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ANALYSIS OF A STOCHASTIC MODEL FOR COMMUNICATIONS-ELECTRONIC SYSTEMS FAILURE RATES USING DYNA-METRIC

THESIS

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THESIS

Presented to the Faculty of the School of Systems and
Logistics of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
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Master of Science in Logistics Management

Stephen P. Melroy
1st Lieutenant, USAF

September 1988

Acknowledgments

The list of people to thank in this research effort is a long one. They have all devoted their time and effort in an unselfish manner in order to make this a successful thesis. I would like to, however, single out two major contributors. To my advisor, Lt. Col. Bruce Christensen, whose patience and wisdom made this whole process a meaningful learning process. His support has been unwavering and his guidance sound in both this effort, as well as other academic endeavers. In addition, I would like to thank Richard D. Mabe of The Analytic Sciences Corporation (TASC). His devotion of time as well as a historical perspective on the problem have proved invaluable.

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Finally, I would like to dedicate this work to the memory of my godfather, Colonel Martin Kallighan, USAF Ret., who passed away this year. His traits of leadership and officership live on in me.

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(Communications Electronics War Readiness Spares Kit)

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Abstract

The current (~~CE WRSK~~) configuration process is not standardized. There are many different inputs used by AFLC to determine requirements. A model to predict CE system failure rates has been developed and validated. This model separates failures into two categories, on-time failures and cycle-up failures. This validated model was tested, using Dyna-METRIC, against two other possible failure rates. These failure rates were based on ~~(1)~~ possessed hours and ~~(2)~~ on-time hours. The stockage runs produced by Dyna-METRIC were compared to actual failures over a 120 day time period. The validated model produced a higher stockage level, as well as a lower MSE than the other two failure rates. The current failure rate used by AFLC to aid in CE WRSK configuration showed a discernible trend to underestimate stockage levels. The Air Force should use the validated model to determine CE WRSK configuration and implement the appropriate policies and data gathering systems.

Keywords: Theses, Logistics Management, (KR)

ANALYSIS OF A STOCHASTIC MODEL FOR COMMUNICATIONS-ELECTRONIC SYSTEMS FAILURE RATES USING DYNA-METRIC

I. Introduction

Overview

The visible mission of the Air Force is to "fly and to fight." However, an unseen but important factor in this mission is that of communications-electronic (CE) systems. These systems make possible the necessary flow of information between operational units. The support of these CE systems in the beginning phases of wartime are provided by War Readiness Spares Kits (WRSK). A WRSK is a set of reparable spares used by a weapon system that can be removed, repaired, and replaced (RRR). The configuration of a WRSK is determined by the failures of system spares over a specified period of time. The WRSK is then stocked with those items expected to fail. The difficulty in CE WRSK configuration is the accurate prediction of failure rates.

This difficulty in predicting failure rates led to the development of a model to predict CE system spares failure rates. This model was proposed by Captain Thomas M. Skowronek in his 1986 Air Force Institute of Technology (AFIT) thesis "Analysis of a Stochastic Model to Determine

Failure Rates for Communications-Electronic Systems." The model was to be used to compute failure rates and enhance the automation of non-airborne WRSK configuration. Presently, non-airborne WRSK levels are determined annually, based on maintenance expertise and past experience (1:35).

Captain Skowronek proposed a CE failure rate that was a function of two types of failures, on- and off-time. On-time failures were measured by operating hours. However, off-time failures were the result of power-up phases, power-down phases, and mechanical jostling due to the environment of mobile CE systems. The result of Captain Skowronek's research was a three dimensional model of off-time, on-time failures, and resultant total failures.

Captain Skowronek was unable to complete a comprehensive validation of this model. Validation was completed the following year in a follow-on thesis.

Major Dennis G. Willeck, in his AFIT thesis, "Validation of a Stochastic Model to Determine Failure Rates for Communications-Electronic Systems," supplied the necessary field data to complete a validation of Skowronek's model. The data used by Major Willeck was supplied by the 2nd Combat Control Group (2CCG) of Patrick AFB, for the MPN-14 and TPN-19 radar systems (14:13-4). The data was assembled into 30-day operating periods, or epochs, which were in turn used to predict failures. For example, data collected in an epoch was used to predict failures in the same epoch (14:15). A further discussion of Major Willeck's methodology will be included in Chapter 2. His conclusions lay the ground work for further research.

> The results indicate that the model was a good predictor for dynamic operating environments. . .the Skowronek model should be used for WRSK computations because it is more sensitive to the dynamics of the CE environment (14:34).

It is important to recognize that Major Willeck's validation used actual maintenance data to compute predicted failure rates using Captain Skowronek's model, and compared the results to the present methodology of computing CE WRSK by Air Force Logistics Command (AFLC). However, Major Willeck did not compare different methods for implementing the model into CE WRSK configurations.

The conclusions of Captain Skowronek and Major Willeck present a workable model to determine CE system spares failure rates. This validated model can now be implemented into the Air Force management structure to aid the determination of non-airborne CE WRSK configuration. However, a method to implement the model must be determined.

Specific Problem

The Air Force has not yet adapted a definitive method to compute non-airborne WRSK levels. A model has been developed and validated which approximates the on- and off-time failure rates of CE systems. To implement this model into the CE WRSK configuration process, various procedures must be tested. These procedures include the use of Captain Skowronek's model as a tool to compute accurate CE system spare failure rates, and in turn, CE WRSK configuration.

General Approach

The validation of Captain Skowronek's model by Major Willeck was accomplished using a Lotus 1-2-3 spreadsheet program. In this research effort, the Mini Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC), a personal computer (PC) version of the Dyna-METRIC equations will be used. The logic of the Dyna-METRIC equations will be discussed in Chapter 2. The resultant spares requirements computed by Dyna-METRIC will be compared to actual failures. The spreadsheet program calculated Captain Skowronek's model as a stand alone model, without the effect of the Dyna-METRIC algorithms.

The Dyna-METRIC model will introduce "workarounds" to the Skowronek model to adapt it to the CE environment because Dyna-METRIC is presently used to forecast airborne system spares failures. The workarounds to the Dyna-METRIC equations will be presented in Chapter 3. If it can be determined that Dyna-METRIC is useful in calculating CE systems stockage levels, then it can be implemented into the CE WRSK configuration process.

The following is a list of steps that must be accomplished to compare the results of the computed failure rates.

1. The data collected by Major Willeck must be converted into a Dyna-METRIC input file to compute the necessary failure rates on the Dyna-METRIC model.
2. The Dyna-METRIC model will be run a total of four ways to test the various "workarounds" to the Dyna-METRIC logic (More on the workarounds can be found in Chapter 3).
3. The results of the forecasts run on Dyna-METRIC will be compared to actual failure rates. The difference between the predicted failure rates and the actual failure rates will be computed using the Mean Squared Error (MSE). The rationale for evaluating the difference using the MSE will be fully discussed in Chapter 3.
4. The resulting differences between predicted failure rates and actual rates will be analyzed and conclusions will be drawn.

Justification

The Air Force must determine a more definitive method to determine non-airborne WRSK configurations. The results of Captain Skowronek's and Major Willeck's research are that the model effectively mirrors the CE systems spares failure rates in a wartime condition. However, to incorporate the validated model into the configuration of CE WRSK, different processes for this implementation must be examined and compared to determine if there is a "best".

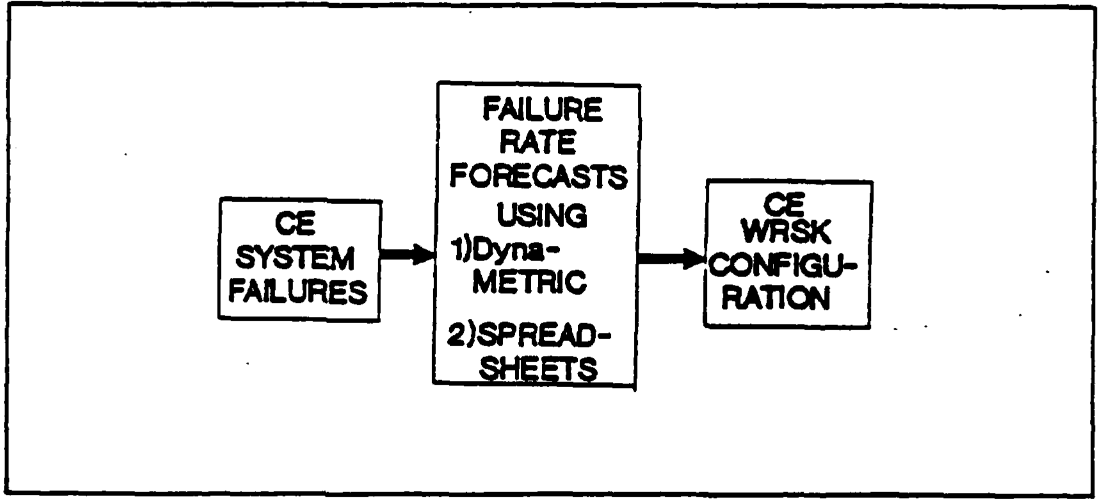


Figure 1. Methods for Forecasting CE Failures

Scope and Limitations

This research effort will be limited to the use of data used by Major Willeck in the validation process. The failure rates collected by Major Willeck were of the MPN-14 and TPN-19 radar systems, but only data collected for the MPN-14 will be used due to the lack of workable data collected on the TPN-19. This lack of workable data arose from severe data collection limitations discussed in Chapter 2.

The second limitation will be the use of the Dyna-METRIC model to compute failure rates. Since the Air Force now accepts the Dyna-METRIC model as a valid technique for computing spares requirements for airborne systems, this research centers on ways to adapt or modify the Dyna-METRIC model to CE system spares failure computation.

A third limitation lies in the conclusions of Captain Skowronek and Major Willeck. The assumption is made that their conclusions are correct. That is, the goal is not to test the Skowronek model itself, but its application.

Summary

This section has outlined the problem to be researched and analyzed. Chapter 2 will discuss the background development of Captain Skowronek's model, as well as Major Willeck's validation process. In addition, an overview of the Dyna-METRIC model will be given. Chapter 3 will outline the methodology to be used in determining the "best method" of implementing the model into the computing CE WRSK configuration. Chapter 4 will present the results of the computations of failure rates using the different methods proposed. Chapter 5 will discuss the conclusions and the recommendations of the author.

II. Literature Review

Overview

This section will review the development of Captain Skowronek's model and a summary of the validation process of Major Willeck. In addition, the data used by Major Willeck, an overview of War Reserve Materiel (WRM), and development of the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) model are included.

Development of the Original Model

The model proposed by Captain Skowronek is characterized by a stochastic process. This stochastic process reflects a series of numbers drawn randomly from a probability distribution (10:494). This probability distribution centers around a specified parameter. The parameter in Captain Skowronek's model is the failure rate.

The failure rate in Captain Skowronek's model is a function of two elements, on- and off-time failures. The total failure rate is identically distributed to the two failure rates, but the on- and off-time rates lie in an independent distribution. The probability distribution assumed in Captain Skowronek's model is Poisson, because the Poisson distribution gives a good approximation of the number of events that will occur in a specified period of time (8:188). The Poisson parameter used in Captain Skowronek's model to portray the total failure rate is the mean, or lambda (λ). The model attempts to explain the randomness in the probability distribution around the failure rate in a manner that is useful for forecasting purposes (10:494).

Captain Skowronek's research focused on the development of a model that effectively mirrored CE system failure rates. That is, a model that would determine on- and off-time failures in a single computation. The determination of on-time failures is simply the total number of failures for a part during operating hours. However, the impact of non-operating failures on the total failure rate was much less apparent due to the peculiarities of CE systems. They are subject to power surges through the system at times of power-ups and -downs. In addition, a mobile CE system could sustain damage in an off-power state as the result of transporting the unit from one location to another. An example of these mobile CE systems are radar systems used by United States Air Forces in Europe (USAFE) Tactical Air Control System (TACS). They are the "eyes and ears" of a front line battle with Warsaw Pact Forces, and must be mobile to adapt to changing battlefield conditions (7:1). Damage sustained during transportation on CE systems is difficult, if not impossible to predict. Therefore, Captain Skowronek concentrated his research on the effect of power-up and -down cycles. His in-depth literature review into this area led him to the conclusion

> that non-operating failures contribute in part to total failure rate, and should be considered when building a model to determine spares requirements. (12:16)

In addition, Captain Skowronek proposed that these off-time failure possibilities be lumped into one, aggregate off-time failure rate because they would only be discovered, and be based, on power-up cycles.

Captain Skowronek's next step was to build a model based on the combination of on- and off-time failure rates. This meant the failure rate was a function of on-time and power-up cycles. This relationship of the two failure rates on a single failure resulted in a plane of failures on a three dimensional axis (see Figure 2). The following formula expresses Captain Skowronek's model.

$$Z = (Za/Xa)(X) + (Zb/Yb)(Y)$$

where

Za = Expected on-time failures,

Xa = On-time hours in current period,

X = Transition on-time in next period,

Zb = Expected off-time failures,

Yb = 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 (12:68-9).

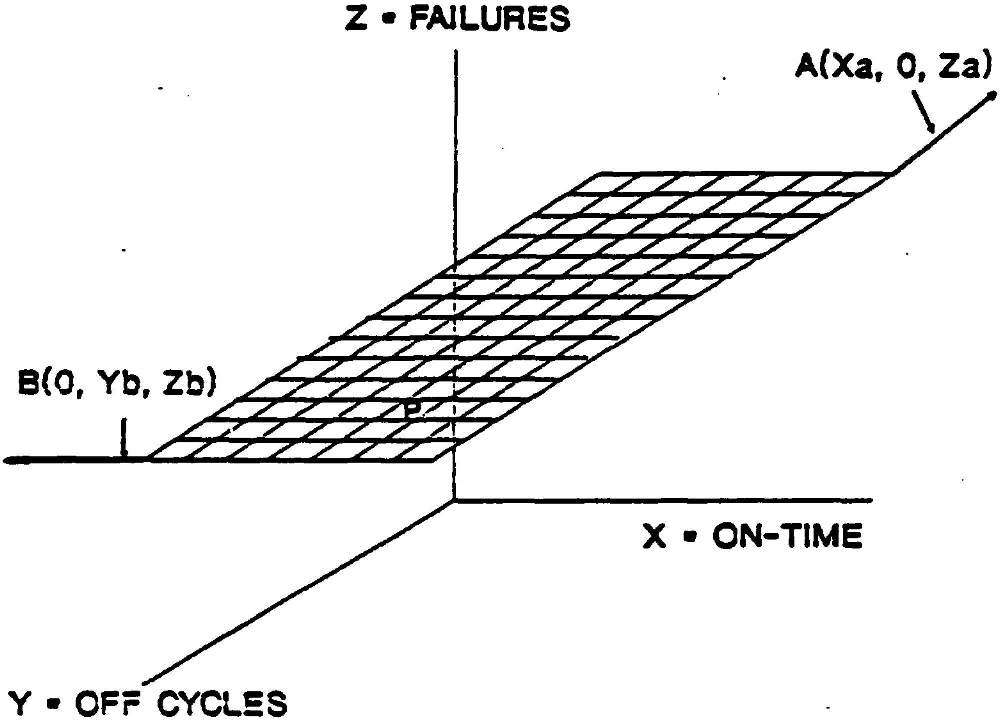


Figure 2. Structural Diagram of the Failure Plane (12:24)

The final step was to assume the combined failure rate was Poisson distributed with a mean of Lambda. Since on- and off-time failure rates would have differing mean values, a multivariate Poisson distribution was needed to solve the model. This model would then be a function of both time and cycles. This, associated with a "growth" process of failures over time and cycles, produced a three dimensional probability distribution function (PDF), which represents the total failure rate given a specified time and specified number of cycles. This PDF is represented in Figure 3.

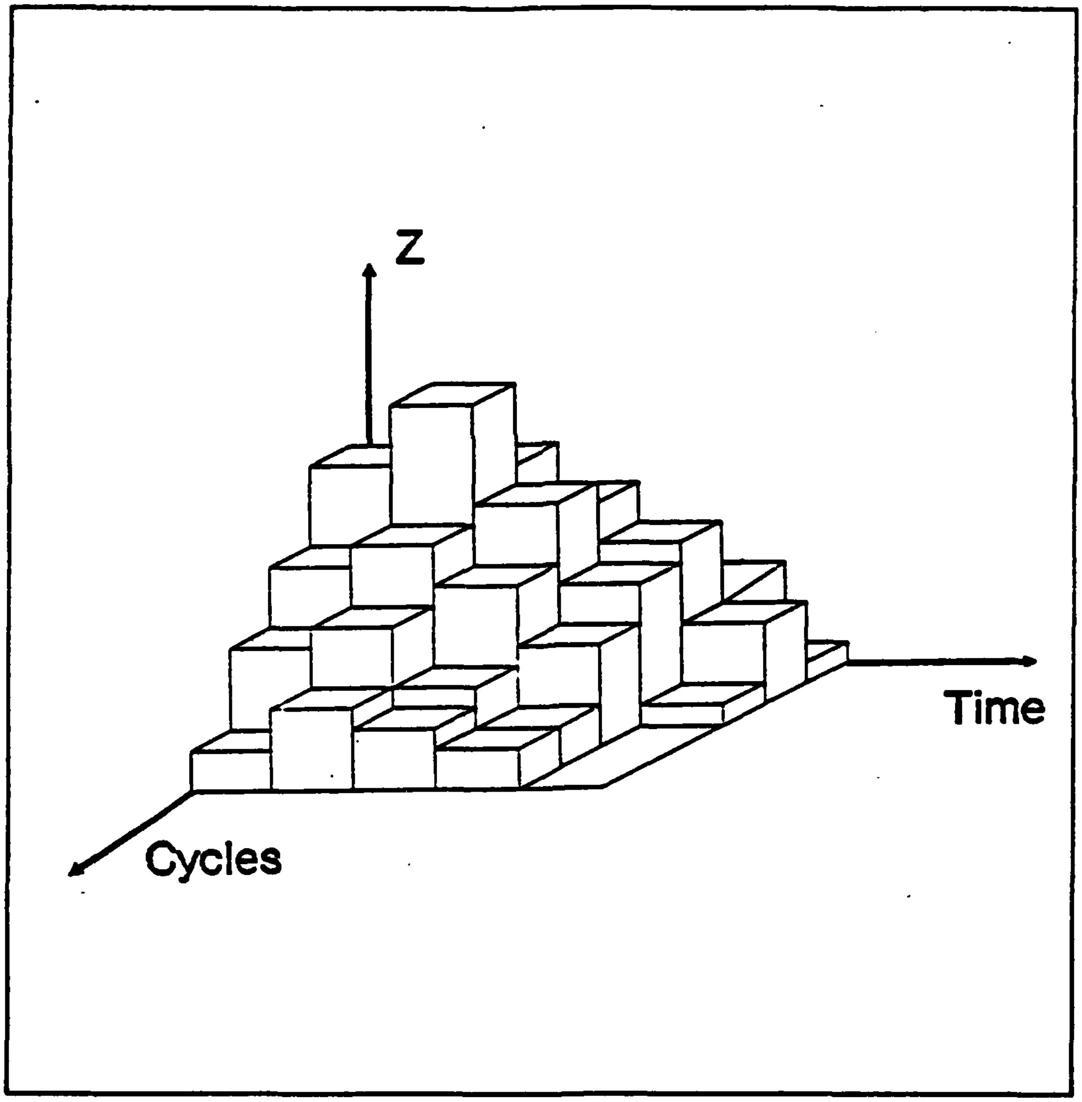


Figure 3. Three Dimensional Poisson Distribution (12:69)

Validation of Model

Major Willeck's validation made a small adjustment to Skowronek's model. He substituted actual failures for expected operating failures (Za) from the previous epoch. This substitution was facilitated by the capability to identify failures as both on- and off-time. Computing an imputed on-time failure rate was not necessary for the validation (14:12).

The data used by Major Willeck was collected by the 2nd Combat Control Group (2CCG) of Patrick AFB. The data collected was sorted into elements to fit the Skowronek model. Of the six months collected, two were from actual data collection forms created by Major Willeck, while the remaining four months had to be extracted from a maintenance data collection (MDC) system. The data collected from the MDC had limitations. The first limitation was that during maintenance times, the units were subject to frequent power-ups and downs, and the particular item causing the failure was not recorded. In addition, the total number of power ups of a system was not recorded, and if an item failed during this time, it was not recorded. The second limitation was that only the occurrence of the failure was recorded and not the moment it occurred (power-up or on-time). Finally, if a part did fail and was replaced, then the replacement part immediately failed, it could not be determined if this was either an on- or off-time failure (14:31-2).

The assumption Major Willeck made to work around this potential gap in data was that the failures recorded were the same used by AFLC in the calculation of CE WRSK. Therefore, they were working from the same database, and a valid comparison could still be made. Next, Major Willeck assumed that he could take the operations of the two months of primary data he had collected, and apply the same conditions to the previous four months. For example, the cycles experienced per month in the last two months of data collection were the same for the previously unrecorded months (14:32). However, Major Willeck only used the data collected (four epochs) for his validation because of the lack of primary data collected (13:31).

The data for the two radar systems, the MPN-14 and the TPN-19, were not of equal value in Major Willeck's validation. The MPN-14 data provided enough off-time failure data to produce an adequate database for testing, while the TPN-19 did not. Therefore, Major Willeck excluded the data collected from the TPN-19 from his validation (14:35).

The data collected were separated into 30-day operating periods, or epochs. An epoch represents 30 days of on-hours and power-up cycles. A WRSK is generally sorted into 30-day operating time periods, and therefore, the 30-day epochs better suit a wartime scenario.

Major Willeck summed the total possessed hours, on-hours, and cycles for all four epochs. In addition, failures corresponding to on-time and off-time were likewise summed. The result was an aggregate failure rate used to predict failures in each epoch.

The computation of failure rates involved three different forecasts using a LOTUS 1-2-3 spreadsheet. Forecast one predicted all failures over possessed time, the total operational time of the system. This is the current methodology used by AFLC to compute non-airborne WRSK requirements (14:30). The second forecast used total failures over on-hours. The difference between on-hours and possessed hours is a 30 minute system "warm up" time. The warm up time enables the system to reach a steady state temperature, where operation effectiveness is achieved. The third forecast was made using Captain Skowronek's model. A summary of Major Willeck's forecasts are shown in Figure 4.

Results of Validation

Unexpectedly, Major Willeck determined that Forecast One was the most acceptable because it produced the lowest Mean Absolute Deviation (MAD) when compared to the other forecasts. He concluded this occurred because the MPN-14 operating time over the course of data collection was

$$\text{Forecast 1} = \frac{\text{Total Failures}}{\text{Possessed Hours}} \times \begin{array}{c}\text{Expected Number}\\ \text{of}\\ \text{Possessed Hours}\end{array}$$

$$\text{Forecast 2} = \frac{\text{Total Failures}}{\text{On-Hours}} \times \begin{array}{c}\text{Expected Number}\\ \text{of}\\ \text{On-Hours}\end{array}$$

$$\text{Forecast 3} = \frac{\text{On-Fails}}{\text{On-Hours}} \times \begin{array}{c}\text{Exp'td}\\ \text{On-Hours}\end{array} + \frac{\begin{array}{l}\text{Cycle}\\ \text{Fails}\end{array}}{\text{Cycles}} \times \begin{array}{c}\text{Exp'td}\\ \text{Cycles}\end{array}$$

Figure 4. Forecasts Made in Validation (14:27)

steady state and did not reflect a truly CE dynamic environment with frequent power-ups and downs. As actual hours of operation for an epoch began to vary from steady-state, Captain Skowronek's model became more effective (14:34). In summary, Major Willeck concluded

> Although Forecast 1 is acceptable for the peacetime environment, it appears to drive requirements lower than needed during contingencies or wartime conditions. . .the Skowronek model. . .is more sensitive to the dynamics of the CE environment (14:34).

War Reserve Materiel

The objective of War Reserve Materiel (WRM) is to provide the necessary support to fighting forces in wartime. A key division of WRM is War Readiness Spares Kits. WRSK, as defined by AFR 400-24, War Reserve Materiel Policy, is

> An air transportable package of selected WRM spares, repair parts, and supplies required to sustain planned wartime or contingency operations for a specified period of time pending resupply (3:49).

WRSK configuration for airborne weapon systems is calculated using failures of spare parts during its operational use (flying hours). These failure rates are then compiled in the D040, a master data base used by Air Force Logistics Command (AFLC). Since flying hours during wartime will be more intense, AFLC converts the peacetime failure rates in the D040 into a format that would reflect the surge in flying hours. This conversion process takes place in the D029 program, know as the Master Authorization List. The accumulated failure rates are then used by AFLC to determine WRSK configuration (2:14-43). The failure rate for an item is multiplied by the expected number of flying hours to be flown. For WRSK determination, this is generally 30 days, because it is assumed initial resupply could be accomplished by that time (3:16).

The CE WRSK configuration process is not as standardized. There is no accumulation of CE system failures in a master data base (1:35). An estimate of a failure rate is computed by AFLC, using total failure rates over total operational hours. However, literature reviewed earlier in this chapter pointed out the need to determine the effect of off-time failure rates on the total failure rate, so this method is subject to potentially erroneous failure rates. The current CE WRSK configuration process is based on this computed failure rate, coupled with CE maintenance personnel expertise (1:35). The result is a non-definitive method for the configuration of CE WRSK.

Development of the Dyna-METRIC Model

The Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) model is a series of mathematical equations which is used to forecast the expected quantity of spare parts needed for an airborne weapon system in a wartime environment. It is multi-echelon because it incorporates the impact of the repair and shipment pipelines at both the depot and base level. The purpose of Dyna-METRIC is to predict system spares requirements for a user defined level of fully mission capable (FMC) aircraft over a specified period of time. Dyna-METRIC can also predict the level of FMC aircraft available given a specified level of spare parts and an investment constraint.

The pipeline aspect is the key to the Dyna-METRIC equations (11:vii). The shipment pipeline is the quantity of parts required to fill the time of transition from the depot to the base or from the base to the depot, given an expected shipment time. The repair pipeline is defined as the number of units in repair, at either the base or the depot, given a stated repair time for that particular component. These pipelines, when summed, are the total number of parts necessary to accomplish a user defined FMC rate.

The expected failure rates of an item and the lead-times of parts between echelons are incorporated into the Dyna-METRIC equations using a queuing theorem known as Palm's Theorem. Palm's Theorem states that when demands for an item (a failed part) arrive according to a Poisson distribution with a mean of lambda (λ) and a service time (shipment time or repair time) independent of the failure rate, with a mean of Tau (τ), then the number of units in resupply (k) can be defined as

Probability of k units in resupply =

$$P(k) = \frac{(\lambda\tau)^k e^{-\lambda\tau}}{k!} \qquad (5:5)$$

The Dyna-METRIC equations will predict expected failures of a component given a user defined FMC level. In another mode, Dyna-METRIC, given a level of initial spare parts and an investment constraint, will provide a listing of parts that, when procured, will produce the highest FMC rate attainable given these initial conditions.

The present Dyna-METRIC equations are a result of numerous iterations of models developed to represent the Air Force reparable inventory management process. Dyna-METRIC provides the best forecast of spares requirements and is in use now by AFLC to determine WRSK requirements for airborne systems. Yet, as with any forecasting model, it cannot predict the future with certainty, and certain assumptions must be built in with the development of this forecasting method. The following is a list of the major assumptions built into the Dyna-METRIC equations:

1. There are no queuing delays in the repair process. This would tend to overstate capability when flying hours reach a maximum.
2. The demand rates for an item are a function of flying hours.
3. The repair process is stationary, so that repair surges and slow downs are not evaluated.
4. The repair process of a component at all echelons is assumed to be identical.
5. The demand rates for components are not adjusted to reflect previous FMC sorties accomplished.

6. The forecast sortie rates do not reflect flight line resources.

7. The aircraft within each base are assumed to be interchangeable.

8. There is no lateral resupply between bases (11:viii), (9).

The adaptation of the Dyna-METRIC equations from the prediction of aircraft weapon systems to the prediction of CE equipment will be further discussed in Chapter 3.

For the purpose of this experiment, the personal computer (PC) version of Dyna-METRIC was used. The PC version, known as Mini Dyna-METRIC, was used because the amount of data is relatively small, and the use of a mainframe computer, needed to run the full Dyna-METRIC model, was unnecessary.

Summary

There is a fully developed and validated model for determining CE system failure rates. As a result, it is possible to compare stockage levels, using Dyna-METRIC, to actual failures for non-airborne systems using Captain Skowronek's model as the tool to forecast failure rates. The next chapter outlines the methodology to adapt the Dyna-METRIC equations into the CE environment and in turn, determine spares requirements for CE systems.

III. Methodology

Overview

This chapter presents the formulas and computer program necessary to perform the research steps outlined in Chapter 1. The data was sorted into appropriate categories to perform the calculations. The computer program necessary is Mini Dyna-METRIC and the experiment described in this chapter takes the failure rates computed by Major Willeck on the Lotus 1-2-3 spreadsheet and inputs these failure rates into the Dyna-METRIC equations to forecast spares requirements, and in turn CE WRSK configuration.

Structural Model

Three failure rates have been forecast, all three using distinct formulas embedded in the Mini Dyna-METRIC model. The first formula was total failures over possessed time, or the total amount of time the unit was in operation for an epoch. The second forecast was total failures over total on-hours for a given epoch. On-hours do not include a thirty minute cycle-up period at equipment turn-on. The third forecast used Captain Skowronek's model, using multiple runs of the Mini Dyna-METRIC model. A discussion of the workarounds made to the Mini Dyna-METRIC model to fit the CE environment will be discussed under "Experimental Design." Major Willeck's failure rates, calculated on the Lotus 1-2-3 spreadsheet program, attempted to replicate the Dyna-METRIC calculations, where the failure rate (lambda in Palm' equation) is calculated using Captain Skowronek's model. Figure 5 shows the forecasts used.

Forecast 1 (Mini Dyna-METRIC) $= \dfrac{\text{Total Failures}}{\text{Possessed Hours}}$

Forecast 2 (Mini Dyna-METRIC) $= \dfrac{\text{Total Failures}}{\text{On-Hours}}$

Forecast 3 = Run 1 + Run 2 Both runs on Mini Dyna-METRIC

Run 1 $= \dfrac{\text{On-Fails}}{\text{On-Hours}}$

Run 2 $= \dfrac{\text{Cycles Fails}}{\text{Cycles}}$

Major Willeck's Forecast $= \dfrac{\text{On-Fails}}{\text{On-Hours}} \times \text{Expected On-Hours} + \dfrac{\text{Cycle Fails}}{\text{Cycles}} \times \text{Expected Cycles}$

Lotus 1-2-3
Spreadsheet
Program

Figure 5. Forecasts Made on Dyna-METRIC and Spreadsheet

The difference between forecast three and Major Willeck's forecast is the effect of the Dyna-METRIC algorithms on the forecasts. Figure 6 displays the different forecasts, in the sequence of their calculations.

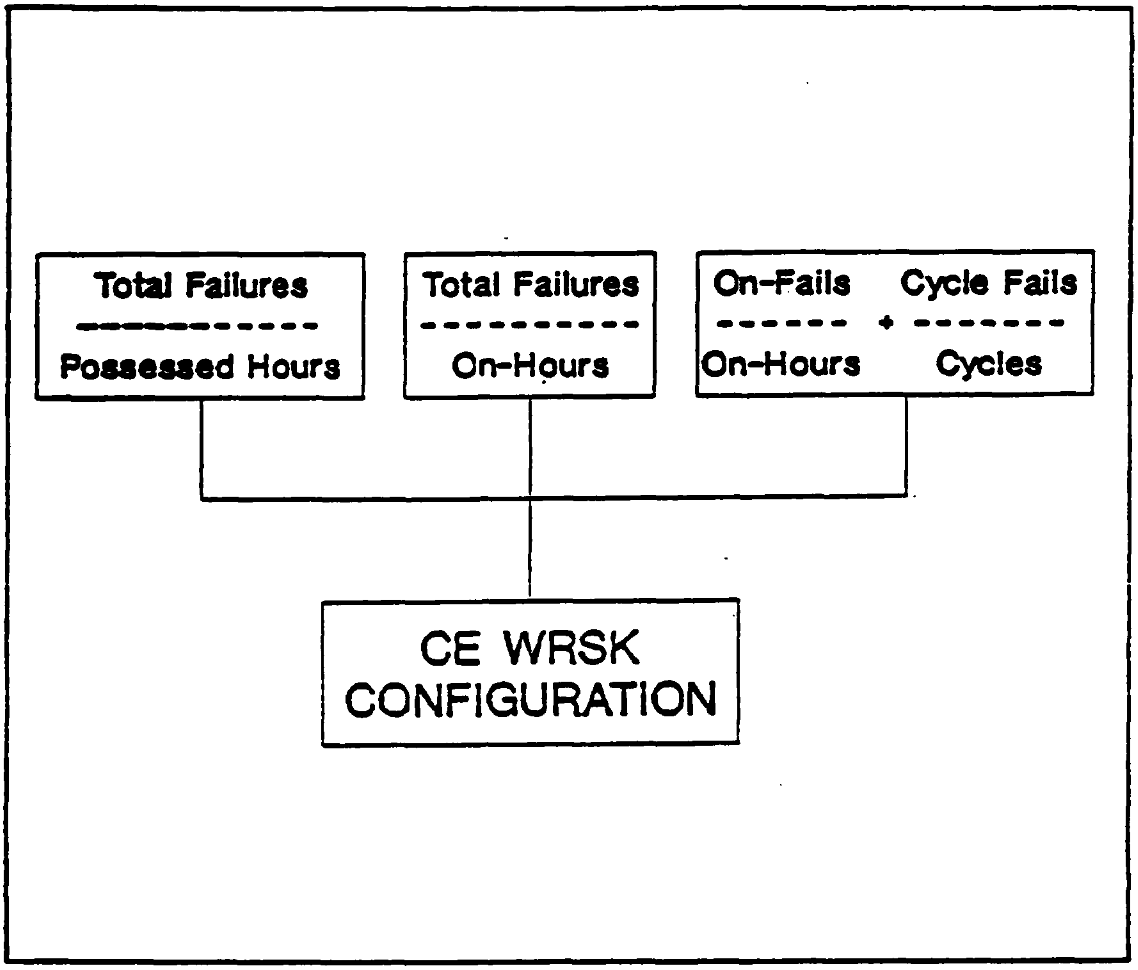


Figure 6. Sequence of Dyna-METRIC Forecasts

Experimental Design

The Skowronek formula was used as a basis for the experiment, while the Dyna-METRIC equations and the Lotus 1-2-3 spreadsheet were used as the tools to calculate the best method for CE WRSK computation. This section outlines the methods employed to accomplish each of the research steps leading to the determination of the best computation method.

In October 1987, a Weapon Systems Management Information System (WSMIS) Program Management Review (PMR) was held. At this PMR, Richard D. Mabe of The Analytic Sciences Corporation (TASC), an AFLC contractor, proposed the following methods to compute CE WRSK requirements (6).

1. Maintain the status quo of CE WRSK requirement computation. That is, calculate predicted failure rates as a function of total failures divided by possessed hours (Forecast one).
2. Run the Mini Dyna-METRIC equations computing a failure rate based on total failures divided by on-hours (Forecast two).
3. Run the Mini Dyna-METRIC equations twice. The first run using on-time failures over on-hours. The second run would be off-failures over cycles. The two computed rates would then be summed (Forecast three).
4. Rebuild the Mini Dyna-METRIC equations on a spreadsheet (Major Willeck's forecast).

This experiment will run data using the models suggested in the first three suggestions on the Dyna-METRIC algorithms. The spares requirements calculated by Dyna-METRIC will be compared to the actual failure rates. All input files and data used, as well as Miniature Dyna-METRIC output are listed in Appendix A.

Research Step One - Data Formatting

The failure rate for suggestion four was calculated by Major Willeck in the validation process. In his validation, Major Willeck summed the possessed hours, on-time hours, and cycles of all four epochs. In addition, the corresponding on-time and cycle failures were summed. Next, Major Willeck divided the aggregate totals to arrive at a single, average failure rate for each of his forecasts. Finally, he multiplied this rate by expected possessed hours, on-time hours, or cycles, depending on the forecast for each individual epoch. Therefore, an expected number of failures per epoch were calculated.

The failure rate used in this experiment as Dyna-METRIC input will be the aggregate failure rate. The resultant spares requirements calculated by Dyna-METRIC will be compared to the actual totals. Since Major Willeck's failure rates were determined using actual failures over four epochs, it was not possible, using Dyna-METRIC, to compare Major Willeck's failures to Dyna-METRIC's spares requirements epoch by epoch. Therefore, the Dyna-METRIC spares requirements will be compared to the total failures over four epochs, using Major Willeck's failure rates as the input for each forecast.

Research Step Two - Using Mini Dyna-METRIC

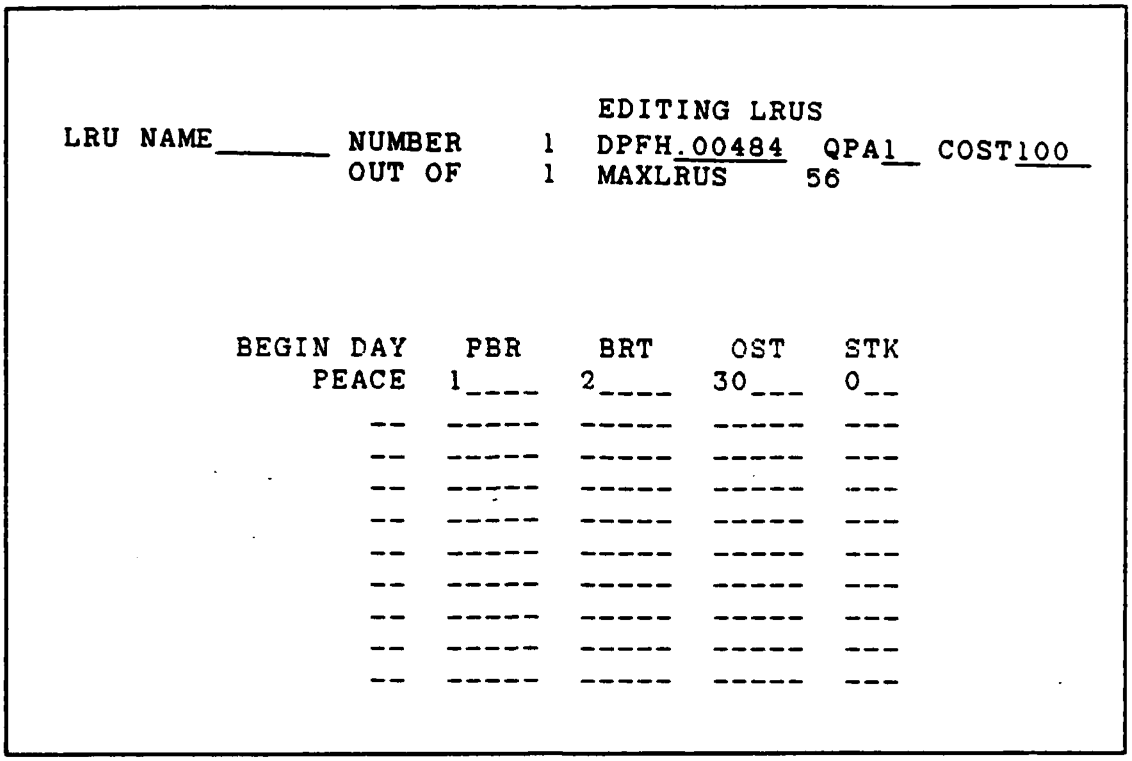
The data to be input into the Dyna-METRIC equations must be transformed from the CE environment into compatible components to fit the airborne elements in Dyna-METRIC. The Dyna-METRIC equations are run using two distinct files. The first file contains pertinent information on parts contained in the weapon system. The second file used is the scenario file, which portrays capabilities of the weapon system.

Parts File.

Each part in the Dyna-METRIC equation is identified as a line replacement unit (LRU). Some LRU's may then be indentured into a shop replacement unit (SRU). The indenturing aspect of Dyna-METRIC shows the potential dependence of a reparable unit on a sub-component. This indenturing capability will not be used for this experiment. The purpose of this experiment is to provide a baseline stockage level using Dyna-METRIC and therefore as many variables as possible will be held constant.

Figure 7 is a sample of the listing used to input data into the parts file.

The LRU name is the national stock number (NSN) of an item. Demands Per Flying Hour (DPFH) symbolizes the expected number of failures of an item given a level of operation. For CE equipment, this will be possessed hours, total on-time, and cycles. Figure 8 shows how the



```
                                      EDITING LRUS
LRU NAME______  NUMBER      1   DPFH.00484  QPA1_  COST100_
                OUT OF      1   MAXLRUS     56



           BEGIN DAY   PBR      BRT      OST      STK
               PEACE   1____    2____    30___    0__
                  --   -----    -----    -----    ---
                  --   -----    -----    -----    ---
                  --   -----    -----    -----    ---
                  --   -----    -----    -----    ---
                  --   -----    -----    -----    ---
                  --   -----    -----    -----    ---
                  --   -----    -----    -----    ---
                  --   -----    -----    -----    ---
                  --   -----    -----    -----    ---
```

Figure 7. Sample of Dyna-METRIC Parts File

FORECAST 1

$$\text{DPFH} = \frac{\text{Total Failures}}{\text{Possessed Hours}}$$

FORECAST 2

$$\text{DPFH} = \frac{\text{Total Failures}}{\text{On-Hours}}$$

FORECAST 3

Run 1

$$\text{DPFH} = \frac{\text{On-Failures}}{\text{On-Hours}}$$

Run 2

$$\text{DPFH} = \frac{\text{Cycle-Fails}}{\text{Cycles}}$$

Figure 8. Illustration of DPFH Calculation

DPFH is modified to make it compatible with the CE environment, using the three failure rates run on Dyna-METRIC.

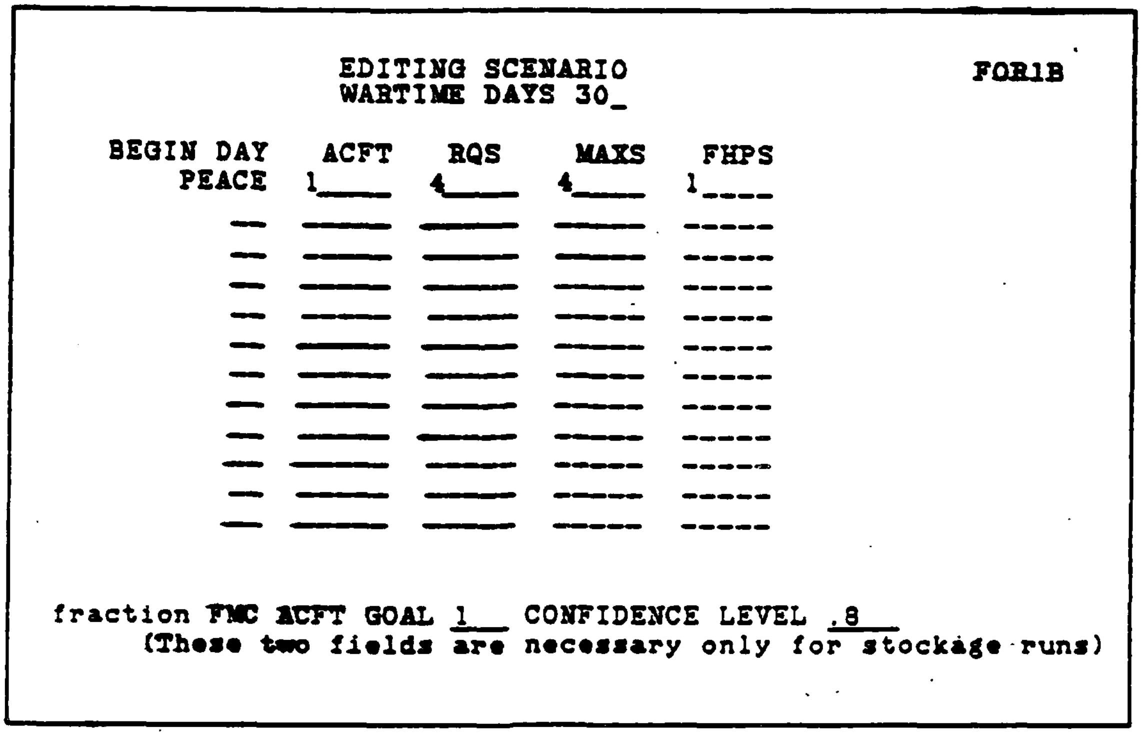
The DPFH is the key ingredient in the Dyna-METRIC equations, and unlike other variables in this experiment, will differ from part to part.

The Quantity Per Aircraft (QPA) for each NSN in the MPN-14 radar system is usually one, but some line items have a quantity of two, three, or six.

The cost will be held constant at $100 per unit.

The listings below the heading describe the different characteristics of each part, in addition to changes which might occur when transitioning from peacetime (first line) into wartime. For the purpose of this experiment, these variables will also be held constant. The percentage of base repair (PBR) will be held at a constant of 1.0. The WRSK unit provides for self-sufficiency for the first thirty days of a war. Therefore, it is assumed that each part can be repaired locally. The base repair time (BRT) will be held constant at two days. This is the accepted BRT for most CE components (6). The order and ship time (OST) will be held at a constant of thirty days for the same self-sufficiency reasoning associated with WRSK. The initial stock level (STK) will be zero.

Scenario File. The second file used by Dyna-METRIC is the scenario file which reflects the capabilities of the weapon system. Figure 9 is a sample listing of the scenario file.



```
                EDITING SCENARIO                              FOR1B
                WARTIME DAYS 30_

    BEGIN DAY    ACFT     RQS      MAXS     FHPS
        PEACE    1____    4____    4____    1----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----
          __     _____    _____    _____    -----


 fraction FMC ACFT GOAL 1__  CONFIDENCE LEVEL .8__
      (These two fields are necessary only for stockage runs)
```

Figure 9. Sample of Dyna-METRIC Scenario File

The first entry into this file will be the length of the contingency, and for this experiment it will be 30 days. Since Mini Dyna-METRIC can only handle a 30 day scenario, and it is necessary to run stockage requirements for a 120 day scenario, other inputs will be adjusted accordingly. Required sorties (RQS) will be either the operating hours of the MPN-14 per day, or the number of cycles per day, depending on the forecast. The number of operating hours per day is a constant 7.5, and on-cycles are only 1 per day. However, since the scenario is for 120 days, or 4 30 day scenarios, this RQS must be multiplied by 4, for a total of 30 operating hours. This will generate the adequate number of operating hours to create an adequate 120 day comparison. Likewise, since the expected number of cycles is 1 per day, this will have to be multiplied by 4 to be commensurate with a 120 day scenario. This same concept applies to maximum number of sorties (MXS).

The maximum number of sorties (MXS) are the same as the RQS, because this is the maximum operating time of the MPN-14 during an operating day. The flying hours per sortie (FHPS) represents the number of operating hours or cycles per sortie. Since each sortie represents 30 operating hours or 4 on-cycles, this number will be 1. This is illustrated in Figure 10.

$$\begin{aligned} \text{FHPS} &= \frac{\text{Operating Hours}}{\text{Sortie Length}} \\ &= \frac{30}{30} = 1 \\ &= \frac{\text{On-Cycles}}{\text{Sortie Length}} \\ &= \frac{4}{4} = 1 \end{aligned}$$

Figure 10. Illustration of FHPS Calculation

In addition, the number of aircraft (ACFT) for this experiment will be one, because only one MPN-14 radar system is being modeled.

These variables will be held constant in all three forecasts using Dyna-METRIC. At the bottom of the scenario file is the fraction of fully mission capable aircraft goal (FMC ACFT GOAL). This is the percentage of aircraft desired at the end of the scenario. For this experiment, it must be one, because it is desired to have a fully mission capable MPN-14 at the end of the scenario. In addition, a confidence level is required. A confidence level of 80% was selected. In essence, the confidence level states that the MPN-14 will be FMC with 80% confidence (4:11). The 80% confidence level is the accepted level in the Air Force for WRSK configuration (6).

By holding as many variables as possible constant in both files, a baseline requirements computation can be evaluated. After the initial forecasts using Dyna-METRIC have been achieved, it is then possible to do sensitivity analysis involving the different variables.

Finally, the requirements computation using Dyna-METRIC was used in the regular mode. That is, it forecast the number of parts needed to keep the MPN-14 radar system at an FMC status for the length of the scenario. Although a WRSK is usually equipped to handle only 30 days, this experiment will determine if Dyna-METRIC can be used to predict CE systems spares failures, using Captain Skowronek's model. Since the failure rate computed by Major Willeck was over 120 days, the Dyna-METRIC scenario must reflect this, so an adequate comparison can be made to the actual failures.

Research Step Three - Data Assembly

A table was built to aid in the analysis of the failure rates computed. The analysis of the results was based on the (MSE) of the four failure rate forecasts. Major Willeck's validation used the (MAD) for the evaluation of forecast performance. However, the MAD treats all errors with equal weight, while the MSE weighs larger errors heavier than smaller errors. As a result, larger errors will not be "washed out" and can be judged more objectively. Results are shown and discussed in Chapter 4. Table 1 is a sample of the tableau built for evaluating the forecasts.

Table 1. Sample Summary Tableau

NSN	Actual Fails	DM Run # 1	Sqd Error	DM Run # 2	Sqd Error	Sum of DM Runs 2 & 3	Sqd Error
1							
2							
3							
4							
			MSE		MSE		MSE

Actual failures are total failures of a line item in that epoch. This was repeated for each line item across each epoch.

Research Step Four - Conclusions

Conclusions were drawn from the tabled results and recommendations made as to the best method of computing CE WRSK requirements. The conclusions and recommendations are included in Chapter five.

Summary

This chapter has outlined the process of testing the method of implementation of CE system failure rates into the Air Force management structure. The research steps discussed the use of the Mini Dyna-METRIC model and the application of a Lotus 1-2-3 spreadsheet program by Major Willeck to calculate failure rates from an existing database of CE system failures. In addition, workarounds to the Dyna-METRIC algorithms to make them fit the CE environment were presented. Results of the calculations are presented next.

IV. Results and Analysis

Overview

This chapter presents the results of the four Dyna-METRIC stockage runs using Major Willeck's failure rates. The expected and actual results will be discussed, as well as an analysis of possible trends and reasons why forecasts differed from one another.

Experiment Summary

The Dyna-METRIC equations were run a total of four times in the stockage requirements mode. The results of these stockage runs are listed in Appendix A. The stockage levels are listed by NSN, and since it was desired to learn the stockage levels produced by Dyna-METRIC on the last day of the scenario, only the thirtieth day stockage levels are listed. The operating hours of the MPN-14 were increased to reflect a 120 day scenario, so as to be comparable with the actual total failures. The comparisons between actual and Dyna-METRIC stockage requirements are listed in Appendix B.

Expected Results

The possessed hours forecast was expected to be the lowest, due to the small failure rate. Next, the on-hours forecast was expected to be higher than the possessed hours. This was expected due to the reduction in the denominator from possessed hours to just on-hours. This creates a higher failure rate, and therefore, more failures for the same amount of operating hours. Finally, the third forecast, Captain Skowronek's model using multiple runs of Dyna-METRIC, was expected to be as high or higher than Forecast Two. Although failures were broken out between on-time and off-time, the off-time failures should reflect a high failure rate because of the few number of cycles relative to the failures as compared with two previous forecasts. Figure 11 summarizes the failure rates input into Dyna-METRIC to produce stockage levels. The shipment and repair pipelines, calculated by Dyna-METRIC, were expected to be at or close to zero. This was expected due to the low failure rates involved.

$$\text{Forecast 1} = \frac{\text{Total Failures}}{\text{Possessed Hours}}$$

$$\text{Forecast 2} = \frac{\text{Total Failures}}{\text{On-Hours}}$$

$$\text{Forecast 3} = \frac{\text{On-Hour Failures}}{\text{On-Hours}} + \frac{\text{Cycle Fails}}{\text{Cycles}}$$

Figure 11. Summary of Dyna-METRIC Forecasts

Actual Results

Forecast One, total failures over possessed hours, did indeed produce the lowest stockage requirements of the three forecasts, and also produced the highest MSE (1.79). Most stockage levels for this forecast were one, with some levels of zero. The second forecast, as expected, produced a higher level of stockage than Forecast One, with most stockage levels at one. However, it did produce stockage levels of two on four occasions, with only one zero stockage level. Forecast Two also produced a lower MSE (1.38) than Forecast One. Finally, Forecast Three produced the highest level of stockage, which was not unexpected. It produced more stockage levels of two than did Forecast Two, but generally most levels were of one. The stockage levels for Forecast Three were calculated by making one run on Dyna-METRIC using the failure rate of on-time failures divided by on-time hours, then summed with a second stockage level, using the cycle fails divided by cycles failure rate. This forecast also produced the lowest MSE (1.32). The shipment and repair pipelines were at or close to zero, which was expected.

Analysis of Results

A test was made to determine if there was a statistical difference between any two of the MSE's produced. This test is known as the Large Sample Test about the Difference Between Two Population Means. It involves two assumptions, listed below.

1. The two samples are randomly selected in an independent manner from the two populations. This assumption is valid because the stockage levels in one run in no way effect the levels computed in other runs.

2. The sample sizes are large enough so that the means each have approximately normal sampling distributions so that the sample variances provide a good approximation to the population variances. This will be true if $n_1>30$ and $n_2>30$. This assumption is also valid because the sample sizes (the 56 LRU stockage levels) are large enough to satisfy the $n > 30$ criteria. Therefore, the sample variances calculated do provide a good approximation to the population variances (8:335).

Each forecast had a unique stockage level as calculated by Dyna-METRIC. These stockage levels were summed, and a mean and variance were calculated for each individual forecast. This was necessary in order to compute a test statistic, the Z-statistic. This statistic will be used to determine if there is a difference between two MSE's.

$$Z = \frac{(\bar{X}_1 - \bar{X}_2)}{\delta(\bar{X}_1 - \bar{X}_2)}$$

where

$\bar{X}_1$ = mean of a forecast

$\bar{X}_2$ = mean of another forecast

$\delta(\bar{X}_1 - \bar{X}_2)$ = standard deviation of the sampling distribution (8:335)

The test was a two-tailed test. That is, it was desired to test if there was any difference between the means, not if one mean was just greater than or less than another mean. The hypotheses for the test are as follows:

$$\text{Null Hypothesis (Ho): } \bar{X}_1 - \bar{X}_2 = 0$$

$$\text{Alternate Hypothesis (Ha): } \bar{X}_1 - \bar{X}_2 \neq 0$$

$$\text{Rejection Region} = \quad Z < -1.96$$

$$Z > 1.96$$

The table below summarizes the mean and variance calculated for each forecast.

Table 2. Mean and Variances of the Forecasts

Forecast	Mean	Variance
Forecast 1	.75	.191
Forecast 2	1.054	.088
Forecast 3	1.107	.134

The standard deviation of the sampling population is calculated using the following formula.

$$\delta(\bar{x}_1 - \bar{x}_2) = \sqrt{\frac{\delta_1^2}{n_1} + \frac{\delta_2^2}{n_2}}$$

where

δ_1^2 = variance for first mean

δ_2^2 = variance of second mean

n_1 = population size for first mean

n_2 = population size for second mean (8:334)

The population size for each mean is 56, since stockage levels for 56 NSN's were produced.

The resultant Z-value, when compared with the tabled Z-Value at an appropriate alpha (α) level, will determine if there is a statistical difference between the means compared. The alpha level for this experiment is .05, which is converted into a corresponding tabled Z-value of 1.96. If the Z-value produced in the comparisons between the means is greater than 1.96 or less than -1.96, then there is a statistical difference between the two means. If the number is less than 1.96 but greater than -1.96, then the test fails to reject that the two means are not significantly different. In addition, a significance level, or p-value, can be calculated. This p-value states that the probability (assuming the null hypothesis is true) of observing a test statistic (in this case, the Z-statistic) that is at least as contradictory to the null hypothesis, and as supportive of the alternative hypothesis, as the one computed from the sample data (8:299). Table 3 summarizes the results of the test.

Table 3. Summary of Statistical Test

Difference Between	Z-Value	Z	Significant?	P-Value
Forecast 1 & 2	4.28	1.96	Y	<.0001
Forecast 1 & 3	4.69	1.96	Y	<.0001
Forecast 2 & 3	.842	1.96	N	.1628

Since the Z-Values calculated for the difference between Forecast One and Two, as well as the difference between Forecast One and Three are greater than 1.96, we reject the null hypothesis that there is no significant difference between the pairs of means, and conclude a difference does exist, at an alpha equal to .05. However, since the Z-Value for the difference between Forecast Two and Three is less than 1.96, we fail to reject the null hypothesis that there is no significant difference between the means of these Forecasts at an alpha of .05.

The only discernible pattern present between Forecast Two and Three is that when the Skowronek model outperformed the on-hours forecast, it was directly attributable to the adding in of the on-cycles failures. That is, in Forecast Two, when stockage levels of 1 were produced, the same LRU, if it had a cycle failure rate, produced an additional level of stock (for a total of 2) in Forecast 3.

There is only one instance where Forecast Two outperformed Forecast Three (NSN 5820004943621). In Forecast Two, the stockage level was one, while in Forecast Three the stockage level was zero, even though there was a cycle failure rate. This was discussed with Captain John E. Sullivan, Instructor of Logistics Management, AFIT. The only plausible explanation was that the stockage requirement of meeting an FMC MPN-14 80% of the time was achieved, and therefore no stockage level for this LRU was necessary (13). Indeed, a stockage run was made using a 95% FMC ACFT GOAL, and Dyna-METRIC stocked one part for this item.

Summary

This chapter provided the results of stockage runs on Dyna-METRIC to produce levels commensurate with a 120-day scenario. Forecast One, total failures over possessed time, produced the highest MSE (1.79), while Forecast Two, total failures over on-time, produced the second lowest MSE (1.38). Forecast Three, the Skowronek model, produced the lowest MSE of all the forecasts, that of 1.32. A test was performed to determine if there was any statistical difference between individual Forecasts. The difference between Forecasts One and Two, as well as Forecasts One and Three produced a significant difference, at an alpha equal to .05, but there was no discernible difference between Forecasts Two and Three at the same alpha level.

Chapter 5 will present the conclusions and recommendations.

V. Conclusions and Recommendations

Overview

This chapter will present the conclusions and recommendations of the author based on the results achieved and shown in Chapter 4. It will be divided into three segments. The first segment will discuss the effectiveness of Dyna-METRIC in the calculation of stockage levels for CE equipment. The second segment examines the effectiveness of Captain Skowronek's model verses the other formulas on the Dyna-METRIC algorithms. The third segment will present the recommendations for further research in the area of CE WRSK configuration.

Effectiveness of Dyna-METRIC

The Air Force presently uses the Dyna-METRIC algorithms to predict airborne weapon systems failures. Therefore, the application of Dyna-METRIC to ground based CE systems might seem "a fish out of water." However, the same basic principles apply to the prediction of CE system failures as they do with airborne systems. There are reparable spares on both systems that fail and need to be repaired and replaced. There are also shipment and repair leadtimes with both systems. These shipment and repair times could be at the base or depot level, depending on the extent of the repair. Additionally, although this experiment did not pursue it, a level of indenturing does exist with CE equipment as it does with airborne systems. Finally, a sound basis is needed to forecast future stock levels, based on historical demand patterns, for both CE equipment and airborne systems. A formal set of procedures for calculating airborne systems failures, and in turn, WRSK exists. However, no such well structured system exists for CE WRSK configuration.

Dyna-METRIC was applied to the CE environment successfully, providing sound data on all three forecasts. Although the three forecasts themselves differed, there were no inexplicable patterns or unknowns. That is, the stockage levels produced by Dyna-METRIC were stable, workable data. They did not fluctuate wildly and were consistent with the expected failures.

Effectiveness of the Model

The first forecast, using the actual failures over possessed hours failure rate, produced a considerably lower stockage level than Forecasts Two and Three. This was due to the low failure rate. It was shown that this forecast statistically differed from the other two forecasts, based on the stockage levels produced by Dyna-METRIC. The MSE of this forecast (1.79) was also the highest of all three forecasts. In addition, it continually produced levels that were lower than actual failures. However, this forecast is the one that is used by AFLC to aid in its determination of CE WRSK configuration. This forecast, predicting lower failures, would have the following impacts.

1. CE WRSK would be understocked. This could affect readiness and maintainability in a contingency.
2. The possibility that, even though not enough parts are being procured, the wrong parts are the ones procured. The ones with potentially the most significant impact on readiness may not be the ones being purchased.

These conclusions are based solely on the results of the Dyna-METRIC output and the statistical analysis. However, the glaring weakness of this forecast to undershoot on failure predictions cannot be overlooked.

The second and third forecasts produced much lower MSE's, and higher stockage levels. Although these levels were not significantly different at an alpha of .05, there are certain points that merit attention.

Captain Skoronek's model, by breaking out failures by on-time and cycles, provided the additional boost a stockage level needed to bring it up to the level of actual failures. For example, NSN 5945002499813 in Forecast Two had a stockage level of one. In Forecast Three, since the failures were broken out between on-time and cycles then summed, the stockage level was bumped up to two, because of the one additional stock level provided by the cycle fail. The actual number of failures was two. This extra stockage level gave the Skowronek model a lower MSE than Forecast Three, and the ultimate difference between the two forecasts. The one instance where Forecast Two outperformed Captain Skowronek's model was determined to be that the FMC ACFT GOAL had been achieved, and therefore, the Dyna-METRIC algorithms did not stock a part.

There were relatively few NSN's involved in the application of Captain Skowronek's model to the Dyna-METRIC equations. It was only a select number of parts from a certain ground based radar system. However, it did provide a good sampling of CE equipment. With this sampling, it was determined that the breaking out of failures by on- and off-time provided the best forecast, based on the MSE.

Unfortunately, it was not feasible to compare the results of the Dyna-METRIC stockage levels to the prediction of failure rates using a spreadheet, produced by Major Willeck in his validation. Major Willeck used the actual failures in the 120-day time period for his failure rates to, in turn, create 30 day epoch failure rates. However, since Major Willeck's validation produced 30 day failure rates, and this effort produced 120 day stockage levels, a meaningful comparison could not be made between the two.

Recommendations

The results and conclusions of the stockage levels produced by Dyna-METRIC have been presented. Based on these, the author has four recommendations.

The first recommendation is that the Air Force should use Captain Skowronek's model in its determination of CE WRSK. This is based on the model's ability to adapt to fluctuating operating hours, brought out in Major Willeck's validation. In addition, the present failure rate used by AFLC to aid in CE WRSK configuration shows a discernible trend to underestimate stockage levels. This trend could affect the readiness of ground based CE systems during wartime because there are more operating hours and cycle-ups during wartime. During peacetime, hours are relatively steady-state and do not fluctuate. The Skowronek model has shown itself a reliable performer in a fluctuating environment, and therefore should be used by AFLC.

The second recommendation is the development of a master database for CE equipment items to track on- and off-time failures. This would be comparable to the airborne weapon systems database, the D040. With this master database, AFLC could vastly improve its accuracy in the building of CE WRSK.

A third recommendation is that a sensitivity analysis be accomplished using Dyna-METRIC. This would entail procuring actual unit dollar costs and pipeline times for each part. It could then be determined if there are stockage levels that need to be increased or decreased, depending on the dollar values and pipeline times. Also more problem parts could be identified to aid management. In the same vein, more LRU's, or even a different system than the MPN-14, shoud be tested using the Skowronek model to get a better picture as to its effectiveness.

The final recommendation is that a follow on thesis be accomplished. This thesis would predict CE system failures one period ahead, using historical failure rates. This experiment would be done using both Dyna-METRIC and spreadsheet failure formulas like the one used in this experiment. The resultant failure rates would then be compared to a hold out sample of actual failure rates. In addition, the stockage runs on Dyna-METRIC and spreadsheet failure predictions could be compared to one another to determine if there is a "best" method. This best method could then be used by AFLC in formalizing its CE WRSK configuration process.

Summary

Captain Skowronek's model proved to be an effective tool using the Dyna-METRIC algorithms. The added stock level provided by the cycle failure rate in Forecast Three is the difference between it and Forecast Two. Forecast One, used by AFLC to aid in CE WRSK configuration, showed a significant trend to understock spares, showing an impact to readiness. Finally, four recommendations were presented which outline the author's ideas for further work on CE WRSK management.

Appendix A: Mini Dyna-METRIC Output

Explanation

The output is listed on the thirtieth day of the scenario. It is listed by LRU number (NO), and by national stock number. The New Stock column list the stockage level Dyna-METRIC has calculated. In the upper right hand corner a file name has been designated for each forecast. Table 4 summarizes the designation used for each forecast.

Forecast	Designation
Forecast 1	For1b
Forecast 2	For2b
Forecast 3	For3b and For4b

Forecast 3 is the sum of Dyna-METRIC runs For3b and For4b, where For3b is the On-Hours failure rate and For4b is the the cycle failure rate.

```
                         Day 30              a:forlb

       forlc AND forl WERE USED TO CREATE THIS FILE

        NO          LRU                     NEW STOCK

         1     5945006657444                    1
         2     5950008724383                    1
         3     5895004844743                    1
         4     5895002285226                    1
         5     5945002015144                    1
         6     5960008939402                    1
         7     5905009599603                    1
         8     5905006656356                    1
         9     5950006442476                    1
        10     5840006433820                    1
        11     5945002899813                    1
        12     5945000274107                    1
        13     5945002017822                    1
        14     5945002015182                    1

        NO          LRU                     NEW STOCK

        16     5910008251637                    1
        17     5905009590725                    1
        18     5945002596399                    1
        19     5840010902036                    1
        20     5905001100991                    1
        21     5840010900139                    0
        22     5960002920160                    1
        23     5895001055204                    1
        24     5895002295267                    1
        25     5900008069629                    1
        26     5840005051313                    1
        27     5910001126794                    1
        28     5840008446217                    1
        29     5960004259740                    1
        30     5950001025136                    1
```

NO	LRU	NEW STOCK
31	5961004218956	1
32	5840008508824	1
33	5990006364151	1
34	5840005571588	1
35	5945004661346	1
36	5835004790461	1
37	5840004836149	1
38	5935008396719	1
39	5910007587777	1
40	5960005427181	1
41	5895011091624	1
42	5840004835887	1
43	5840004936110	1
44	5950011307663	0
45	5840010227534	0

NO	LRU	NEW STOCK
46	5945003038222	0
47	4140010542185	0
48	5945001985499	0
49	5835000196977	0
50	6145000804383	0
51	5820011549046	0
52	5820011061794	0
53	5820004943621	0
54	5895002177019	0
55	5960002359107	0
56	5840006962047	0

Day 30 a:for2b

forlc AND for2 WERE USED TO CREATE THIS FILE

NO	LRU	NEW STOCK
1	5945006657444	1
2	5950008724383	1
3	5895004844743	1
4	5895002285226	1
5	5945002015144	1
6	5960008939402	1
7	5905009599603	1
8	5905006656356	1
9	5950006442476	1
10	5840006433820	1
11	5945002499813	1
12	5945000274107	1
13	5945002017822	1
14	5945002015182	1
15	5915009535410	1

NO	LRU	NEW STOCK
16	5910008251637	1
17	5905009590725	1
18	5945002596399	1
19	5840010902036	1
20	5905001100991	1
21	5840010900139	2
22	5960002620160	1
23	5895001055204	1
24	5895002285267	1
25	5900008069629	1
26	5840005051313	1
27	5910001126794	1
28	5840008446217	1
29	5960004259740	1
30	5950001025136	1

NO	LRU	NEW STOCK
31	5961004218956	1
32	5840008508824	1
33	5990006364151	1
34	5840005571588	1
35	5945004661346	2
36	5835004790461	2
37	5840004836149	1
38	5935008396719	1
39	5910007587777	1
40	5960005427181	1
41	5895011091624	2
42	5840004835887	1
43	5840004936110	1
44	5950011307663	1
45	5840010227534	1

NO	LRU	NEW STOCK
46	5945003038222	1
47	4140010542185	0
48	5945001985499	1
49	5835000196977	1
50	6145000804383	1
51	5820011549046	1
52	5820011061794	1
53	5820004943621	1
54	5895002177019	1
55	5960002359107	1
56	5840006962047	1

Day 30 a:for3b

for1c AND for3 WERE USED TO CREATE THIS FILE

NO	LRU	NEW STOCK
1	5945006657444	1
2	5950008724383	1
3	5895004844743	0
4	5895002285226	1
5	5945002015144	1
6	5960008939402	1
7	5905009599603	1
8	5905006656356	1
9	5950006442476	1
10	5840006433820	1
11	5945002899813	1
12	5945000274107	1
13	5945002017822	1
14	5945002015182	1
15	5915009535410	1
16	5910008251637	1
17	5905009590725	1
18	5945002596399	1
19	5840010902036	0
20	5905001100991	1
21	5840010900139	2
22	5960002920160	0
23	5895001055204	0
24	5895002295267	0
25	5900008069629	1
26	5840005051313	0
27	5910001126794	1
28	5840008446217	1
29	5960004259740	1
30	5950001025136	1

NO	LRU	NEW STOCK
31	5961004218956	0
32	5840008508824	1
33	5990006364151	1
34	5840005571588	1
35	5945004661346	1
36	5835004790461	1
37	5840004836149	1
38	5935008396719	1
39	5910007587777	1
40	5960005427181	1
41	5895011091624	1
42	5840004835887	1
43	5840004936110	1
44	5950011307663	1
45	5840010227534	1
46	5945003038222	1
47	4140010542185	1
48	5945001985499	1
49	5835000196977	1
50	6145000804383	1
51	5820011549046	1
52	5820011061794	1
53	5820004943621	0
54	5895002177019	1
55	5960002359107	1
56	5840006962047	0

Day 30 a:for4b

forlc AND for4 WERE USED TO CREATE THIS FILE

NO	LRU	NEW STOCK
1	5945006657444	0
2	5950008724383	0
3	5895004844743	1
4	5895002285226	0
5	5945002015144	0
6	5960008939402	0
7	5905009599603	0
8	5905006656356	0
9	5950006442476	0
10	5840006433820	0
11	5945002899813	1
12	5945000274107	0
13	5945002017822	0
14	5945002015182	0
15	5915009535410	0
16	5910008251637	0
17	5905009590725	0
18	5945002596399	0
19	5840010902036	1
20	5905001100991	0
21	5840010900139	0
22	5960002920160	1
23	5895001055204	1
24	5895002295267	1
25	5900008069629	0
26	5840005051313	1
27	5910001126794	0
28	5840008446217	0
29	5960004259740	0
30	5950001025136	0

NO	LRU	NEW STOCK
31	5961004218956	1
32	5840008508824	0
33	5990006364151	0
34	5840005571588	1
35	5945004661346	1
36	5835004790461	1
37	5840004836149	0
38	5935008396719	0
39	5910007587777	0
40	5960005427181	1
41	5895011091624	1
42	5840004835887	0
43	5840004936110	0
44	5950011307663	0
45	5840010227534	0

NO	LRU	NEW STOCK
46	5945003038222	0
47	4140010542185	0
48	5945001985499	0
49	5835000196977	0
50	6145000804383	0
51	5820011549046	0
52	5820011061794	0
53	5820004943621	0
54	5895002177019	0
55	5960002359107	0
56	5840006962047	0

Appendix B: Comparison of Actual Failures and Dyna-METRIC Stockage Runs

Column Letter	Definition
A.	National Stock Number: Alpha Numeric
B.	Actual Failures: Value
C.	Forecast One Stockage Level: Value $\frac{\text{Total Failures}}{\text{Total Possessed Hours}}$
D.	Error Squared: Value (Column B - Column C)^2
E.	Forecast Two Stockage Level: Value $\frac{\text{Total Failures}}{\text{Total On-Hours}}$
F.	Error Squared: Value (Column B - Column E)^2
G.	Forecast Three Stockage Level $\frac{\text{On-Hours Failures}}{\text{On-Hours}} + \frac{\text{Cycle Failures}}{\text{Cycles}}$
H.	Error Squared: Value (Column B - Column G)^2

A	B	C	D	E	F	G	H
NSN	ACTUAL FAILS	POSSESSED HOURS	ERR SQD	ON-HOURS	ERR SQD	ON-HOURS PLUS CYCLES	ERR SQD
5990006364151	2	1	1.00	1	1.00	1	1.00
5840005571588	2	1	1.00	1	1.00	2	0.00
5945004661346	3	1	4.00	2	1.00	2	1.00
5835004690461	3	1	4.00	2	1.00	2	0.00
5840004836149	1	1	0.00	1	0.00	1	0.00
5935008396719	1	1	0.00	1	0.00	1	0.00
5910007587777	1	1	0.00	1	0.00	1	0.00
5960005427181	2	1	1.00	1	1.00	2	0.00
5895011091624	4	1	9.00	2	4.00	2	4.00
5840004835887	1	1	0.00	1	0.00	1	0.00
5840004836110	1	1	0.00	1	0.00	1	0.00
5950011307663	1	0	1.00	1	0.00	1	0.00
5840010227534	1	0	1.00	1	0.00	1	0.00
5945003038222	1	0	1.00	1	0.00	1	0.00
4140010542185	1	0	1.00	0	1.00	1	0.00
5945001985499	1	0	1.00	1	0.00	1	0.00
5835000196977	1	0	1.00	1	0.00	1	0.00
6145000804383	1	0	1.00	1	0.00	1	0.00
5820011549046	1	0	1.00	1	0.00	1	0.00
5820011061794	1	0	1.00	1	0.00	1	0.00
5820004943621	1	0	1.00	1	0.00	0	1.00
5895002177019	1	0	1.00	1	0.00	1	0.00

A	B	C	D	E	F	G	H
NSN	ACTUAL FAILS	POSSESSED HOURS	ERR SQD	ON-HOURS	ERR SQD	ON-HOURS PLUS CYCLES	ERR SQD
5960002359107	1	0	1.00	1	0.00	1	0.00
5840006962047	1	0	1.00	1	0.00	1	0.00
5945006657444	1	1	0.00	1	0.00	1	0.00
5950008724383	3	1	4.00	1	4.00	1	4.00
5895004844743	1	1	0.00	1	0.00	1	0.00
5895002285226	1	1	0.00	1	0.00	1	0.00
5945002015144	2	1	1.00	1	1.00	1	1.00
5960008939402	2	1	1.00	1	1.00	1	1.00
5905009599603	2	1	1.00	1	1.00	1	1.00
5905006656356	2	1	1.00	1	1.00	1	1.00
5950006452476	1	1	0.00	1	0.00	1	0.00
5840006433820	1	1	0.00	1	0.00	1	0.00
5945002499813	2	1	1.00	1	1.00	2	0.00
5945000274107	1	1	0.00	1	0.00	1	0.00
5945002017822	8	1	49.00	1	49.00	1	49.00
5945002015182	1	1	0.00	1	0.00	1	0.00
5915009535410	2	1	1.00	1	1.00	1	1.00
5910008251637	2	1	1.00	1	1.00	1	1.00
5905009590725	1	1	0.00	1	0.00	1	0.00
5945002596399	2	1	1.00	1	1.00	1	1.00
5840010902036	2	1	1.00	1	1.00	1	1.00
5905001100991	3	1	4.00	1	4.00	1	4.00

A	B	C	D	E	F	G	H
NSN	ACTUAL FAILS	POSSESSED HOURS	ERR SQD	ON-HOURS	ERR SQD	ON-HOURS PLUS CYCLES	ERR SQD
5840010900139	1	0	1.00	2	1.00	2	1.00
5960002620160	1	1	0.00	1	0.00	1	0.00
5895001055204	1	1	0.00	1	0.00	1	0.00
5895002285267	1	1	0.00	1	0.00	1	0.00
5900008069629	1	1	0.00	1	0.00	1	0.00
5840005051313	1	1	0.00	1	0.00	1	0.00
5910001126794	1	1	0.00	1	0.00	1	0.00
5840008446217	1	1	0.00	1	0.00	1	0.00
5960004259740	1	1	0.00	1	0.00	1	0.00
5950001025136	1	1	0.00	1	0.00	1	0.00
5961004218956	1	1	0.00	1	0.00	1	0.00
5840008508824	1	1	0.00	1	0.00	1	0.00
		MSE	1.79	MSE	1.38	MSE	1.32

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The current CE WRSK configuration process is not standardized. There are many different inputs used by AFLC to determine requirements. A model to predict CE system failure rates has been developed and validated. This model separates failures into two categories, on-time failures and cycle-up failures. This validated model was tested, using Dyna-METRIC, against two other possible failure rates. These failure rates were based on (1) possessed hours and (2) on-time hours. The stockage runs produced by Dyna-METRIC were compared to actual failures over a 120 day time period. The validated model produced a higher stockage level, as well as a lower Mean Squared Error (MSE) than the other two failure rates. The current failure rate used by AFLC to aid in CE WRSK configuration showed a discernible trend to underestimate stockage levels. The Air Force should use the validated model to determine CE WRSK configuration and implement the appropriate policies and data gathering systems.