



**ANALYZING PERFORMANCE IN AIR FORCE
FACILITY MAINTENANCE AND REPAIR**

THESIS

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FACILITY MAINTENANCE AND REPAIR

THESIS

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Captain, USAF

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FACILITY MAINTENANCE AND REPAIR

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Abstract

The purpose of this research is to facilitate improvement of United States Air Force (USAF) Facility Maintenance and Repair (FM&R) performance through improved data analysis and visualization. There is not currently a standardized, efficient way to analyze USAF facility maintenance and repair performance. The USAF focuses on improving data collection but fails to provide FM&R leadership performance analysis tools or guidance.

This research provides a framework to fill this void using the R programming language and R packages Shiny and ggplot2. Shiny helps build an interactive web framework and ggplot2 plots and displays graphics. This research uses FM&R data from four bases and looks at Manpower Output, Priority Impact, Facility Impact, and Scheduling Compliance at each base to provide a baseline of performance and a visual analysis of potentially influential factors.

Using the analysis application, this research identifies inconsistencies between Preventive Maintenance priority and Preventive Maintenance execution, facilities requiring inordinate Corrective Maintenance, and excessive errors or omissions in data collection. As a remedy, this research recommends a greater emphasis on data analysis to improve FM&R performance and to improve data quality. The value of this research is in the usability and applicability to the FM&R leadership as a data analysis tool.

To my daughter, Raelyn for teaching me true priorities

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Jim H. Daniels III

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ANALYZING PERFORMANCE IN AIR FORCE FACILITY MAINTENANCE AND REPAIR

I. Introduction

General Issue

The mission of the United States Air Force (USAF) is to fly, fight, and win in air, space, and cyberspace. The USAF tasks its Civil Engineering (CE) Airmen to build, maintain, and repair facilities to ensure mission readiness. Gen Henry H. “Hap” Arnold, the only USAF general to hold a five-star rank, stressed the importance of this responsibility saying, “Air bases are a determining factor in the success of air operations. The two-legged stool of men and planes would topple over without this equally important third leg” (Byers, 2013). Furthermore, USAF fiscal responsibility dictates timely facility maintenance and repair (FM&R) of these facilities. Over time, changes in the CE Airmen’s scope, roles, and responsibilities have left gaps in FM&R practices. One of the main gaps found in USAF FM&R is in performance analysis. The USAF does not currently have a standardized tool, program, or efficient method of analyzing collected FM&R data. This research takes existing data collected by the USAF and uses updated analysis methods to create a prototype performance analysis tool for USAF FM&R.

Problem Statement

One significant problem within USAF FM&R is that it does not have a standardized tool, program, or method of analyzing FM&R performance. USAF CE

Airmen have data collection tools and resources but rely on individual flight leadership for performance analysis. Because of this, each base puts varying degrees of importance on performance analysis and uses a wide range of methods for determining performance with varying degrees of accuracy. This gap in capability introduces variance into USAF FM&R performance leading to insensible leadership decisions resulting in sub-optimal financial management in a time where the current political environment requires increased fiscal responsibility. The CE personnel performing the maintenance and repair at each base are subject matter experts (SME) in performing the repair and in the intricacies of their base. If they are given better analysis tools, when combined with their expertise, they may be able to make changes to improve their maintenance and repair performance through more efficient repair processes and extended facility life.

Research Objectives

The objective of this research is to foster an environment where USAF FM&R decisions are based on accurate data assessment. The purpose of this research is to answer the following questions:

1. How does the USAF look at FM&R performance and which factors are expected to affect performance?
2. How can the USAF use readily available software to better analyze FM&R performance?
3. What issues inhibiting FM&R performance or performance analysis are common between USAF installations?

Research Focus

The focus of this research is to show the importance of performance data analysis and deliver the tools to begin standardizing and accurately analyzing FM&R data. The product of this research is a prototype FM&R analysis tool that is easy to understand and apply across the USAF for installation FM&R analysis. The scope of this research is limited initially to four bases, but the analysis code is written without site-specific features for universal application across the USAF. Finally, the goal of the analysis is to produce usable conclusions that can enable CE Airmen to identify, implement, and improve FM&R performance. These goals are in line with USAF Civil Engineering Strategic Plan which emphasizes efficiency using data-based decisions and information technology due to a reduced budget environment citing the reduction in both federal spending and the national deficit and their effect on the Department of Defense (DoD) budget (Headquarters United States Air Force, 2011).

Investigative Research

The goal of the literature review is to find where USAF FM&R lacks capabilities and understand how it views performance. To add to the academic conversation, it is necessary to understand the history of FM&R in the USAF as well as its current processes and capabilities. It is also important to understand how the civilian sector handles FM&R. This research compares these two approaches to identify areas where current USAF processes or capabilities are lacking. Once the gaps are identified, this research attempts to find best practices to formulate a way forward to improve USAF FM&R.

Methodology

Discussed in depth in the Methodology chapter, this research explores FM&R performance based on existing Interim Work Information Management System (IWIMS) data. For data analysis, this research uses the R programming language for statistical computing and graphics. The R package Shiny provides a framework to build an interactive web application that enables performance analysis anywhere with a web connection. The R program code extracts and manipulates the data collected in IWIMS into an interactive interface for analysis using ggplot2 for graphics. The analysis of the web application evaluates performance in FM&R with ties to both facility and personnel performance based on previous FM&R performance measures and the hypotheses of SME by looking at Manpower Output, Priority Impact, Facility Impact, and Scheduling Compliance. This enables standardized visual data analysis at the base level and shows the CE Airmen how their actions affect the performance outcomes over time.

II. Literature Review

Chapter Overview

This research initiated with the goal of finding where USAF FM&R lacked capability and developing a solution. To find where USAF FM&R lacks capability, this literature review explores the history of FM&R in the USAF from conception through current processes and capabilities. This research takes these processes, capabilities, and goals and compares them to those of the civilian sector. Finally, this research looks at upcoming capabilities and goals based on USAF CE initiatives currently under development. This review found a gap in capability in performance analysis and builds on current best practices to aid in the creation of the research methodology.

United States Air Force Facility Management

USAF CE Airmen manage a robust infrastructure requiring a vigorous FM&R program. This section of the literature review looks at how USAF CE Airmen manage its facilities and finds areas that could benefit from advanced technologies or improvement. First, it looks at the evolution of FM&R as the building blocks of the processes and capabilities in place today. Second, it breaks down processes or programs currently in implementation. This helps identify performance analysis as an area that needs implementation and improvement.

History

The military has been maintaining and repairing facilities since before the early airfield sites in 1907, but the true structure started taking shape in 1947 when President Truman signed the National Security Act establishing an independent Air Force. The new

Air Force included building permanent bases and setting up an organization to manage the existing and added facilities. They transferred these responsibilities to the Air Installation Officer (AIO), which relied heavily on and patterned its FM&R regulations in line with the United States Army Corps of Engineers and Army Air Forces preceding regulations. These regulations included the basics of procurement maintenance and repair of installation facilities and included an Installation Maintenance and Repair Branch. In 1951, AFR-85-5, Maintenance of Installations established the basic maintenance standards. These standards set the grounds for performance in FM&R when Colonel Mayes observed his program's performance increase at Fairchild AFB in 1954 stating, "Instead of 900 people we had 500 and some-odd and we were doing 10 times the amount of work they were doing with 900-odd people, because people were doing their jobs" (Hartzer, Walker, Gatewood, Grandine, & Kuranda, 2012). Around this time, the preventive maintenance program was added on. By 1956, an organizational chart for the Preventive Maintenance Section was included in AFR 20-42.298 (Hartzer et al., 2012).

The collection of data was introduced with real property inventory records and base master plans. These concepts are still in place and valuable records of data with continued policy updates. February 4, 2004, Executive Order 13327 updated Federal Real Property Asset Management to "promote the efficient and economical use of America's real property assets and to assure management accountability" (Bush, 2004). Executive Order 13327 established additional guidelines stressing the importance of better defining and improving asset management. In 2002, the Secretary of the Air Force created the Air Force Real Property Agency (AFRPA). Then, in 2012, USAF merged AFRPA and its real property responsibilities with the Air Force Center for Environmental Excellence and

the Air Force Civil Engineer Support Agency to form the Air Force Civil Engineer Center (AFCEC). Real Property Inventory remains a crucial part of the Financial Improvement & Audit Readiness (FIAR) goal of achieving full audit readiness.

In 1964, the Chief of Staff of the Air Force pushed for the development of a data automation system. Civil Engineering Airman began developing specifications for a program that integrated all CE functions into one database including real property records, labor utilization, work scheduling, etc. The introduction of this database led to the development of the Base Engineer Automated Management System (BEAMS). The idea of automation was slow to spread as evident in Maj. Gen. Clifton D. “Duke” Wright, Jr.’s comment, serving as Deputy Chief of Staff for Engineering and Services at Headquarters USAFE 1974-1975, when he recalled his introduction to BEAMS stating the following:

“That was my first exposure to the world of automated management systems...we knew that automated systems were the wave of the future and struggled to get the system on line. The worst part of it was volume. The reams and reams of computer-generated data and reports that the system created were virtually useless to the poor civil engineers working to keep bases glued together. I think BEAMS came to haunt every Air Force civil engineer, but it was the beginning of automation in our business.” (Hartzer et al., 2012)

Even from the beginning, the USAF had a wealth of data but did not have a good plan to analyze it.

Over the next several years, the CE workload increased, and workload management became a priority. Eventually, they knew that BEAMS needed improvement. The next major update made data accessible in real time rather than on a quarterly basis. First, they tried to create an umbrella system to support CE and services needs into one software package called Engineering and Services Information

Management System (ESIMS). Out of the EWIMS project came the Work Information Management System (WIMS).

WIMS was designed for simplicity with real-time data access and flexible data queries to facilitate base level management decisions. One of the most notable features was the ability to replace manual work order logs with computer generated Work Orders (WO) in the standard form at the time. It could also be used to track work order request status (Hartzer et al., 2012).

In the 1980s, USAF CE Airmen started to see the effects of the now 30-year-old facility infrastructure. Maintenance and repair cost increased considerably requiring additional work and costs. This is where issues with backlog work and deferred maintenance began contributing to accelerated facility deterioration requiring major repair (Hartzer et al., 2012).

Drafting is another field that CE has seen change over time. The USAF advanced their capabilities through the experimentation through geographic information system (GIS) mapping in the 1990s. The 10th CES at the United States Air Force Academy (USAFA) developed its own GIS maps using AutoCAD and GeoSQL. Both are commercial-off-the-shelf programs intended to link with WIMS. The USAF used these parameters to roll out the GeoBase program for installation geospatial information and services capabilities across the USAF. By 2004, the USAF contracted Trimble to add Global Positioning System (GPS) capabilities to its surveying and mapping.

Continuing with the development of data automation systems, in 1996, the USAF released a Civil Engineer Automation Strategic Plan. The main goal of this initiative to improve automation was to:

“...transition the WIMS framework into a relational database linked to full graphical applications, supporting the full range of operational and contingency responsibilities. The envisioned system will be appropriately integrated and standardized to maintain Air Force uniformity, but allow major command/base flexibility.” (Hartzer et al., 2012)

The new system developed to take on this task was the Automated Civil Engineer System (ACES). To prepare for the transition to the new ACES system, the USAF needed to convert WIMS to the same software. In 1998, USAF CE transferred the WIMS system to a UNIX-based system known as the Interim Work Information Management System (IWIMS). ACES continued to develop and by 2004, ACES included Personnel and Readiness, Real Property, Program Management, Housing Management, Explosive Ordnance Disposal, and Fire Department systems. However, ACES-Operations continued to have issues with interfacing with other systems across the USAF such as the financial system. Eventually, ACES-Operations was abandoned and IWIMS remained the primary data collection system for maintenance and repair (Hartzer et al., 2012).

In 2007, the USAF started the Agile Installation Management (AIM) initiative with the main goal of easily managing data from a complete CE perspective replacing both ACES and IWIMS establishing a single database. The information technology component of the AIM initiative turned into Next Generation Information Technology (NexGen IT). CE also conducted a military requirement review to make sure they had at least the minimum levels of manning to their Prime Base Engineer Emergency Force (Prime BEEF) and Rapid Engineer Deployable Heavy Operations Repair Squadron Engineer (RED HORSE). These initiatives started a CE Transformation focused on centralization and included reorganizing the CE Squadrons (Headquarters United States Air Force, 2007).

In October of 2012, the USAF continued the CE Transformation initiative including the merge of AFCEC to provide “tip of the spear” support, move to a centralized requirement’s based funding model, and adapt the preventive maintenance program to prioritize based on facility condition and performance indicators (Byers, 2013). The transformation represented a re-engineering of CE processes and an upgrade in information technology. Changes were based on industry-proven methods of Asset Management looking at commercial off-the-shelf technology solutions (Hartzer et al., 2012). The Program Action Directive (PAD) 12-03 provides direction to implement these initiatives with the goals of cutting cost and improving efficiency. Most changes implemented in the transformation were in leadership centralization and restructuring. Furthermore, it brushes on the role of technology identifying the need for research, development, testing, and evaluation (RDT&E) activities for new information technologies at every level and even sets up an Operations Engineering section at the installation level specifically focused on sustainment (Headquarters United States Air Force, 2012).

Most recently, Headquarters United States Air Force (HAF) published PAD 14-04. These directives further implement the centralization focused on management above the wing level. It consolidates all installation and mission support capabilities to one focal point at a single intermediate organization by establishing Air Force Installation and Mission Support Center (AFIMSC) (Headquarters United States Air Force, 2015b).

Current Capability

Looking at the current organization, 2017 USAF CE processes are a mixture of old and new information technologies. The organization is in the implementation phase of

the CE Transformation and is working toward the full implementation of NextGen IT. The new commercial off the shelf (COTS) program developed for NextGen IT is International Business Machine's TRIRIGA system. TRIRIGA is a cloud-based IT system with Integrated Asset Management, Cost Accounting, Operations & Material Control, Energy, Real Property, Project Management, and Energy Management capabilities. It replaces IWIMS, ACES-Real Property, ACES-Project Manager, ACES-Financial Management and other CE data tracking systems. TRIRIGA has advanced reporting capabilities that replace IWIMS data calls. It also quickly and more efficiently assigns and manages Corrective and Preventive Maintenance tasks to available resources as well as create job plans and schedules (AFCEC FMO, 2016).

BUILDER™ is a Sustainment Management System (SMS) adopted by the USAF through the United States Army Corps of Engineers (USACE). It is the authoritative data source for TRIRIGA Real Property. BUILDER™ is a progression toward more efficient, maintenance and repair. It is moved to a condition-based preventive maintenance program which prioritized work based on performance indicators and facility condition (Byers, 2013). BUILDER™ SMS is a web-based application designed to help decide when and how to best maintain building infrastructure. It starts with existing real property data, and more detailed information is added to this inventory to create a Condition Index (CI) to predict the facilities expected stage in the total life cycle. Additional periodic inspections on different facility components to verify condition are based on component criticality. Additionally, functionality assessments can be performed on these real property facilities to reflect compliance and requirement changes (United States Army Corps of Engineers, 2015).

CE Capabilities Initiative

The CE Capabilities Initiative is currently under development and not yet published but based on some projected ideas, could tie in to future performance analysis. Starting in 2014 the USAF CE developed the idea for an Air Force Civil Engineering Capabilities Initiative. The goal is to improve installation sustainment even through manpower reduction and budget cuts. This initiative coordinates with PAD 14-04 and aligns with the Secretary of the Air Force (SecAF) and the Chief of Staff of the Air Force's (CSAF) 2014 Air Force Strategy. This initiative takes CE core tasks and breaks down the CE capabilities used to accomplish the core tasks like those outlined in Table 1 (Hamilton, 2016).

Table 1: Adaptation from CE Capabilities Integration Update

Capability	Work Type
Planning Integration	Ability to develop, link, and de-conflict realistic and achievable resourced schedules of activities to support and inform decision-making
Asset Visibility	Ability to provide auditable, accurate, credible, dynamic, disciplined, standardized, and sustainable asset and performance data
Requirements Identification	Ability to articulate valid requirements in a consistent and standardized fashion
Asset Analysis and COA Development Risk Assessment	Ability to analyze asset opportunities and constraints to fulfill mid-future mission needs and actions, in accordance with service levels Ability to articulate risk to mission and force across the enterprise
Performance Management and Continuous Improvement	Ability to measure and analyze results relative to resources used against planned objectives Ability to iteratively improve efficiency to achieve planned objectives

Under Performance Management, CE could eventually develop metrics to most accurately measure and assess performance. The working documents for these capabilities prioritize Execution Planning to include risk assessment and performance

management (Headquarters United States Air Force, 2015a). Although the plans and playbooks outlining these capabilities are still under construction at AFCEC, they are in line with this research and will be beneficial to future research in this area.

Comparison to Civilian Sector Facility Management

To find areas that need improvement, USAF CE systems and techniques are compared to those of industry leaders. Then, leading industry techniques are examined. Any key differences or potential improvements are extracted from the academic conversation.

Improving FM&R is not a new topic in the literature. Optimization, efficiency, and cost reduction became an integral basis for FM&R improvement after the re-engineering, “Toyota Way,” and Six Sigma movements in the 1990s. The USAF response to this was Air Force Smart Operations (AFSO) 21. In this instance, 21 stands for the 21st century. Because of these movements, FM&R in the industry is constantly evolving and improving. Many of the improvements are because of newly implemented information technologies. Some of the main areas of improvement are building information modeling (BIM), geographic information systems (GIS), budget projecting, and personnel performance.

As detailed below, construction industry leaders now implement BIM as an integral part of FM&R. BIM is three-dimensional modeling software that contains building renderings and stores building information. BIM aids in building design, construction, maintenance, and operation of facilities by showing how different facility components work together and the exact location in three-dimensions. This new medium

creates a better spatial understanding than traditional two-dimensional blueprints or drawings can articulate. When implemented properly, BIM also has the potential to encompass many data sources for facility maintenance. Since BIM is used for design, construction, and maintenance, the initial data is not lost through miscommunication or transfer error between multiple fragmented systems. Its unique capabilities even allow for maintainability considerations during the design process (Becerik-Gerber, Jazizadeh, Li, & Calis, 2012).

BIM has also shown to improve safety within FM&R processes. On a day-to-day basis, management technicians are repeatedly in high-risk situations. Even with proper Occupational Safety and Health Administration (OSHA) practices, inaccurate, out-of-date drawings often put technicians in the path of unnecessary risk. Safety is currently relayed through training, pamphlets, and meetings, but few of these are site specific. Research has shown that the more time required retrieving safety information, the less likely the worker is to retrieve that information (Wetzel & Thabet, 2015). Using a BIM-based framework, site-specific safety information will be easier to retrieve and more accurate in a specific maintenance or repair situation. This study shows that BIM-based FM&R processes increase performance and the safety of the workers when they are performing their management tasks (Wetzel & Thabet, 2015).

Out of its many system databases, the USAF does not have BIM capability. Beyond the three-dimensional modeling, the main benefit is the use of one main system for all data collection. Facility maintenance data is stored in the same location instead of several different systems, and the original design and construction data is retained within the system. This eliminates the issue of mismanagement or transfer of data between

systems. The ease of access can also deliver more accurate and reliable safety information keeping the technicians safe. System compatibility and accurate data are essential in efficient FM&R.

Industry leaders are also using GIS in conjunction with BIM databases. The integration of these two technologies is very important because GIS contains key data in location. Location is a helpful aid in the management of utilities, where many are hidden underground and often difficult to locate. While both GIS and BIM display spatial information, GIS is the outdoor modeling aspect. Any unnecessary data can cause confusion, and simple access to location from GIS in combination with the accurate data from BIM allow these two information databases to offer invaluable insight into facility issues (Kang & Hong, 2015).

The USAF has not integrated its GeoBase system with any of its facility maintenance systems. Integration of these two systems could potentially decrease FM&R process times. This is another example of how multiple programs that are not coordinated can potentially create issues with data accuracy and usability.

Budgeting for FM&R is an area where the USAF is improving with the introduction of BUILDER™ and the CE Transformation introduction of the Operations Engineering section. Optimal maintenance policies study the stochastic behavior of systems to balance maintenance cost and system reliability (Wang, 2002). Industry leaders have developed numerous ways to budget for facility maintenance ranging from an antiquated basic estimate based on initial cost/replacement value to the current industry standard of assessment based on the facility's current/projected facility condition. These other models represent a better budget for management such as:

estimates based on quantifiable attributes of the plant, life cycle cost analysis of individual facility systems, and assessment of facility system physical condition. Industry leaders use many criteria stemming from these approaches in a formula budgeting approach to look long term. These models not only consider the status of the facility infrastructure and help model the most cost-effective repairs, but they also project budgets into the future so they can be planned for, reducing the risk of failure (Ottoman, Nixon, & Lofgren, 1999).

More recently, industry leaders focused on minimizing the fluctuation within the facility maintenance budget. Industry leaders are continually revising and improving formula budgeting models. Building components and building materials each have different life expectancies or usable lives. Conversely, because it is easier to budget for a more consistent management cost annually, it is best to adjust budget projection formulas to regulate or minimize fluctuation in management. If the budget is not high enough to cover the required management, that management is deferred. Failing to perform adequate, timely management has negative effects on the life cycle and performance of the facility leading to increased costs in the future. Industry leaders are adapting models to stabilize annual facility maintenance costs. This prevents the postponement of management activities and increases the life expectancy of their buildings (Kim, Han, & Hyun, 2015).

BUILDER™ and the CE Transformation introduction of the Operations Engineering section improve the work management process to address things like lifecycle management, building condition, and mission priority. BUILDER™ uses the facility conditions and predicts future failure. Once this is accomplished, it is important to

take steps to decrease annual budget fluctuation, which reduces deferred maintenance, leading to improved life expectancy of its facilities and decreased life cycle costs (Kim et al., 2015).

The final tool utilized by industry leaders is assessment of personnel performance. The construction industry did not start tracking personnel performance until the early 2000s. When analyzed, between the 1970s and the late 1990s, personnel performance increased due to advancements in technology. Studying direct work rate, labor cost, and construction output, researchers drew conclusions on how changes in equipment costs and changes in technology affected the daily construction output. Using this analysis, project managers were finally able to quantify how daily output affected labor cost over time and how spikes in daily equipment cost affected the daily output (Allmon, Haas, Borcharding, & Goodrum, 2000).

Currently, the most common approach to increase construction performance is by using models. These models use input and output factors to help facilitate decision-makers to draw accurate conclusions based on performance analysis. Construction-related models are based on factors of individual performance and/or process based views. Models are then adapted to pull out the most advantageous traits and benchmarked to set a basis for performance. Two common models, the performance-value and performance-quantity models, are set up where performance is based in terms of value and where performance is based in terms of quantity, respectively (Becker et al., 2012).

Paula Linna (2009) explores defining and measuring performance in the public sector and finds that because of different perceptions in the public sector this limits the ability for one simple performance equation. Instead, multiple aspects of productivity and

overall effectiveness need to be explored (Linna, Pekkola, Ukko, & Melkas, 2010). Productivity or efficiency of performance is generally defined as a measure of the amount of output generated, but can be described as an efficiency measure of output/input, a combination of efficiency and effectiveness with output/input + output/goal, or it can be taken from a wide approach including everything improving organization function (Linna et al., 2010).

USAF CE has not published a set of metrics or standards to analyze USAF FM&R performance even though the USAF collects large amounts of performance data. TRIRIGA is vastly improving the user interface and collection methods that should help reduce redundant data. However, it does very little to assess, visualize, or improve personnel performance. Capt John Dolan explores performance in USAF CE FM&R in an informal survey conducted of seven either past or present CE Operations Flight Commanders. He found consensus in mission description from these leaders but found that none of the seven survey responses listed the same metrics for measuring success. Some responses even measured success by “feel” or simply absence of failure. When his research studied performance in FM&R, he identified time based WO completion rate completed, and establishing standards based on the amount of money given for sustainment (Dolan, 2016).

FM&R Performance Analysis

Overall, there appears to be a gap in capability USAF FM&R performance analysis, but value added from performance analysis in the civilian sector. In developing

a tool to fill this gap, it is important to remain in line with other lines of research and capabilities in other sections of the USAF to include AFIMSC and HAF A9.

USAF Data Analysis

CE's leadership organization AFIMSC has division completely focused on the science of improving. The AFIMSC Operations Research Division (RMO) depicts their mission on their website as "The Science of Better" ®. They "add 'science' to decision making through the application of analytical methods and tools." Currently, they are working on an Air Force Business Intelligence Tool (AFBIT). This tool takes user data and provides visual analysis capabilities helping the user capture the impact of their data. The AFIMSC/RMO is exploring the use of Tableau in the USAF because Tableau provides analytics by the conglomeration and display of information. Their initial tests experimented with BUILDER™ data, and the results showed enough promise to begin pursuing an enterprise license which will cost \$325K with an additional annual \$65K for maintenance and support (Tableau, 2016). However, there is precedence for this implementation because Air Force Installation Contracting Agency (AFICA) already deploys Tableau.

Mr. Keven E. Williams, SES, is the HAF A9 Director of Studies, Analyses, and Assessments. In 2016, Mr. Williams directed the Air Force Analytic Community toward a preferred software suite detailed in Figure 1 (Williams, 2016).

AFAC Operations Research Analysis Preferred Software Suite

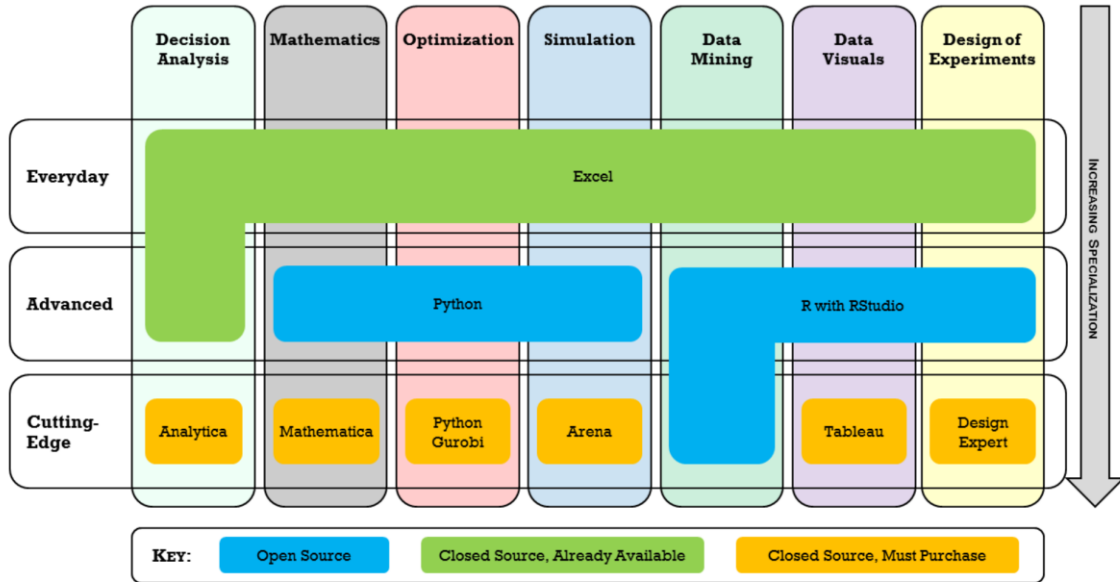


Figure 1: Attachment from Preferred Software Suite for Operations Research Analysis Memorandum

Under Data Visuals, Excel, R, and Tableau are all included in the best alternatives by the highest level of Data Analysis leadership. Many Operations Flights attempt to analyze data using Microsoft Excel® charts and graphs. Microsoft Excel® is a good tool but has very limited capabilities compared to R or Tableau.

Overall, CE is looking to analyze performance and is working to develop metrics to analyze it. AFIMSC is looking for ways to analyze data, and HAF has provided preferred analysis tools. Microsoft Excel® is the most familiar to USAF CE, but lacks the capabilities of R or Tableau. Tableau is potentially easier to learn and use, but has a high price tag. In order to explore high capability and low price, this research uses the R programming language for its data analysis.

Identifying Performance Metrics

To pick the metrics to analyze for USAF FM&R performance, this research starts with its simple measure of output: WO closed. WO closed is a dependent variable that has many factors explaining its variance. If this output is analyzed with respect to the factors that cause variance, it is possible to see over time which factors have a greater influence on output and begin to understand efficiencies in performance. Based on the literature and inputs from SME at AFCEC, this research will initially look at simple Manpower Output through WO closed benchmarked over time. It will look at WO type through Priority Impact using the WO priority system put in place during the CE Transformation. This research looks at problem facilities through the Facility Impact graph to look at facilities that require the most maintenance and repair. Finally, this research looks at the impact of accurate scheduling in each shop using the Scheduling Compliance graph to see if planning work helps depict future workload.

III. Methodology

Chapter Overview

This research uses the statistical analysis tool, R, in combination with a Shiny Applications interface to meet the research objectives. The combination of R and Shiny possess the ability to extract the data collected in IWIMS and clean, analyze, and export it to an interactive interface that outputs a visual data analysis and shows how adjustments can affect performance outcomes. This research aims to aid identifying trends in hindering USAF FM&R. With this analysis, the USAF CE Airmen can make the appropriate changes to their FM&R programs to continue improving and saving taxpayer money.

Tools and Materials

The required tools and materials for this research are limited to IWIMS data and the R programming language for statistical computing and graphics. This research will not require any experiments, labs, or testing. It will only analyze existing data to draw its conclusions. Beyond R, this research uses the RStudio environment and its open-source packages Shiny and ggplot2 to build a web application with enhanced data visualization.

R is a programming language and environment built for statistical graphing and analysis. R is a GNU (reverse acronym GNU's Not UNIX) project and is an open source free software under the GNU General Public License. R offers an assortment of statistical and graphical techniques beyond that of spreadsheet platforms such as Microsoft Excel and does not have the cost of Tableau.

RStudio is professional software for the R environment. Its main product is an Integrated Development Environment (IDE) to assist in R programming and data analysis that is helpful for writing R code. Two of RStudio's packages Shiny and ggplot2 are also an integral part of this research. This research uses the Shiny package to build a web application and allow easy-to-use web hosting that is free for up to five applications and 25 active hours per month. RStudio's ggplot2 is a package that enhances data visualization and allows multi-layer graphics.

IWIMS data was chosen because at the time of this research, NextGen IT/TRIRIGA is in mid-deployment and contains mostly data imported from IWIMS. To simplify this process, this research pulled the maintenance and repair data from the information pulled out of IWIMS to go into TRIRIGA. This research chose R in combination with the RStudio Shiny web application because it is a Free Software and web hosting allows easy access even on USAF networks. The elimination of cost barriers gives anyone interested in using parts of this research access to the applicable tools. Open Source code encourages wider sharing or collaboration in findings and techniques improving reproducibility and fostering improvement.

Data Collection

Data Format

IWIMS data is stored at Maxwell AFB-Gunter Annex, Alabama and is currently in the process of implementation into TRIRIGA. To do this, each installation has its own root folder for the transfer. Each root folder contains seven active files and a history folder. The data out of the seven active files contains information on all open WO and

closed WO for 365 after date closed. The seven active files end in the same four letters detailed below:

- IFAC – Multi-use file identifying facility breakout
- MCDS – Work Order (WO) description and justification
- MRMK – WO remarks
- MWCN – Shops associate to the work order
- MWKP – Work performed
- MWOA – WO file
- MWTF – WO tracking status codes

After 365 days, the data is stored in the History folder. The History folder contains the same first six files with the WO that were closed between 365 and 730 days earlier. All the files are in ASCII (text) format with a pipe delimiter to denote column headings. The data layout in the history folder is identical to the active data.

Selecting Data

IWIMS data was chosen because at the time of this research, NextGen IT/TRIRIGA was mid-deployment and contained mostly data imported from IWIMS. Four bases were selected as an initial test for importing and analysis: Dover AFB, Dyess AFB, Minot AFB, and Scott AFB. These four bases cover different regions of the continental United States to represent some different climates. However, this research writes the R code in a manner to analyze any base with data directly out of its root file so the multiple bases are primarily included to show research capabilities.

Data Preparation

To pull out meaningful analysis from the collected IWIMS data, there needs to be a purpose or end goal. Each theoretical analysis may not work, initially because of inconsistencies in the data, but the process needs to be started so there is something on which to improve. The method of data preparation will be initially for visual performance measures. With data visualization, it is easier to see trends or anomalies in data. The initial performance measures explored are Manpower Output, Work Priority Impact, Facility Impact, and Scheduling Compliance. These areas are based on input from SME at AFCEC.

Data Cleaning

The overall setup of the analysis starts by loading the data for the four bases. Using the IWIMS data collected out of the root folder of the data withdrawn for implementing into TRIRIGA, this research only uses the MWCN and the MWOA files. These two files deal with the WOs and the shops associated to the WOs. These two subsets are then merged together to create one large dataset. They are merged per WO number. Even within this subset of the IWIMS data, there are still many areas that are either not helpful for this research or are predominantly missing data. Therefore, the dataset is further reduced to the following columns:

- MWOA.WOTITLE – Title of WO
- MWOA.FACIDNR – Facility number
- MWCN.SHOPCODE – Code identifying shop
- MWOA.SICODE – WO priority

- MWCN.EST.HRS – Estimated WO hours
- MWCN.MIL.HRS – Hours spent on WO military
- MWCN.CIV.HRS – Hours spent on WO civilian
- MWOA.DATEOPEN – Date WO opened
- MWOA.DATECLOS – Date WO closed

Next, the R code converts the cells that are dates from number format to date format so R recognizes them as dates. This provides a blank slate of usable data from each base.

Next, to analyze the data in other subsets besides the base the data is broken down into editable fields through drop menus. The first dropdown menu subsets the data set by shop. Each shop name calls the corresponding shop code (MWCN.SHOPCODE) and limits the dataset to only that shop. If the user selects “All,” the dataset remains whole.

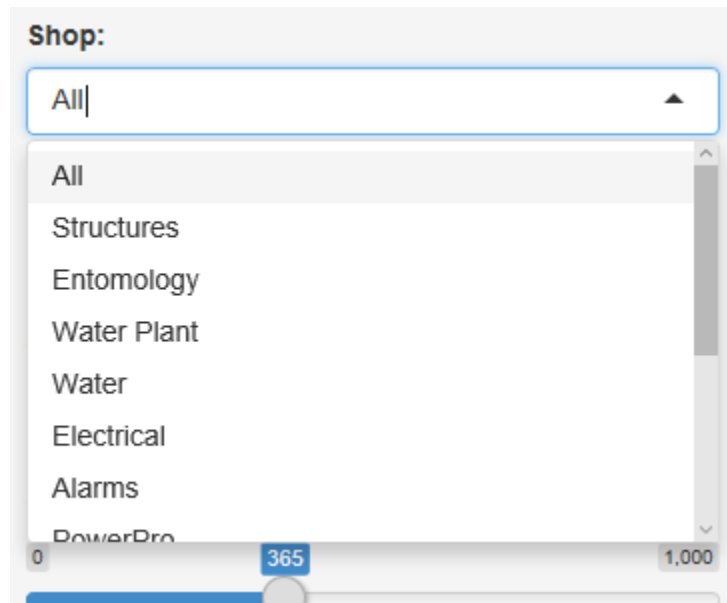


Figure 2: Example Drop Down Menu

This process repeats for each subset selector that includes Base, Shop, and Priority. These dropdowns are reactive and each dropdown selection cuts down the dataset, updating each visual analysis chart.

The data is then subset by the range of date closed and the length the WO has been open with sliders. This research uses the Date WO Closed Range slider to analyze certain times of year or change over time. Sliders cut out some of the outlier data. This is better for data analysis since, WOs that have been open for more than five years are not likely to still present accurate data. However, this does not allow the user to see the inaccurate data points that are still in the exporting system. The sliders are completely selectable over the days in the data available as shown in Figure 3.

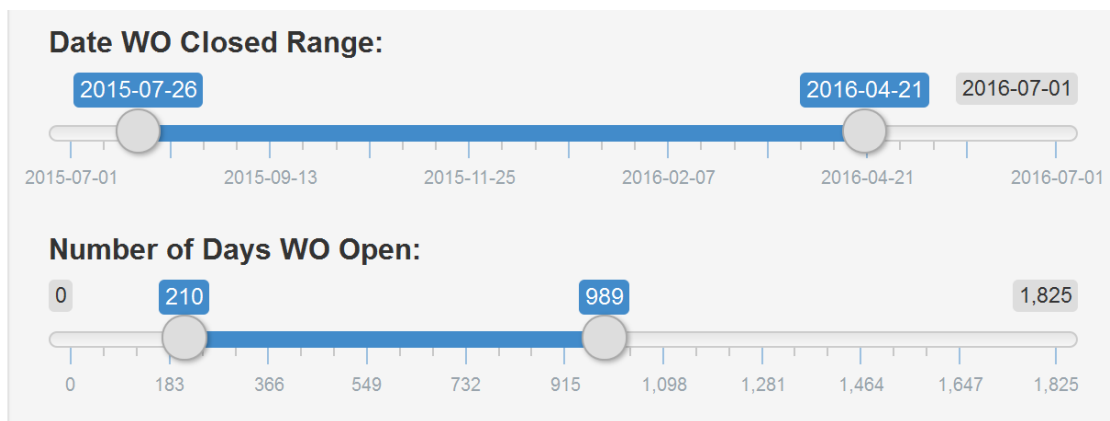


Figure 3: Example Slider

Web Application

The web application incorporates a pane to the left side of the application with all the reactive subset selectors. The analysis charts are on the right and the data involved in the analysis subsets is shown in a table. Each of these graphs has its own selectable tab. Figure 4 shows an example of the web application layout.

Air Force Maintenance and Repair Data Analysis

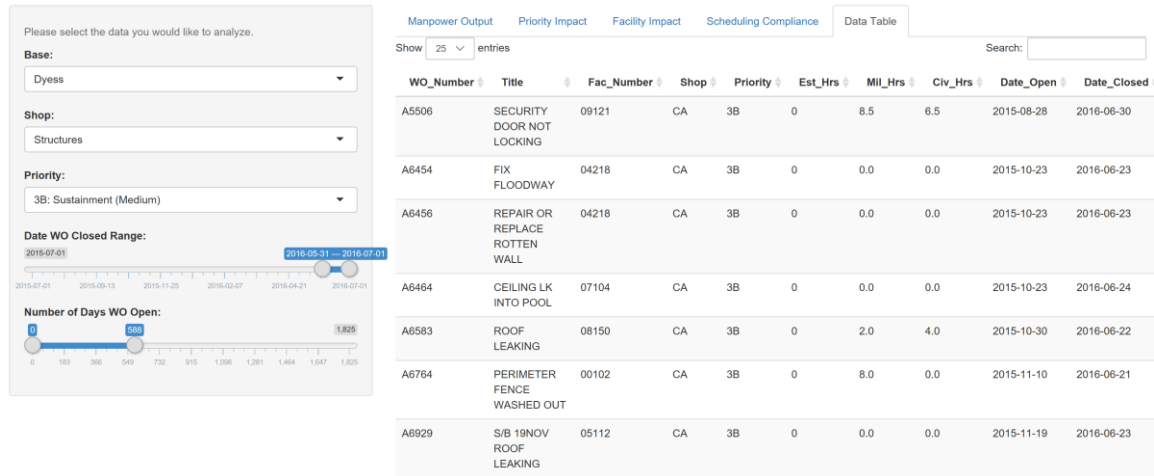


Figure 4: Example Web Application Layout

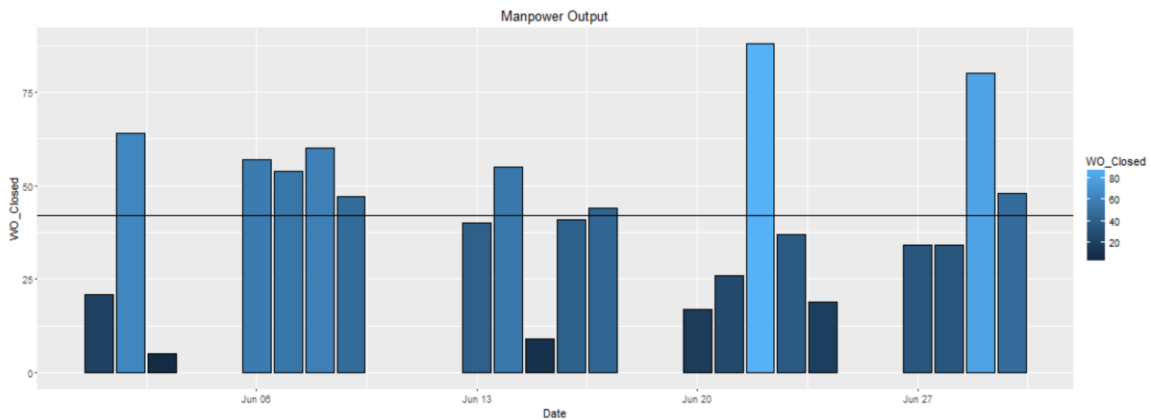
Shiny offers web hosting for the application that is free for up to five applications and 25 hours a month. Web hosting gives the web application many interoperability advantages, but is not necessary for use. The application retains its capabilities without web hosting on any computer that has R and a graphical user interface such as RStudio installed.

Manpower Output

To begin to understand USAF FM&R performance or efficiency, first, this research analyzes outputs involved in FM&R activities. In maintenance and repair, the output is a maintained or repaired facility. IWIMS tracks this metric with WO closed. This simple analysis provides a basic measure of performance.

This analysis is set up to react to the data inputs based on the slider and dropdown selections. The R code running the web application takes the given data and simplifies it to only the date the WO closed. Then the application performs a count of the number of

WO closed each day. The capabilities of the Date WO Closed Range allow benchmark analysis over time. The Manpower Output graph shows a bar chart with the number of WO closed each day. Finally, to help benchmark different timeframes, the Manpower Output graph includes a line marking the average number of WO closed per day. Figure 5 shows the Manpower Output each day over the month of March for all of Dover AFB.



**Figure 5: Example Manpower Output Chart
(Minot AFB, June 2016)**

The main issue with this particular manpower analysis is that it aggregates all the hours worked over several days and adds them to the day the WO closed. This creates more variance per day. However, the IWIMS output shown in this data set categorizes by WO not by date. It would also be helpful when exploring labor to look at hours working vs hours available. Some indirect work hours are collected in IWIMS but it does not collect total hours because not all indirect work hours are collected. However, TRIRIGA is not taking the indirect work hours from IWIMS. Since this dataset is for transfer to TRIRIGA, this dataset does not contain any indirect work hours.

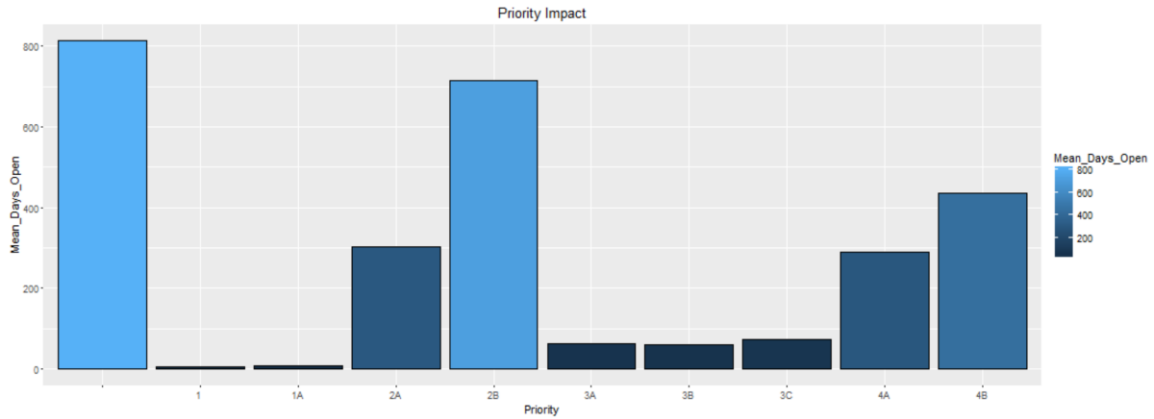
Priority Impact

The Priority Impact analysis is set up to look at how WO priority affects WO close out time. Priority comes from AFI 32-1001 shown in Table 1 (Headquarters United States Air Force, 2016).

Table 2: Adaptation from Work Prioritization System AFI 32-1001

Work Priority	Work Type
1	Emergency Corrective Maintenance Work
2A (High)	Preventive Maintenance (PM)/Physical Plant Operations
2B (Medium)	Contingency Construction Training
3A (High)	Scheduled Sustainment Work (Corrective Maintenance High Priority)
3B (Medium)	Scheduled Sustainment Work (Corrective Maintenance Medium Priority)
3C (Low)	Scheduled Sustainment Work (Corrective Maintenance Low Priority)
4A	Scheduled Enhancement Work
4B	All other Enhancement Work

The expected finding is that the higher the priority, the quicker the close out time. This metric should highlight where workers are putting off higher priority WO for a lower priority task. This occurrence would identify itself by having a higher mean days open than the mean days open of the lower priority. An example Priority Impact chart is shown in Figure 6 for Scott AFB.

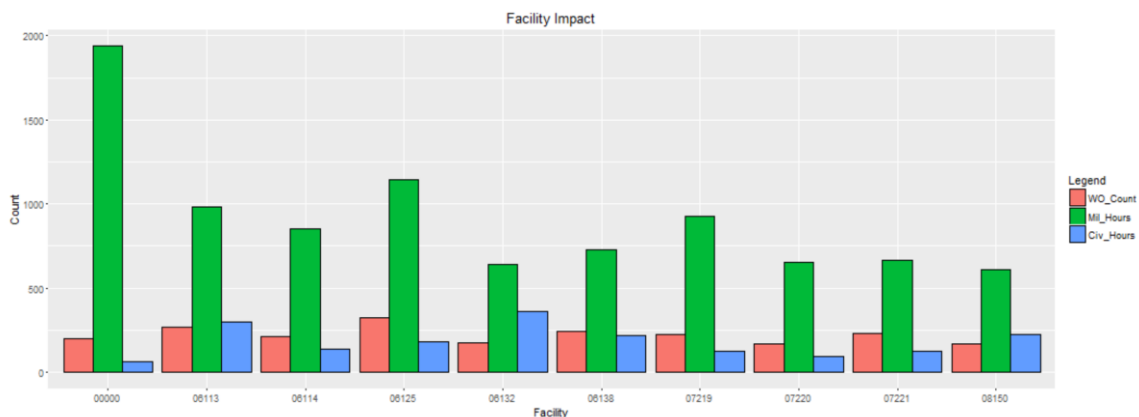


**Figure 6: Example Priority Impact Chart
(Dover AFB, July 2015-June 2016)**

Priority Impact is calculated by counting the number of WO closed in each priority. It also sums the days open per WO as a reference to how long the WO are taking to close out. The total days open are divided by the total number of WO to find mean days open which is then graphed according to priority. The unlabeled bar at the far left of the chart is in place to identify unclassified priority WO. There should not be any unclassified WO, so if there is an unlabeled bar on the graph, it is an identifier that there is missing priority WO included in the dataset. Priority 1 should be extremely low. Priority 1A does not exist. These bases are mislabeling Priority 1. Priority 2A should also be extremely low but likely higher than Priority 1. Priority 2B is the exception to the rule. A large project can take longer, but should be less than 365 days. Priority 3A-4B should be increasing in time open as they decrease in priority. Figure 6 is a good example of what Priority 1 and 3A-4B should look like.

Facility Impact

Facility Impact counts all the WO tracked to a facility then sorts the facilities by the top 10 with the most WO closed. This way the base level leadership can see if any of the facilities are consuming an extra-large amount of time or attention. This graphic is setup by counting all the WO closed per facility number. It then sums the hours charged on each of these facility numbers as a point of reference for time spent on each WO. Next, the program sorts the count of WO closed per facility from high to low and removes all the facilities that are not in the top 10 from the dataset. The format of the dataset is converted to long format for plotting using the gather function (Wickham, 2017). The data is plotted on a bar chart using ggplot2 (Wickham, 2009). The purpose of this graph is to show the base level leadership which buildings are taking the most time. Looking at each facility number across the x-axis, the first bar shows how many WO closed in that facility. The second bar shows the total military hours charged to those WO closed, and the third bar shows the total civilian hours charged to the WO closed. Figure 7 shows an example Facility Impact chart for Dyess AFB.



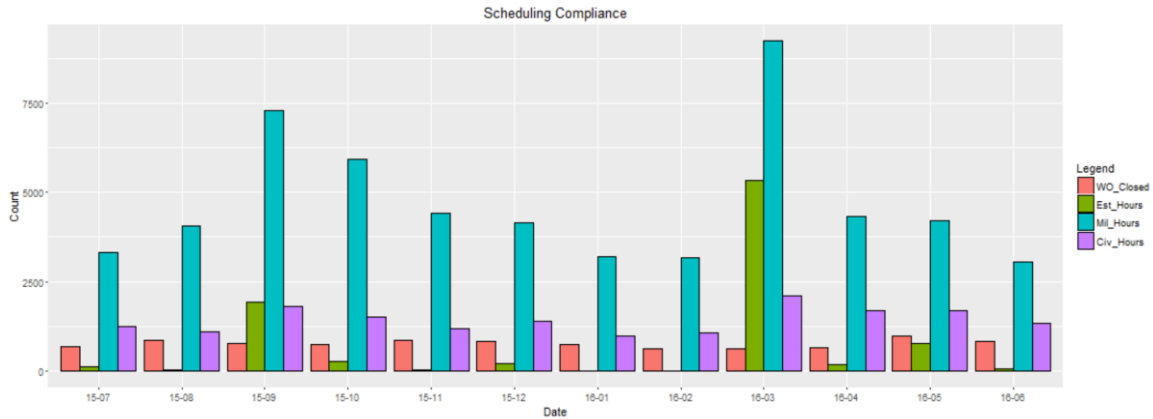
**Figure 7: Example Facility Impact Chart
(Dyess AFB, July 2015-June 2016)**

With the help of BUILDER™, the base level leadership can check the condition index of the building and identify problem systems or problem areas to fix at the project level. These buildings could have a variety of issues ranging from the facility age, the type construction, or the mission of the organization occupying the facility. Identifying the facility as an issue is the first step in fixing the problem.

Scheduling Compliance

Scheduling Compliance attempts to look at how accurately the shops are adhering to their scheduled hours. Each base schedules CM as WO come in. This unknown can lead to greater scheduling variance. However, each base knows the PM ahead of time and follows a recurring schedule. This research expects the high accuracy of PM schedules. In the Scheduling Compliance graph, the Est_Hours (or hours scheduled) should roughly equal the sum of Mil_Hours and Civ_Hours. If everything is accurately scheduled, then it would be possible to level resources by executing recurring work such as PM in off peak Corrective Maintenance (CM) times.

The R programming code builds the Scheduling Compliance graph by taking the reactive data from the dropdowns selections and adding a column taking each date closed and only tracking the month and year. The R code counts the amount of WO closed during each of those monthly timeframes and places them in a new table. This research also includes the counts of hours estimated, military hours charged, and civilian hours charged and add them to the table. The format of the dataset is converted to long format for plotting using the gather function (Wickham, 2017). The data is plotted on a bar chart using ggplot2 (Wickham, 2009).



**Figure 8: Example Facility Impact Chart
(Minot AFB, July 2015-June 2016)**

Reading the Facility Impact chart in Figure 8 shows each month YY-MM across the x-axis, the first bar shows how many WO closed in that facility. The second bar shows the sum of how many hours the base scheduled for each WO closed. The third bar shows the total military hours charged to those WO closed, and the fourth bar shows the total civilian hours charged to the WO closed. Theoretically, the scheduled hours bar should be approximately the same height as the military and civilian hours' bars combined.

Assumptions/Limitations

The main limitation for this research is incomplete or missing data. This research assumes that the data is representative of the data in IWIMS when pulled from the system, but there are large portions of inaccurate, nonsensical, or missing data. Initially, the analysis is only as good as the input data. Errors in data input may skew findings. However, continued use of the analysis application will identify the holes in the data and allow improvement in those areas. A second limitation of this research is the transition

from IWIMS to TRIRIGA. This limits the long-term usability of the R code. However, TRIRIGA is still too new in its implementation to have reliable data. The findings of this research will still apply, but the code will need continuous monitoring and improvement for continued use after the full implementation of TRIRIGA. The dataset put into TRIRIGA only contained one year of data. To show a better overall baseline of performance, it would be good to look at additional data.

IV. Analysis and Results

Chapter Overview

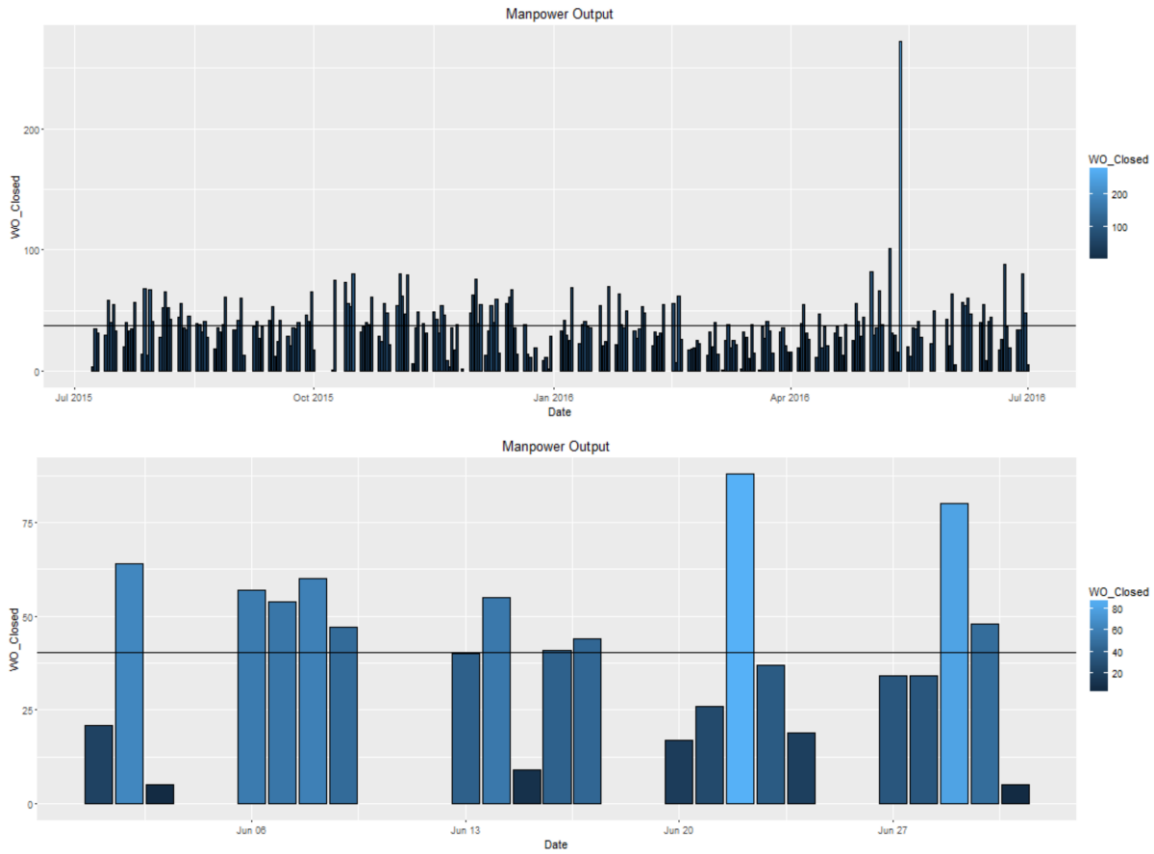
The web application data analysis tool used in this research study provides many different options via the sliders and drop down menus to look at individual details of each shop, priority, and timeframe at each base. Therefore, this analysis, and these results are based on just a few of the possible findings through this web application. Each graph set is covered and this research explores an example finding that is representative of a general theme or finding throughout the bases.

Analysis Methods and Findings

Manpower Output

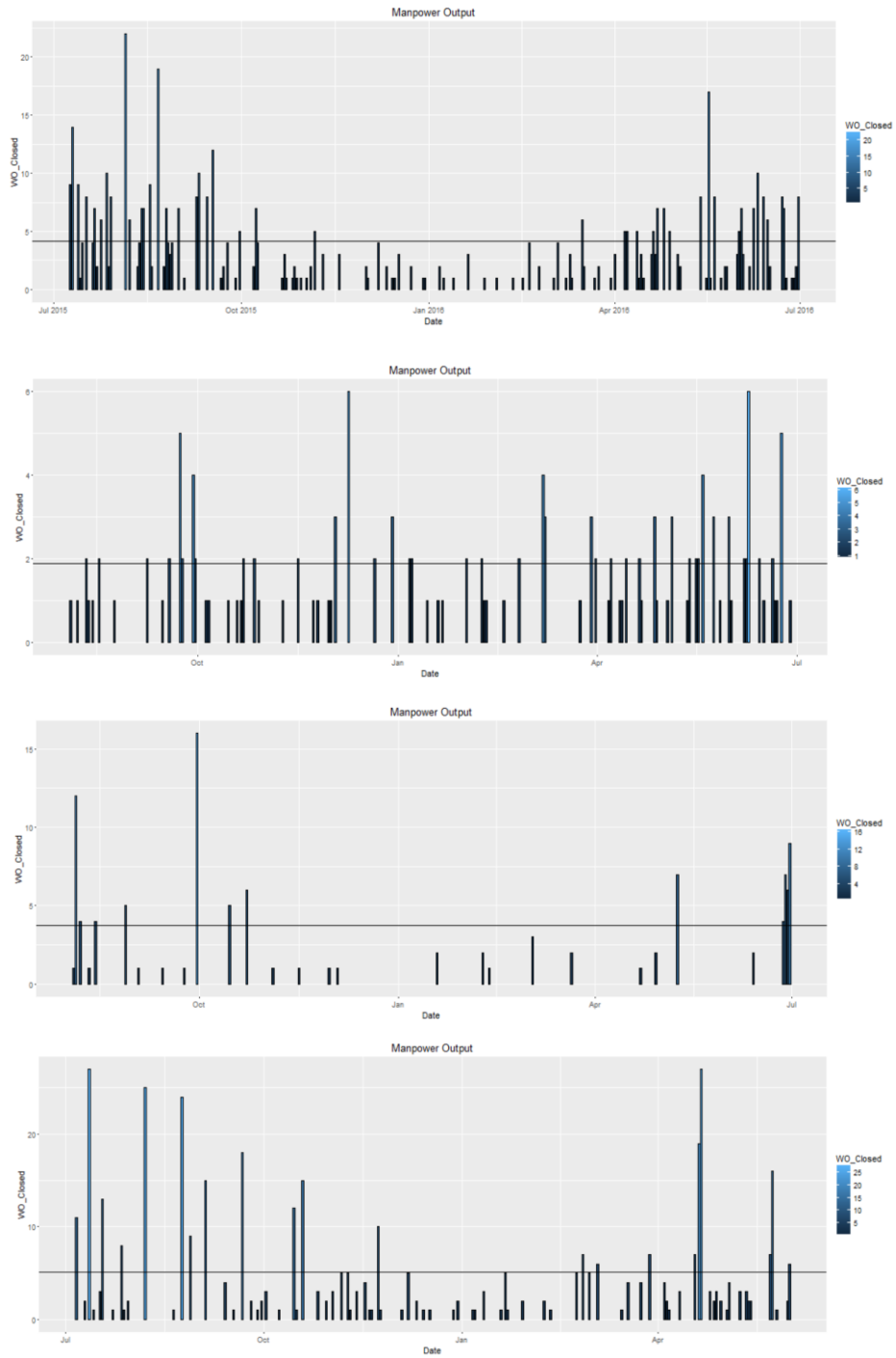
Analyzing Manpower Output is good for basic work output analysis but has helpful features in analyzing how recent output compares to the yearly average. It can also show how time of year affects certain shops and recognize certain anomalies in the data.

Comparing different timeframes for work output is helpful to see if there are changes in recent weeks or months compared to the status quo. This is particularly helpful if base level leadership has made changes to the output process or has attempted to increase motivation for a period. To show this capability, this analysis compares the most recent month of the dataset for Minot AFB to the data for the year in Figure 9. The results in this instance are minimal changes. The average for both daily WO closed hovers around 40.



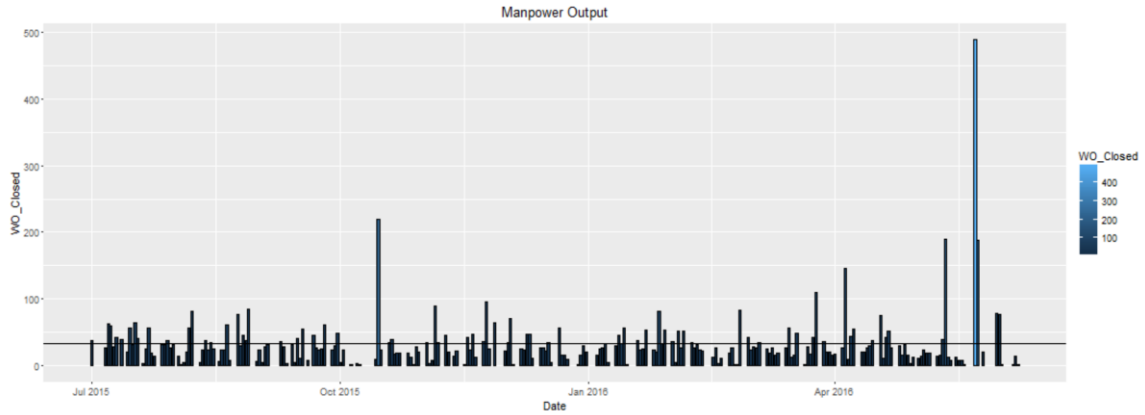
**Figure 9: Timeframe Comparison - Daily Manpower Output
(Minot AFB, July 2015-June 2016)
(Minot AFB, June 2016)**

Manpower Output is also an effective tool to compare times of year on different shops. Overall, the best example of how time of year affects certain shops is with the Entomology shop at Dover AFB. Season can affect both the ability to complete WO and the rate of WO coming in. At the onset of winter, Entomology has less work and the Manpower Output graph depicts this in Figure 10. This clarifies manning and requirements placed on each base or individual shop. The other base entomology shops are included for reference.



**Figure 10: Base Comparison - Entomology Daily Manpower Output
(Dover AFB, July 2015 – June 2016)
(Dyess AFB, July 2015 – June 2016)
(Minot AFB, July 2015 – June 2016)
(Scott AFB, July 2015 – June 2016)**

The Manpower Output graph is also helpful in recognizing data cleaning anomalies in the data. Figure 11 walks through the steps for one example of this is the single date where Scott AFB closed out nearly 489 WO in one day. To analyze this situation, reduce the range to focus on only that single day. Then, looking at the Data Table tab shows that 254 of the WO were over a year old and 141 were over two years old. This also shows that 121 of them were old 2A Preventive Maintenance WO that had never been closed out. This is a good example of how data can be misleading and shows the importance of the Data Table tab to be able to reference the underlying data. Finally, repeat these steps for each anomaly to understand what happened. Figure 12 shows the same graph for all four bases and points out examples of the anomalies. The y-axis is set for these graphs from 0-500 WO closed for continuity between graphs.



Air Force Maintenance and Repair Data Analysis

Please select the data you would like to analyze.

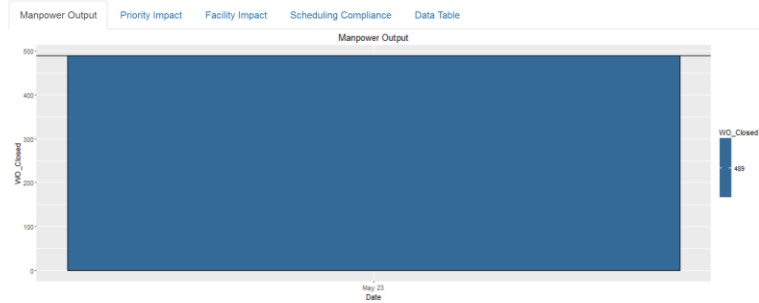
Base:

Shop:

Priority:

Date WO Closed Range:

Number of Days WO Open:



Air Force Maintenance and Repair Data Analysis

Please select the data you would like to analyze.

Base:

Shop:

Priority:

Date WO Closed Range:

Number of Days WO Open:

Manpower Output | Priority Impact | Facility Impact | Scheduling Compliance | Data Table

Show 25 entries

WO_Number	Title	Fac_Number	Shop	Priority	Est_Hrs	MIL_Hrs	Civ_Hrs	Date_Open	Date_Closed	Days_Open
03308	LIFT STATION INSPECTION	MULTI	SY		0	43.0	1331.8	2014-06-05	2016-05-23	718
06005	INSPECT STORM DRAINS BASEWIDE	08200	PX	2A	0	244.0	226.0	2013-03-22	2016-05-23	1158
06006	INSPECT/INSTL SIGNS BASEWIDE	06033	PX	2A	0	170.0	99.5	2013-03-22	2016-05-23	1158
06008	SQ VEHICLE CONTROL OFFICER	00517	PX	2A	0	177.5	10.0	2013-03-22	2016-05-23	1158
06113	(BASE)-TREE TRIMMING	91001	PX	2A	0	18.0	20.5	2013-03-22	2016-05-23	1158
06118	FIRE SYSTEM-WET PIPE 4"	00003	EC	2A	0	0.0	2.0	2013-04-10	2016-05-23	1139
06119	FIRE SYSTEM-PUMP INSPECTION	00003	EC	2A	0	2.6	5.0	2013-04-10	2016-05-23	1139
06120	FIRE SYSTEM-PREACTION 4"	00005	EC	2A	0	0.0	3.0	2013-04-10	2016-05-23	1139
06121	FIRE SYSTEM-DRY PIPE 3"	00005	EC	2A	0	6.0	3.4	2013-04-10	2016-05-23	1139

Figure 11: Anomaly Analysis - Daily Manpower Output

(Scott AFB, July 2015 – June 2016)

(Scott AFB, 23 May 2016)

(Scott AFB, 23 May 2016)

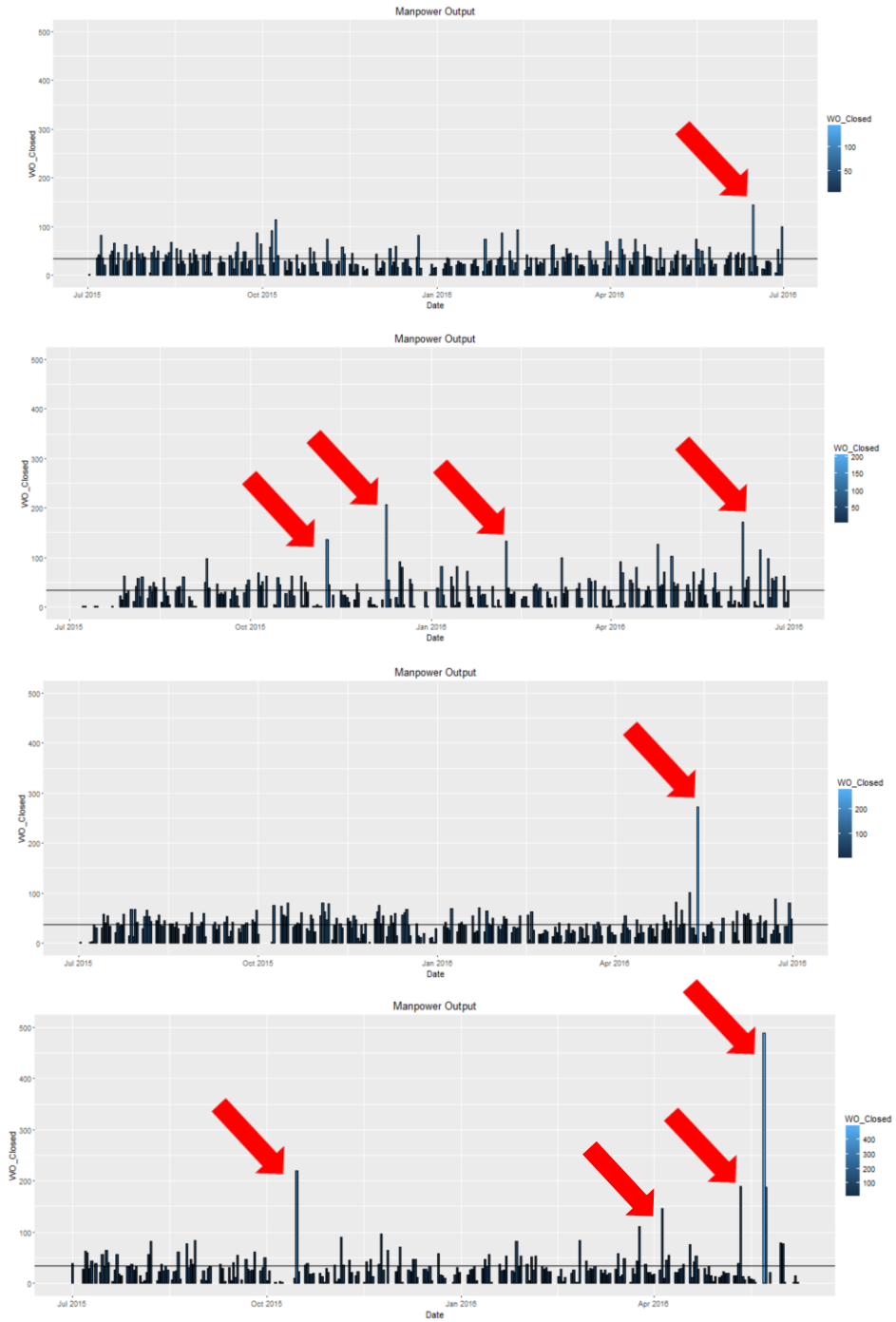
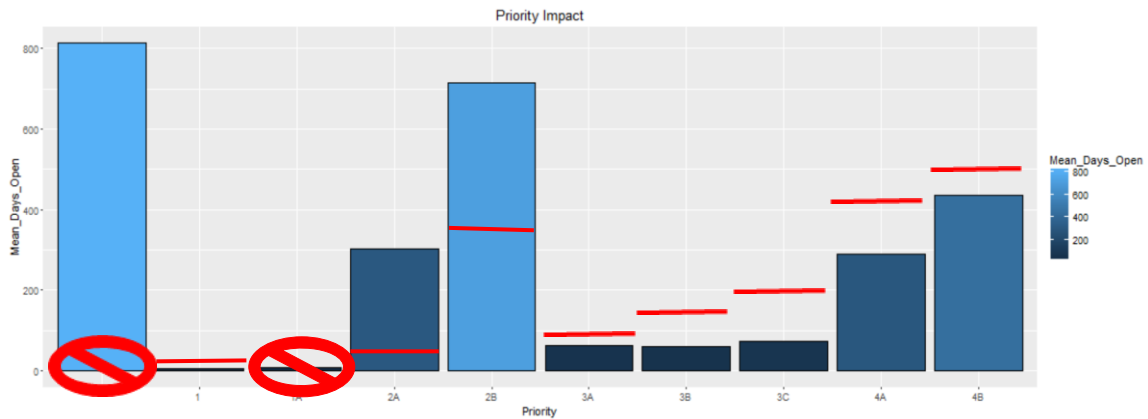


Figure 12: Base Comparison - Anomaly Analysis Daily Manpower Output
(Dover AFB, July 2015-June 2016)
(Dyess AFB, July 2015-June 2016)
(Minot AFB, July 2015-June 2016)
(Scott AFB, July 2015-June 2016)

Priority Impact

Analyzing Priority Impact is important because the new WO priority is one of the main tenants of the CE Transformation. The shift to place PM before CM is a key component to extending facility life. However, after exploring the Priority Impact graph, PM is only higher priority in theory. Looking at the data available in the Data Table, we find that Dover AFB, Dyess AFB, and Minot AFB all have less than three WO prioritized at 2A, so Scott AFB's Priority Impact is shown in Figure 13. The analysis of this graph results in some key takeaways.



**Figure 13: Mean Days Open by Priority
(Dover AFB, July 2015-June 2016)**

Figure 13 includes an example bar placed on the graph to show expected growth. Since the bars cross the projected height, priority 2A, 2B, and the unprioritized WO do require further investigation.

Scott AFB's 2A Preventive Maintenance WOs are the most concerning. Each bases should accomplish PM quickly and efficiently on a recurring basis. However, a mean closure nearing 1000 days means there is something wrong. Looking at the data in

the Data Table tab, it looks like they PM was set up but never accomplished or not closed out after accomplishing them. The lack of information or inaccurate information appears to be common for Priority 2A at each of the four bases. These inaccuracies are due to ineffective methods of entering PM in IWIMS.

Priority 2B is Contingency Construction Training and consists of one large WO per year that serves as deployment training for the unit. This complex task should take more time than the other WO but should not extend past one year. It makes sense that Priority 2B should not follow the same trend as the other priorities based on its inherently large scale, but it should not exceed 365 days. Looking at the Data Table tab for Priority 2B at Scott AFB, it looks like the only issue is that the previous two years' Contingency Construction Training projects Scott AFB did not close out the WO completely during the actual training year.

Finally, looking at the Data Table tab there are 219 WO without a priority. The blank priority is included in the Priority Impact tab to catch this and identify that there are WO being closed that do not have priorities. If each base accurately assigns all the WO priorities, the blank priority then no priority bar will not show up on the Priority Impact graph. Figure 14 shows an example from all the bases for reference. This shows how Priority 2A being overlooked and unprioritized WO are common issues.

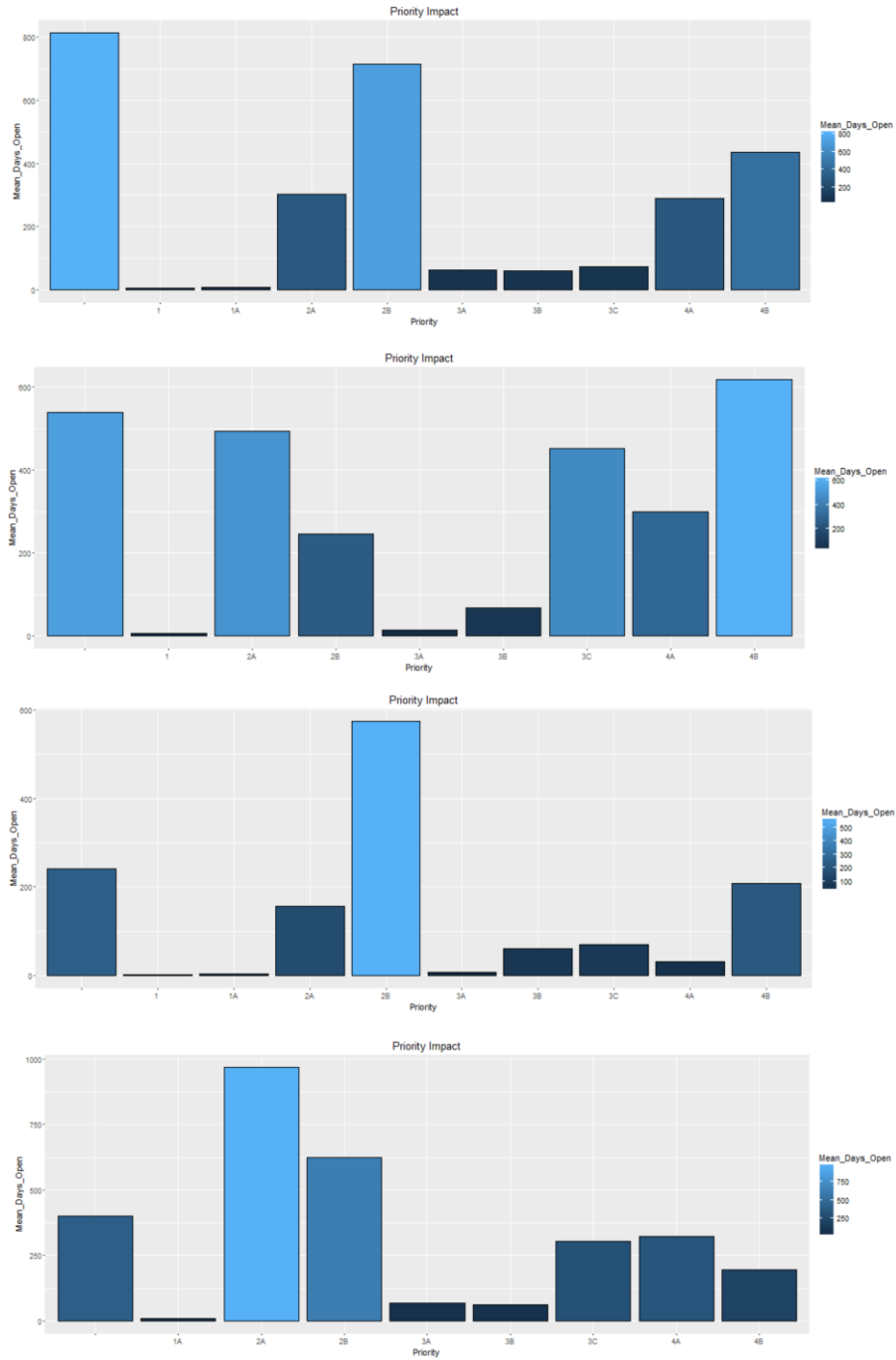
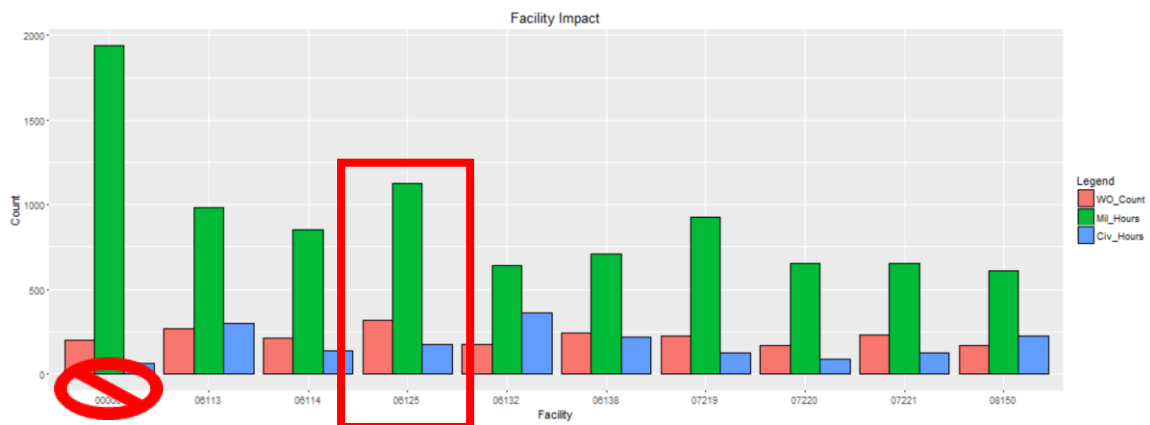


Figure 14: Base Comparison - Mean Days Open by Priority
(Dover AFB, July 2015-June 2016)
(Dyess AFB, July 2015-June 2016)
(Minot AFB, July 2015-June 2016)
(Scott AFB, July 2015-June 2016)

Facility Impact

The Facility Impact graph is a good quick-check graph to see which facilities each shop is going back to the most often. Its analysis is straightforward. The Facility Impact graph shows the top 10 most returned to facilities. Figure 15 is looking at Dyess AFB's top 10 facilities with the most closed WO over the past year. This graph shows where the F&MR personnel must return the most often. Building 06125 has had 323 WO completed over the last year including 141 to just the HVAC shop. This identifies an issue with the overall HVAC system. This finding should include consulting and updating BUILDER™. This information provides significant justification for either a new HVAC system or even a new facility.

The second result pulled from this analysis is the prevalence of the use of Facility number 0000. Catch all facility numbers or missing facility numbers is an example of poor data management, and the CE Transformation integration of utility linear segmentation should put an end to this practice. Figure 16 shows all four bases for reference.



**Figure 15: Top 10 Most Burdensome Facilities
(Dyess AFB, July 2015-June 2016)**

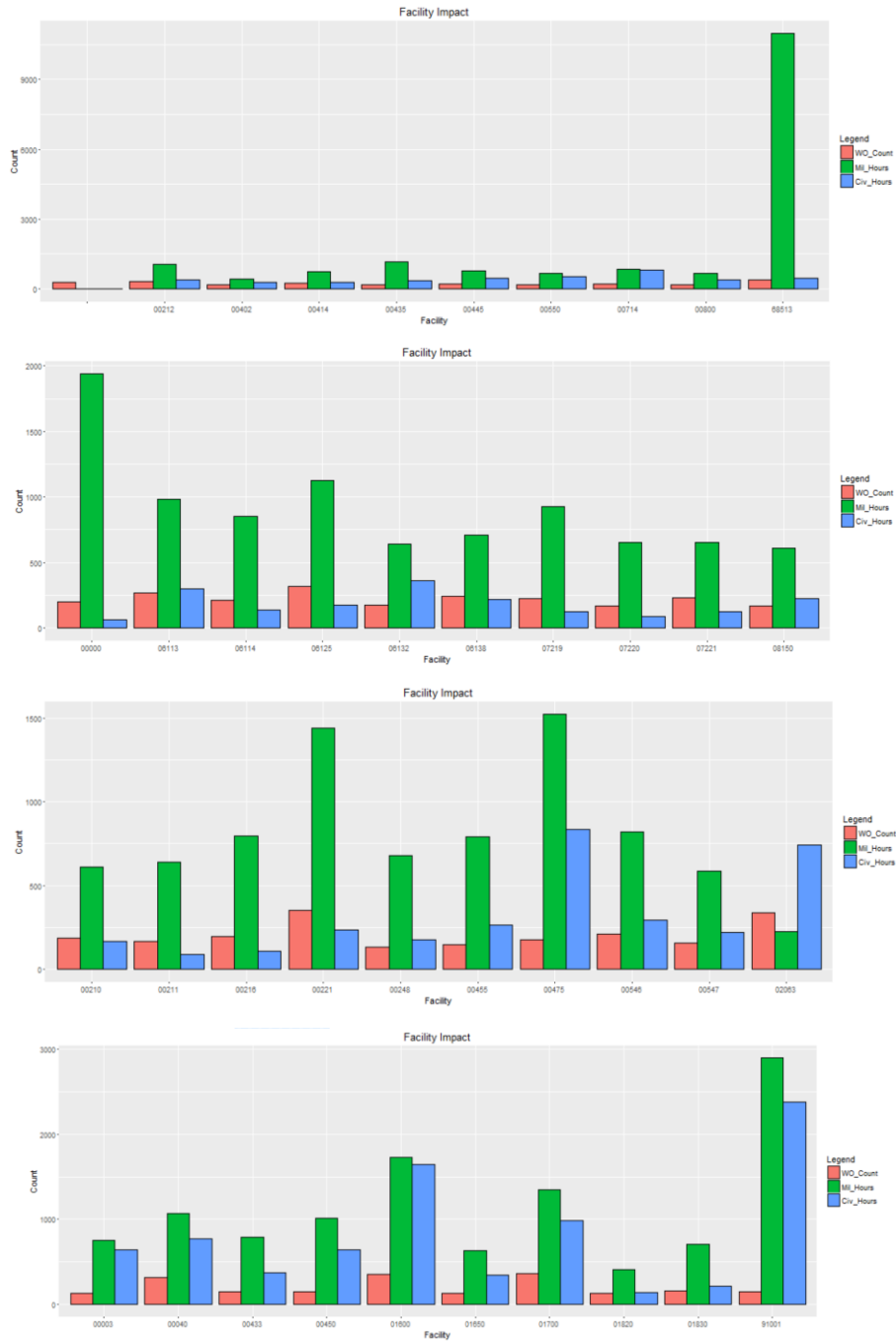
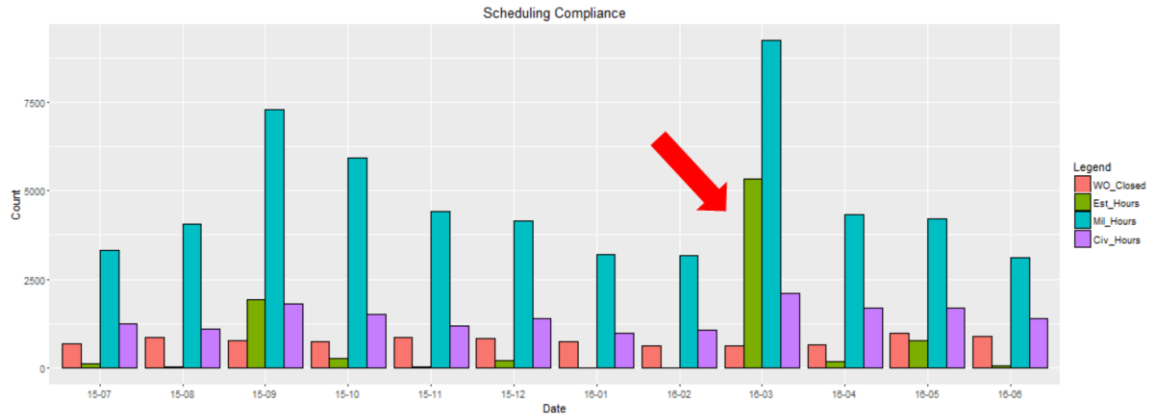


Figure 16: Base Comparison - Top 10 Most Burdensome Facilities
(Dover AFB, July 2015-June 2016)
(Dyess AFB, July 2015-June 2016)
(Minot AFB, July 2015-June 2016)
(Scott AFB, July 2015-June 2016)

Scheduling Compliance

This research adds Scheduling Compliance to analyze how accurately shops were estimating the upcoming workload and see if there was potential for resource leveling. However, as shown in the analysis of Minot AFB's data shown in Figure 17, the estimated hours for each WO were either non-existent or vastly underestimated. The other three bases show the same issue as seen in Figure 18. If base level leadership would like to see if there are benefits from work scheduling, they will need to assess and schedule work more consistently.



WO_Number	Title	Fac_Number	Shop	Priority	Est_Hrs	Mil_Hrs	Civ_Hrs
79784	SEAL CRACKS IN BASE ROADS	01912	PX		1200	1076.0	0.0
79780	AIRFIELD RUNWAY CLOSURE	01917	PX		1000	1747.0	0.0
79753	REPAIR SIDEWALK (292)	01908	PX	4B	700	758.5	0.0
79786	DEMO FACILITY	01082	PX		500	547.0	0.0
79058	REPLACE ROLL UP DOORS	00777	1A		300	164.8	81.0
79320	REPLACE/REPAIR BAY DOORS (16)	00543	1A		300	122.5	45.0

**Figure 17: Scheduling Compliance
(Minot AFB, July 2015-June 2016)**

Users can easily assess abnormal data by selecting the data in that timeframe, March 2016 in Figure 17, then looking at the Data Table and sorting by estimated hours. In this case, the data shows two large WO closed out during this month that skews the data. This graph also shows the rough estimate of percentage military to civilian hours. All four of these bases are between 70-80 percent military and the data in Figure 18 reflects that larger military workload.



Figure 18: Base Comparison - Scheduling Compliance
(Dover AFB, July 2015-June 2016)
(Dyess AFB, July 2015-June 2016)
(Minot AFB, July 2015-June 2016)
(Scott AFB, July 2015-June 2016)

Investigative Questions Answered

How does the USAF look at FM&R performance and which factors are expected to affect performance?

Although the USAF does not have specific FM&R performance measures identified, this research explores the use of performance based on output and in the case of FM&R, output is WO closed. Based on the outcomes of the analysis, this research finds that WO priority, facility, and schedule each affect performance and shows that each of these factors do influence WO output. However, the data analyzed did not have enough complete and accurate information to perform statistical analysis. WO Priority appeared to affect the output as expected, and the lower priority WOs had slower closure rates. The exception to this was the 2A Preventive Maintenance WOs that were predominantly either non-existent or inaccurate. The facility impact did show where the output was overabundant showing where manpower was continuously used fixing the same recurring problems. Overall, this research started a foundation to build on for future FM&R performance research.

How can the USAF use readily available software to better analyze FM&R performance?

This research has shown how a combination of R capabilities is useful to analyze data using the same analysis code for multiple bases. R has many advantages over Excel and presents the opportunity to apply one preset tool to multiple bases.

This research uses a standardized data format pulled into R and analyzed, and then uses the Shiny web application framework the data can be analyzed interactively to

allow deeper analysis with ease and investigate apparent anomalies. This research only began to realize the full capabilities of R and it has already proven useful and effective.

What issues inhibiting FM&R performance or performance analysis are common between USAF installations?

Maintenance and repair outputs vary from base to base but have some findings in common. When the bases are compared side by side, base size and season appear to have an effect, but it is not as large as expected. The most common inhibiting factor was the failure to prioritize Priority 2A Preventive Maintenance. Large close out spikes of Manpower Output data appeared through all four bases and each base failed to estimate work consistently. This research opens the door for continued exploration of differences and perhaps efficiencies between bases.

V. Conclusions and Recommendations

Chapter Overview

The overall conclusions of this research are that R is an excellent tool that applicable throughout the USAF for maintenance and repair data analysis at a time where CE information technologies appear to have a lack of capability in data analysis. Furthermore, although this research can extrapolate some helpful findings from this data, information input into the data sources needs to be much more accurate and comprehensive.

Conclusions of Research

The most significant conclusion of this research is in the potential applicability and use of R in combination Shiny package for a web application and the ggplot2 package for data analysis graphics. Its capabilities give it applicability for use to any standardized data pull, at any base, with the potential to draw from multiple sources. This is easier and more efficient than using a macro in Excel and has better interactive qualities and interoperability through the web application format.

This analysis confirms the need for data analysis of this type. If bases performed data analysis on a regular basis, many of the issues identified through this research would not be an issue. Furthermore, the fact this research developed the R programming code and Shiny web application for one base but accurately analyzes all four bases, shows the potential applicability at CE Squadrons USAF wide.

The most common finding stems from the need for more accurate recording. If the data is not recorded accurately, completely, and consistently, its usefulness is severely

compromised. Bases leave WO open well beyond their need and bases enter many important data points erroneously. This leads to large amounts of variance in the data before assessing the variance introduced by true external factors. This research also made progress on improved ways to assess maintenance and repair performance finding that looking at WO closure over time can be a proficient means of assessing performance, and that looking at mean days a WO is open can show how rigidly a base is committed to following the new WO priority system.

Significance of Research

This research has the potential to be very helpful at multiple levels of leadership in the CE community. Performance data analysis is important but under executed likely because of the lack of an efficient method. This research contributes by extracting findings through visual analysis from existing data shown in a way that an everyday user can understand it. It also sets a baseline that shows the quality of the data to see if the implementation of TRIRIGA improves data gathering accuracy and usability. It also helps CE customer education. The graphs produced can give an accurate assessment of the work output of the squadron and help the CE customer understand how their WO falls into the bigger picture. Overall, this research gives the CE base-level leadership an outline for how to standardize and efficiently analyze maintenance and repair performance.

Recommendations for Action

There are several recommendations resulting from this research. The first is to implement a process for old record cleanout and to fix inaccurate data. Bases need a way

to remove incomplete WO because of low priority or because they are old. They also need to delete or fix the data if inaccurate because simply closing them makes them look complete. It shows that they provided an action fixing an issue when they let the WO sit until a new WO took its place or there was no longer a requirement for that WO. An example of inaccurate data that needs to be corrected is that Scott AFB and Minot AFB use Priority 1A extensively. Priority 1A does not exist. Emergency WO are Priority 1. These bases should start entering future Priority 1 WO accordingly. Data points that are not tracked consistently and accurately waste the valuable time of the FM&R personnel.

The intent of AFI 32-1001 explains the importance of PM. Before the CE Transformation, PM (formally known as Recurring Work Program) bases commonly either delayed or ignored all together. To prevent this from happening, the CE Transformation raised the PM priority. Unfortunately, it looks like the postponement and ignoring of PM is continuing or IWIMS lacks capabilities for accurate PM scheduling and assessment.

Finally, this research recommends performing data analysis. Even if base leadership uses another method, program, or software to look at the data, continued implementation of data analysis allows improvement. It identifies errors in the data collection and can help remove variance and improve performance through changes to the maintenance and repair process. If the data is not helpful in data analysis, then this research suggest bases stop tracking those data points. This effort becomes waste and degrades efficiencies in performance.

Recommendations for Future Research

Data Quality Analysis

Based on the findings of the poor-quality accuracy and completeness of the data, it would be helpful to look at open WO and analyze for inconsistencies and missing data. Many of the inaccuracies in the data found through this analysis serve little purpose fixing since the WO in this analysis are already closed. However, looking at open WO allows time to correct the inaccuracies. Looking at longest open WO can help remove WO before they become obsolete and can prevent spikes in WO closed by preventing the need for old data cleanout. During the data-cleaning portion of this analysis, it is important to add a table of all WO removed from the analysis. This allows bases to delete or fix their WO before closure to ensure accurate performance analysis.

Additional Data Sources and Deeper Analysis

The main limitations of this research revolved around data. Future research should focus on TRIRIGA because it will soon become the primary data collection source. Adapting the code to input and assess the outputs from TRIRIGA is the next step forward. TRIRIGA is supposed to incorporate BUILDER™ data, but if it does not, information from BUILDER™ would be extremely helpful in improving the Facility Impact analysis. Furthermore, the manning document and typical deployment battle rhythm would explain more of the unknown variance in the Manpower Output and help create an output efficiency metric. There are more metrics available for analysis, and future research can improve on the existing analysis methods. Potential metrics to be Output Efficiency seen in Figure 19 shows average hours charged per WO building on

Manpower Output, look at facility type using facility codes building on Facility Impact, or Indirect vs Direct hours instead of Scheduling Compliance.

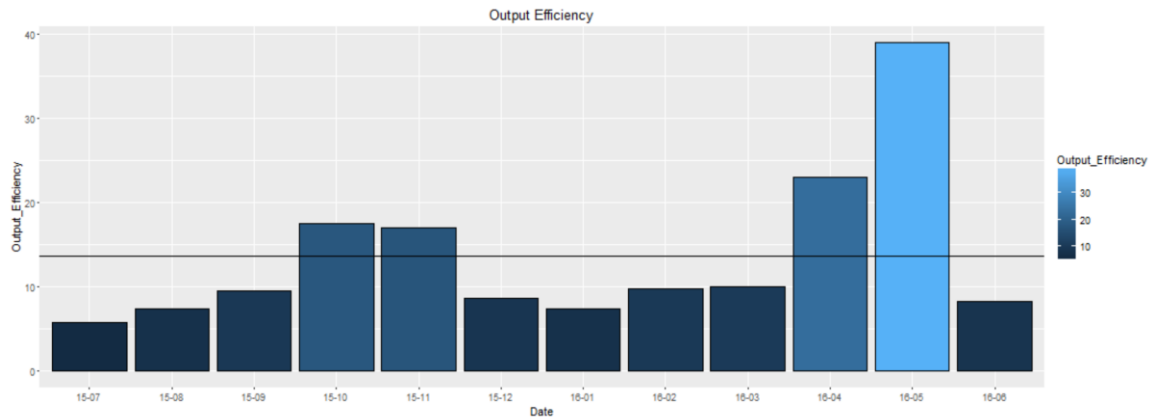


Figure 19: Monthly Output Efficiency
(Scott AFB, July 2015-June 2016)

As the data improves, future research should include improved statistical analysis. Box plots replacing of bar charts are more informative, and analysis of variance (ANOVA) can show statistical significance of factors affecting performance. As seen in Figure 20, even additional drop downs to increase interactive plotting capabilities can have a profound effect on future research.

Air Force Maintenance and Repair Data Analysis

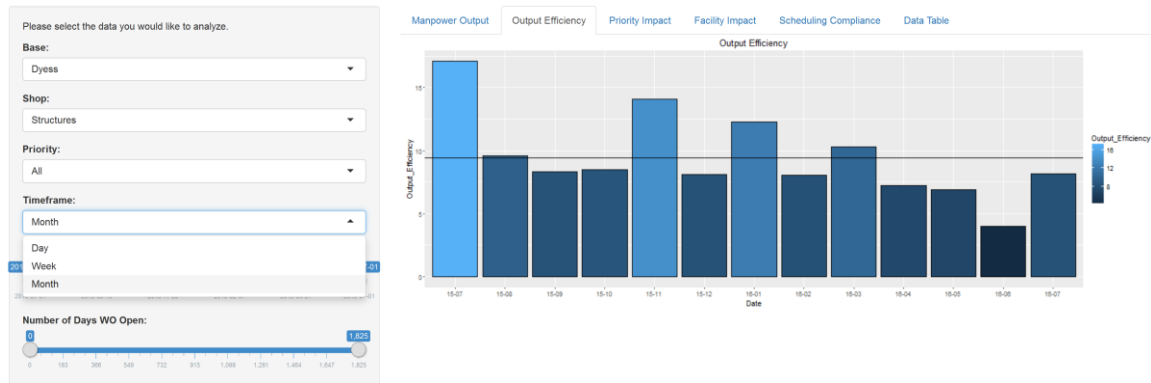


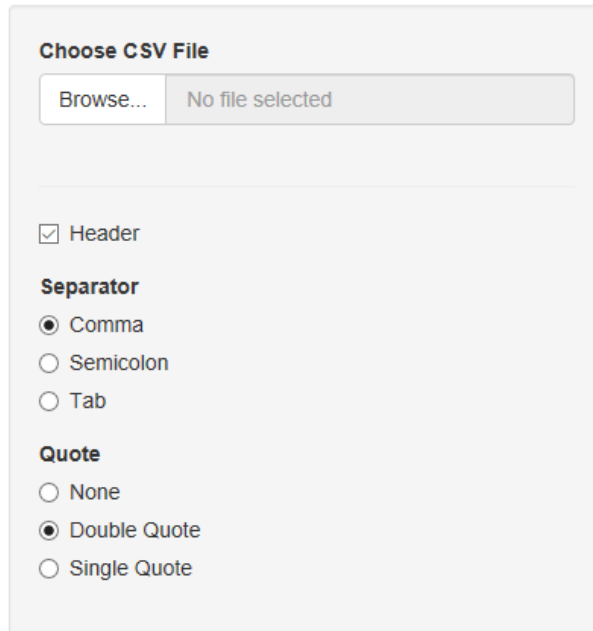
Figure 20: New Dropdown Capabilities

Overall, more data sources make a more comprehensive study when independent data streams are combined, more sources of variance are analyzed and additional methods of analysis are explored. There is room for improvement in all key areas.

Field Testing

Testing the application at actual bases will provide the most beneficial feedback on how to improve the capabilities of this application. The foremost experts on maintenance and repair at each base are the ones executing the maintenance and repair. Future research would need to modify the code to accept external data inputs shown in Figure 21 or scrape the data directly from the data sources. If the individual base leadership looks at the analysis, they will be able to draw conclusions that are more accurate and provide better feedback for application improvement.

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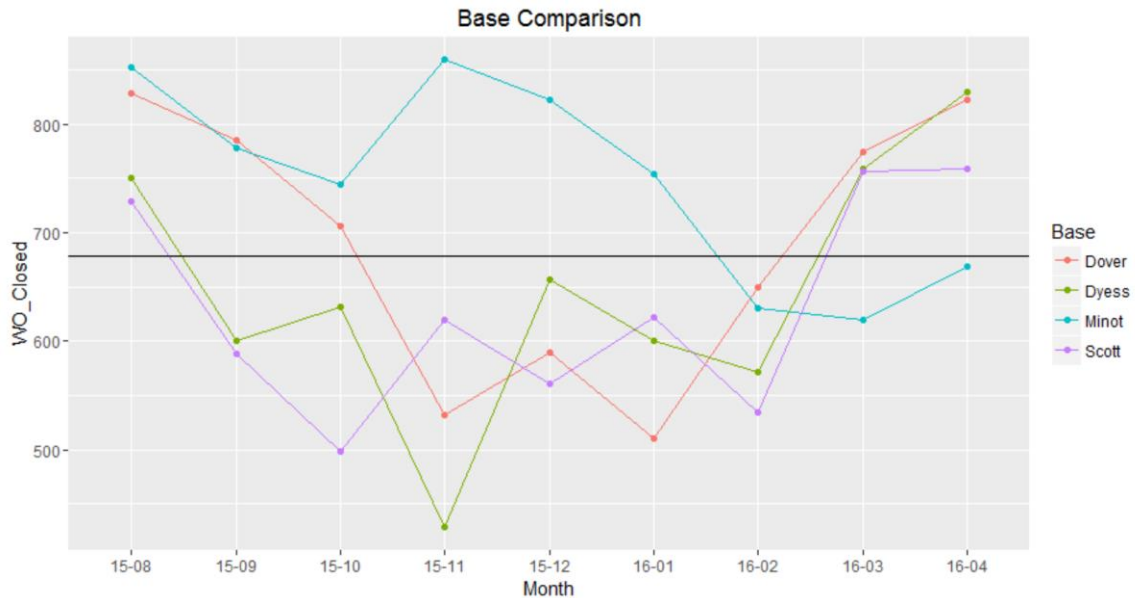
Figure 21: Individual Base Data Load Capability

Higher-Level Leadership Focused

Finally, future research could adapt an R based web application to look at each base from a higher-level standpoint. This would include much more base comparison such as looking at an entire Major Command (MAJCOM) of bases. This research would take the data from multiple bases and incorporate it into one graph. This research also briefly explored the possibility of the comparison between bases to assess additional applicability. This is a higher-level leadership approach, but the need for data analysis is the same. Multiple bases were included in this research to show the universal applicability of the evaluation system between bases.

The R code for this graph takes each base's data and looking at only August 2015 through April 2016. This is the area where the data pulled for all four bases overlap.

Next, the R code takes the month and year from the date the WO closed and counts the WO closed during each month. The data from each base is stacked and graphed using a line graph and a mean line for the overall WO closed per month shown in Figure 9.



**Figure 22: Example Base Comparison Chart
(July 2015-June 2016)**

The base comparison is helpful to see how the bases compare in their outputs. This could be helpful at higher leadership levels if one similar size base is doing better at a metric, they can use that base and its best practices. It also does a good job showing the overall status of the different bases. For the bases involved in this research, Minot AFB has the largest Operations Flight of roughly 300 military and civilian, and the other three range from about 160 to 190. Looking at the base comparison below, Minot AFB does have a higher output, but not in comparison to the larger number of personnel. There are other factors to consider, but these findings do begin to show the capabilities of an R based web application for base comparison.

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Vita

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