.0126	2000.00
2880.0000	0.1111	0.0133	2000.00
2880.0000	9.0000	0.0015	2500.00
2880.0000	5.6667	0.0022	2500.00
2880.0000	3.0000	0.0037	2500.00
2880.0000	1.0000	0.0074	2500.00
2880.0000	0.3333	0.0111	2500.00
2880.0000	0.1765	0.0126	2500.00
2880.0000	0.1111	0.0133	2500.00
2880.0000	9.0000	0.0015	3000.00
2880.0000	5.6667	0.0022	3000.00
2880.0000	3.0000	0.0037	3000.00
2880.0000	1.0000	0.0074	3000.00
2880.0000	0.3333	0.0111	3000.00
2880.0000	0.1765	0.0126	3000.00
2880.0000	0.1111	0.0133	3000.00
2880.0000	9.0000	0.0004	2000.00
2880.0000	5.6667	0.0006	2000.00
2880.0000	3.0000	0.0010	2000.00
2880.0000	1.0000	0.0020	2000.00
2880.0000	0.3333	0.0030	2000.00
2880.0000	0.1765	0.0034	2000.00
2880.0000	0.1111	0.0036	2000.00
2880.0000	9.0000	0.0004	2500.00
2880.0000	5.6667	0.0006	2500.00
2880.0000	3.0000	0.0010	2500.00
2880.0000	1.0000	0.0020	2500.00
2880.0000	0.3333	0.0030	2500.00
2880.0000	0.1765	0.0034	2500.00
2880.0000	0.1111	0.0036	2500.00

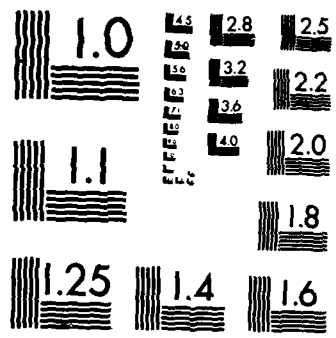
2880.0000	9.0000	0.0004	3000.00
2880.0000	5.6667	0.0006	3000.00
2880.0000	3.0000	0.0010	3000.00
2880.0000	1.0000	0.0020	3000.00
2880.0000	0.3333	0.0030	3000.00
2880.0000	0.1765	0.0034	3000.00
2880.0000	0.1111	0.0036	3000.00
2880.0000	9.0000	0.0001	2000.00
2880.0000	5.6667	0.0001	2000.00
2880.0000	3.0000	0.0002	2000.00
2880.0000	1.0000	0.0004	2000.00
2880.0000	0.3333	0.0006	2000.00
2880.0000	0.1765	0.0007	2000.00
2880.0000	0.1111	0.0007	2000.00
2880.0000	9.0000	0.0001	2500.00
2880.0000	5.6667	0.0001	2500.00
2880.0000	3.0000	0.0002	2500.00
2880.0000	1.0000	0.0004	2500.00
2880.0000	0.3333	0.0006	2500.00
2880.0000	0.1765	0.0007	2500.00
2880.0000	0.1111	0.0007	2500.00
2880.0000	9.0000	0.0001	3000.00
2880.0000	5.6667	0.0001	3000.00
2880.0000	3.0000	0.0002	3000.00
2880.0000	1.0000	0.0004	3000.00
2880.0000	0.3333	0.0006	3000.00
2880.0000	0.1765	0.0007	3000.00
2880.0000	0.1111	0.0007	3000.00

ON TIME FAILURES pNo(pu)t	LAMBDA CYCLIC = F(No) On+Off /OffTime	LAMBDA CYCLIC = F(No) On/On+Off/Off	LAMBDA NORMAL = F(on time) Tot Fail/ On-Time
26.6400	0.0105	0.0036	0.0032
25.1600	0.0107	0.0041	0.0032
22.2000	0.0109	0.0051	0.0032
14.8000	0.0116	0.0077	0.0032
7.4000	0.0122	0.0103	0.0032
4.4400	0.0125	0.0113	0.0032
2.9600	0.0126	0.0118	0.0032
33.3000	0.0128	0.0042	0.0032
31.4500	0.0128	0.0047	0.0032
27.7500	0.0128	0.0056	0.0032
18.5000	0.0128	0.0080	0.0032
9.2500	0.0128	0.0104	0.0032
5.5500	0.0128	0.0114	0.0032
3.7000	0.0128	0.0119	0.0032
39.9600	0.0152	0.0048	0.0032
37.7400	0.0150	0.0052	0.0032
33.3000	0.0148	0.0061	0.0032
22.2000	0.0141	0.0084	0.0032
11.1000	0.0135	0.0106	0.0032
6.6600	0.0132	0.0115	0.0032
4.4400	0.0131	0.0119	0.0032
7.2000	0.0028	0.0010	0.0009
6.8000	0.0029	0.0011	0.0009
6.0000	0.0030	0.0014	0.0009
4.0000	0.0031	0.0021	0.0009
2.0000	0.0033	0.0028	0.0009
1.2000	0.0034	0.0031	0.0009
0.8000	0.0034	0.0032	0.0009
9.0000	0.0035	0.0011	0.0009
8.5000	0.0035	0.0013	0.0009
7.5000	0.0035	0.0015	0.0009
5.0000	0.0035	0.0022	0.0009
2.5000	0.0035	0.0028	0.0009
1.5000	0.0035	0.0031	0.0009
1.0000	0.0035	0.0032	0.0009

10.8000	0.0041	0.0013	0.0009
10.2000	0.0041	0.0014	0.0009
9.0000	0.0040	0.0016	0.0009
6.0000	0.0038	0.0023	0.0009
3.0000	0.0036	0.0029	0.0009
1.8000	0.0036	0.0031	0.0009
1.2000	0.0035	0.0032	0.0009
1.4400	0.0006	0.0002	0.0002
1.3600	0.0006	0.0002	0.0002
1.2000	0.0006	0.0003	0.0002
0.8000	0.0006	0.0004	0.0002
0.4000	0.0007	0.0006	0.0002
0.2400	0.0007	0.0006	0.0002
0.1600	0.0007	0.0006	0.0002
1.8000	0.0007	0.0002	0.0002
1.7000	0.0007	0.0003	0.0002
1.5000	0.0007	0.0003	0.0002
1.0000	0.0007	0.0004	0.0002
0.5000	0.0007	0.0006	0.0002
0.3000	0.0007	0.0006	0.0002
0.2000	0.0007	0.0006	0.0002
2.1600	0.0008	0.0003	0.0002
2.0400	0.0008	0.0003	0.0002
1.8000	0.0008	0.0003	0.0002
1.2000	0.0008	0.0005	0.0002
0.6000	0.0007	0.0006	0.0002
0.3600	0.0007	0.0006	0.0002
0.2400	0.0007	0.0006	0.0002

AD-A174 394 ANALYSIS OF A STOCHASTIC MODEL TO DETERMINE FAILURE RATES FOR COMMUNICATI (U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST T M SKOWRONEK 2/2

UNCLASSIFIED SEP 86 AFIT/GLM/LSM/86S-77 F/G 14/4 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Appendix F: Multi-Plan Spreadsheet Validation Formulas

Column Number

1. National Stock Number: Alpha Character

2. Total Failures in [Ø,t]: Value

3. Expected On-Time Failures in [Ø,t]:

   (Total failures * percent on-time failures)

4. Expected Off-Time Failures in [Ø,t]:

   (Total failures * percent off-time failures)

5. "On-Program" in [Ø,t] (unit hours) at start:

   (1 radar unit * 7 hours/day
   * 19 days/month * 12 months/year)

6. "Off-Program" in [Ø,t] (power-up cycles) at start:

   (1 radar unit * 1 cycles/day
   * 19 cycles/month * 12 months/year)

7. Expected On-Time Failures Divided by Expected Off-Time Failures, Ratio (p):

   (Expected on-failures/expected off-failures)

8. Expected Off-Time Failures Divided by Power-Up Cycles ($N_Ø$):

   (Expected off-failures/average power-ups)

9. Power-Ups Attempted in [Ø,t], "(pu)t": Value

10. Imputed On-Time Failures, "$pN_{0}(pu)t$":

{(Expected on-time failures/expected off-time failures) * (expected off-time failures/average power-up cycles) * (power-ups attempted in [0,t])}

or

Column 7 times, column 8 times, column 9

11. Lambda Cyclic, Imputed On-Time Failures Plus Expected Off-Time Failures Divided by Off-Time.

[(Imputed on-time failures + expected off-time failures)/(off-time)]

12. Old Lambda based on Hours and Cycles:

[(Imputed on-time failures/on-time) + (off-time failures/off-time)]

or

[(Column 10/column 5) + (column 4/column 6)]

13. Lambda Normal, Total Failures Divided by On-Time:

(Total failures/on-time)

14. "On-Program" in [0,t] (unit hours) forecasted:

a. (1 radar unit * 24 hours/day * 30 days/month *12 months/year)
b. (1 radar unit * 12 hours/day * 30 days/month *12 months/year)
c. (1 radar unit * 12 hours/day * 30 days/month *12 months/year)
d. (1 radar unit * 12 hours/day * 30 days/month *12 months/year)

15. "Off-Program" in [0,t] (power-up cycles) forecasted:

a. (1 radar unit * 1 cycle/year)

b. (1 radar unit * 2 cycles/day
* 30 days/month * 12 months/year)

c. (1 radar unit * 4 cycles/day
* 30 days/month * 12 months/year)

d. (1 radar unit * 8 cycles/day
* 30 days/month * 12 months/year)

16. Same as column 7.

17. Same as column 8.

18. Same as column 15.

19. Imputed On-Time Failures, "$pN_{0}(pu)t$":

{(Expected on-time failures/expected off-time failures) * (expected off-time failures/average power-up cycles) * (power-ups attempted in [0,t])}

or

Column 16 times, column 17 times, column 18

20. Total Failures based on Lambda #1:

[Lambda #1 * (pu)t]

or

Column 11 times column 18

21. 'Z' Value based on Hours and Cycles:

{[(Expected on-time failures/on-time) (forecasted on-time)] + [(expected off-time failures/off-time)(forecasted off-time)]

22. Total Failures based on Lambda #3:

[Lambda #3 * (pu)t]

or

Column 13 times column 14

Appendix G: Multi-Plan Spreadsheet Validation Results

NATIONAL STOCK NUMBER	TOTAL FAILURES IN [0,t]	EXPECTED ON-FAILURES IN [0,t]	EXPECTED OFF-FAILURES IN [0,t]	ON PROGRAM IN [0,t] (Unit-Hours)
		(Varying Ratios From 0.95 to .05)		
8172	14	2.1000	11.9000	1596
8172	14	1.9600	12.0400	1596
8172	14	1.8200	12.1800	1596
8172	14	1.6800	12.3200	1596
8172	14	1.5400	12.4600	1596
8172	14	1.4000	12.6000	1596
4882	3	2.5500	0.4500	1596
4882	3	2.5050	0.4950	1596
4882	3	2.4450	0.5550	1596
4882	3	2.4000	0.6000	1596
4882	3	2.3250	0.6750	1596
4882	3	2.2500	0.7500	1596
8473	11	1.1000	9.9000	1596
8473	11	0.9900	10.0100	1596
8473	11	0.8800	10.1200	1596
8473	11	0.7700	10.2300	1596
8473	11	0.6600	10.3400	1596
8473	11	0.5500	10.4500	1596
6246	8	7.6000	0.4000	1596
6246	8	7.5200	0.4800	1596
6246	8	7.4400	0.5600	1596
6246	8	7.3600	0.6400	1596
6246	8	7.2800	0.7200	1596
6246	8	7.2000	0.8000	1596
9908	4	3.8000	0.2000	1596
9908	4	3.7600	0.2400	1596
9908	4	3.7200	0.2800	1596
9908	4	3.6800	0.3200	1596
9908	4	3.6400	0.3600	1596
9908	4	3.6000	0.4000	1596
8044	6	3.0000	3.0000	1596
7181	9	1.8000	7.2000	1596
9116	1	0.9500	0.0500	1596

7019ZK	2	0.4000	1.6000	1596
5267ZK	5	1.0000	4.0000	1596
8386ZK	9	1.8000	7.2000	1596
8716ZK	7	1.4000	5.6000	1596
8707ZK	8	1.6000	6.4000	1596

OFF PROGRAM IN [0,t] (Pwr-Up Cycles)	EXPECTED ON FAILS OVER EXPECTED OFF FAILURES (The Ratio 'p')	EXPECTED OFF-TIME FAILURES PER POWER -UP CYCLE (No) = E(off)/Avg Cycles	POWER-UPS ATTEMPTED IN [0,t] (pu)t
228	0.1765	0.0522	228
228	0.1628	0.0528	228
228	0.1494	0.0534	228
228	0.1364	0.0540	228
228	0.1236	0.0546	228
228	0.1111	0.0553	228
228	5.6667	0.0020	228
228	5.0606	0.0022	228
228	4.4054	0.0024	228
228	4.0000	0.0026	228
228	3.4444	0.0030	228
228	3.0000	0.0033	228
228	0.1111	0.0434	228
228	0.0989	0.0439	228
228	0.0870	0.0444	228
228	0.0753	0.0449	228
228	0.0638	0.0454	228
228	0.0526	0.0458	228
228	19.0000	0.0018	228
228	15.6667	0.0021	228
228	13.2857	0.0025	228
228	11.5000	0.0028	228
228	10.1111	0.0032	228
228	9.0000	0.0035	228
228	19.0000	0.0009	228
228	15.6667	0.0011	228
228	13.2857	0.0012	228
228	11.5000	0.0014	228
228	10.1111	0.0016	228
228	9.0000	0.0018	228
228	1.0000	0.0132	228
228	0.2500	0.0316	228
228	19.0000	0.0002	228

228	0.2500	0.0070	228
228	0.2500	0.0175	228
228	0.2500	0.0316	228
228	0.2500	0.0246	228
228	0.2500	0.0281	228

ON-TIME FAILURES pNo(pu)t (IMPUTED)	LAMBDA CYCLIC = F(No) On+Off /OffTime	LAMBDA CYCLIC = F(No) On/On+Off/Off	LAMBDA NORMAL = F(on time) Tot Fail/ On-Time
2.1000	0.0614	0.0535	0.0088
1.9600	0.0614	0.0540	0.0088
1.8200	0.0614	0.0546	0.0088
1.6800	0.0614	0.0551	0.0088
1.5400	0.0614	0.0556	0.0088
1.4000	0.0614	0.0561	0.0088
2.5500	0.0132	0.0036	0.0019
2.5050	0.0132	0.0037	0.0019
2.4450	0.0132	0.0040	0.0019
2.4000	0.0132	0.0041	0.0019
2.3250	0.0132	0.0044	0.0019
2.2500	0.0132	0.0047	0.0019
1.1000	0.0482	0.0441	0.0069
0.9900	0.0482	0.0445	0.0069
0.8800	0.0482	0.0449	0.0069
0.7700	0.0482	0.0454	0.0069
0.6600	0.0482	0.0458	0.0069
0.5500	0.0482	0.0462	0.0069
7.6000	0.0351	0.0065	0.0050
7.5200	0.0351	0.0068	0.0050
7.4400	0.0351	0.0071	0.0050
7.3600	0.0351	0.0074	0.0050
7.2800	0.0351	0.0077	0.0050
7.2000	0.0351	0.0080	0.0050
3.8000	0.0175	0.0033	0.0025
3.7600	0.0175	0.0034	0.0025
3.7200	0.0175	0.0036	0.0025
3.6800	0.0175	0.0037	0.0025
3.6400	0.0175	0.0039	0.0025
3.6000	0.0175	0.0040	0.0025
3.0000	0.0263	0.0150	0.0038
1.8000	0.0395	0.0327	0.0056
0.9500	0.0044	0.0008	0.0006

0.4000	0.0088	0.0073	0.0013
1.0000	0.0219	0.0182	0.0031
1.8000	0.0395	0.0327	0.0056
1.4000	0.0307	0.0254	0.0044
1.6000	0.0351	0.0291	0.0050

Appendix H: Multi-Plan Spreadsheet Forecasted Results

STARTING CALCULATIONS——————>——————————>

NATIONAL STOCK NUMBER	TOTAL FAILURES IN [0,t]	EXPECTED ON-FAILURES IN [0,t]	EXPECTED OFF-FAILURES IN [0,t]	ON PROGRAM IN [0,t] (Unit-Hours (Start)
8172	14	2.1000	11.9000	1596
8172	14	2.1000	11.9000	1596
8172	14	2.1000	11.9000	1596
8172	14	2.1000	11.9000	1596
6246	8	7.6000	0.4000	1596
6246	8	7.6000	0.4000	1596
6246	8	7.6000	0.4000	1596
6246	8	7.6000	0.4000	1596
8044	6	3.0000	3.0000	1596
8044	6	3.0000	3.0000	1596
8044	6	3.0000	3.0000	1596
8044	6	3.0000	3.0000	1596

OFF PROGRAM IN [0,t] (Cycles) (Start)	EXPECTED ON FAILS OVER EXPECTED OFF FAILURES (The Ratio (p))	EXPECTED OFF-TIME FAILURES PER POWER -UP CYCLE (No) = E(off)/Avg Cycles	POWER-UPS (pu)t ATTEMPTED IN [0,t]
228	0.1765	0.0522	228
228	0.1765	0.0522	228
228	0.1765	0.0522	228
228	0.1765	0.0522	228
228	19.0000	0.0018	228
228	19.0000	0.0018	228
228	19.0000	0.0018	228
228	19.0000	0.0018	228
228	1.0000	0.0132	228
228	1.0000	0.0132	228
228	1.0000	0.0132	228
228	1.0000	0.0132	228

ON-TIME FAILURES pNo(pu)t (IMPUTED)	LAMBDA CYCLIC On+Off /OffTime LAMBDA #1	OLD LAMBDA BASED ON HOURS & CYCLES	LAMBDA NORMAL TotFail/OnTime LAMBDA #3
2.1000	0.0614	0.0535	0.0088
2.1000	0.0614	0.0535	0.0088
2.1000	0.0614	0.0535	0.0088
2.1000	0.0614	0.0535	0.0088
7.6000	0.0351	0.0065	0.0050
7.6000	0.0351	0.0065	0.0050
7.6000	0.0351	0.0065	0.0050
7.6000	0.0351	0.0065	0.0050
3.0000	0.0263	0.0150	0.0038
3.0000	0.0263	0.0150	0.0038
3.0000	0.0263	0.0150	0.0038
3.0000	0.0263	0.0150	0.0038

FORECASTED CALCULATIONS——————>——————————>

ON-PROGRAM IN [0,t] (Unit-Hours) (Forecasted)	OFF-PROGRAM IN [0,t] (Pwr-Up cycles) (Forecasted)	EXPECTED ON FAILS OVER EXPECTED OFF FAILURES [The Ratio (p)]
8640.0000	1.0000	0.1765
4320.0000	720.0000	0.1765
4320.0000	1440.0000	0.1765
4320.0000	2880.0000	0.1765
8640.0000	1.0000	0.1765
4320.0000	720.0000	0.1765
4320.0000	1440.0000	0.1765
4320.0000	2880.0000	0.1765
8640.0000	1.0000	0.1765
4320.0000	720.0000	0.1765
4320.0000	1440.0000	0.1765
4320.0000	2880.0000	0.1765

EXPECTED OFF-TIME FAILURES PER POWER -UP CYCLE (No) = E(off)/Avg Cycles	POWER-UPS (pu)t ATTEMPTED IN [0,t]	ON-TIME FAILURES pNo(pu)t (IMPUTED)
0.0522	1.0000	0.0092
0.0522	720.0000	6.6327
0.0522	1440.0000	13.2654
0.0522	2880.0000	26.5307
0.0018	1.0000	0.0003
0.0018	720.0000	0.2229
0.0018	1440.0000	0.4459
0.0018	2880.0000	0.8918
0.0132	1.0000	0.0023
0.0132	720.0000	1.6721
0.0132	1440.0000	3.3442
0.0132	2880.0000	6.6884

REQUIREMENTS ——————————>——————————>

TOTAL FAILURES BASED ON LAMBDA #1	Z VALUE BASED ON HRS & CYCLES	TOTAL FAILURES BASED ON LAMBDA #3
0.0614	11.4206	75.7895
44.2105	43.2632	37.8947
88.4211	80.8421	37.8947
176.8421	156.0000	37.8947
0.0351	41.1446	43.3083
25.2632	21.8346	21.6541
50.5263	23.0977	21.6541
101.0526	25.6241	21.6541
0.0263	16.2538	32.4812
18.9474	17.5940	16.2406
37.8947	27.0677	16.2406
75.7895	46.0150	16.2406

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VITA

Captain Thomas M. Skowronek was born on 9 January 1956 in Toledo, Ohio. He graduated from St. Francis de Sales high school in 1974 and attended both the University of Toledo and Bowling Green State University. He received a Bachelor of Science degree in Chemistry from the University of Toledo in 1978, and upon graduation, was commissioned a Second Lieutenant in the USAF through the ROTC program at Bowling Green State University. He completed the Aircraft Maintenance Officer Course at Chanute AFB, Illinois in 1980 and was assigned to the 31st Tactical Fighter Wing, Homestead AFB, Florida. He served in numerous first and second line maintenance officer positions until selected for exchange officer duty with the Royal Air Force in 1983. At RAF Coningsby, he was Officer Commanding Rectification Flight, 228 Operational Conversion Unit, a position similar to an OIC AMU, as well as the squadron flight safety officer. Also during his RAF tour, he was Officer Commanding Phantom Servicing Flight, a position similar to EMS Maintenance Supervisor. In 1985, he was selected to attend the School of Systems and Logistics, Air Force Institute of Technology, where he was a graduate student in the Maintenance Management option until September 1986.

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Work accomplished by Headquarters Air Force Logistics Command (AFLC) demonstrates a need to consider both "on-time" and "off-time" failures when computing communication-electronic spares requirements. However, AFLC has been unable to verify and validate a method that would integrate both failure types into a single requirements algorithm. This thesis attempts to verify and validate a method which integrates the two distributions.

On-time failures are derived through a stochastic growth process, where expected on-failures are divided by expected off-failures, then multiplied by both an initial off-failure rate and power-ups. The initial off-failure rate equals expected off-failures divided by average power-ups attempted. Off-failures occur through unsuccessful attempts to power-up a system.

The resultant total failure rate equals the cross product of the two failure functions, and is a failure plane instead of a line. If a linear rate is required, then the sum of the two failures could also be distributed over either on-hours or power-ups to arrive at a requirement.

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