STATISTICAL PROCESS CONTROL: AN APPLICATION IN AIRCRAFT MAINTENANCE MANAGEMENT

THESIS

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MAINTENANCE MANAGEMENT

THESIS

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Abstract

Maintenance management at the 135th Airlift Wing, Maryland Air National Guard desires a visualization tool for their maintenance performance metrics. Currently they monitor their metrics via an electronic spreadsheet. They desire a tool that presents the performance information in a graphical manner.

This thesis effort focuses on the development of a visualization tool utilizing two of the seven tools offered by Statistical Process Control (SPC). This research demonstrates the application of p-charts and Pareto diagrams in the aircraft maintenance arena. P-charts are used for displaying mission capable (MC) rates and flying scheduling effectiveness (FSE) rates. Pareto diagrams are then used to highlight which aircraft subsystems are affecting those two performance indicators.

STATISTICAL PROCESS CONTROL: AN APPLICATION IN AIRCRAFT
MAINTENANCE MANAGEMENT

1. Introduction

1.0 Background

The 135th Maintenance (MX), attached to the 135th Airlift Group and part of

Maryland's 175th Air National Guard (ANG) Wing, is located at the Martin State Airport

in Baltimore, Maryland. The 135th MX is responsible for performing all maintenance

activities required to support the day-to-day flying schedule (i.e., sortie generation) for

the Group's eight C-130J aircraft. To accomplish their mission, the 135th MX employs

full-time and traditional guardsman maintenance technicians spanning all C-130J

maintenance specialties.

The 135th Deputy Commander for Logistics (DCL) is responsible for the overall day-

to-day sortie generation and maintenance repair activities accomplished by the assigned

maintenance technicians. The 135th Squadron Maintenance Officer (SMO) assists the

DCL in meeting those responsibilities. Together, the DCL and SMO monitor a number

of maintenance performance indicators that provide them insight into the 135th MX's

effectiveness and efficiency.

Currently, the 135th's Maintenance Data Analyst (MDA) maintains an electronic

spreadsheet, updated monthly, listing several maintenance-related statistics. The MDA's

spreadsheet consists of four pages listing 108 different maintenance-related data entries (see Appendix A). The DCL, SMO, and other maintenance managers within the 135th MX complex have access to an electronic version of the analysis spreadsheet via the base's local area network. This spreadsheet is currently their primary tool for monitoring the 135th MX's key maintenance performance indicators (Maurer, Ruane).

1.1 Problem Statement

According to the DCL and SMO, monitoring current performance, recognizing trends, and detecting potential problem areas within the 135th MX is difficult using the current analysis spreadsheet (Maurer, Ruane). To overcome this problem, they desire a visualization tool that provides a quick and easy method for monitoring maintenance performance. This tool should provide the ability to identify trends in maintenance performance and provide an indication of the underlying problem area whenever their unit's maintenance performance slips below established standards. The visualization tool also needs to be easy to understand and easy to construct (Maurer, Ruane).

1.2 Scope of Research

The organizational structure of the 175th Wing is shown in Figure 1. The 175th DCL is responsible for the A-10A aircraft maintenance, the 135th DCL is responsible for the C-130J maintenance, and the 175th LG is responsible for the Wing's overall maintenance complex. The 135th DCL's span of responsibility includes the 135th Maintenance Squadron (MXS), 135th Aircraft Generation Squadron (AGS), and 135th Logistics

Support Flight (LSF). Collectively, the MXS, AGS, and LSF are referred to as the 135th MX.

```
                          +------------------+
                          |   175th Wing     |
                          |   Commander      |
                          +------------------+
                                   |
   +-----------+-----------+-------+-------+-----------+-----------+
   |           |           |               |           |
+----------+ +----------+ +----------+ +------------+ +----------+
|  175th   | |  175th   | |  175th   | |   175th    | |  135th   |
|Operations| | Logistics| | Support  | |  Medical   | | Airlift  |
|  Group   | |  Group   | |  Group   | | Squadron   | |  Group   |
|Commander | |Commander | |Commander | | Commander  | |Commander |
+----------+ +----------+ +----------+ +------------+ +----------+
     |            |
+----------+  +----------+
|175th DCL |  |135th DCL |
+----------+  +----------+
     |       +------+------+-------------+
+----------+ +----------+ +----------+ +-------------+
|175th MXS | |135th MXS | |135th AGS | |135th Logistics
+----------+ +----------+ +----------+ |Support Flight |
     |                                 +-------------+
+----------+
|175th AGS |
+----------+
     |
+-------------+
|175th Logistics
|Support Flight|
+-------------+
     |
+-------------+
|   175th     |
|Logistics Squadron|
+-------------+
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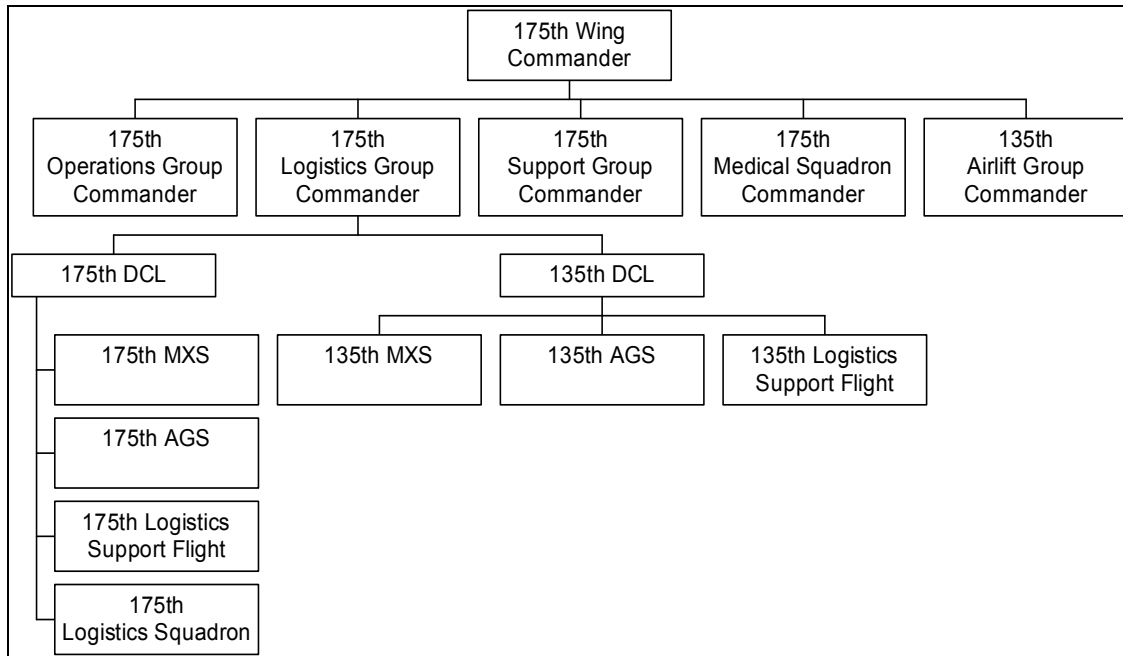
Figure 1. 175th Wing Organizational Chart

(175th Wing web site, http://www.mdang.ang.af.mil/175WING/UNITS.HTML)

The 175th MX organization differs from the typical active duty AMC organizational structure (see Figure 2) where there is a single Logistics Group (LG) Commander directly responsible for all the maintenance squadrons within the Group (*AMCI 21-101*). Due to the unique nature of the 175th's LG, this thesis will only focus on those maintenance indicators for which the 135th DCL's is responsible (i.e., C-130J maintenance performance indicators produced by the 135th AGS, MXS, and LSF). The control chart and Pareto diagram tools offered by statistical process control (SPC) will be used to construct the visualization tool for the 135th maintenance performance indicators. It is a

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logical extension to implement the SPC techniques in the other maintenance squadrons (and their respective performance indicators) normally found within a Logistics Group.

```
                          ┌─────────────────┐
                          │ Wing Commander  │
                          └────────┬────────┘
     ┌──────────────┬─────────────┼──────────────┬──────────────┐
┌──────────┐  ┌──────────┐  ┌──────────┐  ┌──────────┐  ┌──────────┐
│ Support  │  │ Logistics│  │Operations│  │  Medical │  │   Comm   │
│  Group   │  │  Group   │  │  Group   │  │  Group   │  │  Group   │
│Commander │  │Commander │  │Commander │  │Commander │  │Commander │
└──────────┘  └────┬─────┘  └──────────┘  └──────────┘  └──────────┘
┌──────────┐  ┌──────────┐  ┌──────────┐  ┌──────────┐
│   AGS    │  │   MXS    │  │ Logistics│  │Transport-│
│          │  │          │  │ Support  │  │  ation   │
│          │  │          │  │ Squadron │  │ Squadron │
└──────────┘  └──────────┘  └──────────┘  └──────────┘
┌──────────┐  ┌──────────┐
│  Supply  │  │Contracting│
│ Squadron │  │ Squadron │
└──────────┘  └──────────┘
```
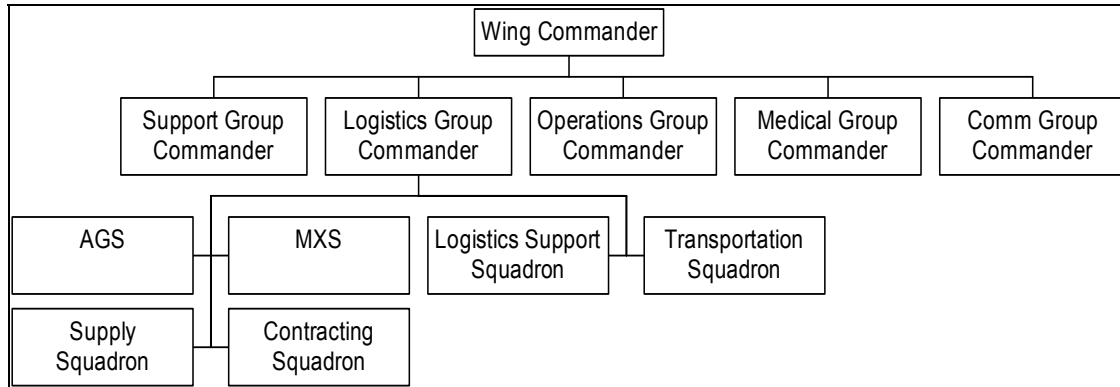
Figure 2. AMC Wing Structure

(AMCI 21-101)

1.3 Thesis Overview

In Chapter 2, we review the current Air Force (AF) and ANG guidance on maintenance unit metrics and the literature with respect to the types of charts (i.e., the visualization tools) currently used by aircraft maintenance managers in monitoring their organization's performance. We also describe how the C-130J weapon system is organized by subsystem to lay the groundwork for the thesis analysis methodology presented in Chapter 3. In Chapter 3, we present the specific SPC tools employed and the two measures of performance chosen to demonstrate SPC's applicability to aircraft maintenance management. In Chapter 4, we construct the visualization tool and analyze the results of the tool as applied to the two measures of performance. Analyses of the visualization tool, as well as opportunities for future research, are discussed in Chapter 5.

2. Literature Review

2.0 Air Force Maintenance Metrics and Their Definitions

In December 2001, the Air Force Logistics Management Agency (AFLMA) produced the *Metrics Handbook for Maintenance Leaders* to provide aircraft maintenance managers with a single authoritative source for maintenance metrics information. In the handbook's Forward, Brigadier General Gabreski, Director of Logistics for the United States Air Force Material Command, states that maintenance metrics "are critical tools to be used by maintenance managers to gauge an organization's effectiveness and efficiency" (*Metrics Handbook*). He further states, "A good maintenance manager will not strive to improve a metric but will use them to improve the performance of the organization" (*Metrics Handbook*). Metrics, or performance indicators, are used at all levels of aircraft maintenance management and are key to maintenance managers upholding their responsibility to provide the Operations Group (OG) with aircraft to fulfill the Wing's mission requirements (*Metrics Handbook*).

Most aircraft maintenance performance indicators can be separated into one of two broad categories - fleet availability and flying program execution. Fleet availability indicators, such as mission capability (MC) rate, provide a measure of the LG's ability to provide enough aircraft to the OG to satisfy the Wing's mission requirements (*Metrics Handbook*). Flying program execution indicators, such as flying scheduling effectiveness rate (FSE), provide a measure of the Wing's ability to execute a preplanned flight schedule (*Metrics Handbook*).

The individual performance indicators within the two overarching categories of maintenance performance indicators are classified as either leading or lagging (*Metrics Handbook*). Leading indicators measure those items that have a direct impact on the ability of the LG to provide the resources necessary to fulfill mission requirements. An example of a flying program execution-leading indicator is the FSE rate (*Metrics Handbook*). FSE is a measure of the number of scheduled sorties flown minus any deviations (i.e., sortie cancellations or additions) to the schedule (*AMCPAM 21-102*). Lagging indicators provide maintenance managers with insight into established maintenance trends. An example of a fleet availability-lagging indicator is the MC rate (*Metrics Handbook*). MC rate is a measure of the number of assigned aircraft that were available to support flight operations (*AMCPAM 21-102*). Appendices B and C list the leading and lagging indicators associated with fleet availability and flying program execution, respectively.

Metrics are also categorized as results metrics or process metrics (Schneiderman). Results metrics measure how effectively a process is meeting a customer's needs and typically involve processes transparent to customer (Schneiderman). On the other hand, process metrics are usually invisible to the customer as they deal with the inner workings of the process and are measures of how results are achieved (Schneiderman). Using these definitions, both MC rate and FSE rate are classified as results metrics. These are the metrics that a maintenance organizations customer, such as the OG Commander and Wing Commander, would have visibility. However, the customer would probably not have visibility into the performance of the inner workings of those processes, such as supply issue effectiveness rate and fix rates, that have a direct impact on MC rate.

2.1 Characteristics of a Good Metric

The *Metrics Handbook for Maintenance Leaders* discusses several traits of a good maintenance metric. First, it must be understandable by those who are using the metric (*Metrics Handbook*). Metrics are simply tools to help maintenance management gauge their unit's performance. If the user cannot understand the metric, then the value of the tool is questionable. The second trait of a good metric is that it must address those problems or issues that the unit faces on a daily basis. For example, MC and FSE rates are issues that aircraft maintenance managers are concerned with on a daily basis. Finally, a good metric must show the unit's performance against the established standard. The individual major commands, as well as the ANG and the Air Force Reserves, within the United States Air Force establish aircraft-specific goals for many of the aircraft maintenance performance measures.

In addition to the three attributes discussed above, a metric must be linked to the stakeholder's satisfaction, must have documented and operational definitions, and derive their usefulness as part of an ongoing improvement process (Schneiderman). For example, the 135[th] DCL and SMO are concerned about their C-130Js MC rate. Higher MC rates are considered desirable and result in increased management satisfaction with aircraft availability. A metric that displays MC rate information would therefore be linked to stakeholder satisfaction. In addition, we have documented and operational definitions for MC rate (e.g., see ANGPAM 21-103, Attachment 6) and MC rate can be

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used as an indication of the results of process improvements in metrics supporting

processes (e.g., fix rates, spare parts availability, maintenance scheduling, etc.).

In summary, the three desirable characteristics of a metric are:

1. Understandable – ease of understanding by the intended user. This includes having a clearly documented and operational definition.

2. Applicable – to the issue facing the maintenance manager and to the metric of interest. This encompassed the condition that a good metric be directly linked to the stakeholder's satisfaction.

3. Comparable – standards exist to which the unit's performance can be compared. This can be extended to include the condition that a good metric has the ability to show the results of any process improvement efforts.

2.2 Examples Charts

The charts on the following page are examples of the types of charts maintenance

managers, as well as their customers, view to monitor their maintenance performance

indicators. The first chart (see Figure 3) is a chart for MC rate that reflects a Wing's

aircraft availability. The second chart (see Figure 4) is a chart for FSE rate that reflects

the Wing's ability to follow a preplanned flying schedule.
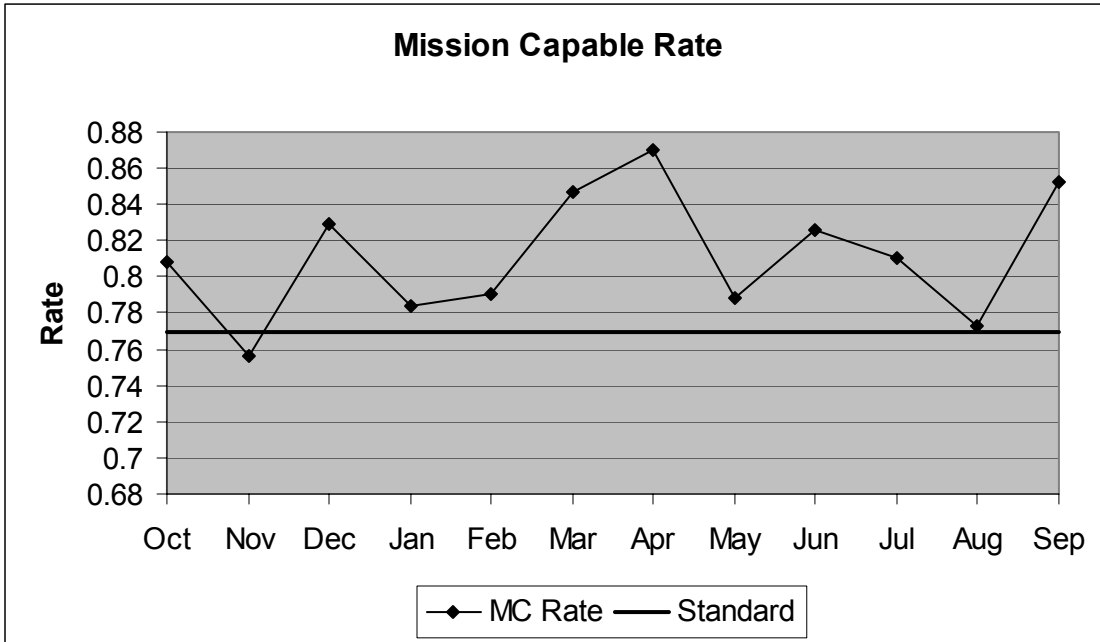
Figure 3. Example MC Rate Chart
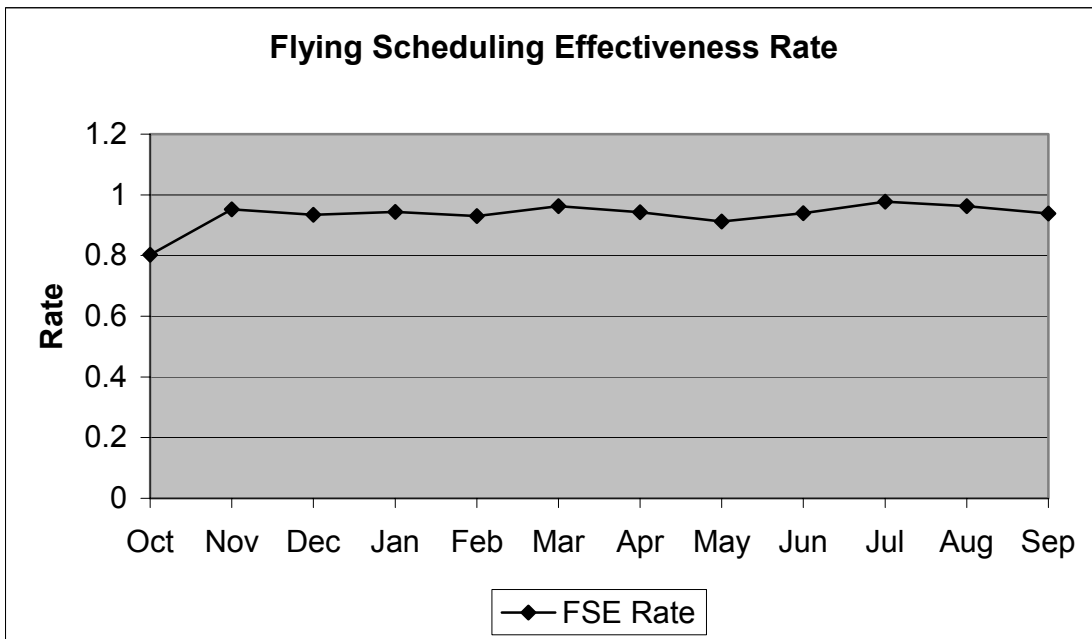
Figure 4. Example FSE Rate Chart

2.3 ANG Maintenance Reporting Requirements

The ANG Readiness Center requires its subordinate aircraft maintenance units to submit an ANG 7401 logistics summary on a monthly basis (*ANGI 21-101*). Sixty-seven reportable items on the ANG 7401 report highlight the maintenance performance indicators important to the ANG Readiness Center. However, not all of the reportable entries are applicable to the 135th MXS (e.g., the number of hours flown in support of an Air Expeditionary Force) nor does the ANG 7401 address all of the leading and lagging indicators suggested by the *Metrics Handbook for Maintenance Leaders*. The 135th MDA uses the data from the analysis spreadsheet (see Appendix A) to complete the ANG 7401 report. See Appendix D for a sample ANG 7401 report.

2.4 ANG Maintenance Performance Standards

Since the C-130J is a newly fielded aircraft, the ANG has not set any maintenance standards for this weapon system. However, the ANG does have standards for its older C-130E/H's for three of the reportable items on the 7401 report. These include MC, total not mission capable due to supply (TNMCS), and total not mission capable due to maintenance (TNMCM) rates. The C-130H standards for these three lagging indicators are as follows (Rollins):

MC – 75.6 percent

TNMCS – 15.8 percent

TNMCM – 21.5 percent

The ANG standards are set at a level such that the subordinate units can expect to meet or exceed 70 percent of the time (Rollins). This puts the standards at a high-enough level to compel their subordinate units to strive for continuous improvement but at a low-enough level to not cause frustration (Rollins). Note that these standards only apply to the ANG's C-130E/H aircraft. The ANG has not set any standards for the C-130J aircraft or for any of the other leading or lagging metrics indicated on the 7401 report.

2.5 C-130J Major Subsystem Overview

The myriad of subsystems and components that comprise the C-130J are organized into 33 different major subsystems (T.O. 1C-130J-06). Furthermore, each of the 33 major systems consists of several subsystems and subcomponents that work together to perform the intended function of the major subsystem. For bookkeeping purposes, each of these subcomponents is given a unique 5-digit alphanumeric work unit code (WUC). The first two digits identify which major subsystem the subcomponent belongs to and the remaining three digits identify the subsystem and specific subcomponent (T.O. 1C-130J-06). For example, WUC 22YA0 refers to system 22 (the power plant, or engine), subsystem Y (the engine starting system), component A0 (the engine starter). Table 1 contains a brief description of each of the 33 major systems and the first two digits of the system's WUC.

Table 1. C-130J Major Subsystems

System Number	Description
11	Airframe
12	Cockpit and fuselage compartments
13	Landing gear
14	Flight control
22	Turbo prop power plant
24	Auxiliary power plant
32	Hydraulic propeller
41	Air conditioning, pressurization and surface ice control
42	Electrical power supply
44	Lighting system
45	Hydraulic and pneumatic power supply
46	Fuel system
47	Oxygen system
49	Misc. utilities
51	Instruments
52	Autopilot
55	Malfunction analysis and recording equipment
56	Accident investigation recording system
61	HF communications
62	VHF communications
63	UHF communications
64	Interphone
65	IFF
66	Emergency communications
68	Satellite communication
69	Misc. communication equipment
71	Radio navigation
72	Radar navigation
76	Electronic countermeasure
82	System integration and display
91	Evacuation and emergency equipment
96	Personnel and misc. equipment
97	Explosive devices and components

(TO 1C-130J-06)

2.6 Statistical Process Control

Statistical process control is a management approach that is intended to improve an organization's product or service quality by reducing variation in the work processes (Houston, Shettel-Neuber, Sheposh). SPC can be applied to both industrial and non-industrial processes and, in its practical application, can help the organization realize continuous improvement (O'Con). SPC consists of a set of seven basic analytical tools that can be employed by an organization's management and employees. All of these tools are graphical in nature and can be used in combination with group problem-solving methods, such as brainstorming, to help an organization reach its product or service quality goals (Houston, Shettel-Neuber, Sheposh). These seven tools are the histogram or stem-and-leaf display, check sheet, Pareto diagram, cause-and-effect diagram, defect concentration diagram, scatter diagram, and control chart (Montgomery).

Histograms

The histogram is an effective tool for showing the general shape, location or central tendency, and spread or variation in a given population (Montgomery). It can also show if there are any gaps in the data (Besterfield). An example of a histogram constructed using the first fifty-week's of 135[th] AW fiscal year 2002 (FY02) MC data is shown in Figure 5.
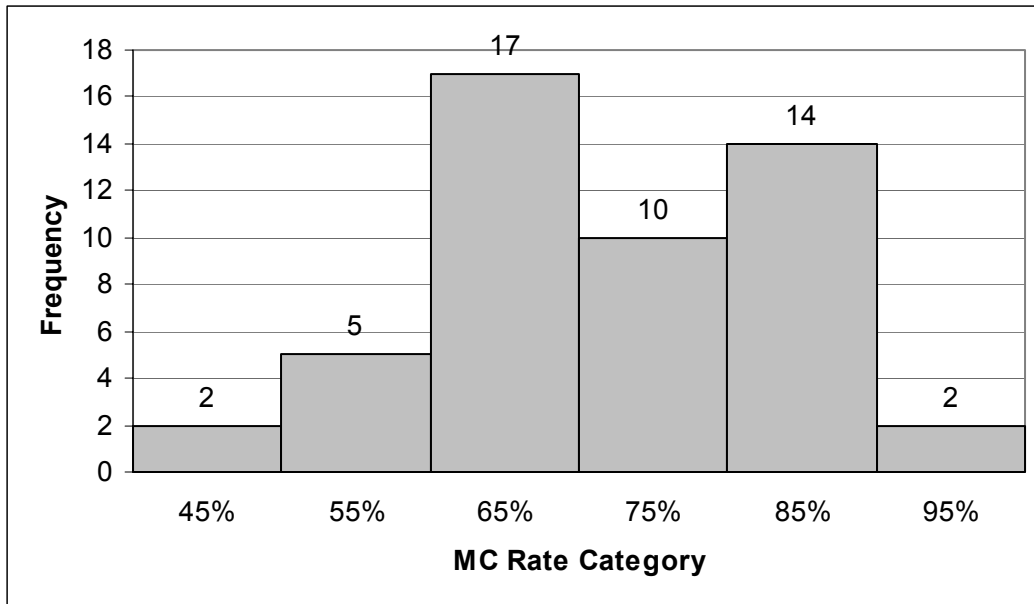
Figure 5. Histogram for the 135th's FY02 C-130J MC Rates

The chart shows the number of times a given week's MC rate fell within one of the MC rate categories. For example, the histogram shows that seventeen of the fifty weeks had MC rates between 60 percent and 70 percent.

Check Sheets

Accurate data collection is a fundamental to SPC. The main purpose of check sheets is to provide data collection personnel with a standardized data collection tool to ensure the data are collected carefully and accurately (Besterfield). The exact form of the check sheet is tailored to each situation. However, it should be designed so that it is user friendly and captures both time and location information to facilitate data analysis (Besterfield). See Besterfield and Montgomery for more discussion and examples of check sheets.

Pareto Diagrams

The Pareto diagram is a graph that ranks data classification in descending order from left to right (Besterfield). Pareto diagrams differ from histograms in that the horizontal axis of a Pareto diagram is categorical (e.g., subsystem number) whereas the horizontal axis of a histogram is numerical. The Pareto diagram can be used to quickly identify which category along the horizontal axis is the most frequently occurring. However, the Pareto diagram does not automatically identify the most important category (Montgomery). For example, a Pareto diagram might be constructed to show which aircraft subsystem fails the most frequently. However, if the user of the chart is interested in which subsystem is creating the largest drain on the maintenance budget, then the Pareto diagram would not be displaying the most important information. In other words, frequency does not always have a direct correlation with importance. See Figure 6 for an example Pareto diagram.
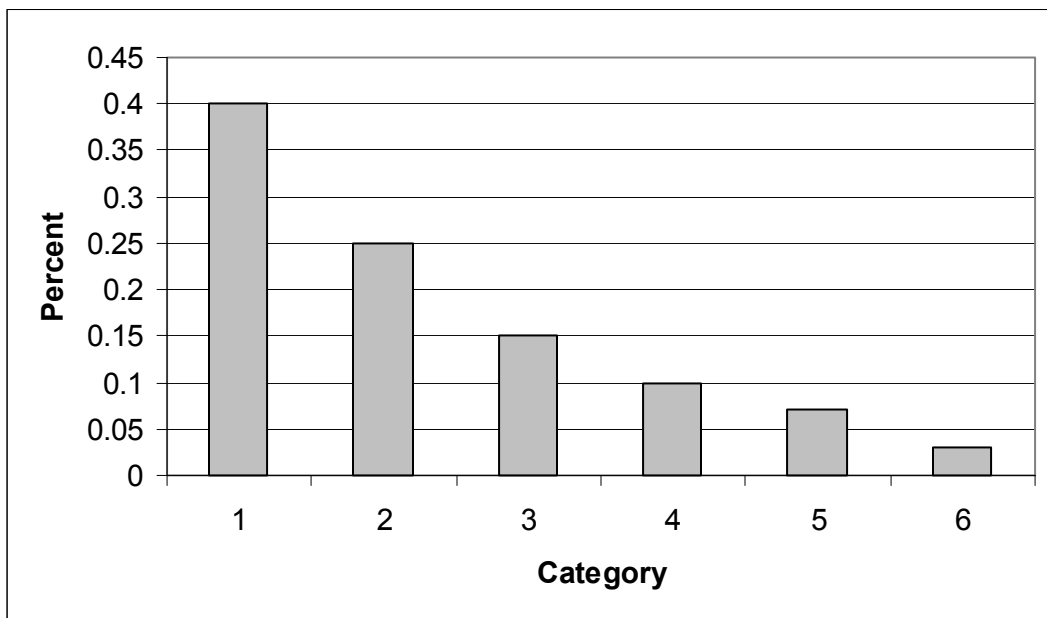
Figure 6. Example Pareto Diagram

Cause and Effect Diagrams

The cause-and-effect (CE) diagram is another useful tool in the SPC toolkit. They help us discover the root causes for a particular problem or undesirable effect that has been previously identified (Montgomery). The person or team that is trying to discover the root cause of a problem constructs the CE diagram by first listing the undesirable effect. They next list the major possible cause categories and minor possible cause categories. The minor cause categories are associated to one or more of the major cause categories, which are then connected to the undesirable effect in the manner shown in Figure 7 (Besterfield). Once all the minor and major causes are identified, solutions are developed to correct the most likely causes in an effort to eliminate the undesirable effect (Besterfield).
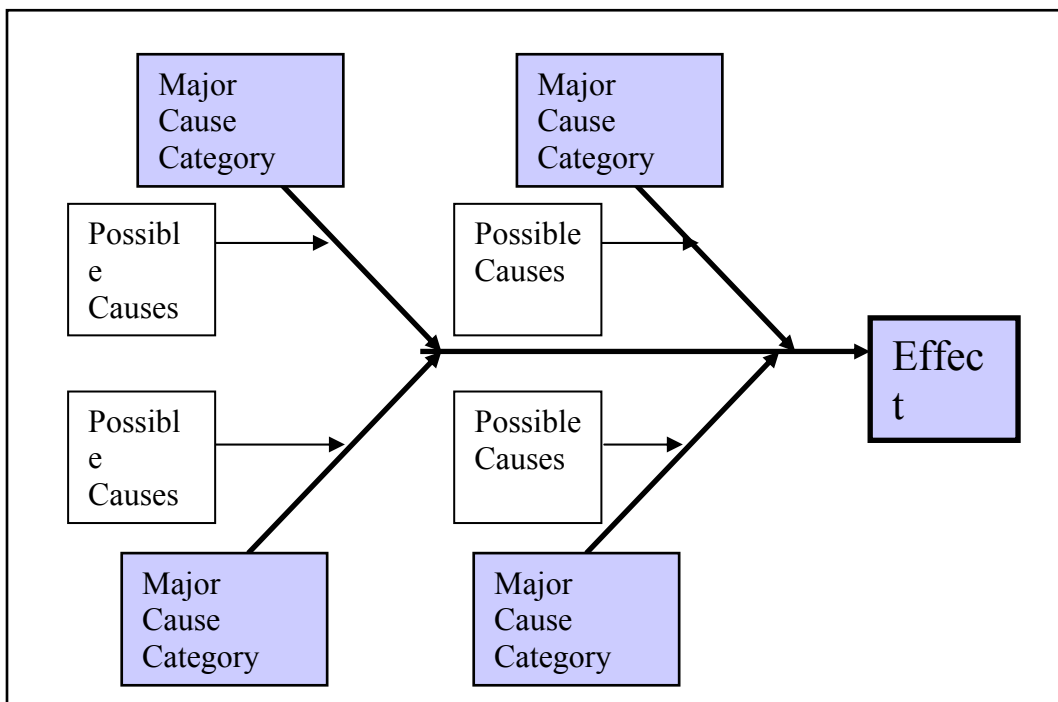
Figure 7. Example Cause and Effect Diagram

Defect Concentration Diagram

A defect concentration diagram is a pictorial representation of some physical item that is being inspected for defects. Any defects found on the item during inspection are noted on the defect concentration diagram in such a way that the position of the defect is understood (Montgomery). The diagrams are then analyzed in an effort to find common causes for any defects that appear to be concentrated in type or location (Montgomery). For example, an inspector charged with inspecting the upper surfaces of a recently painted aircraft could use a defect concentration diagram similar to the one shown in Figure 8. Management would then compare this diagram with others collected by the inspector in an effort to identify any patterns that might contain information as to the cause of the defects.
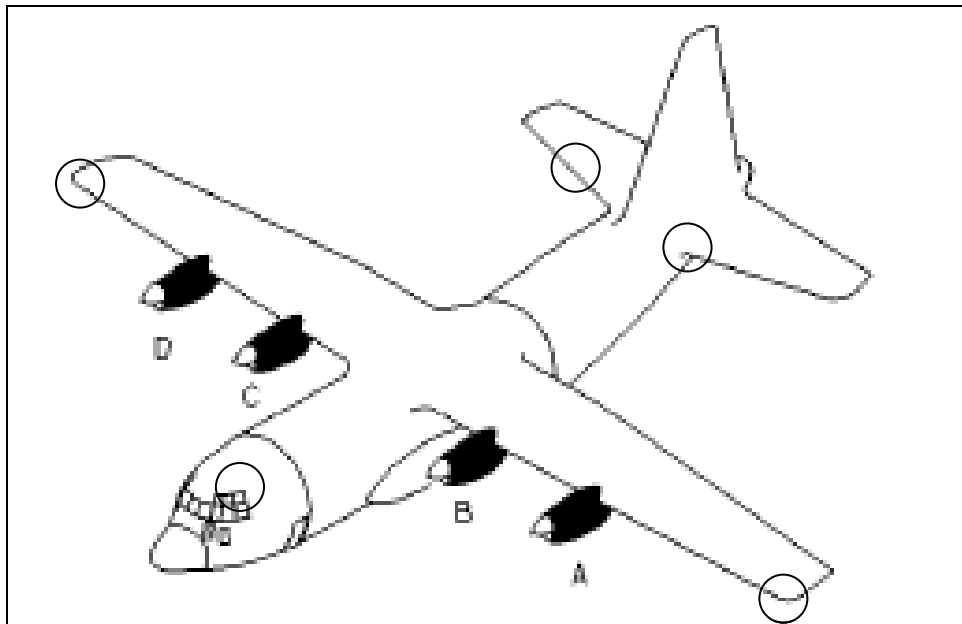
Figure 8. Example Defect Concentration Diagram

Scatter Diagrams

Scatter diagrams are used to help identify potential correlation, or dependency, between two process variables (Montgomery). The data on the two variables are collected and plotted in pairs. If a correlation exists between the two variables, it will be reflected as a visible trend in the scatter plot. If the trend appears to be sloping upward then a positive correlation may exist. If the trend appears to slope downward then a negative correlation may exist. If the data points appear to be randomly placed on the scatter diagram, then most likely there is no correlation between the two random variables (Besterfield). Figure 9 is a scatter diagram that plots the number of sorties cancelled per week due to weather conditions (Wx Canx) against the FY02 week number. Although it appears that a seasonal trend may exist during the spring and early summer weeks, there does not appear to be any strictly positive or negative correlation between the week number and the number of sorties cancelled due to weather conditions
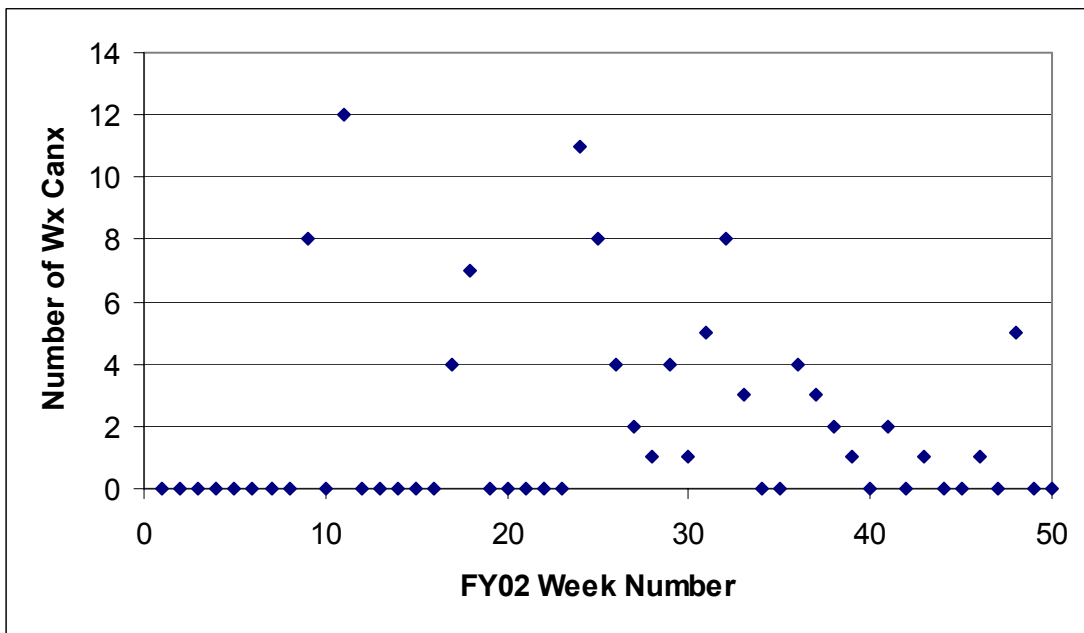
Figure 9. Example Scatter Diagram

Control Charts

Of all the tools offered by SPC, the control chart is the most technically sophisticated (Montgomery). Control charts are graphical tools that help a user differentiate between random and nonrandom process output. Random output is caused by the natural process variation according to chance. Nonrandom process output is not caused by the natural process variations. In the case where nonrandom process output is present, control charts help us identify the underlying reason(s) (Montgomery).

There are two basic types of control charts: those for variable data and those for attribute data (Montgomery). Variables control charts are used when the quality characteristic can be expressed in terms of a continuous numerical scale. Examples of variable data include product weight, volume, dimensions, etc. When the quality characteristic is not a numerical variable, and instead is expressed as an attribute such as conforming/nonconforming or not defective/defective, attributes control charts are used. Examples of process characteristics that are attribute data include whether or not a finished product meets quality standards, whether or not a service satisfied customer requirements, the number of defects on a finished product, etc.

Both variables and attribute control charts have the same general appearance. Both have centerlines, which represent the process average, and both have upper and lower control limits, which define the range of random output (Montgomery). Use of the charts consists of collecting periodic samples from the process output, computing the appropriate statistic (e.g., sample mean, sample range, etc.), and plotting that value on the control chart. Data points that plot between the upper and lower control limits and display a random pattern suggest the process is operating within its natural variation and

is in control. Data points that plot above the upper control limit or below the lower control limit suggest that the process is not operating with only natural variation present and is out of control (Montgomery).

The placement of the control limits on the control chart is a critical step in the design of a control chart. Placing the control limits too far from the centerline increases the chance that an out-of-control data point will plot within the bounds of the control limits, suggesting to the user that the process is in control when in reality it is not. This is called a Type II error (Besterfield). Placing the control limits too close to the centerline increases the chance that an in-control data point will plot beyond the bounds of the control limits, suggesting to the user that the process is out of control when in reality it is not. This is called a Type I error (Besterfield). In practice, the control limits are determined by a function of the average and variance in the sample data. Usually this function is ± 3 standard deviations from the average sample value. However, the control limits could also be established upon an acceptable probability of Type 1 error (Montgomery).

Control limits are different from product or process specification limits. While control limits are established as a function of the sample data, specification limits are established as the permissible variation in the process (Besterfield). In other words, specification limits are established a priori to reflect desired process requirements while control limits are established a posteriori and reflect the process's actual capability. Control charts do not determine if a process is meeting specifications. Rather, control charts simply inform the user whether the process is producing according to its natural variation. Ideally, a

process's average and natural variation will cause its output values to plot within the upper and lower control limits on the control chart.

2.7 Previous Applications of SPC

Statistical process control has been successfully implemented in both service and manufacturing industries (Montgomery). Montgomery describes a successful SPC application in a printed circuit board fabrication facility. The company decided to implement SPC after experiencing high levels of defects and extensive work backlogs. Successful application of cause-and-effect diagrams, check sheets, Pareto analysis, and an additional statistical technique known as design-of-experiments enabled the company to realize a reduction of work backlog and a reduction in the number of defective parts by a factor of 10 (Montgomery).

In the service industries, SPC techniques are applied by treating process errors similarly to the way they are treated in a manufacturing setting (Montgomery). For example, errors on billing statement, documentation errors on loan application paperwork, errors in computer software, etc. can all be considered as defects. In 1996, McAree applied SPC to spirometry examination results at Wright-Patterson AFB. The results of this application established practices used by the Medical Group at Wright-Patterson AFB to help determine if a relationship exists between an employee's health and their work area (McAree).

The 445[th] Reserve Airlift Wing at Wright-Patterson AFB uses control charts to monitor their aircraft's MC and mission abort rates (Azar, Percival). The 302[nd] Reserve

Airlift Wing at Peterson AFB uses control charts to monitor a multitude of performance indicators related to their C-130 aircraft (Wolf). However, the 445th is using the wrong type of control chart for their application. Instead of using the x-bar control chart for variables they should be using the individuals control chart for attributes (Azar, Percival). The 302nd also incorrectly uses the x-bar control chart. In addition, neither unit attempts to relate poor performance to potential underlying sources.

3. Methodology

3.0 Approach

The approach taken toward developing a visualization tool will strive to satisfy the three objectives set forth by the 135[th] MX management. The objectives of the visualization tool are to provide the 135[th] MX with the ability to identify trends, provide an indication of underlying problem areas, and to be easy to use and understand. Furthermore, the approach will strive to achieve the attributes of good metrics: they must be applicable to an issue of interest to maintenance management and be comparable to a standard.

To satisfy these objectives, SPC techniques will be applied to maintenance data gathered from the 135[th] for FY02. The maintenance data will be used within a Microsoft Excel spreadsheet to facilitate analysis and visualization tool development. The SPC technique will be chosen by its ability to link adverse performance trends to the underlying problem area(s). This drill-down approach will be used for all tools employed to satisfy the objectives of maintenance management.

For the sake of brevity, we will demonstrate the approach using only two maintenance performance indicators. The first performance indicator is MC rate. MC rate is a lagging fleet availability indicator and is one of the best indicators of a unit's maintenance performance (*Metrics Handbook*). The second performance indicator chosen for illustration is FSE rate. FSE rate is a leading flying program indicator and provides managers with an indication of how well they are planning and executing their flying

schedule (*Metrics Handbook*). These two performance indicators were chosen because they are representative of both major classes of performance indicators as well as current importance to the 135[th] MX management (Maurer, Ruane). These two performance indicators also illustrate the applicability of SPC to aircraft maintenance management and demonstrate a model to follow when applying the SPC techniques to the remaining fleet availability and flying program performance indicators.

3.1 Mission Capability Rate Explanation

MC rate is the percentage of time an aircraft or a fleet of aircraft is available to perform at least one of its assigned missions as defined by the minimum essential subsystem list (MESL) (AFI 21-103). The MESL also list the aircraft's systems or subsystems that must be operational for the aircraft to perform those missions. Each mission type identified on the MESL has an associated basic subsystems list (BSL) detailing which aircraft subsystems must be operational in order for the aircraft to perform that particular mission. The complete list of all mission type basic systems is called the full system listing (FSL) (AFI 21-103).

MC rate is a sum of the fully mission capable (FMC) and partially mission capable (PMC) rates. FMC, PMC, as well as not mission capable (NMC) are all status codes used to describe the maintenance status of an aircraft (AFI 21-103). MC rate is computed using the following formula (*Metrics Handbook*)

$$MC\ Rate = \frac{FMC\ hours + PMCM\ hours + PMCS\ hours + PMCB\ hours}{Possessed\ hours} \times 100 \quad (3.1)$$

MC rate is computed for a specific time period and can be computed for an individual aircraft or as an aggregate for a group of aircraft.

FMC hours are the elapsed clock hours where all systems on the FSL are operational (AFI 21-103). PMCM hours are the elapsed clock hours where not all of the BSL systems are operational due to a maintenance problem (AFI 21-103). PMCS hours are the elapsed clock hours where not all of the BSL systems are operational due to a part being on order from the supply system (AFI 21-103). PMCB hours are the elapsed clock hours where not all of the BSL systems are operational due to both maintenance and supply issues (AFI 21-103). Possessed hours are the total elapsed clock hours within a given time period multiplied by the number of aircraft for which the MC rate is being computed (ANGPAM 21-103).

If an aircraft were unable to perform any of the missions types listed on the MESL, the aircraft would be given the maintenance status of not mission capable (NMC). Like PMC, NMC can be further defined by adding the appropriate suffixes such as M for maintenance, S for supply, and B for both (AFI 21-103).

Anytime a unit possesses an aircraft, that unit has to assign and report a maintenance status code for that aircraft (AFI 21-103). Given that all possessed time must be reported as either FMC, PMC or NMC, an alternate expression for MC rate is given by

$$MC\ rate = 100 - NMC\ rate \quad\quad\quad (3.2)$$

The proof for (3.2) follows.

From the *Metrics Handbook* we have:

$$MC\ Rate = \frac{FMC\ hours + PMCM\ hours + PMCS\ hours + PMCB\ hours}{Possessed\ hours} \times 100 \quad (3.3)$$

From AMCPAM 21-102 we have:

$$NMC\ Rate = \frac{NMCM\ hours + NMCS\ hours + NMCB\ hours}{Possessed\ hours} \times 100 \quad (3.4)$$

We know from AFI 21-103 that:

$$Possessed\ hours = FMC\ hours + PMC\ hours * + NMC\ hours ** \quad (3.5)$$

Thus, we have:

$$\frac{Possessed\ hours}{Possessed\ hours} = \frac{FMC\ hours + PMC\ hours * + NMC\ hours **}{Possessed\ hours} \quad (3.6)$$

$$1 = \frac{FMC\ hours + PMC\ hours *}{Possessed\ hours} + \frac{NMC\ hours **}{Possessed\ hours} \quad (3.7)$$

Multiplying both sides by 100 to convert to rate:

$$100 = MC\ Rate + NMC\ Rate \quad (3.8)$$

$$MC\ Rate = 100 - NMC\ Rate \quad (3.9)$$

* PMC hours = PMCM hours + PMCS hours + PMCB hours (*Metrics Handbook*)

** NMC hours = NMCM hours + NMCS hours + NMCB hours (*Metrics Handbook*)

The only time an aircraft is coded NMC is when one of the basic systems listed on the MESL is inoperative or when the aircraft is undergoing a lengthy scheduled maintenance activity such as an isochronal (ISO) inspection or home station check (HSC) (AFI 21-103). Therefore, one can compute individual NMC rates for each of the basic systems listed on the MESL and for the ISO/HSC scheduled maintenance activities. This detail will be used to drill-down to the underlying problem area(s) as well as to compute the overall MC rate. That is, MC rates will be computed as a sum of the individual basic system's and ISO/HSC NMC rates using (3.9).

MC Rate Standard

The ANG has not established an MC rate standard for the C-130J aircraft. However, using the ANG criteria of setting the standard such that the unit can expect to achieve it 70 percent of the time (Rollins), 135[th] maintenance management has established an internal standard of 75 percent (Maurer, Ruane). In addition, they have decided to adjust their MC rate standard for scheduled maintenance activities. For example, if one of their eight C-130J aircraft is undergoing an HSC, the 75 percent standard will be adjusted down by the percentage of time the aircraft was undergoing HSC. If the aircraft was in HSC during the entire period for which the MC rate is calculated, the standard will be adjusted down by 12.5 percent to 62.5 percent. These standards were established using the FY02 MC rate data.

3.2 Flying Scheduling Effectiveness Rate Explanation

Maintenance, Operations, and Wing management are concerned with the FSE rate since it provides them with an indication of how well they are meeting the flying plan (Maurer, Ruane). At the beginning of each fiscal year, the ANGB releases a predetermined number of C-130J flying hours to the 135[th]. The 135[th] Plans and Scheduling (P&S) office uses these flying hours to build weekly, monthly, quarterly, and yearly flying plans (Benham). Along with each of the flight hours comes a fixed amount of money that is used to pay for the operation and maintenance expenses incurred by the 135[th] as a result of flying and maintaining their C-130Js. The 135[th] MX budgets this money to purchase the supplies and spare parts required to maintain their fleet of aircraft. If, however, the Wing is unable to execute all the flying hours allotted to them, then the flight hours, along with the operating and maintenance dollars tied to those hours, is given back to the ANGB (Ruane).

Plans and Scheduling uses the historical FSE rate to compute their schedule inflation factor. Currently, the 135[th] Airlift Group inflates their weekly flying hours by 15 percent to compensate for unplanned deviations (Benham). This is based upon the FSE rates they realized when operating the C-130E aircraft (prior to converting to the C-130J aircraft) (Benham). For example, if they need to fly 100 hours during a given week to meet their monthly flying plan, they will schedule 115 flight hours (Benham). The expectation is that by the end of the scheduling period, they will have over flown enough sorties and hours to offset those times when they are unable to fly the required hours due to schedule deviations.

There are several different ways to compute the FSE rate. However, each method involves the number of sorties originally scheduled and the number of sorties subsequently added or subtracted from the original schedule. Deviations to the original schedule can occur for many reasons including weather, higher headquarters taskings, logistics (e.g., maintenance problems), operations (e.g., aircrew problems), air traffic control, etc. (*Metrics Handbook*). Deviations are classified as chargeable and nonchargeable. A chargeable deviation is one that the unit has control over (maintenance, supply, aircrew, scheduling, etc.) (ANGPAM 21-103). A nonchargeable deviation is one that the unit does not have control over (e.g., weather, higher headquarters, air traffic control, etc.) (ANGPAM 21-103).

In the Air Mobility Command, there are actually two different FSE rate computations: one for logistics, and one for operations. These two rates are calculated as follows (AMCPAM 21-102):

$$FSE\ Rate\ (Logistics) = \frac{Sched.Departures + All\ Adds - Logistics\ Canx}{Sched.Departures + All\ Adds} \times 100 \quad (3.10)$$

$$FSE\ Rate\ (Operational) = \frac{Sched.Departures + All\ Adds - All\ Canx}{Sched.Departures + All\ Adds} \times 100 \quad (3.11)$$

The FSE rate (Logistics) only considers those deviations charged to logistics while the FSE rate (Operational) considers all chargeable deviations regardless of whom those deviations are charged.

The *Metrics Handbook* states FSE rate is computed as

$$FSE\ Rate = \frac{Adjusted\ Sorties\ Scheduled - Chargeable\ Deviations}{Adjusted\ Sorties\ Scheduled} \times 100 \qquad (3.12)$$

The *Metrics Handbook* does not provide a definition of "Adjusted Sorties Scheduled" and only factors in those deviations that the unit has direct control over. It does not include nonchargeable deviations to the schedule caused by weather, higher headquarters, etc.

The Air Combat Command (ACC) computes their FSE rates according to the following equation (ACCI 21-118):

$$FSE\ Rate = \frac{Total\ Scheduled - Deviations}{Total\ Scheduled} \times 100 \qquad (3.13)$$

In the ACC equation "Total Scheduled" includes any additions to the original schedule and "Deviations" includes all deviations – chargeable and nonchargeable. This is similar to the FSE Operational rate used by AMC.

The ANG computes their FSE rates using the following equation (ANGPAM 21-103):

$$FSE\ Rate = \frac{Total\ Deviations}{Total\ Sorties\ Scheduled} \times 100 \qquad (3.14)$$

"Total Deviations" includes both chargeable and nonchargeable additions and cancellations (ANGPAM 21-103). Using the ANG equation, if a unit scheduled perfectly and did not experience any deviations, they would achieve a 0 percent FSE rate. On the other hand, if they had 100 scheduled sorties and 200 total deviations (100 adds and 100 cancellations), they would achieve a 200 percent FSE rate. Neither condition makes

sense from an effectiveness rating perspective. Table 2 details two FSE scenarios and

how the ANG computation would compare to the ACC computation.

Table 2. ANG and ACC FSE Rate Computation Comparison

Scenario	ANG FSE Rate	ACC FSE Rate
Scheduled: 100 Additions: 0 Cancellations: 0	$\dfrac{0}{100}*100 = 0\%$	$\dfrac{100+0-0}{100+0}*100 = 100\%$
Scheduled: 100 Additions: 0 Cancellations: 100	$\dfrac{100}{100}*100 = 100\%$	$\dfrac{100+0-100}{100+0}*100 = 0\%$

Maintenance, Operations, and Wing management at the 135[th] currently monitor their

FSE rate on a weekly basis via an e-mail sent out from the 135[th] MX P&S office. The

method the 135[th] uses to compute their FSE rate is as follows

$$FSE\ Rate = \frac{Total\ Scheduled + Total\ Adds - Total\ Deviations}{Total\ Scheduled} \times 100 \qquad (3.15)$$

Similar to the ANG method (equation 3.14), this method allows for the possibility of FSE

rates greater than 100 percent.

The primary use of FSE rate in the 135[th] is to assess how well they are progressing

towards fulfilling their yearly flying hour allotment (Ruane). They also want to use their

FSE rate to help determine their scheduling inflation rate (Ruane, Benham). Given these

two uses, they are interested in an FSE rate that includes both chargeable and

nonchargeable deviations. Following this logic, their current method of computing FSE

rate is not satisfying their requirements. As such, we will use the FSE rate computation outlined in ACC 21-118 when constructing the visualization tool.

The overall FSE rate can be separated into component rates for each of the chargeable and nonchargeable categories (ACCI 21-118, ANGPAM 21-103). For example, we can compute that portion of the overall FSE rate due to weather deviations or to deviations caused by maintenance. This is the approach used to identify the underlying problem areas for FSE rate. In addition, for those deviations charged to maintenance, a further drill-down will be provided in the way of identifying the subsystem causing the deviation.

FSE Rate Standard

The ANG does not establish FSE rate standards. However, a standard can be derived based upon the fact the 135[th] inflates their flying schedule by 15 percent. Let S be the number of sorties scheduled, R the number of sorties required to satisfy the flying plan, and X represent the required sortie success rate so that

$$S * X = R \tag{3.16}$$

$$X = R/S \tag{3.17}$$

Since the 135[th] inflates their flying schedule by 15 percent, then $S = R + (R * 0.15)$. This implies

$$X = \frac{R}{R + (R * 0.15)} \tag{3.18}$$

$$X = \frac{R}{R(1+(1*0.15))} \qquad (3.19)$$

$$X = \frac{1}{1.15} \qquad (3.20)$$

$$X = 0.8696 \qquad (3.21)$$

Thus, if the 135[th] can fly 87 percent of their inflated flight schedule, they will satisfy their true sortie requirements. Based upon a 15 percent inflation factor, the FSE standard should be set at 87 percent.

3.3 Choosing the Appropriate SPC Technique

We will use control charts for fraction conforming (p-charts) to display MC and FSE rates and Pareto diagrams to facilitate drill-down to the underlying problem areas. P-charts are chosen because they do not require normally distributed data and are applicable to both MC and FSE performance indicators. Pareto diagrams are used for the drill-down (i.e., subsystem NMC rates and deviation categories) due to their ability to plot current performance against historical performance. Both types of charts are easy to construct and understand.

P-charts are applicable to attribute type data (Montgomery). In the case of p-charts, the attributes are conforming or nonconforming and the p-chart simply plots the percentage of units that are classified as conforming (Montgomery). For MC rate, each possessed hour will be classified as conforming if it has been coded as either FMC or PMC and nonconforming if it has been coded as NMC. For FSE rate, a sortie will be

classified as conforming if it was flown as scheduled and as nonconforming if it was not flown as scheduled.

Pareto diagrams are used to show the linkage between MC or FSE rates that do not meet standards and the underlying problem area. We will demonstrate when MC or FSE rate displays a data point beyond the standard there is a direct relationship with an underlying cause.

3.4 Constructing MC Rate and FSE Rate Charts

Data for both MC rate and FSE rate were collected for each week in FY02. The MC rate data were gathered from G081 and the FSE data were gathered from the 135[th] P&S office. Each week's proportion conforming, or rate, is plotted against the standard. When a point plots below the standard, Pareto diagrams are constructed to illuminate the potential problem areas.

MC Rate Data

Weekly MC rate data were pulled from G081 via the 9025 program for each week. The output from this program consists of a listing of all aircraft that were NMC during the week, the subsystem and the reason (e.g., supply, maintenance, both) for which the aircraft were NMC, and the number of hours the aircraft were in the NMC status. This data was then entered into a Microsoft Excel spreadsheet. Appendix E contains all FY02 MC rate data. There are 1344 possessed hours in each week (eight aircraft multiplied by seven days multiplied by 24 hours per day). The spreadsheet converts individual

subsystem NMC hours reported on the 9025 output to NMC rate by dividing subsystem

NMC hours by 1344. MC rate is computed using formula (3.9).

MC Rate P-Chart

Figure 10 shows the weekly FY02 MC rates for the 135[th]'s eight C-130J aircraft. The

standard is computed as 75 percent minus the percent of time the aircraft spent

undergoing either isochronal or home station check inspections (i.e., work unit code 37

activities). Therefore, any data points that plot below the standard are due solely to high

subsystem(s) NMC rates. This allows management to see the impact of high subsystem

NMC rates without the confounding affect of ISO/HSC. We have also plotted an upper

limit to show management the maximum theoretical MC rate when adjusted for

scheduled maintenance activities.
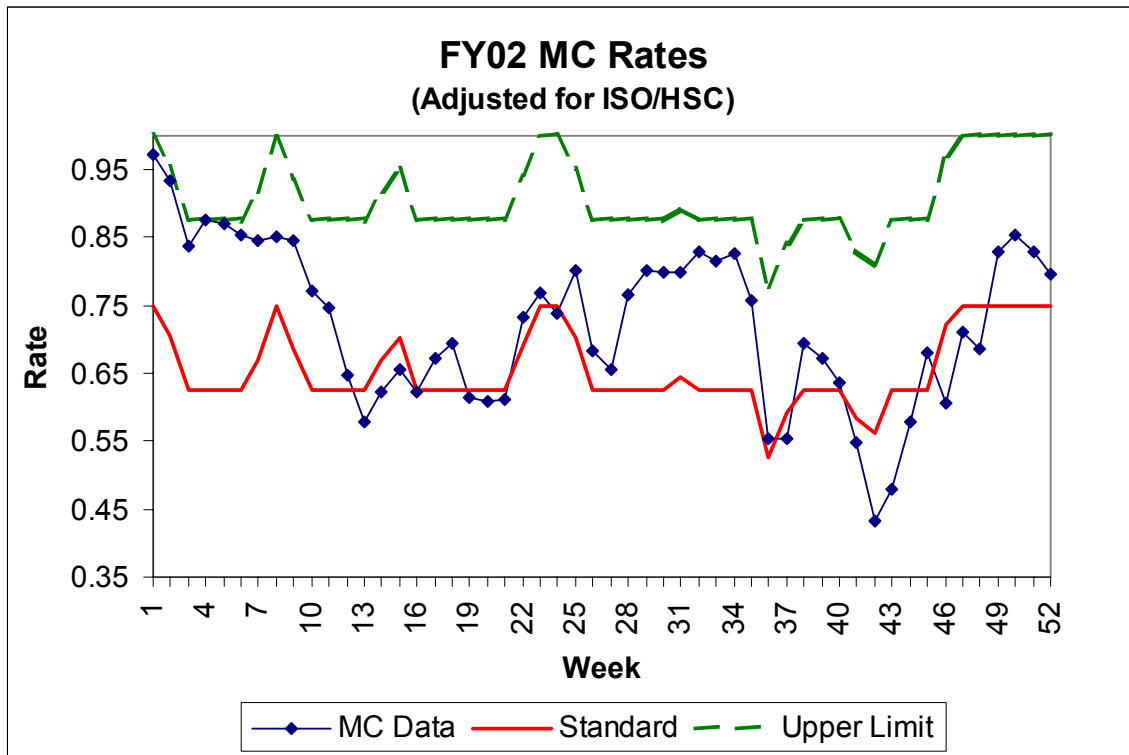
Figure 10. FY02 MC Rates

NMC Rate Pareto Diagrams

The MC rates during weeks 13, 14, 15, 16, 19, 20, 21, 24, 37, 41, 42, 43, 44, 46, 47, and 48 fell below the adjusted MC rate standard. When the subsystem NMC times are compared to their average NMC times (see Appendix F) for those weeks, it becomes apparent which subsystems are driving the substandard MC rate. For example, Figure 11 compares the subsystem performance for week 13 against the average subsystem NMC time.
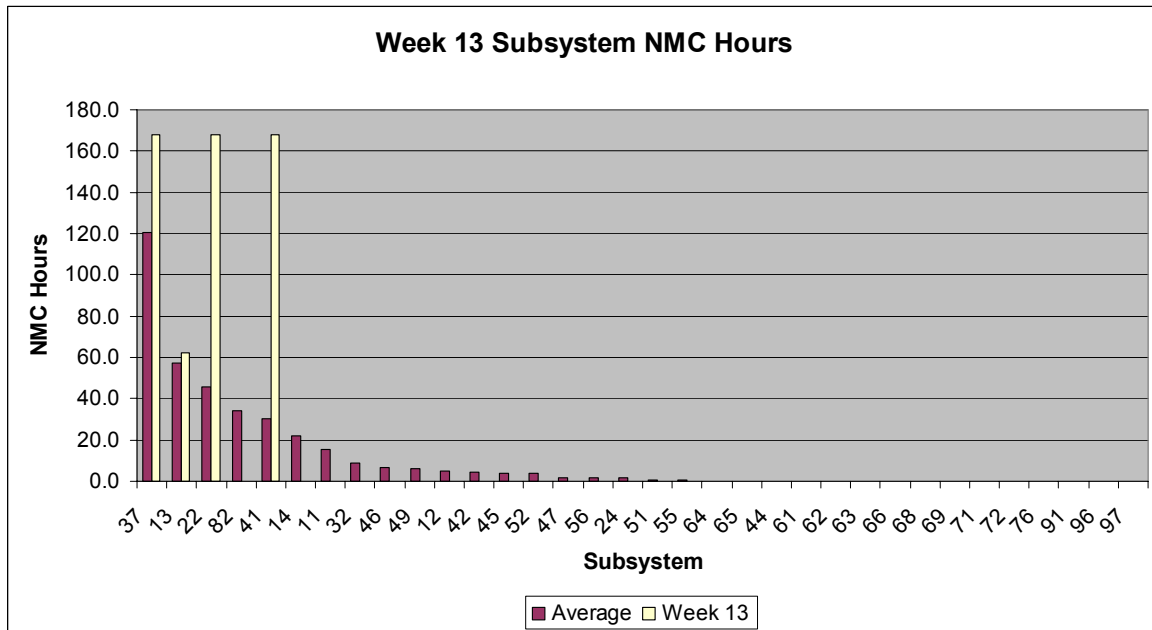
Figure 11. Week 13 Subsystem NMC Time

The same pattern holds for all substandard MC rate weeks, every instance of a substandard MC rate week is attributed to at least one subsystem. Table 3 lists all weeks when the MC rate did not meet the standard and the subsystems that had above-average NMC rates for that week.

Table 3. Substandard MC Rate Weeks and Contributing Systems

Subsystem	Substandard MC Rate Week #															
	13	14	15	16	19	20	21	24	37	41	42	43	44	46	47	48
37	X				X	X	X		X	X	X	X	X			
13	X	X	X	X	X	X	X	X						X	X	
22	X	X	X					X	X	X	X	X		X	X	X
82					X	X		X							X	X
41	X	X	X	X						X		X				
14								X		X	X	X				
11												X	X		X	X
32					X	X	X		X	X	X	X	X			
46														X		
49												X	X			
12															X	X
42											X			X		
45										X						
52										X	X					
47			X												X	
56					X											
24													X			
51													X			
55					X											
64																
65								X								
44																
61																
62																
63																
66																
68																
69																
71																
72																
76																
91																
96																
97																

FSE Rate Data

FSE data were collected from the P&S office. At the beginning of each week, P&S compiles an e-mail detailing the previous week's flying activities. Items include the number of sorties originally scheduled, the number of sorties added, and the number of sorties that were cancelled. If there were additions or cancellations, P&S includes a short description of the reason for the deviation. The e-mail is sent to both maintenance and operations management personnel for review.

The weekly FSE rate data was entered into the same Microsoft Excel spreadsheet used for the MC rate data. The deviations are categorized according to the reason for the cancellation. This includes those cancelled due to operations, logistics (includes maintenance and supply), weather, higher headquarters, and other. "Other" cancellations are those attributable to sympathy (e.g., the number two aircraft scheduled for a two-ship sortie cancels due to a maintenance cancellation with the number one aircraft) and air traffic control (e.g., air space restrictions over the airfield) (ACCI 21-118). The spreadsheet is configured to automatically calculate the weekly FSE rate using (3.13). With the exception of weeks 51 and 52, Appendix H contains all of the 135th's FY02 FSE rate data.

FSE Rate P-Chart

Figure 12 shows the 135th's FSE rates for the first 50 weeks in FY02. Thirty-eight of the 50 weeks did not meet the standard. This agrees with the fact the 135th did not meet their flying plan for FY02; they had to reallocate their flying hours three times during the fiscal year, resulting in a return of 250 flight hours to the ANGB.
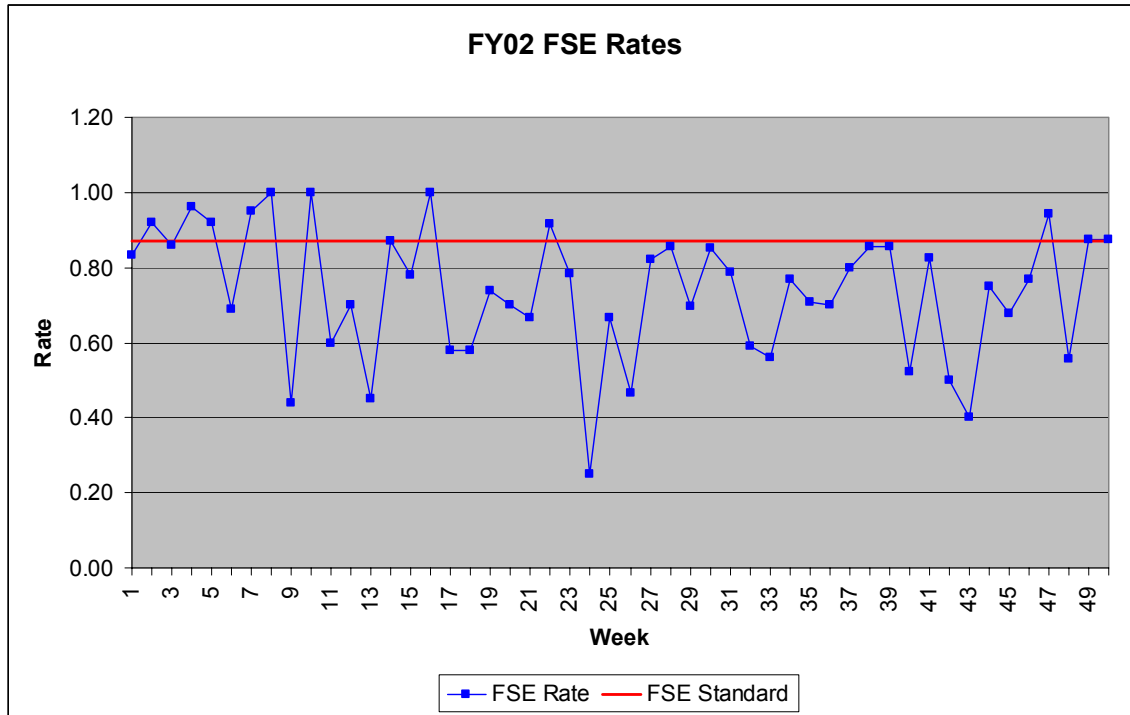
Figure 12. FY02 FSE Rates

FSE Rate Pareto Diagrams

For each of the 38 weeks in FY02 when the FSE rate does not meet the standard, there is at least one deviation category that exceeded its' average deviation rate. For example, Figure 13 shows the deviation categories for week number six. Here the high maintenance sortie cancellation rate (i.e., deviation rate) was the cause for the substandard FSE rate.
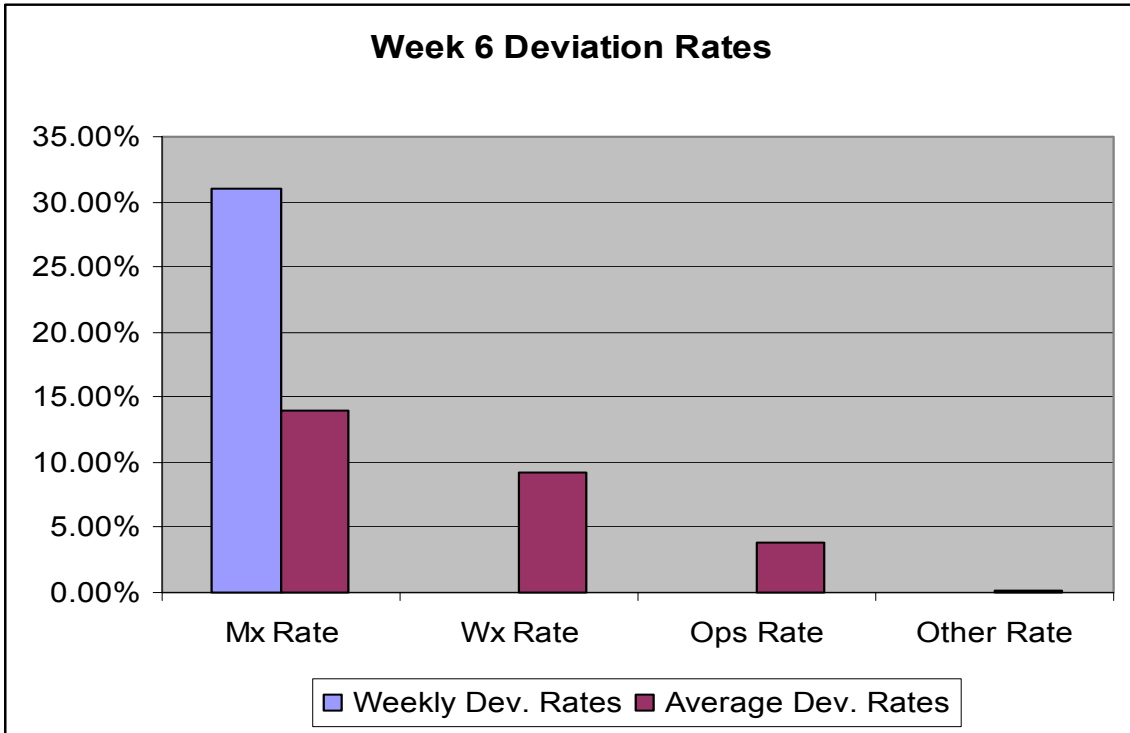
Figure 13. Week 6 Deviation Categories

Table 4 lists all 38 weeks when the FSE rate did not meet the standard and the deviation categories that caused the substandard performance (i.e., caused a higher-than-average number of cancellations during that week).

Table 4. Substandard FSE Weekly Rates and Contributing Category

Substandard Week	Mx Rate	Wx Rate	Ops Rate	Other Rate
1			X	
3			X	
6	X			
9	X	X		X
11		X		
12	X		X	X
13	X			
15	X		X	
17	X	X	X	
18		X		
19	X			
20			X	
21	X			
23	X			
24		X	X	
25		X		
26	X	X		
27				
28				
29		X	X	
30			X	
31		X		
32		X	X	
33	X	X	X	
34	X			
35	X			
36		X		
37		X		
38		X		
39			X	
40	X		X	
41			X	
42	X			
43	X		X	
44	X		X	
45	X		X	
46	X			
48	X	X		

FSE Rate Maintenance Pareto Diagrams

Of the 38 weeks with substandard FSE rates, 30 have an above-average number of maintenance cancellations. The deviations caused by maintenance can be further classified by the subsystem that caused the deviation. Figure 14 shows the classification of maintenance-related deviations for week 6.
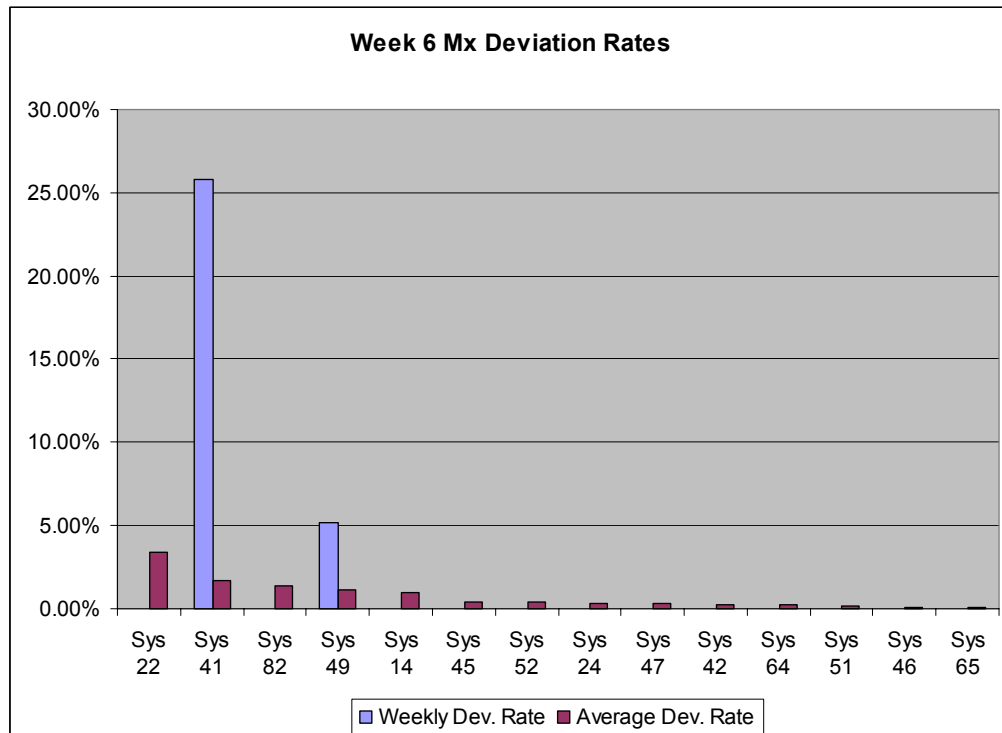
Figure 14. Week Six Mx Deviation Rates

Subsystem 41 (air conditioning, pressurization, and ice control) and subsystem 49 (misc. utilities) caused a higher-than-normal cancellation rate during week 6. Table 5 lists the 30 substandard FSE rate weeks that had an excessive number of deviations driven by maintenance and the subsystem(s) that were driving the maintenance cancellations for

that week. "Driving" in this case implies the subsystem attributed more than its' normal share to the total number of maintenance cancellations for that week.

Table 5. Substandard FSE Weekly Rates With Excessive Mx Deviations

Week	Sys 22	Sys 41	Sys 82	Sys 49	Sys 14	Sys 45	Sys 52	Sys 24	Sys 47	Sys 42	Sys 64	Sys 51	Sys 46	Sys 65
1	X													
3														
6		X		X										
9			X											
11			X											
12	X									X				
13	X													
15	X					X			X					
17								X						
18					X									
19						X								
20		X												
21			X											
23	X	X												
24									X					X
25														
26	X				X									
27		X												
28			X											
29			X											
30						X								
31														
32														
33		X												
34	X										X			
35										X				
36	X													
37														
38														
39														
40	X			X		X				X				
41				X										
42		X			X		X							
43	X			X										
44			X	X									X	
45					X									
46		X												
48														

43

4. Results

4.0 Mission Capable Rate Analysis

Figure 15 shows each subsystem WUC, including WUC 37 which represents ISO/HSC, in rank order from the highest NMC driver to lowest. The "Other" category represents the remaining subsystem WUCs, which for FY02 did not contribute to the fleet's NMC rate. Appendix G lists each subsystem and its average NMC hours per week for FY02
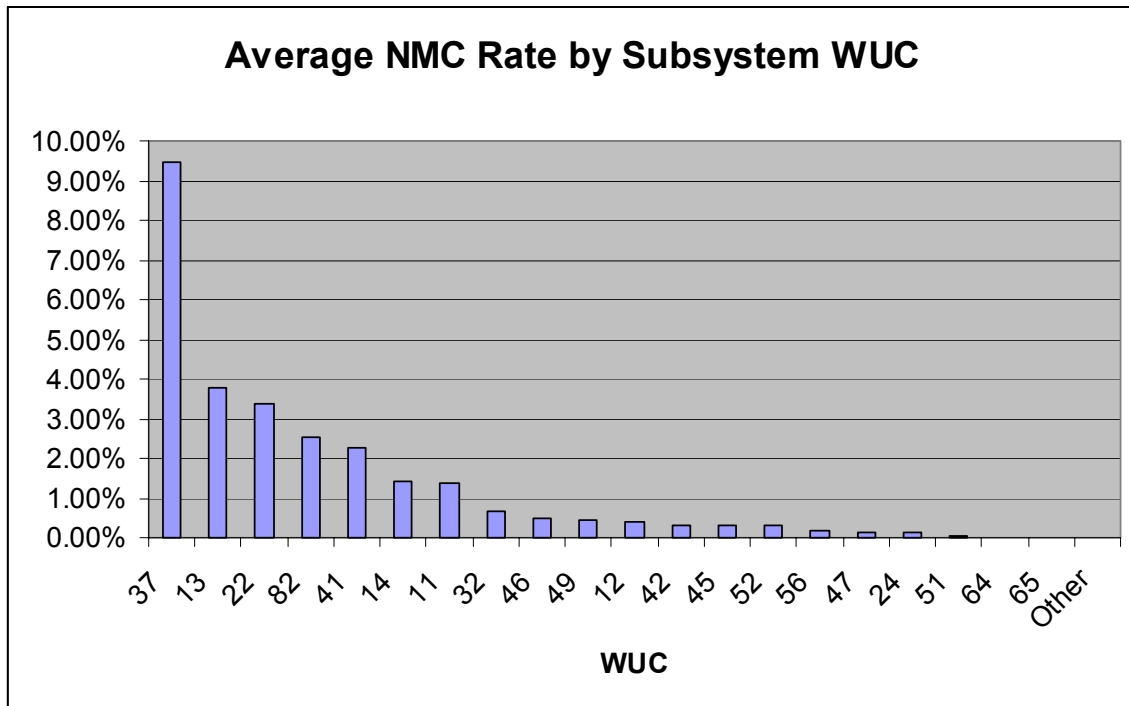
Figure 15. FY02 NMC High-Drivers

Work Unit Code 37 – ISO and HSC Inspections

ISO and HSC represent the 135[th]'s largest NMC driver. ISO and HSC are scheduled maintenance inspections that must occur on time to ensure the long-term health of the fleet (Ruane). While aircraft-specific directives establish the scope and frequency of the inspections, available resources such as personnel, space, parts, etc. determine the duration of the activity. There are three primary reasons why ISO and HSC might be contributing so much NMC time to the fleet – small fleet, technician work schedules, and combining depot-type work with the ISO/HSC.

The Baltimore ANG has eight C-130J aircraft assigned to its 135[th] Airlift Wing. Each aircraft represents 12.5 percent of the fleet. Anytime an aircraft is coded NMC, the instantaneous MC rate is decremented by 12.5 percent. The longer the aircraft is NMC, the more profound the effect on the weekly MC rate. The fleet size is fixed at eight aircraft, so the only way to mitigate the negative impact on MC rate caused by a small fleet is to reduce the amount of time the aircraft spends in ISO/HSC (i.e., reduce the activities flow time).

The 135[th] Mx currently has one 10-hour maintenance shift per day for four days per week – representing approximately 23.8 percent of the available work-hours per week. Any aircraft that is undergoing an ISO or HSC, and accumulating NMC time, sits idle during off-shift hours (i.e., the remaining 76 percent of the time). It may be possible to reduce the ISO/HSC flow time by adjusting the work schedules of those maintenance technicians assigned to conduct the ISO/HSC.

The ISO/HSC rates might also be inflated to some degree because the 135[th] schedules aircraft modifications and upgrades at the same time the aircraft is undergoing its

scheduled ISO or HSC (Rees). It may be possible to improve the ISO/HSC NMC rate by decoupling modifications and upgrades from the ISO/HSC flow. Putting the aircraft in a depot status during modifications and upgrades could also improve the MC rate by reducing the amount of time the 135[th] possessed the aircraft. In effect, the time it took the contractor to perform the modification or upgrade would be subtracted from the unit's total possessed hours.

Other NMC Rate High-Drivers

There are only three cases when an aircraft subsystem produces NMC hours: the system is broken and being repaired, the system broken and has parts on order, and the system is broken and being repaired with parts on order (i.e., "both"). Figure 16 shows the breakdown in percentage of time in FY02 the fleet was NMC. The total time the fleet was NMC due to maintenance problems is 83 percent and the total time the fleet was NMC due to supply problems is 69 percent (this includes the "both" time).
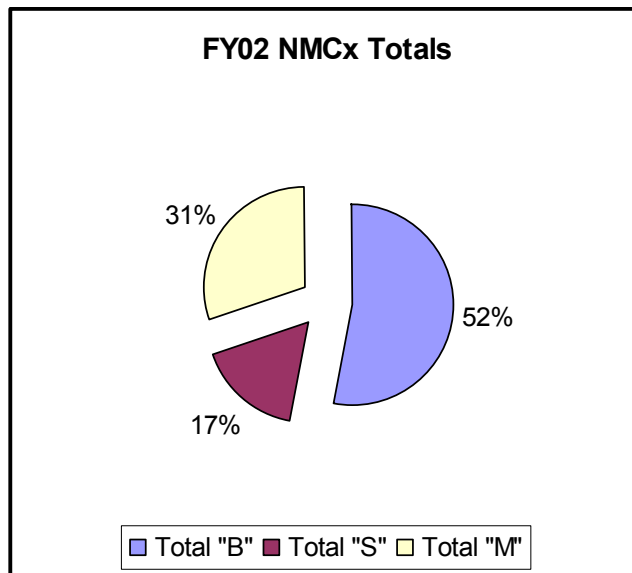
Figure 16. FY02 Subsystem NMCx Totals

Appendix G list the average number of NMC hours for each subsystem WUC attributable to maintenance (M), supply (S), and both maintenance and supply (B). 135[th] personnel need to examine each of these systems to determine the underlying cause(s) in an attempt to identify possible solutions to decrease the system's NMC hours. Since NMCM represents the largest portion of the fleet's overall NMC time, focusing on root causes within their maintenance processes may prove to be the most beneficial way of reducing the fleet's overall NMC rate. This may involve adjusting internal maintenance processes or engaging the aircraft's manufacturer through the aircraft's program office to address repair procedures or subsystem reliability.

4.1 Flying Scheduling Effectiveness Analysis

The 135[th]'s average weekly FSE rate for FY02 is 73.5 percent, therefore 26.5 percent of all planned sorties were cancelled by maintenance, weather, operations, or for other reasons. Figure 17 illustrates how the cancellations are distributed across the four deviation categories. Deviations attributable to maintenance cause the largest number of sortie cancellations and have the largest impact on the unit's ability to maintain their planned flying schedule. Maintenance deviations fall under the responsibility of the DCL and SMO. Deviations caused by weather are unavoidable. However, the P&S office does consider seasonality when planning the flying schedule (Benham). Deviations attributable to the operations and other categories do not fall under the realm of the 135[th] Mx and are not addressed in this research.
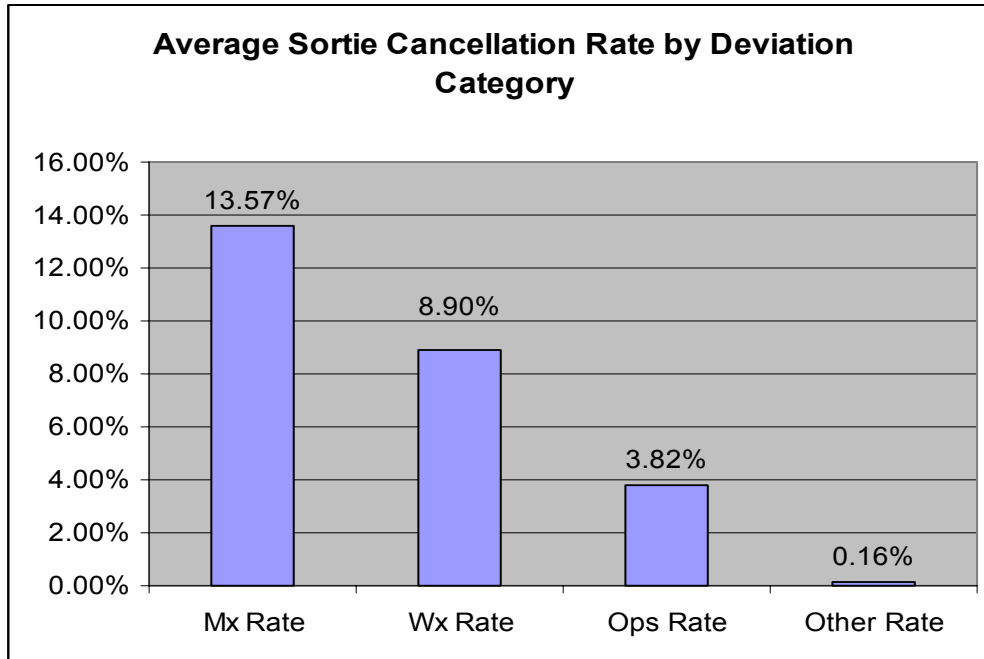
Figure 17. FY02 Sortie Cancellation Rates

Maintenance-Related Deviations

Nonconforming sorties due to maintenance can be further isolated by the subsystem

that caused the cancellation. In FY02 there were 137 sorties cancelled due to

maintenance problems with the aircraft's subsystems. Figure 18 illustrates how these

maintenance cancellations are distributed across the C-130J's 33 subsystems (Figure 18

only shows those subsystems with maintenance cancellations charged to them).
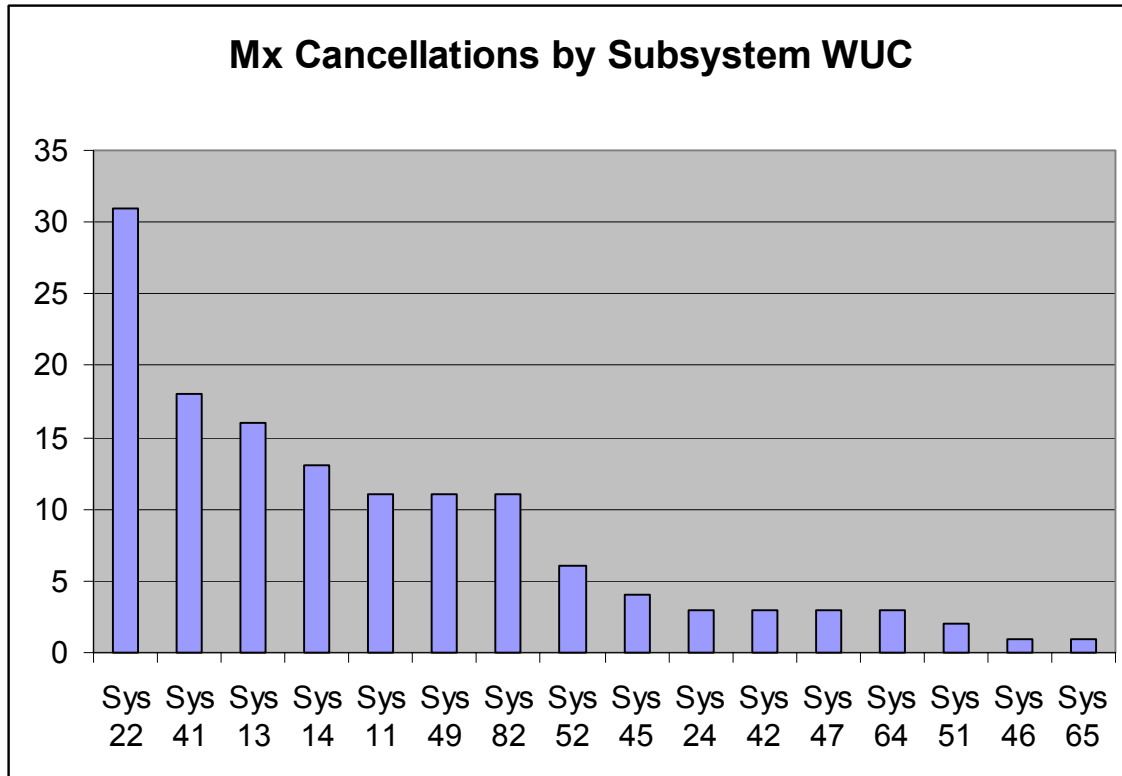
Figure 18. Mx Cancellations by Subsystem WUC

Flying Schedule Inflation Factor

The 135[th] currently uses a flat 15 percent sortie inflation factor when building their flying schedules. In FY02, this was not enough to guarantee they would meet their flying hour goals. Instead, they lost 26.5 percent of all their scheduled sorties, forcing them to return 250 flying hours to the ANGB (Benham). In the absence of any reductions in the number of cancelled sorties, the P&S office will have to increase the inflation factor to ensure the unit satisfies their flying hour goals. A more realistic inflation factor is 36 percent. The derivation for this inflation factor is shown below.

If a given number of sorties are required to satisfy the true flying hour plan, then an additional number of sorties need to be added to the schedule to compensate for the percentage of cancelled sorties. Stated as an equation, we have

$$\text{Required sorties} + \text{Additional sorties} - \text{Cancelled sorties} = \text{Required sorties} \quad (4.1)$$

The "Additional sorties" = (Required sorties * Inflation Factor), giving us

$$\text{Required} + (\text{Required} * \text{Inflation Factor}) - \text{Cancelled} = \text{Required} \quad (4.2)$$

The number of Cancelled sorties = [(Required + Required * Inflation Factor) * Attrition Factor], giving us

$$\text{Required} + (\text{Required} * \text{Inflation Factor}) -$$
$$[(\text{Required} + \text{Required} * \text{Inflation Factor}) * \text{Attrition Factor}] = \text{Required} \quad (4.3)$$

Substituting with variables, let A ≡ # of required sorties, B ≡ inflation factor, and C ≡ attrition factor. Rewriting, we have

$$[A + AB] - [(A + AB)*C] = A \quad (4.4)$$

Solving for B gives us

$$(A + AB) * (1 - C) = A \quad (4.5)$$

$$A * (1 + B) = A / (1-C) \quad (4.6)$$

$$B = [1 / (1 - C)] - 1 \quad (4.7)$$

During FY02 the attrition factor (i.e., C) proved to be 0.265. Solving the above equation for the new inflation factor B, we have

$$B = [1 / (1-0.265)] - 1 \quad (4.8)$$

$$B = [1 / 0.735] - 1 \qquad\qquad (4.9)$$

$$B = 1.36 - 1 \qquad\qquad (4.10)$$

$$B = 0.36 \text{ or } 36 \text{ percent}$$

Revising the scheduling inflation factor necessitates recomputing the FSE rate standard. Modifying (3.18) with the new scheduling factor, we have

$$X = \frac{R}{R + (R*0.36)} \qquad\qquad (4.11)$$

$$X = 0.7353 \text{ or } X = 0.74 \qquad\qquad (4.12)$$

This is the FSE rate standard the 135th should use in the future.

4.2 Common Causes

Table 6 lists the top 10 drivers, from highest to lowest, for both MC rate and FSE rate. Subsystems 13, 22, 82, 41, 14, 11, and 49 are on both metrics top-10 lists, showing a 70 percent high-driver overlap between the MC rate and FSE rate indicators. These seven systems need to be examined closely for underlying causes as any improvements with these subsystems is likely to have a positive affect on both MC and FSE rate.

Table 6. MC Rate and FSE Rate High Drivers

Rank	MC Rate Drivers	FSE Rate Mx Drivers
1	37	22
2	13	41
3	22	13
4	82	14
5	41	11
6	14	49
7	11	82
8	32	52
9	46	45
10	49	24

5. Conclusions

5.0 Analysis of Statistical Process Control Application

The p-charts applied to the MC rate and FSE rate measures provide a quick method for maintenance managers to ascertain their unit's maintenance performance. They are applicable to the problem management faces on a daily basis and are charted against a standard. The p-chart also provides management with a visual indication of the presence of trends. The p-chart is well suited for both applications given the definitions of a nonconforming hour and a nonconforming sortie. The FSE rate p-chart also highlights the need for a larger scheduling inflation factor.

The Pareto diagrams used for the drill-down provide a quick method to elucidate potential subsystem problems. For weeks with substandard MC or FSE rates, at least one of the aircraft's subsystems are experiencing above-average maintenance or supply problems (or both). However, the converse is not necessarily true. For example, a week may have an acceptable MC or FSE rate yet still have a subsystem with an above-average NMC or deviation rate.

For MC rate, this phenomenon is the most pronounced. Of the 52 weeks, 16 have substandard MC rates and each of those 16 weeks have at least one subsystem with a higher-than average NMC rate. However, 35 of the other 36 weeks also have at least one subsystem WUC with a higher-than-average NMC rate. Table 7 lists the 35 weeks with acceptable MC rates and the subsystem(s) with above NMC rates for those weeks.

Table 7. Subsystems With Above-Average NMC Rates During Weeks With Acceptable MC Rate Weeks

Week	Subsystem	Week	Subsystem
2	45	28	37, 82, 46
3	37, 45	29	37, 22, 82
4	37	30	37, 22, 49
5	37	31	37, 22, 46
6	37	32	37, 46
7	46, 47	33	37, 13
8	13, 46, 47	34	37, 64
9	13	35	37, 22, 46
10	37, 41	36	37, 22, 49
11	37, 41, 56	38	37, 22, 82, 41, 14
12	37, 22, 41, 56	39	37, 82, 41, 14
17	37, 13, 41, 56	40	37, 14, 49, 52, 45
18	37, 13, 11, 52	45	37, 11, 46, 12, 42, 24
22	13, 82, 32	49	22, 82
23	13, 22, 14, 32, 65	50	82, 42
25	13, 11	51	82
26	37, 82, 11	52	22, 82, 41
27	37, 22, 82, 11		

Figure 19 shows the aircraft subsystems and the number of weeks during FY02 the subsystems have above-average NMC rates. Comparing this to Figure 20, which shows the aircraft subsystems and their average weekly NMC rate, the top ten drivers in the Pareto diagrams are the same. The systems with the greatest number of weeks of above-average NMC rate are the same systems that have the highest overall NMC rate.

Figure 19. Weeks With Above-Average Subsystem NMC Rates

Number of Weeks With Subsystems > Avg. NMC Rates

Weeks (y-axis): 0, 5, 10, 15, 20, 25, 30, 35, 40

Subsystem (x-axis): 37, 22, 13, 82, 41, 11, 14, 32, 46, 49, 42, 52, 45, 47, 12, 56, 24, 51, 64, 65
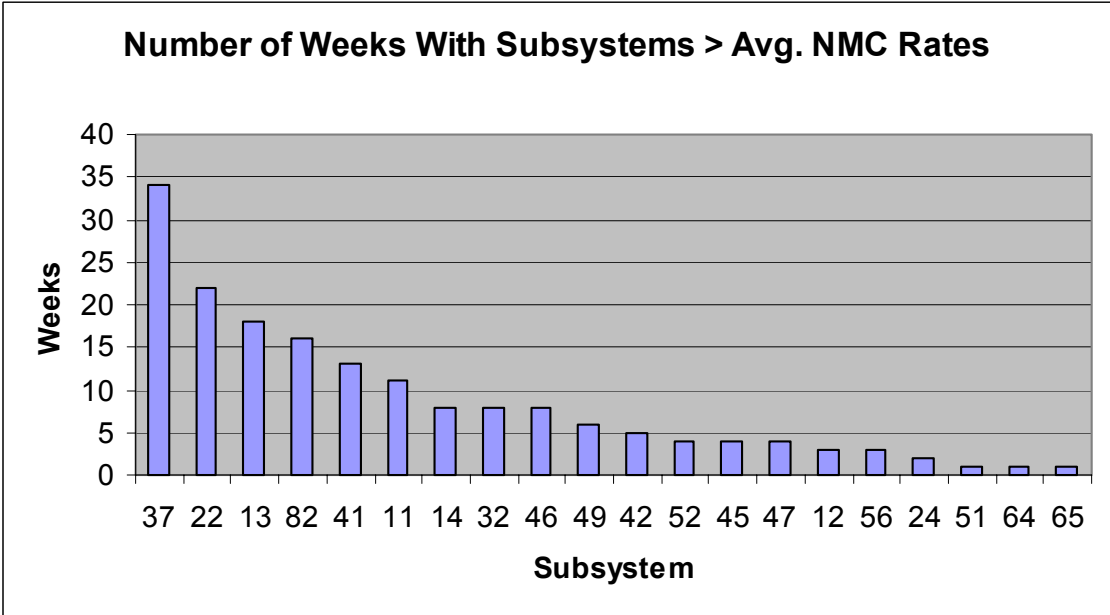
Figure 20. Subsystem Average NMC Rates

Subsystem Avg. NMC Rate

Avg. NMC Rate (y-axis): 0, 0.02, 0.04, 0.06, 0.08, 0.1

Subsystem (x-axis): 37, 13, 22, 82, 41, 14, 11, 32, 46, 49, 12, 42, 52, 56, 45, 47, 24, 51, 64, 65
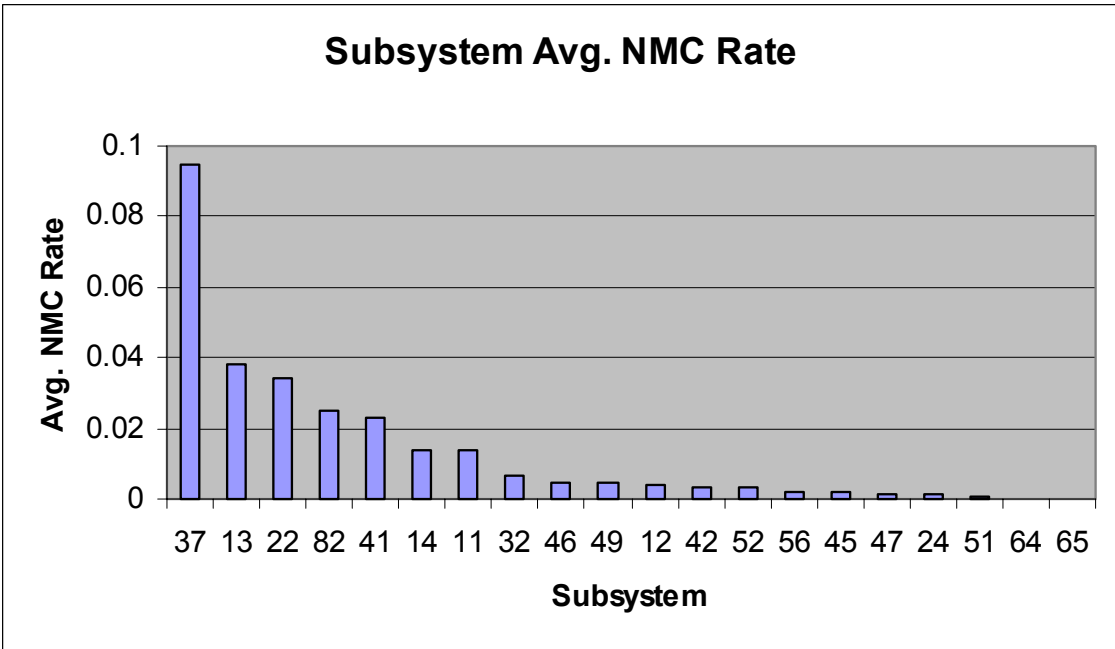
For FSE Rate, five of the 12 weeks that meet standards have a subsystem with above-average chargeable deviations (even though the overall number of maintenance cancellations for that week was below average). Table 8 list the five weeks with acceptable FSE rates (and acceptable maintenance cancellation rate) and the subsystem(s) which themselves have a higher-than-average cancellation rate.

Table 8. Subsystems With Above-Average Deviation Rates During Weeks With Acceptable FSE Rate Weeks

Week	Subsystem
5	22
7	46
11	82
14	11
22	22

The MC and FSE rate Pareto diagrams provide 135[th] management personnel a useful tool which they can use to help isolate underlying problem areas and focus their improvement efforts. In addition, they highlight common drivers for both performance indicators, allowing management to further concentrate improvement efforts.

5.2 Analysis of the Visualization Tool

The p-charts and the Pareto diagrams satisfy the 135[th]'s request for an analysis tool: that is easy to use, understandable, provides a visual indication of performance, and an indication of the underlying cause. The charts also meet the characteristics of "good" metrics as defined in the *Metrics Handbook*. They are understandable by the user, they address issues that face the unit on a daily basis, and they show the unit's performance against an established standard.

The visualization tool consists of a set of charts built into a single Excel spreadsheet. All FY02 data is entered and appropriate charts are built. The MDA and P&S personnel need to update the data sheets on a weekly basis to maintain currency. This single spreadsheet provides the 135[th] MDA and P&S personnel a central repository to archive maintenance performance data. Currently, separate methods are used to archive data. This simple step alone yields a large improvement over current practice. Also, by virtue of being a single database, management only has to look in one place instead of two to retrieve up-to-data MC and FSE rate data.

5.3 Future Research

The Excel spreadsheet needs to be expanded to include additional maintenance performance measures of interest to the 135[th]'s maintenance managers. The MDA currently maintains data (see Appendix A) that could be used to construct charts for many of the measures identified in the *Metrics Handbook*.

The MDA would like to have an automated data collection feature added to the spreadsheet (Reese). This feature needs to interface with AMC's G081 maintenance data collection system, query for the appropriate data, and extract that data to the appropriate cell within the spreadsheet.

The 135[th]'s ISO and HSC processes need to be studied in an effort to uncover ways to reduce the flow time. It may be possible to complete some of the ISO/HSC maintenance items on off-shifts or before or after the aircraft is in ISO/HSC. These reductions would

not be able to come at the expense of the integrity of the maintenance process. Rather, they would have to be realized through the application of efficiency improvements.

The different maintenance specialists assigned to the 135th are organized by shop. Each shop has a unique type of specialist assigned. For example, the Propulsion shop has engine mechanics assigned and the Hydraulics shop has hydraulics systems mechanics assigned. Now that the 135th has had the C-130J aircraft for a couple of years and has amassed a sizable amount of failure and repair data on the aircraft, it may be a good time to take a look at how the available manning is allocated to the different shops. It might be possible to reduce some of the NMCM time simply by adjusting the shop's manning levels. This could also mean assigning additional personnel to the ISO/HSC process if it is warranted.

Appendix A. Sample 135th MX MDA Spreadsheet

175WG C-130J MAINTENANCE STATISTICS (FY 01-02)						
MONTH:	APR02	MAY02	JUN02	JUL02	AUG02	SEP02
F H ALLOCATED/PROG	256.0	237.0	262.0	280.0	244.0	244.0
F H CUMULATIVE ALLOCATED	256.0	493.0	755.0	1035.0	1279.0	1523.0
F H SCHED	379.9	328.6	271.3	291.8	338.7	296.6
F H CUMULATIVE SCHED	379.9	708.5	979.8	1271.6	1610.3	1906.9
F H FLOWN	256.3	237.6	261.2	208.5	285.4	288.0
F H CUMULATIVE FLOWN	256.3	493.9	755.1	963.6	1249.0	1537.0
F H ALLOC VS FLOWN	0.3	0.6	-0.8	-71.5	41.4	44.0
F H SCHED VS FLOWN	-123.6	-91.0	-10.1	-83.3	-53.3	-8.6
F H TRAINING	256.3	237.6	261.2	208.5	285.4	288.0
F H REIMBURSE	0.0	0.0	0.0	0.0	0.0	0.0
F H ALLOC VS TRAINING	0.3	0.6	-0.8	-71.5	41.4	44.0
HSL SORTIES SCHED	128	146	121	132	166	117
SORTIES FLOWN	108	107	108	86	130	105
HSL SORTIES SCHED VS FLOWN	-20	-39	-13	-46	-36	-12
SORTIES REIMBURSE	0	0	0	0	0	0
SORTIES TRAINING	108	107	108	86	130	105
HSL SORTIES SCHED VS TRAINING	-20	-39	-13	-46	-36	-12
AVG SORTIE DURATION	2.4	2.2	2.4	2.4	2.2	2.7
FLY DAYS FOR MONTH	28	28	28	27	27	25
ACFT NO FLY	1	1	2	0	0	1
HOURLY UTE	32.0	29.7	32.7	26.1	35.7	36.0
SORTIE UTE	13.5	13.4	13.5	10.8	16.3	13.1
PAA ASSIGNED ACFT	8	8	8	8	8	8
AVG POSSESSED ACFT	8.0	8.0	8.0	8.0	8.0	8.0
TOTAL LANDINGS	479	439	336	345	448	464
FSL	119	117	114	86	123	121
TOUCH & GO	360	322	222	259	325	343
MAINTENANCE CANCELS	8	17	2	40	26	3
OPS CANCELS	4	6	1	3	4	4
SUPPLY CANCELS	0	0	0	0	0	0
OTHER CANCELS	0	0	0	0	0	0
WEATHER CANCELS	8	16	10	3	6	5
TOTAL CANCELS	20	39	13	46	36	12
HSL MONTHLY ATTRITION RATE	15.6	26.7	10.7	34.8	21.7	10.3
SORTIE RELIABILITY RATE	99.1	96.4	100.0	94.5	97.7	99.1
GROUND ABORTS	1	4	0	5	2	1
GROUND ABORT RATE	0.9	3.6	0.0	5.5	1.5	0.9

Appendix A. Continued

175WG C-130J MAINTENANCE STATISTICS (FY 01-02)						
MONTH:	APR02	MAY02	JUN02	JUL02	AUG02	SEP02
AIR ABORTS	0	0	0	0	1	0
AIR ABORT RATE	0.0	0.0	0.0	0.0	0.8	0.0
TOTAL ABORTS	1	4	0	5	3	1
TOTAL ABORT RATE	0.9	3.6	0.0	5.5	2.3	0.9
ACFT CANNIBALIZATIONS	3	1	5	6	6	9
ACFT CANN RATE	2.8	0.9	4.6	7.0	4.6	8.6
ENG CANNIBALIZATIONS	0	0	0	0	0	0
ENG CANN RATE	0.0	0.0	0.0	0.0	0.0	0.0
T/CANN "T" & "U" MHRS EXP	60.0	21.5	39.5	97.3	49.2	84.8
AIRCREW REPORTED DISC	57	58	50	63	78	57
VERIFIED CODE "3"	1	7	5	14	11	3
CODE "3" BREAK RATE	0.9	6.5	4.6	16.3	8.5	2.9
REPEATS	0	0	0	1	0	0
REPEAT RATE	0.0	0.0	0.0	1.6	0.0	0.0
RECURRS	0	0	0	1	0	0
RECURR RATE	0.0	0.0	0.0	1.6	0.0	0.0
CND'S	11	11	6	17	12	16
CND RATE	19.3	19.0	12.0	27.0	15.4	28.1
FAILURES=RTS A, F, G, K, L, V, Z	115	162	133	132	137	75
NRTS 2,3,5,6	4	5	1	0	0	0
BASE SELF SUFF	96.6	97.0	99.3	100.0	100.0	100.0
AT=G FAILURES	63	84	62	73	84	38
MTBM FAILURES (EXCLUDE "G"'S)	4.9	3.0	3.7	3.5	5.4	7.8
UNSCHED ENG REMOVAL	1	1	0	0	1	0
PCT FLEET TIME (ISO)	59.6	69.6	57.2	74.0	67.5	62.1
ACFT BELOW 30.0 percent TTI	2	1	1	1	0	2
FLY TO FLY DAYS (ISO)	0	57	0	59	45	0
FCF DISC	1	1	0	0	0	0
CHG MAINT DELAY DISC	121	118	131	142	142	147
AVG AWM PER ACFT	15.1	14.8	16.4	17.8	17.8	18.4
CHG SUPPLY DELAY DISC	5	6	8	8	10	15
AVG AWP PER ACFT	0.6	0.8	1.0	1.0	1.3	1.9
TOTAL DELAY DISC	126	124	139	150	152	162
AVG DELAY DISC PER ACFT	15.8	15.5	17.4	18.8	19.0	20.3
MSRP WITHDRAWAL	4	2	0	0	6	7
DIRECT SCHED MAINT MHRS	3237.1	3270.2	3650.7	3769.0	3655.2	3004.3
DIRECT UNSCHED MAINT MHRS	1756.2	2126.4	2146.8	2289.0	3364.8	2511.9

Appendix A. Continued

175WG C-130J MAINTENANCE STATISTICS (FY 01-02)						
MONTH:	APR02	MAY02	JUN02	JUL02	AUG02	SEP02
DIRECT MAINT MHRS	4993.3	5396.6	5797.5	6058.0	7020.0	5516.2
DMMHFH	19.5	22.7	22.2	29.1	24.6	19.2
# OF DOCUMENTS SAMPLED	540	500	593	353	749	294
# OF DOCUMENTS CORRECT	504	480	570	342	720	289
DATA INTEG (PCT GOOD)	93.3	96.0	96.1	96.9	96.1	98.3
MC RATE	76.1	80.6	62.7	51.4	67.2	82.2
FMC RATE	73.7	79.2	57.4	41.7	57.9	73.7
PMCB RATE	0.0	0.0	0.0	0.0	0.0	0.0
PMCM RATE	1.6	0.6	0.6	3.1	1.8	1.2
PMCS RATE	0.8	0.8	4.8	6.7	7.6	7.3
PMC RATE	2.4	1.4	5.4	9.8	9.3	8.5
NMCB UNSCHED RATE	0.0	0.0	0.0	0.0	0.0	0.0
NMCB SCHED RATE	13.5	10.4	15.2	20.8	7.5	10.3
NMCB RATE	13.5	10.4	15.2	20.8	7.5	10.3
NMCM UNSCHED RATE	1.2	4.5	10.6	14.2	13.1	4.1
NMCM SCHED RATE	0.0	1.7	3.0	3.0	5.1	0.0
NMCM RATE	1.2	6.2	13.7	17.2	18.2	4.1
NMCS RATE	9.2	2.8	8.4	10.5	7.1	3.4
TNMCM RATE	14.7	16.6	28.9	38.1	25.6	14.3
TNMCS RATE	22.7	13.2	23.6	31.4	14.6	13.7
TPMCM RATE	1.6	0.6	0.6	3.1	1.8	1.2
TPMCS RATE	0.8	0.8	4.8	6.7	7.6	7.3
FMC HOURS	4241.1	4716.2	3303.3	2477.6	3447.5	4246.5
PMCB HOURS	0.0	0.0	0.0	0.0	0.0	0.0
PMCM HOURS	91.3	32.8	32.3	182.1	104.5	69.8
PMCS HOURS	48.3	49.9	276.0	398.5	449.5	419.9
NMCB UNSCHED HOURS	0.0	0.0	0.0	0.0	0.0	0.0
NMCB SCHED HOURS	778.2	620.0	874.1	1239.5	444.3	591.1
NMCB HOURS	778.2	620.0	874.1	1239.5	444.3	591.1
NMCM UNSCHED HOURS	67.1	267.5	612.5	846.5	779.2	235.2
NMCM SCHED HOURS	0.0	99.0	175.0	177.5	302.0	0.0
NMCM HOURS	67.1	366.5	787.5	1024.0	1081.2	235.2
NMCS HOURS	529.5	166.6	486.0	626.3	425.0	197.5
NMC HOURS	1374.8	1153.1	2147.6	2889.8	1950.5	1023.8
POSSESSED HOURS	5755.5	5952.0	5759.2	5948.0	5952.0	5760.0

(Reese)

Appendix B. Fleet Availability Indicators

Leading	Lagging	Metric	Definition
X		Ground abort rate	Percent of sorties that aborted due to malfunction prior to departure
X		Air abort rate	Percent of sorties that aborted due to malfunction after departure
X		MAF total air abort rate	Sum of the ground and air abort rates
X		Code 3 break rate	Percent of aircraft that return with subsystem discrepancies that render the aircraft NMC
X		8/12-hour fix rate	Percent of aircraft that return NMC that are fixed within established timeframes
X		Repeat rate	A maintenance discrepancy which occurs on the next sortie after corrective action has been taken and the system or subsystem is used and indicates the same malfunction
X		Recur rate	A maintenance discrepancy which occurs on the second through fourth sortie after corrective action has been taken and the system or subsystem is used and indicates the same malfunction
X		Logistics departure reliability	The percent of scheduled sorties that are delayed due to supply, saturation or maintenance problems
X		Avg. delayed discrepancies per aircraft	The average number of delayed discrepancies per assigned aircraft
X		Avg. awaiting-maintenance discrepancies per aircraft	The average number of delayed discrepancies per aircraft due to awaiting maintenance
X		Avg. awaiting-parts discrepancies per aircraft	The average number of delayed discrepancies per aircraft due to awaiting parts.
X		Mx scheduling effectiveness rate	Percent of total scheduled maintenance events starting on time

Leading	Lagging	Metric	Definition
X		Functional check flight release rate	The rate at which aircraft are released back to operations following a functional check flight
X		Cannibalization rate	The average number of parts cannibalizations per 100 sorties
	X	Mission capable (MC) rate	Percent of aircraft possessed hours that were either FMC and PMC over a given time period
	X	Fully mission capable (FMC) rate	Percent of aircraft possessed hours that were fully mission capable (i.e., able to perform all of its assigned missions)
	X	Partially mission capable (PMC) rate	Percent of aircraft possessed hours that were partially mission capable (i.e., only able to perform some of its assigned missions)
	X	PMC for supply (PMCS) rate	Percent of aircraft possessed hours that were PMC due to awaiting parts from supply
	X	PMC for maintenance (PMCM) rate	Percent of aircraft possessed hours that were PMC due to awaiting maintenance
	X	PMC for both (PMCB) maintenance and supply rate	Percent of aircraft possessed hours that were PMC due to both supply and maintenance
	X	Not mission capable for maintenance (NMCM) rate	Percent of aircraft possessed hours that were not mission capable (i.e., not capable of performing any of its assigned missions) due to maintenance over a given time period
	X	Not mission capable for supply (NMCS) rate	Percent of aircraft possessed hours that were not mission capable due to awaiting parts from supply
	X	Not mission capable for both (NMCB) maintenance and supply rate	Percent of aircraft possessed hours that were NMC due to both supply and maintenance
	X	Total NMCM (TNMCM) rate	Combined NMCM and NMCB rates
	X	Total NMCS (TNMCS) rate	Combined NMCS and NMCB rates

(Metrics Handbook)

Appendix C. Flying Program Execution Indicators

Leading	Lagging	Metric	Definition
X		Primary aircraft inventory vs. possessed aircraft rate	Shows the number of aircraft assigned to the unit divided by the number of aircraft actually possessed by the unit.
X		Programmed utilization rate vs. actual utilization rate	Shows the planned aircraft utilization rate versus the realized aircraft utilization rate.
X		Programmed average sortie duration vs. actual sortie duration	Shows the planned average sortie duration versus the realized average sortie duration
X		Flying-scheduling effectiveness rate	A measure of how well the unit planned and executed the weekly flying schedule.
X		Chargeable deviation rate	Deviations from the planned flying schedule attributed to operations or logistics
X		Nonchargeable deviation rate	Deviations from the planned flying schedule attributed to higher-headquarters, air traffic control or weather
	X	Home-station departure reliability	Percent of total departures from the home-station that did not have a delay caused by logistics
	X	First station after home station departure reliability	Percent of total departures from the first station after home-station (i.e., at the first stop) that did not have a delay caused by logistics
	X	En route departure reliability	Percent of total departures from the second and subsequent station that did not have a delay caused by logistics.
	X	Worldwide departure reliability	The percent of all departures that did not have a delay caused by logistics.

(Metrics Handbook)

Appendix D. Sample ANG 7401 Report

CATEGORY	OCT	NOV	DEC	1Q Total
F.H. Allocated/Plan	513.20	486.90	528.20	1528.30
Flying Hour Training Plan	240.00	210.00	220.00	670.00
Flying Hour AEF Plan	273.20	276.90	308.20	858.30
Flying Hours TWCF Plan	0.00	0.00	0.00	0.00
Total F.H. Flown	238.20	208.30	215.00	661.50
Flying Hour Training Exec	238.20	208.30	215.00	661.50
Flying Hour AEF Exec	0.00	0.00	0.00	0.00
TWCF Exec	0.00	0.00	0.00	0.00
F.H. Training Plan vs. Executed	-1.80	-1.70	-5.00	-8.50
Sorties Scheduled	123.00	120.00	126.00	369.00
Total Sorties Flown	110.00	100.00	95.00	305.00
Unit Training Sorties	110.00	100.00	95.00	305.00
Overfly Sorties (Reimbursed)	0.00	0.00	0.00	0.00
Sort Sched. Vs. Tng. Sort Flown	-13.00	-20.00	-31.00	-64.00
Monthly Attrition percent	0.11	0.17	0.25	0.17
Number of Maint Cancels	3.00	11.00	15.00	29.00
Number of Ops Cancels	10.00	1.00	3.00	14.00
Number of Supply Cancels	0.00	0.00	0.00	0.00
Number of Weather Cancels	0.00	8.00	12.00	20.00
Number of Other Cancels	0.00	0.00	1.00	1.00
Avg # Poss'd Acft	8.00	8.00	8.00	8.00
PAA (assigned) Aircraft	8.00	8.00	8.00	8.00
Possessed Hours	5952.00	5760.00	5952.00	17664.00
Hourly UTE Rate	29.78	26.04	26.88	27.56
Sortie UTE Rate	13.75	12.50	11.88	12.71
No. of Air Aborts	2.00	2.00	1.00	5.00
Air Abort Rate	0.02	0.02	0.01	0.02
No. of Ground Aborts	0.00	2.00	2.00	4.00
Ground Abort Rate	0.00	0.02	0.02	0.01
No. of Canns	3.00	3.00	2.00	8.00
Cann Rate Per 100 Sorties	2.73	3.00	2.11	2.62
Cann "T" & "U" Mhrs Exp	30.50	12.00	36.00	78.50
MC Rate	0.90	0.85	0.69	0.81
MC Hours	5359.50	4902.70	4121.10	14383.30
FMC Hours	4183.30	4181.70	3236.00	11601.00
PMCB Hours	0.00	0.00	0.00	0.00
PMCM Hours	474.80	356.50	313.40	1144.70
PMCS Hours	701.40	364.50	571.70	1637.60
NMCB-U Hours	0.00	175.40	0.00	175.40

CATEGORY	OCT	NOV	DEC	1Q TOTAL
NMCB-S Hours	467.00	449.60	926.00	1842.60
NMCM-U Hours	97.00	150.20	770.70	1017.90
NMCM-S Hours	0.00	0.00	0.00	0.00
NMCS Hours	28.50	82.10	134.20	244.80
TPMCM Rate	0.08	0.06	0.05	0.06
TPMCS Rate	0.12	0.06	0.10	0.09
TNMCM Rate	0.09	0.13	0.29	0.17
TNMCS Rate	0.08	0.12	0.18	0.13
Pilot rep Disc. (PRD)	23.00	26.00	50.00	99.00
Verified Ldg Status Code-3's	3.00	6.00	5.00	14.00
Code-3 Break Rate	2.73	6.00	5.26	4.59
No. Repeats Write-ups	0.00	0.00	0.00	0.00
Repeat Rate	0.00	0.00	0.00	0.00
Total Failures	104.00	86.00	119.00	309.00
AT = "G" Failures	43.00	51.00	50.00	144.00
MTBM (Exc "G") Failures	3.90	5.95	3.12	4.01
Unsch Eng Rem	0.00	0.00	0.00	0.00
PCT Fleet time (Phase/ISO)	52.40	57.50	62.80	57.57
No. of ACFT below 30 percent TTI	2.00	1.00	2.00	1.67
Fly to Fly Days (Phase/ISO)	0.00	56.00	0.00	18.67
Sched Maint MHRS	2393.00	2855.90	3293.90	8542.80
Unsch Maint MHRS	1312.90	1734.90	1427.80	4475.60
Avg # Delayed Disc per A/C	11.10	10.80	12.80	11.57
AWM (Mo Avg) per Acft	10.50	10.10	11.90	10.83
AWP (Mo Avg) per Acft	0.60	0.60	0.90	0.70
Data Integrity (Pct GOOD)	0.89	0.95	0.96	0.93
No. of documents Sampled	458.00	602.00	480.00	1540.00
No. of documents Rejected	49.00	33.00	21.00	103.00

(Reese)

Appendix E. FY02 Fleet MC Rate Data

Week #	Week Ending	MC Rate	NMC Rate	11B	11S	11M	12B	12S	12M
1	7-Oct-01	0.9719	0.0281						
2	14-Oct-01	0.9336	0.0664						
3	21-Oct-01	0.8363	0.1637						
4	28-Oct-01	0.8750	0.1250						
5	4-Nov-01	0.8703	0.1297						
6	11-Nov-01	0.8527	0.1473						
7	18-Nov-01	0.8469	0.1531						
8	25-Nov-01	0.8526	0.1474						
9	2-Dec-01	0.8463	0.1537						
10	9-Dec-01	0.7723	0.2277						
11	16-Dec-01	0.7472	0.2528			3.8			
12	23-Dec-01	0.6465	0.3535						
13	30-Dec-01	0.5789	0.4211						
14	6-Jan-02	0.6224	0.3776						
15	13-Jan-02	0.6561	0.3439						
16	20-Jan-02	0.6239	0.3761						
17	27-Jan-02	0.6715	0.3285						
18	3-Feb-02	0.6942	0.3058		24.5	22.5			
19	10-Feb-02	0.6153	0.3847						
20	17-Feb-02	0.6092	0.3908						
21	24-Feb-02	0.6106	0.3894						
22	3-Mar-02	0.7327	0.2673						
23	10-Mar-02	0.7676	0.2324						
24	17-Mar-02	0.7392	0.2608						
25	24-Mar-02	0.8020	0.1980	9		80			
26	31-Mar-02	0.6833	0.3167			84.5			
27	7-Apr-02	0.6548	0.3452			20.7			
28	14-Apr-02	0.7654	0.2346						
29	21-Apr-02	0.8025	0.1975						
30	28-Apr-02	0.7996	0.2004						
31	5-May-02	0.7987	0.2013						
32	12-May-02	0.8289	0.1711						
33	19-May-02	0.8141	0.1859						
34	26-May-02	0.8255	0.1745						
35	2-Jun-02	0.7581	0.2419						
36	9-Jun-02	0.5543	0.4457						
37	16-Jun-02	0.5536	0.4464						
38	23-Jun-02	0.6934	0.3066						
39	30-Jun-02	0.6722	0.3278						
40	7-Jul-02	0.6365	0.3635						
41	14-Jul-02	0.5493	0.4507	31					
42	21-Jul-02	0.4319	0.5681	108		60			
43	28-Jul-02	0.4805	0.5195	103	65				
44	4-Aug-02	0.5794	0.4206	87		81			
45	11-Aug-02	0.6813	0.3187			59		35	
46	18-Aug-02	0.6056	0.3944				79.5	88.5	
47	25-Aug-02	0.7120	0.2880			35.8	32		34
48	1-Sep-02	0.6864	0.3136			85.5			
49	8-Sep-02	0.8299	0.1701						
50	15-Sep-02	0.8527	0.1473						
51	22-Sep-02	0.8304	0.1696						
52	29-Sep-02	0.7967	0.2033						

Appendix E. Continued

Week #	13B	13S	13M	14B	14S	14M	22B	22S	22M	24B	24S	24M
1									26.5			
2												
3												
4												
5			1.1						4.4			
6												
7									4.8			
8	135.9											
9	77.5	29.7	4.2									
10												
11												
12			5.5				83		10.2			
13			62				72		96			
14	87		81				6		56.5			
15	168							17.3	40.4			
16	168											
17	168											
18	168											
19	168								28.3			
20	168											
21	168											
22	168								3.2			
23	168					59.5			60.2			
24	168	60.5	1.5		34	1.1			84.3			
25	79	30	4.1									
26									25.6			
27								24	23.3			
28												
29								53				
30								63.2	2.5			
31		26.6	4.9						69.3			
32		23.1	1.6									
33		56	6									
34		38.4	5.3						17.7			
35			8.5					81.5	20.9			
36								272.5	4.5			
37							154.1	97.2	57.9			
38						64.5			55.7			
39						168						
40				108		49						
41				42		126			56.5			
42					52	147		55	26.5			
43					52.5	74.5		79.7	16.5			
44								39	1	47		4.5
45			1.8			8					30.5	
46			68						61.8			
47	32.5		43.1					52.5	60.5			
48								37	131			
49									83			
50												
51												
52									53.5			

Week #	32B	32S	32M	37B	37S	37M	41B	41S	41M	42B	42S	42M
1												
2				59								
3				168					2			
4				168								
5				168								
6				168					27			
7				110								
8												
9				85.6					3.3			
10				168				74.9	59.1			4
11				168				35	105			
12				168			27		141			9.4
13				168					168			
14				109					168			
15				63			61.7		106.3			
16			1.5	168			168					
17				168			58.5					
18				88	80							
19			14.2	21		147						
20	83		2.6			168			23			
21	111.2		56.8	111		57						
22			57	56		21.6						
23			24.7									
24												
25				64								
26				168								
27				168				16.5	1.2			
28				168								
29				168								
30				168								
31				84	24	35						
32				128		40						
33				168					19.8			
34				168								1.3
35				168								
36				168	133							
37				168		42						
38				168					37.5			
39				168					54.5			
40				168								
41	43.5		6.5	168	56			39	2			
42			20.3	164		90.5						4.5
43				168					34.7			2.5
44				41		127						
45						168					53	
46			30.5			38			5		86	26.3
47												
48												
49												
50												30
51												
52							53.5	84				

Week #	44B	44S	44M	45B	45S	45M	46B	46S	46M	47B	47S	47M
1												
2					28.5	1.8						
3						34.5						
4												
5												
6												
7									53		13.7	
8									25		37.2	
9											1.5	
10												
11												
12												
13												
14												
15												5.5
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28								23.7				0.8
29												
30												
31									26.7			
32									37.2			
33												
34												
35									46.2			
36												
37						25.2						
38									2.9			
39												
40					20	2						
41												
42												
43												
44												
45								42.5	30.5			
46							24.6		21.9			
47										23		15
48												
49												
50												
51					55.5	4.5						
52					34	4.7						

Week #	49B	49S	49M	51B	51S	51M	52B	52S	52M	55B	55S	55M
1			4.6						3.2			
2												
3												
4												
5			0.8									
6			3									
7												
8												
9												
10												
11												
12			31									
13												
14												
15												
16												
17												
18								28				
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30		32.9	2.7									
31												
32												
33												
34												
35												
36			21									
37												
38												
39												
40			25.5					105				
41								35.3				
42									35.7			
43			100.3									
44			91.3		23.8	18.5						
45												
46												
47												
48												
49												
50												
51												
52												

Appendix E. Continued

Week #	56B	56S	56M	61B	61S	61M	62B	62S	62M	63B	63S	63M
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11		24.3	3.7									
12												
13												
14												
15												
16												
17	26.5		20.5									
18												
19	20.6		30									
20												
21												
22												
23												
24												
25												
26												
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46												
47												
48												
49												
50												
51												
52												

Week #	64B	64S	64M	65B	65S	65M	66B	66S	66M	68B	68S	68M
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24						1.1						
25												
26												
27												
28												
29												
30												
31												
32												
33												
34			3.8									
35												
36												
37												
38												
39												
40												
41												
42												
43												
44												
45												
46												
47												
48												
49												
50												
51												
52												

Week #	69B	69S	69M	71B	71S	71M	72B	72S	72M	76B	76S	76M
1												
2												
3												
4												
5												
6												
7												
8												
9												
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11												
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43												
44												
45												
46												
47												
48												
49												
50												
51												
52												

Week #	82B	82S	82M	91B	91S	91M	96B	96S	96M	97B	97S	97M
1			3.4									
2												
3			15.5									
4												
5												
6												
7			24.3									
8												
9			4.8									
10												
11												
12												
13												
14												
15												
16												
17												
18												
19	88											
20	59	21.7										
21	17.7		1.7									
22		49.7	3.8									
23												
24												
25												
26	86.6	60.9										
27	37.3	168	5									
28	20.9	97.7	4.2									
29		39.5	5									
30												
31												
32												
33												
34												
35												
36												
37			55.5									
38		18.2	65.3									
39		50.1										
40	11											
41												
42												
43			1.5									
44			4.2									
45												
46												
47	58.7											
48	168											
49	145.6											
50	168											
51	168											
52	32		11.5									

Appendix F. Subsystem NMC Data

Rank	WUC	System Description	Average NMC Hours
1	37	ISO/HSC	120.7
2	13	Landing Gear	57.5
3	22	Power Plant	45.5
4	82	System Integration & Display	34.2
5	41	A/C, Pressurization, Ice Control	30.3
6	14	Flight Control	22.2
7	11	Airframe	15.2
8	32	Hydraulic Propeller	8.7
9	46	Fuel System	6.4
10	49	Misc. Utilities	6.0
11	12	Cockpit & Fuselage Compart.	5.2
12	42	Electrical Power Supply	4.2
13	45	Hydraulic & Pneumatic P/S	4.1
14	52	Autopilot	4.0
15	47	Oxygen Supply	1.9
16	56	Accident Invest. Recording System	1.8
17	24	Auxiliary Power Unit	1.6
18	51	Instruments	0.8
19	55	Malf. Analysis Recording System	0.6
20	64	Interphone	0.1
21	65	IFF	0.0
22	44	Lighting System	0.0
23	61	HF Communications	0.0
24	62	VHF Communications	0.0
25	63	UHF Communications	0.0
26	66	Emergency Communications	0.0
27	68	Satellite Communications	0.0
28	69	Misc. Communication Equip.	0.0
29	71	Radio Navigation	0.0
30	72	Radar Navigation	0.0
31	76	Electronic Countermeasures	0.0
32	91	Evacuation & Emergency Equip.	0.0
33	96	Personnel & Misc. Equip.	0.0
34	97	Explosive Devices & Components	0.0

Appendix G. Average Subsystem NMCx Time

Subsystem	Avg. NMCx Hours	Subsystem	Avg. NMCx Hours	Subsystem	Avg. NMCx Hours
11B	4.42	49B	0.00	76B	0.00
11S	1.72	49S	0.63	76S	0.00
11M	9.09	49M	5.39	76M	0.00
12B	2.14	51B	0.00	82B	20.40
12S	2.38	51S	0.46	82S	9.73
12M	0.65	51M	0.36	82M	4.05
13B	46.69	52B	0.00	91B	0.00
13S	5.08	52S	3.24	91S	0.00
13M	5.74	52M	0.75	91M	0.00
14B	4.96	55B	0.00	96B	0.00
14S	3.82	55S	0.00	96S	0.00
14M	13.42	55M	0.65	96M	0.00
22B	6.06	56B	0.91	97B	0.00
22S	16.77	56S	0.47	97S	0.00
22M	22.65	56M	0.39	97M	0.00
24B	0.90	61B	0.00		
24S	0.59	61S	0.00		
24M	0.09	61M	0.00		
32B	4.57	62B	0.00		
32S	0.00	62S	0.00		
32M	4.12	62M	0.00		
37B	97.07	63B	0.00		
37S	4.10	63S	0.00		
37M	19.50	63M	0.00		
41B	7.09	64B	0.00		
41S	4.80	64S	0.00		
41M	18.41	64M	0.07		
42B	0.00	65B	0.00		
42S	2.67	65S	0.00		
42M	1.50	65M	0.02		
44B	0.00	66B	0.00		
44S	0.00	66S	0.00		
44M	0.00	66M	0.00		
45B	0.00	68B	0.00		
45S	2.65	68S	0.00		
45M	1.40	68M	0.00		
46B	0.47	69B	0.00		
46S	1.27	69S	0.00		
46M	4.68	69M	0.00		
47B	0.44	71B	0.00		
47S	1.01	71S	0.00		
47M	0.41				

Appendix H. FY02 FSE Data

Week	Week Ending	Scheduled	Added	Ops Canx	Mx Canx	Wx Canx	Other Canx	FSE Rate
1	7-Oct-01	24	0	2	2	0	0	83.33 percent
2	14-Oct-01	13	0	1	0	0	0	92.00 percent
3	21-Oct-01	36	0	5	0	0	0	86.00 percent
4	28-Oct-01	25	0	1	0	0	0	96.00 percent
5	4-Nov-01	25	0	1	1	0	0	92.00 percent
6	11-Nov-01	19	0	0	6	0	0	69.00 percent
7	18-Nov-01	20	0	0	1	0	0	95.00 percent
8	25-Nov-01	12	0	0	0	0	0	100.00 percent
9	2-Dec-01	20	1	0	3	8	1	41.87 percent
10	9-Dec-01	12	0	0	0	0	0	100.00 percent
11	16-Dec-01	25	3	0	1	12	0	53.57 percent
12	23-Dec-01	30	0	2	6	0	1	70.00 percent
13	30-Dec-01	11	0	0	6	0	0	45.00 percent
14	6-Jan-02	15	0	1	1	0	0	87.00 percent
15	13-Jan-02	18	2	1	5	0	0	70.27 percent
16	20-Jan-02	2	1	0	0	0	0	100.00 percent
17	27-Jan-02	19	0	1	3	4	0	57.89 percent
18	3-Feb-02	19	0	0	1	7	0	57.89 percent
19	10-Feb-02	19	0	0	5	0	0	73.68 percent
20	17-Feb-02	10	0	2	1	0	0	70.00 percent
21	24-Feb-02	9	0	0	3	0	0	66.67 percent
22	3-Mar-02	20	4	0	2	0	0	91.67 percent
23	10-Mar-02	22	1	0	5	0	0	78.26 percent
24	17-Mar-02	22	0	2	2	11	0	25.00 percent
25	24-Mar-02	23	1	0	0	8	0	66.67 percent
26	31-Mar-02	15	0	0	4	4	0	46.67 percent
27	7-Apr-02	28	0	0	3	2	0	82.14 percent
28	14-Apr-02	28	0	1	2	1	0	85.71 percent
29	21-Apr-02	22	1	2	1	4	0	69.57 percent
30	28-Apr-02	19	1	1	1	1	0	85.00 percent
31	5-May-02	33	0	1	1	5	0	78.79 percent
32	12-May-02	22	0	1	0	8	0	59.09 percent
33	19-May-02	24	1	3	5	3	0	56.00 percent
34	26-May-02	25	1	0	6	0	0	76.92 percent
35	2-Jun-02	24	0	0	7	0	0	70.83 percent
36	9-Jun-02	20	0	0	2	4	0	70.00 percent
37	16-Jun-02	15	0	0	0	3	0	80.00 percent
38	23-Jun-02	14	0	0	0	2	0	85.71 percent
39	30-Jun-02	14	0	1	0	1	0	85.71 percent
40	7-Jul-02	22	1	1	10	0	0	52.17 percent
41	14-Jul-02	23	0	1	1	2	0	82.61 percent
42	21-Jul-02	30	0	0	15	0	0	50.00 percent
43	28-Jul-02	13	2	1	7	1	0	40.00 percent
44	4-Aug-02	24	0	1	5	0	0	75.00 percent
45	11-Aug-02	34	0	2	9	0	0	67.65 percent
46	18-Aug-02	25	1	0	5	1	0	76.92 percent
47	25-Aug-02	16	1	1	0	0	0	94.12 percent
48	1-Sep-02	26	1	0	7	5	0	55.56 percent
49	8-Sep-02	8	0	1	0	0	0	87.50 percent
50	15-Sep-02	24	0	3	0	0	0	87.50 percent

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14. ABSTRACT

Maintenance management at the 135th Airlift Wing, Maryland Air National Guard desires a visualization tool for their maintenance performance metrics. Currently they monitor their metrics via an electronic spreadsheet. They desire a tool that presents the performance information in a graphical manner.

This thesis effort focuses on the development of a visualization tool utilizing two of the seven tools offered by Statistical Process Control (SPC). This research demonstrates the application of p-charts and Pareto diagrams in the aircraft maintenance arena. P-charts are used for displaying mission capable (MC) rates and flying scheduling effectiveness (FSE) rates. Pareto diagrams are then used to highlight which aircraft subsystems are affecting those two performance indicators.

15. SUBJECT TERMS: Statistical Process Control, SPC, Aircraft, Maintenance, Aircraft Maintenance, Maintenance Management, Mission Capability Rate, Flying Scheduling Effectiveness Rate, p-Chart, Pareto Diagram, Histogram

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