A VISUALIZATION DEVELOPMENT PROCESS
FOR A MILITARY SETTING

A Thesis in
Industrial Engineering

by
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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

December 2013
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ABSTRACT

Information visualization allows users to interpret large quantities of data in order to efficiently make decisions. Visualizations are often selected by what is the easiest to create or what has been done in the past. However, haphazardly chosen visualizations may cause confusion and incorrect interpretation of the data. The author proposes a systematic process that will assist analysts in designing an appropriate visualization for their users in a military setting based on their data and goals. To assess the proposed process, the author demonstrates the method with an oil life model project. A user jury was conducted in order to determine preferences between visualizations developed through the process. The results indicate that the process is successful in developing visualizations for a military environment. The visualization development process can be further developed and evaluated by using it on future projects.
# TABLE OF CONTENTS

List of Figures .................................................................................................................. vi

List of Tables ..................................................................................................................... viii

Acknowledgements ............................................................................................................ ix

Chapter 1 Introduction ....................................................................................................... 1

1.1 Problem Statement ....................................................................................................... 1
1.2 Motivation ...................................................................................................................... 3
1.3 Research Objectives ..................................................................................................... 3
1.4 Thesis Organization ...................................................................................................... 4

Chapter 2 Literature Review ............................................................................................... 5

2.1 Information Processing ............................................................................................... 5
2.2 Information Visualization ............................................................................................. 10
2.3 Information Visualization in the Military ...................................................................... 18
2.4 Structured Interviews ................................................................................................. 19
2.5 Oil Life Algorithm ...................................................................................................... 21

Chapter 3 Proposed Visualization Development Process ............................................... 23

3.1 Phase 1: Analyze Project and Data ............................................................................ 24
3.2 Phase 2: Initial User Interview ................................................................................... 26
3.3 Phase 3: User Jury ....................................................................................................... 28

Chapter 4 Demonstrating the Visualization Development Process .................................. 32

4.1 Phase 1: Oil Life Project ............................................................................................. 32
4.2 Phase 2: Battalion Maintenance Officer Interview ................................................... 35
4.3 Phase 3: Maintainer User Jury .................................................................................. 41
    4.3.1 Case Study 1: Battalion Maintenance Officer ..................................................... 42
    4.3.2 Case Study 2: Maintainer .................................................................................. 45
    4.3.3 Case Study 3: Motor Sergeant .......................................................................... 47
    4.3.4 Case Study 4: Support Supervisor .................................................................... 48
4.4 Analysis ....................................................................................................................... 50

Chapter 5 Conclusions and Future Work ......................................................................... 53

5.1 Summary and Conclusions ....................................................................................... 53
5.2 Future Work ................................................................................................................. 55

References ......................................................................................................................... 57
Appendix A Phase 2 Interview Script ................................................................. 61
Appendix B Visualizations for FMTVs ............................................................ 64
Appendix C Visualizations for HEMTTs ......................................................... 73
Appendix D Visualizations for LHSs ............................................................... 79
Appendix E Visualizations for Line Hauls ...................................................... 84
Appendix F Visualizations for PLSs ............................................................... 88
Appendix G User Jury Script ......................................................................... 97
LIST OF FIGURES

Figure 2-1: Atkinson & Shiffrin (1968) Multi-Store Model ......................................................... 7
Figure 2-2: Variant of Snow’s Map of Cholera Deaths in London .............................................. 12
Figure 2-3: Minard’s Napoleon’s March on Russia ................................................................. 13
Figure 2-4: Schofield’s Joseph Priestly Timeline ........................................................................ 13
Figure 2-5: Orientation Preattentive Process (Ware, 2012, pg. 154) ........................................... 14
Figure 2-6: Bertin’s Sorting of Encoding Mechanisms ............................................................. 16
Figure 2-7: Cleveland and McGill’s Encoding Mechanisms for Quantitative Data ................. 17
Figure 2-8: Mackinlay’s Sorted Mechanisms for Quantitative, Ordinal, and Categorical Data .......................................................................................................................... 17
Figure 3-1: Proposed Visualization Development Process .................................................... 23
Figure 3-2: Visualization Tree ................................................................................................... 25
Figure B-1: Percent Oil Life Remaining for FMTV Vehicles .................................................... 66
Figure B-2: Percent Oil Life Remaining for FMTV Vehicles Including Standard Deviations ........................................................................................................................... 67
Figure B-3: Days vs. Distance Traveled Since Oil Change for FMTVs ........................................... 68
Figure B-4: Days vs. Distance Traveled Since Oil Change Cluster 1 for FMTVs ..................... 69
Figure B-5: Days vs. Distance Traveled Since Oil Change Cluster 2 for FMTVs .................... 70
Figure B-6: Engine Hours vs. Distance Traveled Since Oil Change for FMTVs ....................... 71
Figure B-7: Engine Hours vs. Distance Traveled Since Oil Change Bottom Cluster for FMTVs ............................................................................................................................... 72
Figure C-1: Percent Oil Life Remaining for HEMTT Vehicles .................................................. 74
Figure C-2: Percent Oil Life Remaining for HEMTT Vehicles Including Standard Deviations .......................................................................................................................... 75
Figure C-3: Days vs. Distance Traveled Since Oil Change for HEMTTs .................................... 76
Figure C-4: Engine Hours vs. Distance Traveled Since Oil Change for HEMTTs ..................... 77
Figure C-5: Engine Hours vs. Distance Traveled Since Oil Change Bottom Cluster for HEMTTs ............................................................................................................................... 78
Figure D-1: Percent Oil Life Remaining for LHS Vehicles ................................................. 80
Figure D-2: Percent Oil Life Remaining for LHS Vehicles Including Standard Deviations... 81
Figure D-3: Days vs. Distance Traveled Since Oil Change for LHSs ................................. 82
Figure D-4: Engine Hours vs. Distance Traveled Since Oil Change for LHSs ................. 83
Figure E-1: Percent Oil Life Remaining for Line Haul Vehicles ..................................... 85
Figure E-2: Days vs. Distance Traveled Since Oil Change for Line Hauls ................. 86
Figure E-3: Engine Hours vs. Distance Traveled Since Oil Change for Line Hauls ........ 87
Figure F-1: Percent Oil Life Remaining for PLS Vehicles ................................................ 90
Figure F-2: Percent Oil Life Remaining for PLS Vehicles Including Standard Deviations .... 91
Figure F-3: Days vs. Distance Traveled Since Oil Change for PLSs ................................. 92
Figure F-4: Days vs. Distance Traveled Since Oil Change Cluster 1 for PLSs ............... 93
Figure F-5: Days vs. Distance Traveled Since Oil Change Cluster 2 for PLSs ............... 94
Figure F-6: Days vs. Distance Traveled Since Oil Change Cluster 3 for PLSs ............... 95
Figure F-7: Engine Hours vs. Distance Traveled Since Oil Change for PLS ................. 96
LIST OF TABLES

Table 4-1: Comparison Chart for the User Jury.................................................................50
Table B-1: Data Spreadsheet for FMTVs ........................................................................64
Table C-1: Data Spreadsheet for HEMTTs.................................................................73
Table D-1: Data Spreadsheet for LHSs.......................................................................79
Table E-1: Data Spreadsheet for Line Hauls .............................................................84
Table F-1: Data Spreadsheet for PLSs ......................................................................88
ACKNOWLEDGEMENTS

I would like to thank the Applied Research Laboratory at the Pennsylvania State University, specifically Jeff Banks, Matt Rigdon, and Mark Brought, for their assistance and allowing me to use their resources throughout this work. I would also like to thank Dr. Ling Rothrock for his guidance, inspiration, and support on this work. Thank you to the members of the Pennsylvania National Guard for their time and assistance. Lastly, I would like to thank my parents, John and Sally, my siblings, John and Caroline, my boyfriend, Jordan, and all of my family and friends for their continuous love and support throughout my journey.
Chapter 1

Introduction

1.1 Problem Statement

Every organization today, no matter what industry they belong to, is in possession of a significant amount of data. A common problem that organizations have is knowing how to usefully apply this data to the workplace. The analysts in an organization are required to sort through large quantities of raw data in order to manipulate them into readable files by converting the relevant data into a manageable format and deleting the irrelevant data. Once the data is compiled and organized, the next step is to identify how the most information can be readily gathered from it. In short, how should the data be displayed in order for observers to best understand what it represents?

Commonly, data is displayed simply in a table or spreadsheet format. In other occasions, various charts and graphs are used to try to express what the data is saying. How do analysts determine which type of visualization to use? There are common-knowledge guidelines that most analysts are aware of. For example, if time is a variable, a time-series plot is most applicable; or a histogram is appropriate to observe the distribution of the data. Even with these rules, they often choose the graph that was used last time or that someone told them to use. Choosing a visualization type in this haphazard manner may cause confusion or incorrect interpretation of the data. It is essential that an appropriate graph be utilized because organizations will use these displays to further analyze the data.

Military organizations are continually collecting large amounts of data from the field, whether it is from vehicles, drones, or soldiers on the ground. However, this causes the military
to have to find a balance between how to help soldiers utilize the data properly and how to keep them from being overwhelmed with the large amount of data they are receiving (Shanker and Richtel, 2011). Analysts have taken this data and studied it in order to give deliverables back to the military, but the issue has emerged where the visualizations of the data are not translating to the soldiers working in the field. Technological advances, while helpful in creating new visualizations, are being designed without considering the military personnel that will be using them (Barnes, 1997). A systemized process is therefore needed through which visualizations can be created so that any potential users will be able to understand and analyze the data represented in the graphical representations.

Inspired by working with the analysts at the Applied Research Laboratory, ARL, this research effort developed a process that allows analysts to systematically create visualizations for their military clients. Workers at ARL are tasked with observing data and determining the best ways to learn how the military is using their vehicles. When returning results to the military, the information is only partially translated because of the incorrect use of data visualization techniques. “Effective synergy between humans and visualization systems must be based on design principles that engender human strengths and limitations,” (Barnes, 2003, pg. 1). When working with the military, it is crucial to be thorough because they are in charge of protecting the country and its citizens. Another aspect to keep in mind when working with soldiers is that they may not have training or experience to integrate complex data, whether in raw form or a visualization format. This work aimed to give the military analysts step-by-step instructions on creating the best interfaces for their clients. The systematic procedure will be called the visualization development process.
1.2 Motivation

This research is motivated by the need to have a methodical process to develop and produce beneficial interfaces that will allow the military clients to more efficiently make decisions. While some people are knowledgeable of different types of graphs and when they should be used, the general population is not. If an inappropriate visualization is chosen, observers may not be able to understand the data. This is especially crucial to the military industry because they are required to make time sensitive decisions every day with some decisions involving safety risks for both the soldiers and civilians. If the military personnel are given a graph that they cannot understand, they may be delayed in making the decision or may not be able to make it at all. Using proper information interfaces can allow military personnel to see and understand large quantities of data in a smaller amount of time. Therefore, it is essential that the data analysts choose an appropriate visualization display.

1.3 Research Objectives

Data analysts know how to manipulate and evaluate data, but that does not mean the researchers understand how to present the results to their customer. Therefore, the primary goal of this research is to develop a systematic process that helps the analysts to determine the data visualization tools that are the most beneficial to their client. In this thesis research, the process will be referred to as the visualization development process. The process gives analysts step-by-step instructions that will assist them in creating interfaces for their military customers. The secondary goal is to demonstrate and evaluate the visualization development process through a case study. The project will involve the decision making process that maintainers take when changing the oil in military vehicles. Because potential users of the developed visualizations will
be interviewed, their answers will provide direct information about the proposed process. If the process is successful in discovering potential visualizations, it will allow for the military analysts to have a systematic method in developing visualizations for each of their projects.

1.4 Thesis Organization

Chapter 1 contains an introduction to the research, which is comprised of the problem statement, the motivation, and the research objectives. Chapter 2 reviews literature of the past-related work on several topics, including information visualization, information processing, and structured interviews. Chapter 3 discusses the phases of the proposed visualization development process and what steps analysts should take when creating visualizations for a military setting. Chapter 4 presents a case study, involving an oil life model, using the development process and discusses the results from the user jury. Chapter 5 gives a summary of the research, provides conclusions on the proposed process, and discusses possibilities for future work.
Chapter 2

Literature Review

In order to create the visualization development process, related work was researched and reviewed. Information process theory was surveyed to understand how the human cognitively observes and understands stimuli. Information visualization, both in general and in a military setting, was researched. Using interviews to extract information from potential users was explored. Lastly, the project that will be used to demonstrate the visualization development process as applied to an oil life algorithm, and the research behind this algorithm will be explained.

2.1 Information Processing

Despite decades of research and several proposed models, the process humans take to perceive, encode, and understand a stimulus has not been completely comprehended and proven. Information processing is a subset of cognitive learning theory. These theories pose possible ideas about how learning is made up of cognitive processes, configurations, and representations all within the mind of the learner (Smith & Ragan, 1999). Because it is difficult to truly understand how the human mind operates, the theories and information processing research is widely debated. Several models have been developed, but none have been accepted as the complete and accurate model of human information processing.

Cognitive learning theory focuses on the aspects of the observer rather than the influences in the environment (Smith & Ragan, 1999). In this theory, it is more important how the observer is absorbing the information instead of how the environment is helping or hindering
Cognitive learning theorists posit that learners are constantly observing information and comprehend it based on their prior knowledge (Pellegrino, Chudowsky, & Glaser, 2001). The cognitivists focus on how certain human cognitive processes, such as motivation, encoding, attention, and acquiring knowledge, play a role in how information is organized and stored in the human brain (Wittrock, 1990). The theory solely emphasizes the observer as a receiver of information and how information is comprehend based on the cognitive processes that are taking place in the observer’s brain—not how changes in the environment will affect learning.

Cognitive learning theorists are currently investigating how information is perceived, recognized, contemplated, conceptualized, and converted into useable mental data. The combination of these processes can also be called information processing. Information processing theory is a set of theories that explains learning as information transforming through several hypothesized sections of the human brain (Smith & Ragan, 1999). These parts of the brain are only theorized because research has not been able to find physical locations in the brain; however, theorists have never thought of them in a physical sense.

Cognitive researchers have developed several models and theories of information processing theory. The models suggest an explanation for how humans perceive information and translate it into their memory. Some of these models include Atkinson and Shiffrin’s “Multi-Store Model,” Rummelhart’s Schema theory, and Craik and Lockhart’s Level of Processing theory (Smith & Ragan, 1999). The information-processing model, that is most known and used, is Atkinson and Shiffrin’s Multi-Store Model, which can be seen in Figure 2-1.
The Multi-Store Model has information being processed and kept in three different memory locations: sensory memory, short-term memory, and long-term memory. When an external stimulus is detected, there is an executive control that oversees the entire information processing procedure. The system will regulate which cognitive activities will be used during each phase of the process and ensures that the information resources that are needed to process are available and assigned (Gredler, 2005).

The sensory memory manages the external stimuli that are obtained from the senses. When there are multiple incoming stimuli, they will compete for attention from the sensory memory. The stimuli must be attended to right away because visual stimuli get extinguished after approximately half a second and auditory stimuli after approximately three seconds (Cooper, 1998). If the observer does not pay attention to the stimulus at this stage, it will be forgotten and will not be transferred to the next stage. The person is more likely to notice and transfer the stimulus to short-term memory if it has an interesting feature or has a known pattern to the
observer (Huitt, 2003). The sensory memory helps to sort out which stimuli will be transferred to working memory and which will be ignored. A person’s past experiences, such as knowledge, morals, and beliefs, will impact which external stimuli will be focused on (Smith & Ragan, 1999). The stimuli that have been attended to in the sensory memory are then transferred to short-term memory.

Short-term memory, also known as working memory, is where the information a person is currently thinking about is stored. There are two major limits with short-term memory: (1) the external stimulus will only remain in there for 15 to 20 seconds unless it is echoed then it can remain for up to 20 minutes and (2) the number of external stimuli that can be processed at one time (Huitt, 2003). The “magic number” that can remain in the short-term memory at one time is 7 ± 2 according to a study completed by George A. Miller (1956). The information that is in short-term memory is conscious and is used to respond to an external stimulus. As seen in Figure 2-1, there are arrows to and from short-term memory and long-term memory. Information can be taken from long-term memory in order to help comprehend new data (Smith & Ragan, 1999). Not all information in working memory will be transferred to long-term memory. Only the information that a person remembers for more than a short period of time will be encoded into the long-term memory (Smith & Ragan, 1999).

The encoding process from working memory to long-term memory is most important for those who are trying to learn and retain information. The executive control is in charge of this encoding procedure, believed to be able to hold an almost unlimited amount of a person’s knowledge and skills in a permanently accessible form (Cooper, 1998). Long-term memory includes both preconscious memory, which is data that can easily be recalled, and unconscious memory, which is information that is not available when conscious (Huitt, 2003). Information can be transferred from short-term to long-term memory by elaboration on the subject and periodic review.
There are many theories as to how information is stored and organized in a humans’
long-term memory. Most theorists propose that information is represented in networks of similar
ideas and concepts that are connected through a relationship (Anderson & Bower, 1973).
Depending on how developed and descriptive these relationships are will dictate how well the
person can retrieve the information. Some cognitive theorists suggest that information that is
presented in the form of images is stored as images in the long-term memory (Paivio, 1979).

Other theorists believe that the information in the long-term memory is stored in the form
of schema, which is a specific type of network. Schemata are data configurations that represent
general concepts, such as food, animals, and restaurant, that are stored in the long-term memory
and contain “slots” that are constantly filled with information that are similar to that category
(Rumelhart, 1978). Schemata are updated and reorganized through a dynamic process of
integration and adjustment between the new observed information and the existing information in
the schemata (Anderson & Pearson, 1984). Every time new stimuli are observed and translated to
the working memory, the executive control is trying to find a related schema to encode the
information into the long-term memory.

There are several factors related to information and cognitive processes that affect how
people learn and comprehend information. Some of these factors include the practice effect, the
organization effect, and level of processing effect (Good & Brophy 1986). The practice effect
suggests that each time information is practiced or recited, the longer it will stay in working
memory, and the more likely it will encode to long-term memory. Similar to the way schema
work, organization will assist in retaining information longer and more effectively. When the
organization and relationship with existing information is stronger, the easier it will be for the
executive control to retrieve it from long-term memory. Craik and Lockhart (1972) suggest that
when information is processed deeper, it is more likely to be remembered. They theorize that the
deep processing will strengthen the memory connections in the long-term memory (Smith & Ragan, 1999).

### 2.2 Information Visualization

"Information visualization is the use of computer-supported interactive visual representations of abstract data to amplify cognition," (Card, Mackinlay, and Shneiderman, 1999, pg. 637). The most important aspect of information visualization is included in this definition: “to amplify cognition.” The design and development of visualizations should always take into consideration how they will improve users’ awareness and understanding of the data that is being shown. In this research, information visualization includes the “design, development, and application of computer generated interactive graphical representations of information,” (Chen, 2010, pg. 387).

Visualizations are data that is being transformed into pictures, and then in turn, the pictures being translated into information by humans (Spence, 2007). Data and information are two different things. Data are the numbers and the facts taken from the subject that is being represented by a visualization while information is what the data is trying to explain. It is the trend or behavior that the user is interpreting from the data. There are three types of data: (1) quantitative, (2) ordinal, and (3) categorical data (Spence, 2007). Quantitative data is the most common type of data, numerical, such as car mileage or engine speed. Ordinal data is data that can be counted, such as ratings between 1 and 10. Categorical data is data that can be sorted into groups, possibly depending on their relationships. Textual and qualitative data fall under categorical data. The primary goal of information visualization is that it must allow the user to extract the information from the data (Spence, 2007).
People will interpret the same information in a different way based on their individual experiences and context (Tufte, 1983). The same visualization will mean different things to different people because they have unique life experiences, which causes them to perceive things in an individualized manner. Unique personality and cognitive traits cause these individual differences. Several cognitive factors, such as spatial ability, visual memory, and associative memory, and cognitive and learning styles form peoples’ individual differences and become more apparent when visualizations are involved (Chen, 2004). These differences in humans make designing information visualizations, which are meant to be used by multiple people for the same task, increasingly difficult.

There are three aspects of cognitive behavior found only in experiments that are relevant to information visualization: (1) inattentional blindness, (2) change blindness, and (3) cognitive collage (Spence, 2007). Inattentional blindness occurs when the observer overlooks, or is blind to, a detail that at first appears to not impact the overarching goal (Ware, 2012). Change blindness is a result of the working memory’s inability to hold a large amount of information (Rensink, 2000). In some cases, observers miss significant changes between visualizations because the working memory can only remember a limited amount of information. Cognitive collage occurs when a person combines similar but incorrect information from their memory thereby resulting in an inaccurate judgment (Spence, 2007).

In order to overcome individual differences, information visualizations should be designed with basic rules in mind. Edward Tufte, who is known for being a leader in data visualization, explains that visualizations can be simple and clear to get their message across without being boring. Tufte also strongly advocates the “fundamental principle of information design: 1+1=3 or more,” (Tufte, 1990, pg. 61). This principle expresses that the elements of an information visualization should combine to create an effect that is larger than the sum, possibly
larger than the creator thought. Tufte states that there are three types of information graphics: data maps, time-series plots, and a combination of these two.

Data maps show a large quantity of information through the density of the graphic, which will allow for a quick display of the data in a limited space (Tufte, 1983, 1997, and 2006). Tufte believes these graphics are the most efficient way to display large amounts of data that humans will understand. The densities are visualized in the graphics through points, lines, colors, words, and other markers (Tufte, 1983). Some of the most widely known examples of data maps are Snow’s map of cholera deaths in London (Figure 2-2) and Minard’s graphic of Napoleon’s march on Russia (Figure 2-3) (Tufte, 1983 and 2006).

Figure 2-2: Variant of Snow’s Map of Cholera Deaths in London
Figure 2-3: Minard’s Napoleon’s March on Russia

Time-series plots are believed to be the most commonly used form of graphic design (Tufte, 1983). One of the early uses of this plot was Schofield’s timeline of Joseph Priestley’s lifetime, seen in Figure 2-4 (Schofield, 1997). Tufte remarks that using the natural progression of time in a graphic gives them more strength and efficiency in interpretation (Tufte, 1983). This plot allows for observers to easily spot trends, relationships, or variations over time. However, the main disadvantage of the time-series plots is the assumption of causality and the absence of dimensionality with only one variable (Tufte, 1983).

Figure 2-4: Schofield’s Joseph Priestley Timeline
Tufte summarizes his research very well with a single quote that explains the eight features of a good graphical display:

“Graphical displays should
- show the data
- induce the viewer to think about the substance rather than about the methodology, graphic design, the technology of graphic production, or something else
- avoid distorting what the data have to say
- present many numbers in a small space
- make large data sets coherent
- encourage the eye to compare different pieces of data
- reveal the data at several levels of detail, from a broad overview to the fine structure
- serve a reasonably clear purpose: description, exploration, tabulation, or decoration
- be closely integrated with the statistical and verbal descriptions of a data set.”

(Tufte, 1983, pg. 13)

When designing information visualizations, it is helpful to understand how the vision system works and perceives graphical features. There are two principal psychological theories that explain how vision is beneficial in perceiving features and shapes: Preattentive processing and Gestalt theory (Ware, 2012). Preattentive processing theory describes how some features of visualizations can be perceived quickly and accurately by a person’s low-level vision system (Fekete et al., 2008). An example of a preattentive process is line orientation (Figure 2-5); the human brain can quickly perceive which line is out of alignment of the others. Other features that can be preattentively processed include size, basic shape, color, convexity/concavity, enclosures, and added shapes around others (Ware, 2012). Visualizations that include these features will help overcome individual differences since most people are capable of preattentive processing.

![Orientation](image)

Figure 2-5: Orientation Preattentive Process (Ware, 2012, pg. 154)
Gestalt theory explains how the human brain uses principles that the visual system follows when it is interpreting an image (Fekete et al., 2008). Some Gestalt principles that can be used as a guideline for developing visualizations include proximity, similarity, continuity, symmetry, closure, and relative size (Ware, 2012). The proximity principle involves perceptually grouped items; “things that are close together are perceptually grouped together” (Ware, 2012, pg. 181). The similarity principle explains that the things that are similar will be grouped together. Visual elements that are smooth and continuous tend to be grouped together by the continuity principle. When the vision perceives two symmetric visual elements, they are likely to be perceived as a whole based on the symmetry principle. The closure principle explains that “a closed contour tends to be seen as an object” (Ware, 2012, pg. 186). The relative size principle describes how smaller aspects of a pattern tend to be perceived as an object while larger aspects tend to be perceived as background (Ware, 2012).

Some researchers have taken the preattentive processing theory one step further by describing how certain graphical features are better than others to explain the data. The human brain uses categorizations according to known experiences based on the perceptual and cognitive principles (Bertin, 1983; Cleveland & McGill, 1984; and Mackinlay, 1986). These researchers describe different encoding mechanisms that the vision systems identify quickly, similar to features of preattentive processing. Bertin first identified four common tasks related to information visualization and sorted encoding mechanisms that he thought were beneficial to that task, seen in Figure 2-6 (Spence, 2007). The four tasks that Bertin discusses are (1) association, how similar are the items, (2) selection, how the items are different and could be grouped, (3) order, how can the items be ordered, and (4) quantity, how the marks are proportional to each other. The encoding mechanisms are the rows in Figure 2-6 and are arranged by the number of tasks they will be useful for. Bertin notes that the most appropriate encoding mechanism for a visualization is dependent on the context of the task (Spence, 2007).
Cleveland and McGill (1984) furthered their research through an experiment to assess the accuracy of judging several encoded quantitative data. Some of the encoding mechanisms are the same as Bertin’s, but Cleveland and McGill only looked into how they can be used to represent quantity. Bertin only listed one encoding mechanism that can be used with quantitative data, so Cleveland and McGill’s research essentially expanded this column. The results from the experiment can be found in Figure 2-7, where the encoding mechanisms are sorted according to the accuracy of judging quantitative data (Spence, 2007).
Mackinlay (1986) expanded Cleveland and McGill’s ranking to include non-quantitative data and the encoding mechanisms that go along with them. The rankings have not been empirically verified like Cleveland and McGill, instead the rankings are based on existing psychophysical results and several analyses of different perceptual tasks (Mackinlay, 1986). The different positions of a given encoding mechanism on the three types of data are because additional perceptual tasks are involved. The sorted encoding mechanisms and some examples that support the order of the sorting are found in Figure 2-8 (Spence, 2007).
2.3 Information Visualization in the Military

Despite the significant progression of technology throughout the years, the military continues to use paper maps and sheets of acetate to assess battlefield situations (Durbin et al., 1998). The military is receiving a large quantity of data that they can potentially use to improve their systems and make more efficient decisions, yet they use simple spreadsheets. Several studies have been conducted and used military personnel to evaluate the use of information visualizations in the battlefield; however, the researchers are not using the studies to help determine the best visualizations for the task being studied (Banks and Wickens, 1999; Barnes, 2003; and Thomas, Wickens, and Merlo, 1999). If a systematic process was used that included the soldiers’ input throughout the creation of the visualizations, perhaps the visualizations would have a higher success rate in the field.

One of the research studies on battlefield visualizations investigates issues with the visualizations that limit the commanders’ capability to understand and make decisions regarding the warfare situation (Barnes, 2003). The research breaks down the issues that impact the two basic processes that visualizations assist with. The first process is situational understanding, which includes all of the processes a commander will use to assess and understand the current battlefield situation (Barnes, 2003). While the technology to support the visualizations in the field is established, the human aspect, including task analysis and performance, needs to be clearly defined. The prediction process includes what the commander needs to see in the visualizations in order to plan and execute a mission to obtain a goal state. Again, the issues arise when the decision process of the commander is not considered when developing the visualizations (Barnes, 2003).

Thomas, Wickens, and Merlo (1999) conducted a study to evaluate display frame of reference effects on cognitive biases, integration of information, and spatial judgment. The
research discusses how the display format is an important issue in order for it to assist with multiple decision-making processes. The display format is affected by many different factors, such as frame of reference, the amount of data that is available and shown, and the differing viewpoints being shown. Every factor that affects the display will have a significant impact on its usefulness; therefore, it is critical to figure out an effective combination of the factors that will produce the best display for the command and control tasks of a commander (Thomas, Wickens, and Merlo, 1999).

A study completed by Banks and Wickens (1999) evaluated soldiers completing a task given three different types of displays, a two-dimensional contour display, a three-dimensional static display, and a three-dimensional interactive display. The results from the research showed that each display was better for a certain type of task. The display used also was dependent on the spatial ability of the officer; for example, the officers with lower spatial abilities used the 3D tools more to complete tasks.

2.4 Structured Interviews

Knowledge acquisition is the task of gathering information from a source, while knowledge elicitation is the subtask of gathering information from an expert (Shadbolt & Burton, 1995). Learning information from experts can be incredibly difficult especially when large, complicated systems are involved. Knowledge elicitation is used to obtain information that is vague and abstract, such as information that is not easily recalled. Knowledge elicitation will allow for designers to better understand their customer by discovering potentially new information. There are multiple methods used for knowledge elicitation, but for this research only structured interviews were used.
One of the most common and useful tools for both initial requirements and task analysis as well as for the evaluation of problem solutions is the structured interview (Ware, 2012). The structured interview is designed to allow for extracting information about specific tasks. The organized and controlled design of these interviews allow for easier and more significant analysis of the information. The structured interview is an excellent tool to use for determining what aspects of a visualization are important to the user, and what are potential solutions to their weaknesses (Ware, 2012). One of the benefits of the interview is that information can be gathered about a range of topics with minor effort, and information that was not expected can be found (Ware, 2012).

A structured interview is a formal session where the interviewer has planned the entire session that results in structured transcripts that are easier to analyze (Shadbolt & Burton, 1995). These types of interviews work best when there is only one participant and one interviewer. Group interviews can be conducted, but they can sometimes lead to answer pressuring and biases. Selecting the participant(s) to interview is important as it will dictate how much and how significant the information gathered will be. It is better to try to obtain experts in the field of research, which means users of the system that is being studied who have many years of experience. In order to decrease the chances of biases, the interviewer should be someone that is not associated with the project, and they should be instructed to only ask the questions on the interview script and only deviate if absolutely necessary (Kirwan and Ainsworth, 1992). Interviewers should remember the following guidelines: (1) never get drawn into lengthy explanations, (2) never deviate from the interview script, (3) never let another person interrupt the interview or persuade the interviewee, (4) never offer an answer or an opinion about the answer, (5) never give another interpretation of a question, and (6) never improvise (Fontana & Frey, 1994).
The interviewer should start the interview with discussing the background of the user in order to understand how much experience they have, specifically related to the task in question. The questions that are developed for the structured interview need to be straightforward and easy to understand and answer (Foddy, 1993). The interviewer could request for the user to participate in a cognitive walkthrough. A cognitive walkthrough is a technique that is used for evaluating the design of a visualization interface (Rieman, Franzke, & Redmiles, 1995). At the end of the interview, the script should include an open-ended question that allows the participant to ask any questions or clarify their thoughts. In order to have accurate information, the interview should be recorded, whether by handwritten notes or recording device. The results can be systematically arranged based on the structured questions, and then filtered and categorized in order to analyze the information.

### 2.5 Oil Life Algorithm

Some vehicles today are equipped with tools that estimate the engine oil life remaining. In his unpublished thesis, Anveshan Bommareddi developed an improved version of an oil life algorithm that takes into account more variables than the systems on the market now. Bommareddi created an algorithm that took inputs from military vehicles to estimate the percent oil life remaining. Bommareddi’s proposed algorithm took into account, not only the nominal engine oil life, but other variables such as the engine oil temperature, coolant temperature, engine load, engine speed, engine cranking, and oil aging (Bommareddi, 2009). To accurately predict the oil life remaining, Bommareddi correlated the oil life to time because it is updated with oil deterioration rate.

First, the nominal oil life is set to the standard for the vehicle, and Bommareddi used 500 hours. Then, for every five seconds of operation, the oil life used, the cumulative oil life used,
engine-running time, and cumulative engine running time are calculated (Bommareddi, 2009). A sample was set to be taken every 5 seconds. The oil life used is a variable that keeps track of the estimated amount of oil life that was used during the five-second sample. The cumulative oil life variable keeps a running total of the oil life used. Engine running time and cumulative engine running time are the variables that track the amount of time the engine has been running during a sample and over time since the last oil change. Then the percent oil life remaining is calculated based on the oil life used compared to the nominal oil life.

The oil life used during a five second time period was calculated by taking the cumulative oil life used and adding on what Bommareddi called correction factors multiplied by the time sampled. These correction factors were used to account for oil degradation over time for various reasons. The first correction factor was for engine and coolant temperature. As the temperatures deviate from optimum operating temperature, the engine will experience increased wear and thus affecting the oil (Bommareddi, 2009). The engine load correction factor considers the load on the engine. As the engine speed increases, the engine speed correction factor will also increase. The engine cranking correction factor takes into account not only how frequently the engine is started, but the temperature as well. Cranking the engine often can cause mechanical wear, and cold temperatures only make cranking take longer and thus cause more wear (Bommareddi, 2009). As the oil ages, its effectiveness decreases. The oil aging correction factor will decrease the nominal oil life after it has been in the engine for more than 6 months and has a maximum of 24 months. Lastly, there is a desert environment correction factor that if activated will account for more degradation when in a dusty place.
Chapter 3

Proposed Visualization Development Process

The primary goal of this research is to create a visualization development process for analysts to use. The process will instruct them how to systematically produce data visualization tools and interfaces for their military customers. When designing interfaces for the military, analysts need to keep in mind that their client may have little to no training and experience with reading and interpreting data, whether it is raw data or graphs and charts. To overcome this weakness, the visualization development process, seen in Figure 2-1, includes many interactions and discussions with potential users. The process is organized into three phases: (1) analyze the project and the data, (2) initial user interview and develop visualizations, and (3) conduct a user jury to obtain feedback on visualizations.

![Proposed Visualization Development Process Diagram]

Figure 3-1: Proposed Visualization Development Process
3.1 Phase 1: Analyze Project and Data

Phase 1 of the visualization development process for the military includes essential primary steps for the project. After being assigned the project, the analyst or team of analysts should discuss the overall scope of the project with the project manager, and ideally with the client as well. It is critical to agree on and understand the scope because research has shown that a poor scope definition can lead to project failure and also affects the schedule, cost, and operational properties of the project (Cho and Gibson, 2001). One of the most important parts of the scope is the overall goal of the project, which is crucial to understand before beginning to analyze data and create interfaces. The scope also includes who the potential users of the interface will be. In order to design visualizations that will be beneficial, analysts must understand the user’s job and priorities. Another essential part of the scope that needs to be discussed with the project manager is the schedule. Knowing the schedule will allow the team members to tentatively plan for each of the phases in the process as well as an approximate date for interviews.

Once the scope is well defined and a schedule for the project is made, the data can be examined. Research should be done on what variables and relationships are important to the user. This will allow for the analyst to know what variables must be used in visualizations and which relationships need to be highlighted. They need to observe what, if any, variables interact and affect one another. After analyzing the data, the team members can begin to brainstorm and create initial ideas for the interface. Visualizations do not necessarily need to be created in Phase 1; however, potential ideas can be sketched so they can be taken to interviews in Phase 2.

While brainstorming ideas for visualizations, the analysts should be aware of the common graphical tools that most people know and what they are used for. The most commonly used visualization tools were researched and were sorted according to their use and number of
variables. There were three usage categories that these graphical tools were sorted into: (1) comparison, (2) relationship or trend, and (3) distribution. The comparison category includes visualizations that will allow for data to be compared against each other or over time. The relationship and trend category shows the correlation of data between items. Lastly, the distribution category shows the frequency and distribution of the data. These graphical tools can be seen sorted into their categories in Figure 3-2.

![Visualization Tree](image)

**Figure 3-2: Visualization Tree**

When developing the original ideas on potential interfaces for the client, analysts should constantly keep in mind the overall goal of the user. The researchers need to remember several aspects such as what the interface will be used for, how much data will be behind it, and how
many variables need to be included. While the interview portion in Phase 2 will answer many of these questions, analysts will need to begin to think about how the user would break down the problem or goal and the cognitive steps that the user would take to solve it.

### 3.2 Phase 2: Initial User Interview

Prior to completing the first interview, there are a few critical details to decide on. First, the interviewee needs to be someone who will use the interface, as well as a user that has more experience and has a higher position if possible. Next, a structured interview needs to be constructed. This type of interview is a method that has structured questions that will allow the interviewer to easily extract information about the tasks (Ware, 2012). The interview will go smoother if the interviewer knows exactly what needs to be said, and it will also ensure that nothing is forgotten. If visualization sketches were done and will be taken to show the user, they need to be neat and legible. The interviewer should be prepared to explain the sketches in detail.

The structured interview that is conducted is an excellent way to determine what characteristics of the potential visualizations are truly important to the users (Ware, 2012). The initial user interview will allow the analysts to get a basic understanding of how the customers think and use the potential interface. At the very beginning of the interview, the interviewer needs to explain in detail the purpose of the interview, in case the user is not aware of the project. Before showing the interviewee the sketches, they should be asked to do a cognitive task analysis of the job at hand. The interviewer does not want to show the user the potential sketches before the task analysis because they do not want to influence them into changing their process. A cognitive task analysis requires the user to go through each phase in the process they take to complete the task, including both the physical and mental steps (Smith & Ragan, 1999). It is crucial for the interviewer and other analysts to understand the decision making process that the
customer uses to reach the final goal. In this task analysis, it should be clear what the user currently utilizes to assist them in obtaining a result. Knowing what they currently use to make decisions will allow the analysts to understand the process and what they can improve upon with their interface designs.

After completing the cognitive task analysis, the interviewer can show the user the idea sketches. They will need to explain the drawings; however, if a lot of explanation is needed, it may indicate that it is too complicated for the users. The military is very interested in making efficient decisions quickly, so if an interface requires too much thinking, it may not be beneficial for them to use. The interviewer needs to ask for their honest thoughts about the sketches so that an improved visualization can be created from it. If no sketches were created, the interviewer can bring in the raw data and explain it. The user could have preferences on what variables in the data should be used. They can also discuss if the typical user has experience with reading data and in what format. At the end of the interview, the interviewer needs to have a complete understanding of the task, the user, and the decision making process used.

Following the interview with the user, the analysts assigned to the project can begin to design and create the visualizations. These visualizations need to be directly based on the feedback from the interview as well as the basic visualization tools in Figure 3-2. If the users have more data interpretation experience, more sophisticated tools can be explored. While developing potential interface designs, the analysts need to continuously think about the decision making process of the user. They need to review the information visualization guidelines discussed in Chapter 2 of this thesis. Knowing the general rules of information visualization will help the analysts in creating an interface that meets the needs of the users. After completing the development of the interface, the analysts should do a cognitive walkthrough to validate that the task could be completed with the visualizations.
3.3 Phase 3: User Jury

“The ultimate purpose of visualization aids is to increase the commander’s ability to understand the battle dynamics, consider options, and predict outcomes,” (Barnes, 2003, pg. 1). In order to determine if the visualizations will benefit the military, they must be shown the options and asked to discuss them. That is why the most important step of Phase 3 of the visualization development process is the user jury. A user jury consists of a panel of experienced users who will evaluate and provide feedback on the potential interface with an interviewer present. The panel can be conducted in a group setting or individually and can be survey or interview based. However, before the user jury can be conducted, the analysts must complete some preparation for the interviews. Most importantly the user jury has to be assembled. The team needs to try to find as many experts or experienced users in the field they are working as they can. The more users they can interview, the more feedback they will receive, and the more they can improve the interface.

Similar to the initial interview, the user jury interview will need to be designed. If the user jury will be in a group setting, a survey may be easier to use. If it will be conducted individually, which will give more in-depth results, interviews or a combination of surveys and interviews can be used. In addition to writing interview questions for the user jury, a scenario should be created. The scenario needs to be realistic, require the users to make decisions, and include constraints, for example, limited time or resources. If the scenario involves the participants making decisions and planning, it will force them to use the visualizations. The constrained scenario will answer the questions: how do the users perceive constraints on their resources and how do they make decisions while constrained. It will also give insight into whether they even comprehend the context of the problem. Prior to the interview, the analysts need to prepare both the suggested interface as well as the current interface that the clients use.
Bringing both of these visualizations will allow the users to compare and contrast the two methods. The two methods combined with the scenario will require the users to assess what they are doing and make them choose between visualization tools.

After constructing the user jury, the interviews can finally be conducted. If at all possible, the interviewer should insist on leading individual interviews. Group interviews can be a backup plan, but they can lead to biasing and pressuring between participants. The interviewer should stick as close as possible to the script created so as to not lead or bias the jurors. Staying on script will also allow the answers from every juror to be compared and analyzed. The interview should start with getting a brief background of the user so that differences between jurors can be noted. Next, the interviewer should present the scenario as well as both visualizations to the interviewee and allow them to take their time to work through the scenario. Like the initial interview, the user should be asked to do a cognitive walkthrough to observe how they use and interact with the interface. The interviewer should note which interface the juror uses when completing the scenario and walkthrough. It will also allow for differences between the users in the decision making process to be apparent. Some of the critical questions that the researcher needs to ask are:

1. What are the steps the user takes to complete the task in the scenario?
2. Do they have a preference between the proposed interface and the one they currently use?
3. How do they perceive constraints on their resources?
4. Does their decision-making process change when they are constrained by limited resources?

Once the formal questions are completed, the interviewer can ask for the jurors to expand on their opinions and suggestions on the interfaces. Again, one of the more crucial answers in the user jury is which visualization do they prefer to use when making decisions.
The analysts then will take the feedback from the user jury and analyze it. They should compare each answer across each of the users and document the similarities and differences in them. They also need to understand how each of them make decisions and note any differences in the process. The results will provide insight into how there are cognitive differences between users. Ideally, the jurors will have a similar mindset, and therefore, similar answers, but there is always the chance that significant differences will occur.

If there is a consensus between the jurors, the edits may be simpler to handle. It means that they will be able to use the same type of interface across each of the users, but changes may still need to be made to the visualizations. The users may have given suggestions on changes that they would prefer. However, if they did not, the analysts will need to look over information visualization tools and guidelines for guidance on how to change. Changes need to be made where there was a disconnect between the interface and the decision making process.

In instances where there is not a consensus, the analysts need to determine why there are more differences in opinions. One of the reasons may be the jurors have different jobs and goals in mind, so they need to compare the backgrounds and cognitive processes for each of the jurors. If there are major differences in the background, it may lead to the need for two different interfaces for each type of job. Analysts must remember to match the interface to the cognitive process.

In order to determine how representative the user jury is of the population being studied, inferential statistics can be used. Inferential statistics use probabilistic techniques to make predictions about a certain population based on the analysis of a sample (Asadoorian & Kantarelis, 2005). Before using these techniques, the analysts need to be certain that the user jury sample is representative of the population being studied. Tests of significance can be used to determine the probability that the obtained results are representative of the population being sampled.
After the visualizations are recreated, the team may want to repeat Phase 3 to test the new interfaces. The same jury can be used since they already understand the scenario and process. It may be beneficial to keep the same jury so they can compare the new ones to the previous ones. However, the results may be biased. Phase 3 can be repeated until both the analysts and the users agree that the final visualizations are useable and beneficial. Once the process is finished, the ultimate goal of the project will have been met and the users will have a new interface that will allow them to make more efficient decisions.
Chapter 4

Demonstrating the Visualization Development Process

Once the visualization development process was created, a project was assigned to demonstrate and assess it. This project involves incorporating an oil life model into visualizations that maintainers can use to make decisions and plan missions with their fleet of vehicles. The project aims to aid maintainers in deciding when to change the oil in the vehicles in their fleet.

4.1 Phase 1: Oil Life Project

The idea for this project was inspired by working with analysts at the Applied Research Laboratory at Pennsylvania State University. As stated in Chapter 3, the first and most important step of Phase 1 is to define the scope of the project, which includes the overarching goal, the schedule, and the users of the end result. The project was developed from looking at a series of reports that were seemingly useless for the military customer. A question was posed, “what type of visualizations would be useful for the maintainers to use?” So, the first goal of this project was to research what type of visualizations do the maintainers find useful when given a scenario. Another objective was to determine whether a certain type of visualization was preferred over another in a military setting. It was then decided that the maintainers have a task of changing the oil in each of their vehicles at a certain time, whether the vehicles needed it changed or not. If they had the data and an interface to help track the progress of the oil, they could make better and more efficient decisions about when to change the oil and how to plan missions. A timeline was also created so that tentative dates for interviews could be made.
In Phase 1, the potential users of the interface were determined and researched. Since the scenario was developed to be about oil changes, the most logical user would be a Battalion Maintenance Officer, or BMO, as well as general maintainers. The BMO has several roles in the military and is in charge of the maintenance of an entire battalion fleet of vehicles. There are several maintenance officers underneath them that are in charge of a single unit of vehicles. Some of their more significant roles include overseeing all maintenance activity for a battalion, managing supply levels of vehicle parts and tools, and comparing assets in order to determine which can go on missions. BMOs are constantly looking at large quantities of data in order to keep track of all of the assets, and they do not have a set visualization across the military to observe and interpret the data. One of the tasks that BMOs and Maintenance Officers deal with regularly is changing the oil in their vehicles. Currently, the method in which they change their oil is a little vague and will be determined in Phase 2 of the process.

Next, the data was received and analyzed. In order to help the Maintenance Officers have a better understanding of their vehicles’ oil consumption, it was decided to include a new variable: the percent oil life remaining. Anveshan Bommareddi from the Pennsylvania State University calculated this variable in his unpublished Master’s Thesis, introduced in Chapter 2. The data that was supplied included his research applied to data gathered from military vehicles to determine percent oil life remaining. The data includes several types of vehicles, each with values for the following variables: engine time (hours), equivalent engine time (hours) and the variables to calculate this, total fuel used (gallons), fuel used while rolling and while idle (gallons), distance traveled (miles), idle time (seconds), and other classification data, such as location and serial number. Equivalent engine time is equal to the oil life used variable calculated in Bommareddi’s algorithm, and it increases engine time by an additional wear factor based on how the vehicle was used during the sampling time, seen in Equation 4.1 (Bommareddi, 2009). The percent oil life remaining was then calculated by dividing the equivalent engine time over the
nominal engine oil life of 500 hours, seen in Equation 4.2 (Bommareddi, 2009). Since this algorithm was recently developed, the military personnel had not previously seen it.

\[ Equivalent \ Engine \ Time = Oil \ Life \ Used + \Delta t + C_{\text{temp}} + C_{\text{load}} + C_{\text{rpm}} + C_{\text{crank}} + C_{\text{dust}} \]  \hspace{1cm} (4.1)

\[ Percent \ Oil \ Life \ Remaining = 100\% \times \left\{1 - \frac{Equivalent \ Engine \ Time}{Nominal \ Oil \ Life \times C_{\text{age}}} \right\} \]  \hspace{1cm} (4.2)

where,

\[ \Delta t = \text{data sampling interval} \]
\[ C_{\text{temp}} = \text{temperature correction factor} \]
\[ C_{\text{load}} = \text{engine load correction factor} \]
\[ C_{\text{rpm}} = \text{engine speed correction factor} \]
\[ C_{\text{crank}} = \text{engine cranking correction factor} \]
\[ C_{\text{dust}} = \text{dust/desert correction factor} \]
\[ C_{\text{age}} = \text{oil aging correction factor} \]

Before including this new variable, the other variables and their relationships were considered because they were the ones that the client would have worked with previously. When deciding whether or not to change the oil in any vehicle, the main variables that the maintainer considers are miles driven, engine hours, and time since oil change. Each of these variables are positively correlated, meaning if one increases the others will also increase. There are vague guidelines on how often to change the oil in vehicles, but it typically only estimates about every 3,000. Military vehicles get used in a significantly different manner than civilian vehicles, so it is logical that their oil be changed by a different method as well. One of the ideas brainstormed for a new visualization involved creating a scatterplot of miles driven versus engine hours, and the marker on the plot changing colors if the engine coolant temperature reached a maximum value. However, the data that was received did not have coolant temperature, so it was decided to wait until after the initial interview whether to include it or not.
Initially the new variable, percent oil life remaining, was excluded from the sketches because the permission of the user wanted to be obtained. If he did not understand or agree with the use this variable, it would need to be omitted. Next, the analyst observed how this variable was affected by the other variables involved. As miles driven, days since oil change, and engine hours increased, the percent oil life remaining decreased. This is because as the vehicle gets used the dirtier the oil will get and thereby decreases the oil life.

4.2 Phase 2: Battalion Maintenance Officer Interview

The first part of Phase 2 of the visualization development process is to find an experienced user to interview and write up the structured interview. The interview was scheduled with a Battalion Maintenance Officer, or BMO. The BMO is not only a potential user, but he/she also has a higher position and therefore will have more experience and knowledge about the data and visualizations. Next, the interview script was created and altered to meet the needs of what the project needed to understand. A script for the interview can be found in Appendix A. It was decided not to bring any sketches to the interview because the interviewer wanted to get the unbiased opinion of the user about the data and visualizations.

The interview had a basic design of starting with background and working towards more specific details. At the beginning, the interviewer explained a brief overview of the project and asked about the user’s current methods involving oil change. This was to get an understanding of what the current process as well as the interfaces being used to track the process. Also, this time was used to see if BMOs and other maintainers would use a method to track their vehicles’ oil changes. After obtaining the background information, the project and data was explained in greater detail, specifically the percent oil life remaining variable. The data was explained in order to validate the algorithm with the user. Then, the user was asked about where he could see it
being beneficial in his job and how would he use it during planning for oil changes. To make sure the visualizations would include variables that the user needs, he was asked what factors were important when deciding about oil changes. Also, constraints that the BMOs have when dealing with oil changes were discussed, so that the interface can be designed in a manner that can help them plan according to their resource or time limitations.

The current process that the military uses to change the engine oil is dependent on the model of the vehicle. Approximately two-thirds of the military fleet is enrolled in the Army Oil Analysis Program, or AOAP. For this program, an oil sample will be taken and sent into a laboratory every six months for tactical vehicles and every 90 days for combat vehicles. The lab will check the viscosity of the sample and the amount of fuel and metal content and conduct other tests. After the samples are evaluated, the results of the test will be sent back to the unit with a recommendation to either change the oil or the filters, both, or neither. However, the one-third of the vehicles that are not enrolled in the AOAP get their oil changed on a time basis, approximately every six months. The interviewee stated that these vehicles’ oil gets wasted because they may have good oil left when they get changed.

In order to keep track of each of the vehicles’ oil sampling and oil changing schedules, they have alerts set in their Standard Army Maintenance System boxes (SAMS) boxes. This is the computer program that the military uses for items such as dispatching, tracking services, ordering parts, and tracking faults. The users assign a service date to a particular vehicle and input the service code into the SAMS box, which stores the date on a service calendar. When the maintenance officers print out a monthly schedule, the oil sample service dates will be on there. The BMO has the responsibility to track the service dates; however, at least in the interviewer’s case, he is not the one who executes the assignment of the services. He will see them, but an administrative person called pressure controllers will break down the service schedule by unit and send it out. Then, the sample coordinator for the units will inform the vehicle operator to pull the
sample. The sample is given back to the coordinator who turns it into the maintenance facility. Another part of the oil tracking in the SAMS box is when the vehicle operator tops off the engine oil he will report that up to his commanders which will go on up the chain of command to the BMO. Most of the data that he and other personnel read is in spreadsheet format. So, they do not have that much experience with interpreting graphs and other visualizations.

After the algorithm and raw data were explained to the user, he stated that he thought this algorithm can better represent the oil life because it is based off of engine time rather than miles driven like other estimating systems. Engine hours will be more accurate in representing the oil life in the military vehicles because it includes the times that the engine is running but the vehicle is not moving, idle time. Idle time is important because military vehicles are often kept running when not moving so that they can be readily available. When asked if he would find it beneficial to see the percent engine oil life remaining, he stated that he would if he were in a forward environment, which is when troops are deployed in a country overseas. While they are in a garrison environment, there is no oil test program in place. The military personnel change the oil based on mileage and the look and feel of the oil. If the interviewee had a program that showed him the percent oil life remaining of each of his vehicles, he could use it to plan which ones to send on missions.

When discussing constraints and priorities for readiness the user had for oil changes, he stated that supply and demand constraints are more of a concern when deployed. Therefore, a program that showed him each vehicles’ information, including percent oil life remaining, would be beneficial in his decision making process for oil changes. He is not concerned with preserving oil while deployed because he wants to “reduce the number of possible adverse conditions to the lowest possible amount.” He is more concerned with priority of timely readiness than conserving oil supplies. He also admitted that being able to see the oil life remaining would affect his
decisions on when he would change the oil. He would move the oil change up or back depending on upcoming missions and their projected number of vehicles required.

One of the factors that the user stated that he would like to know when deciding if he should change the oil is the vehicle personality. While this aspect may be important to the user, it is not one that can be visualized on an interface through data that the analysts have access to. Other factors that he needs to know before planning the mission are the type of vehicle, the projected weight during the mission, the time length of the mission, the distance that will be traveled, and the climate. The variables that he would like to see in an interface are the number of miles driven, the date the oil was changed, percent oil life remaining, engine running time hours, and any oil added. When asked to confirm these variables later, he added average engine load, average engine oil temperature, and average coolant temperature.

The Battalion Maintenance Officer that was interviewed stated that not only would he find these visualizations useful for himself, but for other officers as well. He said it would depend on the caliber of the individuals and whether the BMO would like to transfer down some of the responsibilities to his other workers. The decisions could be made as far down as the Maintenance Noncommissioned Officer, the floor supervisor, or the inspector. He personally trusts his men enough to pass those decisions down to them. However, at maintenance meetings, he would look at their suggestions on which vehicles’ oil to change and combine this information with what he knows about upcoming missions and make a more effective decision.

There are many military personnel that could find these visualizations useful, and they each can have a different use for it. The BMO would use the data for planning how and which vehicles are used. He should be able to plan 60 to 90 days ahead with his supply and demand. The officers below him could take the same data to make suggestions and execute them. The maintenance officers would look at the visualizations and make recommendations to send up to the BMO. Then, the BMO would take and make decisions about planning off of the
recommendations. The interface that the user is envisioning could be a dual-purpose program that can be used for both planning and execution.

At the end of the interview, the user stated that he liked the idea of the vehicle having the ability to report the remaining oil life. He said that he thinks the end result would save the military a lot of money by helping with planning supplies and timing of oil changes. The potential interface would not only be beneficial in forward environments where there is no AOAP system in progress, but also with the one-third of vehicles that are not under the AOAP system at all. It could potentially replace the AOAP system if found successful with those vehicles.

After the first interview was conducted, ideas for visualizations were brainstormed and sketched. Since the Battalion Maintenance Officer requested that the visualizations show the data on an individual vehicle basis, the designs needed to accommodate anywhere from 3 vehicles to 50. Of the variables stated that the user needs, all were available except any oil added, the average oil and coolant temperatures, and average engine load. The data collectors did not have access to maintenance records so they did not know when oil was added, and they were not able to include the average temperatures or the average engine load in the raw data the analyst was given. However, each of these variables was taken into consideration in the percent oil life remaining variable. The analyst decided to use what was available and to see what the user jury thought before trying to gain access to more data.

The user had mentioned liking the idea of having a bar graph for the percent oil life remaining, and the bars would change colors depending on the percent level it was at. In between 60% and 100%, the bar color would be green meaning it was ready to go and most likely recently changed. The next range, 30% to 60%, would be colored yellow and would alert the maintainer that the vehicle’s oil is getting bad but may not need to be changed yet. Finally, between 0% and 30%, the bar would be colored red to alert the maintainer that the vehicle’s oil is very dirty and may need to be changed depending on upcoming missions.
Next, the other variables needed to be incorporated into visualizations. These variables were the engine hours, distance traveled, and days since last oil change. Because the users do not have a lot of experience with interpreting data from visualizations—spreadsheets are more common—the interfaces need to be kept simple so that they can easily understand them without training. For this reason, the analyst decided to create the scatterplots so that the users could easily see how the vehicles are progressing. As shown in Figure 3-2 with the visualization tree, scatterplots are used to show relationships. The users will be able to see the relationship between the two variables shown as well as the other vehicles. Two scatterplots were decided upon: (1) days since oil change versus miles driven since oil change and (2) engine hours since oil change versus miles driven since oil change. The maintenance officers will be able to use these graphs to see how their vehicles have been used since the oil change. For example, if a vehicle has a higher number of engine hours but only a few miles driven on it, the maintainer know that the vehicle has been idling for the majority of the time. Also, the marker on the scatter will change color depending on the percent oil life remaining. The ranges and colors will be consistent with the first visualization.

As learned from the user, the maintenance officers currently do not use an interface to track oil changes, only a calendar and alert notice system. The user also said that when they look at data it is almost always in spreadsheet format. In order to test the visualizations created, the user jury will be given a table with the exact same data as the visualizations to see which they prefer. The data for the visualizations was actual data taken from vehicles at the Bagram Air Base. There were five different types of vehicles that were used: a Palletized Load System (PLS), a Heavy Expanded Mobility Tactical Truck (HEMTT), a Line Haul, a Load Handling System (LHS), and a Family of Tactical Vehicles (FMTV). Each type of vehicle had a set of visualizations created for them. These can be seen in Appendices B through F.
While creating the interfaces, the analyst constantly had in mind the decision making process of the user. The researcher also thought about the other potential users that would employ the interface to execute decisions. After the visualizations were created, a cognitive walkthrough was performed. The walkthrough used a scenario and the visualizations to complete a task that involved planning which vehicles to take on a mission. The walkthrough was successful at meeting the needs of the user. The next step is to conduct a user jury to get their opinions on the visualizations usefulness and a comparison to their current data methods, spreadsheets.

4.3 Phase 3: Maintainer User Jury

A user jury was obtained and gave permission for four individual interviews. The four users that were on the panel had different positions, which will allow insight into how diverse the interface can be. The four positions were: (1) Battalion Maintenance Officer, (2) Maintainer, (3) Motor Sergeant, and (4) Support Supervisor. These positions vary in rank, so some would use it to plan while others may use it to execute. Since there were only four jurors, each interview was treated as a case study to learn how the visualizations could benefit their position. The users were told very little before the interviews were conducted so as not to bias their opinions.

Similar to the initial interview, an interview script was drafted. The user jury script is shown in Appendix G. There were a couple differences with this interview script. The user jury interview includes a scenario that was also printed and given to the interviewees. This scenario was created to give the jurors a mission to plan and to force them to choose which vehicles are mission-ready. In the interviews, the jurors were given the visualizations in Appendices B through F. The five types of vehicles each have three different types of graphs: (1) bar chart of percent oil life remaining, (2) scatterplot of days versus distance traveled since oil change, and (3)
scatterplot of engine hours versus distance traveled since oil change. Each vehicle also has a spreadsheet with the same data to compare which the user prefers. Also included in the visualizations, the percent oil life remaining graph was created with statistics on it. This will be used to gain insight into whether the users would prefer seeing statistical data as well. The interview will determine whether the potential users understand graphical data and if they prefer it to their standard spreadsheets.

4.3.1 Case Study 1: Battalion Maintenance Officer

The first juror that was interviewed was the same Battalion Maintenance Officer (BMO) from the initial interview phase. Since the researcher decided to just treat the interviews as case studies, the same user could be interviewed. The benefit of using the same user was that he had a better background understanding of the goal of the visualizations. The BMO is in charge of the maintenance for the battalion fleet of vehicles.

This juror had a very interesting and precise decision-making process for choosing which vehicles to send on the mission. Since the scenario mission was 180 miles round trip, he did not want to choose any vehicles that had below 70% oil life remaining. Not only was this because of the length of the trip but also because he did not know how much lag and idle time would happen on the mission. He eliminated the vehicles below 70% oil life remaining by using the bar chart, like Figure F-1. After this preliminary process, he would look at the days versus distance traveled since oil change, Figure F-3 for example, and would filter out the red and yellow dots. Then, with the remaining green dots, he would start with looking at the vehicles that have a larger number of days since oil change because he wanted to “keep the rotation fresh.” What the user meant by keeping the rotation fresh is that he wanted to use the lower oil life percentages so the oil would degrade and need changing. If he only chose the vehicles with the highest oil life
percentage, they would be the only vehicles receiving oil changes and thus the only vehicles being used. Using his fresh rotation process would allow for each vehicle to be used and get fresh oil by a certain time frame. He would use the vehicles that have a lower oil life percentage (below 70%) on shorter missions so that they would get their oil changed after the mission and get back into the rotation. He stated that he would use this process for all vehicle types in the scenario except the HEMTT. The HEMTTs would be used as recovery vehicles so he would look for oil life above 80%.

The user did not need any additional information to make decisions about oil changes because he was given the four variables he needed to make a proper choice. Those factors are the percent oil life remaining, distance traveled, days since oil change, and engine hours. When asked if he would change any of the oils in the vehicles based on the given data, he said he would change the HEMTTs C53 and C39, which have a percent oil life of 54% and 42% respectively, as seen in Figure C-1. However, he would not send them on the mission after changing the oil.

Then, the interviewer asked if he would use the visualizations to decide when to change the oil, regardless of mission planning. He said that he would use them to monitor the vehicles’ oil life and keep track of which ones are getting low. He would then use this information for future mission plans.

During his explanation and demonstration of his decision-making process, the user only utilized the graphical visualizations. However, when asked about his preference between the spreadsheet and the graphs, he said, “the spreadsheet would be more user friendly, especially if you attach filters.” Users could make quick and easy decisions with filters on a spreadsheet. With the charts, they would have to flip back and forth which takes more time. He also said he preferred to use the bar chart with the statistics, like Figure C-2. He thought the deviation could be an important aspect as a decision maker, but he suggested having a comparison with the miles driven and engine hours graph. He would like to see, if it is possible, the two visualizations built
into one to illustrate engine oil wear time. With this visualization, he envisions it helping to
determine when vehicles will reach a deviation marker.

There were a few different areas that the BMO thought these visualization tools could be
applied. First, they could be used in selecting and tracking which vehicles they would select for
extended, over 1 day, missions. It would allow them to see how the vehicles are using their
engine oil, for example, how quickly they are degrading the oil life. The maintenance area could
use it to determine when they will perform oil changes and also help him in keeping the rotation
of oil changes below a certain time period. Again, this would allow him to keep the oil change
rotation fresh for each of the vehicles in the fleet.

In addition to answering the interviewers questions about the decision process and his
preferences, the user gave some helpful feedback about the visualizations. He was offering
suggestions on aspects that he thought would make them better for the users. First, he thought
some of the scatterplots were busy, but he was not sure how to clean them up because they are
showing critical information that he needs to make the decisions. The analyst was aware that the
scatterplots were busy, so there were scatterplots that broke down the larger one into clusters so
that each point could be seen. For example, Figure B-3 was broken down into two clusters in
Figures B-4 and B-5. The user did not notice that the graphs were broken down into clusters until
the interviewer pointed it out to him. He did not seem to like the graphs split up into separate
graphs even though they were less busy. In regards to the spreadsheet, he said to make each of
the columns whole numbers instead of decimals and to remove the date it was changed column.
The decimals will only confuse users, and they typically work with whole numbers.

The first juror was very successful in answering questions fully and descriptively. He
gave an in-depth thought process in planning which vehicles he would use for a mission. He
performed a cognitive task analysis for two different types of vehicles, which was very beneficial
for the interviewer to see. While the user executed the analysis with the visualizations, he said
that he preferred the spreadsheets, which was a little unexpected. However, he was very positive in his feedback, and if a new interface were developed, he would be helpful to interview again.

4.3.2 Case Study 2: Maintainer

The next user juror was a lower ranking maintainer, underneath the Battalion Maintenance Officer. His position title was Senior Stryker Mechanic, and he oversees approximately 80 Stryker vehicles, though there are other vehicles under his management as well. The Senior Stryker Mechanic is in charge of the family of Strykers and keeping them maintained to operate and mission capable. When asked about when and how the vehicles’ oil gets changed, he stated that some are on an annual rotation while others are on a biannual rotation.

While the juror was working through the scenario and deciding which vehicles he would send, the interviewer noted that he was using mostly the percent oil life remaining bar chart. He also looked over one of the scatterplots and some of the spreadsheets. After he was finished with the scenario, he described his thought process. First, he looked at the percent oil life remaining bar chart to determine which vehicles had the highest oil life left. Then, before making his determination, he would look at the days versus miles driven scatterplot to see which had been changed more recently. He chose the ones that had been changed most recently because “the vehicles that get more attention are usually a lot more reliable.” He also said that he would like to see if vehicles have maintenance issues and the severity of it.

When asked if he would change any of the oils based off of the data given, he said he would not change any before the mission. However, there were two he would consider: FMTV vehicles, C87 and C88, both have low percent oil life remaining. Using Figure B-1 he saw that they had extremely low oil life remaining. Then, when he looked at Figure B-3, he found that
they were not near needing their annual service and had not even reached 2500 miles driven.

According to this user, the oil has about 10,000 miles in it.

Choosing between the visualizations and the spreadsheet, the juror preferred to use the visualizations, and more specifically, the percent oil life remaining bar charts and the days since oil change versus distance traveled scatterplot. He preferred those because he could quickly look at the bar chart and identify a problem with a vehicle. Then, he would look at the vehicles in the scatterplot to determine their days and mileage since oil change and to give him a better idea of the vehicle’s oil standing. He also said that he would use the spreadsheet to get an overall look at all of the data. However, in terms of expediting the process, he prefers the visualizations. When asked to compare the visualizations with statistics, for example Figure B-1 versus Figure B-2, he said that with how often they change the oils, he felt like he did not need to utilize that information. It may be useful for vehicles that are run more than the ones in the visualizations.

The user thought that the visualizations would be useful for him in other ways, more than just deciding about oil changes. He would use the days since oil change versus miles driven graph for deciding service schedules. He could utilize the spreadsheets for unscheduled maintenance items. He thought having these visualizations would be beneficial to just have around in order to quickly determine which vehicles are his best and ready to go.

Overall, this user preferred the use of the suggested visualizations for planning and deciding oil changes in his vehicles. He would use them for faster, more efficient decision making. However, while the user was utilizing the graphs to make the decisions, he did not seem to agree with them. For example, the FMTV C87 has -20% oil life remaining, but he decided he would not change the oil based on the miles driven. While that does not mean he would not keep his eye on it, it leads the analyst to wonder if he does not trust the algorithm behind the oil life remaining variable.
4.3.3 Case Study 3: Motor Sergeant

The third juror was the Motor Sergeant for the battalion. He oversees the second juror but is underneath the Battalion Maintenance Officer. The company that he is responsible for has approximately 109 pieces of equipment of varying types. These vehicles include Humvees, Strykers, fuelers, and Load Handling Systems (LHS). He is in charge of anything from oil changes to replacement parts on the vehicles. His personnel will troubleshoot the vehicle to determine the issue, and then order the parts to replace. He solely works with the AOAP system to replace the oil in his equipment. This juror will test the oil when he receives notices that request a sample, though the tests do not occur on a fixed schedule.

This juror seemed to struggle with understanding what the interviewer was asking. He did not understand that the AOAP system would not be used, since the task was overseas at the Bagram Air Base. He finally grasped the task and said he would send the better vehicles. By this he means that he would send the vehicles that have less time on their oil. He would not send any that have a low oil life because they may need to be changed soon. He would send the ones that were more recently changed and have a lower number of miles driven on them because they are more reliable. Based off of the data alone, he would not change any of the oils. He would just not send the ones with lower oil life remaining on the mission.

When choosing between the visualizations and the spreadsheets, the juror said that he would prefer to use the spreadsheets because “I understand the spreadsheet more than I could the graphs.” It appeared that this juror did not have much experience interpreting data on graphical visualizations. However, when asked what he found helpful about the graphs, he said that the color-coding was beneficial and easy to distinguish low oil life. He thought it would save him time because the green bars in the graph told him which vehicles are good, and then he would go over to the spreadsheet to get more details. Also, the juror stated that he preferred the bar chart
that included the statistics on it because it showed more detail and “the more information you have, the better you can base your decisions and judgments.”

There were only a few things that the third juror could think of that he would use the data for. He said he would use them to base his services and scheduling filter changes and oil changes. In general, it appeared that the juror’s lack of data reading experience caused him to prefer the spreadsheets methods in planning which vehicles needed an oil change. To interpret the data, he preferred the spreadsheet; however, he said he also liked using the combination of using the bar chart with the spreadsheet.

4.3.4 Case Study 4: Support Supervisor

The final juror that was interviewed had a different job field than the other three jurors. While he was the same level as the Battalion Maintenance Officer, he was not in charge of a vehicle fleet like the others, but he was the support manage team supervisor. He manages the small arms section, the electronics section, and the inspection section, and he is responsible for a small group that works out in the field. The group oversees and inspects nearly all vehicles onsite and in outlying sites because they all have small arms and communications. The juror and his team are responsible for the small arms and communications for approximately 400 vehicles on site and then also look after 76 individual units. In total, he oversees hundreds to thousands of small arms and electronics and does not deal with oil changes or maintenance pertaining to oil services.

After the interviewer explained the scenario and the oil life model to the juror, he voiced his opinion that he did not think the percent oil life remaining should be used. He is an advocate of preventative maintenance checks and services, or PMCS, which is what every driver and crew have to do to their vehicles before they use them. This process involves a list of checks and
services for each part of the vehicle. He believes that the biggest issue that the Army suffers from is a lack of PMCS use. He was concerned that the vehicle operators would use the knowledge of the percent oil life remaining to skip over the oil checks and that could lead to more vehicle maintenance issues. What he did not understand was that the tool would not be used at a vehicle operator level, but more at his level.

Once the juror had a better understanding of whom the visualizations were developed for, he gave his opinion of the visualizations. He thought if the tools were being used in a forward environment it could be effective for a commander or a maintenance technician, but it would need to be in conjunction with other information such as the maintenance reports. Despite thinking it may be useful for commanders, he stated that they would not use it, but instead they would go ask their warrant officer which vehicles to use. When asked if he would change any of the vehicles’ oil based on the data, he said it would not make him change the oil but it would let him know to check the oil and keep an eye on it. Before deciding if he would change, he would take into consideration how often the reports were updated and how that vehicle’s oil life has progressed.

Based on the previous answers, it was obvious that the user preferred the spreadsheet to read the data. He said, “Commanders look for colors, warrant officers look for data.” He preferred the spreadsheet because it could be filtered to arrange the data that would be easy to see. For example, he would arrange it from lowest percent oil life remaining and also by days since last oil change. He also stated that the scatterplots were too busy, and that much data will be overwhelming to someone who cannot decipher it. The visualizations with the statistics were irrelevant to him. He asked the interviewer to explain them and thought that anyone who uses them would need an explanation before using them as well.

There was no task of his to which he could apply these visualizations. He also said that maintenance would not use them either because he thought it would take up too much valuable time flipping between visualizations. This juror only uses spreadsheets to read data, which leads
the analyst to believe that he may not have a lot of training interpreting visualizations. So, he may not realize that visualizations can show data just as well and sometimes better if the user knows how to interpret it.

4.4 Analysis

The data gathered from the user jury proved to be highly beneficial to the researcher. A comparison of the results can be seen in Table 4-1. The decision-making methods were different for each, but that was expected. The second and third juror both chose to send vehicles that had less time on their engine oil, and the first juror had a specific method of choosing vehicles around 70% oil life remaining. These three methods can be used to improve the existing visualizations so that they will enhance their decision-making processes.

Table 4-1: Comparison Chart for the User Jury

<table>
<thead>
<tr>
<th>Position</th>
<th>Visualization Type Preference</th>
<th>Visualization Used during Task Analysis</th>
<th>Statistics Preference</th>
<th>Area of Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battalion Maintenance Officer</td>
<td>Spreadsheet</td>
<td>Graphs</td>
<td>Statistics</td>
<td>Select vehicles for missions, Track vehicles, &amp; Maintain oil rotation</td>
</tr>
<tr>
<td>Maintainer</td>
<td>Graphs</td>
<td>Graphs</td>
<td>No Statistics</td>
<td>Service schedules &amp; Unscheduled maintenance items</td>
</tr>
<tr>
<td>Motor Sergeant</td>
<td>Spreadsheet</td>
<td>Spreadsheet</td>
<td>Statistics</td>
<td>Service schedules</td>
</tr>
<tr>
<td>Support Supervisor</td>
<td>Spreadsheet</td>
<td>No Task Analysis Done</td>
<td>No Statistics</td>
<td>Nothing</td>
</tr>
</tbody>
</table>
As seen in the comparison table of the user jury results, only the second juror said that he preferred using the graphical visualizations to the spreadsheet. It was noted that this juror was the youngest of the four, so perhaps his age or a greater familiarity with technology has an impact on his preference. The fourth juror was the only to completely dislike the graphical visualizations. This could be because he had no use for them in his position, or that he was an adamant enforcer of preventative maintenance checks and services. The first and third jurors both expressed that a combination of the graphs and the spreadsheet would be helpful. As for the preference for statistics being included, the jurors were split. Two of the users thought the statistics were beneficial and two of the users did not. In order to get a consensus, more maintainers would need to be interviewed.

One of the questions seemed to confuse the jurors; in spite of this, the researcher found their answers to be helpful towards future work. This question was: what other information would you need to make decisions (only regarding oil)? Only the first juror understood that the interviewer was asking about what other information did they need to make a decision about oil changes. The other three interviewees gave answers on what other information they would need before sending out vehicles on a mission. Some of the answers they gave included what would they be carrying in the vehicles, what route they would take, the maintenance records, and any issues with the vehicles. While some of this information may affect oil changes, most are separate details. However, analysts could use this information in the future to develop a better tool that the Battalion Maintenance Officers could use to plan missions.

The user jury included four potential users with different positions. This had the researcher hopeful that the graphical visualizations could be beneficial for diverse users. Developing an interface that is useful to many people with differing needs would be advantageous to the military and could potentially have a cost-saving effect. The results of the jury show that the visualizations are not ready for the military to use. The graphical
visualizations need to be further developed using the feedback from the interviews. An interactive interface may be more beneficial to the users than static reports. So, the next step could be creating a dashboard that can allow them to select and sort the data they want to see. After developing a new interface, another user jury with more participants can be conducted, and then the interface could be implemented for maintainers to use.
Chapter 5

Conclusions and Future Work

5.1 Summary and Conclusions

Researchers are constantly working with vast amounts of data to translate into useful information. One of the more common ways to display and quickly interpret a large quantity of data is in information visualizations. Not only is it hard to know what data is significant enough to include in a visualization tool, but it is also difficult to design the tool to be used by someone else. Analysts that are designing graphical tools for customers they have never met can be a difficult task. This task becomes increasingly complicated by the fact that the workers at the Applied Research Laboratory work with military customers who have little experience interpreting data from visualizations. The researcher created a process in order assist these analysts to systematically develop graphs and interfaces for their military clients.

The visualization development process was designed to help analysts to create visualizations for personnel in a military environment. It has a systematic design so that it can be easily followed and deliver useable results. The most important aspect of the process is that it helps the researcher learn about their customers’ needs and goals. In Phase 1, the analysts are to define a thorough scope with the project manager and customer. The scope can lead them in an initial direction when analyzing the data and brainstorming interface ideas. Phase 2 consists of the initial interview with a potential user to discuss their goals and decision-making process of the task as well as the creation of the visualizations for Phase 3. To assess the visualizations, a user jury is conducted. The feedback from the user jury is then used to improve the interface. Phase 3 can be repeated to obtain more feedback and a better visualization for the user.
The researcher demonstrated the proposed visualization development process with an oil life project. The project goal was to create visualizations that would help maintainers to assess the oil life of the vehicles in their fleet and use the information to plan missions. The data that was supplied included a new percent oil life variable, which estimated the remaining life of engine oil based on measurements taken from vehicles. Using the data and information gathered from the initial interview with a Battalion Maintenance Officer, visualizations were created. These visualizations were then taken to a panel of users to assess their usability.

The user jury gave good feedback on the visualizations, and the researcher can take it and improve them. Because only four users were interviewed, it was difficult to determine if there was a consensus. More of the users preferred the spreadsheets to the graphs. One of the reasons for this may be because the scatterplots were busy and hard to read. Three of the four jurors liked the simpler bar chart for the percent oil life remaining. So, if the researcher was to make simpler and less busy visualizations they may prefer using those. The jurors may prefer just seeing one variable at a time on a graph. Another reason they preferred the spreadsheets was because they have more experience with interpreting data off of them. Overall, the user jury was successful because the researcher did not know what they wanted prior to meeting with them. The feedback can now be taken and used to rework the interface.

Overall, the visualization development process was a success. It is critical to get feedback from the customers in order to know what they will use and find helpful. The analysts will not fully understand what their clients want until they go ask them. To understand the users, the researchers must learn their cognitive processes. The process allows the analysts to create visualizations that will allow their military customers to make more informed and efficient decisions.
5.2 Future Work

There are many potential areas for future work for the research with the oil life project. First, the feedback can be taken from the user jury and used to recreate and edit visualizations for the maintainers. Based on the feedback from the users, the maintainers may prefer a dynamic medium. This could allow the users to view both an entire fleet of data and also give them the capabilities to drill down to information for just one vehicle. The interviews showed that the users prefer the spreadsheets because all of the data was located on one page as opposed to flipping pages with multiple graphs. So, in the future a dashboard that includes multiple graphs with all the data could be created to give them all of the information on one page. If a dashboard is created, it could include other aspects of mission planning other than engine oil. For example, some of the jurors ask for factors such as maintenance records and routes.

Another avenue to pursue with the oil life model is to create a new algorithm to predict when the oil life will expire based on usage parameters and add to the percent oil life remaining variable. When this prediction is overlaid onto other visualizations, the maintainers can see approximately when the engine oil will need to be changed. The users would be able to use this tool for better mission planning further out and even to manage supplies. Since half of the jurors said they liked the use of statistics, different statistics could be considered that may be more helpful, possibly some that help predict when the oil will fail.

Once new visualizations and an interface are created, it would be beneficial to obtain more feedback from maintainers. The researcher should find several more users so that they can measure their results. In addition to interviews, surveys can be conducted so that results can be quantified. When the results are measureable, the researcher is able to better determine if the interface is ready for use or what aspects need to be changed.
Future work for this research should include using the visualization development process on other projects. Each time the process is used its power will strengthen. As it gets used each time, researchers can use it to develop standardized visualizations based on the project goal and the data. It will allow the researchers to better understand their customers, and it will become easier to develop visualizations that the military personnel will comprehend and use.
References


Appendix A

Phase 2 Interview Script

I am working on creating an interface that will assist users, specifically Battalion Maintenance Officers, in understanding how their vehicles are being used, and when they may need an oil change.

What is the current process in deciding when a vehicle needs an oil change?
    If it is done every X days, is it still changed even if the vehicle has hardly been used?

How do BMOs or maintainers keep track of when vehicles need an oil change/get an oil change?
    Who keeps track of it (BMOs or maintainers)?
    How do they keep track? Is there a visual system?
    If maintainers keep track of their own vehicles, how do the BMOs keep track of oil changes being done & make sure vehicles oil is being properly maintained?

If given a visual representation of how vehicles are using their engine oil, do you think BMOs would use it? Why or why not?

Analysts have worked to create an oil life model that can estimate how much of the oil has been used based on how the vehicle is being used. Engine time is used because it is better correlated with engine health. The engineering model takes into account the nominal engine oil life and monitors the engine oil temperature, coolant temperature, engine load, engine speed, engine
cranking, and oil aging. It also incorporates driving in a desert and dusty environment. For example, if a vehicle is left idling in a cold environment, the fuel is only partially combusted and the oil becomes contaminated. Then, the model will account for the extra oil degradation due to oil contamination by increasing the equivalent engine time by a calculated correlation factor.

Equivalent engine time is equal to the actual engine time plus the additional time from how the vehicle was used.

[Walk through explanation]

Equivalent Engine Time = Previous Equivalent Engine Time + sampling interval * temperature correction factor * engine load correction factor * engine speed correction factor * engine cranking correction factor * dust/desert correction factor

Do you have an understanding of the oil life model (algorithm)?

   Do you think it is accurately representing how vehicles are being used in the field?
   Is there anything you would add or delete or alter?

Do you think BMOs would benefit in seeing an estimation of how much good oil is left in the vehicle?

   If so, how would it benefit them?
   Would seeing what percent of oil left change when the vehicles’ oils are changed?
   Do you think maintainers would use this visualization as well?

In what situations can you see this tool being beneficial?
What kind of constraints do you (and BMOs) have?

What kind of priorities for readiness do you (and BMOs) have?

If BMOs were able to see an estimate of how much oil life is left, would it affect the timing of vehicle’s oil change?

Would it be changed in either direction (both earlier and later)? For example, if they saw a vehicle had hardly been used but its 6-month oil change is coming up, would they still change it or would they take the advice of the model?

What factors would help you in deciding when to change the oil in a vehicle?

What are the important factors that would be helpful to see along with the estimated oil life?

In the visualization, what variables would be beneficial to see?

Would time since last oil change still be important? Or miles driven?

If BMOs could see each vehicle’s oil life, do you think they would be able to better maintain their supplies?

If so, how would it help them in maintaining their supplies?

If not, why wouldn’t it?

DO you have any final comments or thoughts?
### Appendix B

Visualizations for FMTVs

Table B-1: Data Spreadsheet for FMTVs

<table>
<thead>
<tr>
<th>Model</th>
<th>Bumber Number</th>
<th>Engine Time [hrs]</th>
<th>Equivalent Engine Time [hrs]</th>
<th>Percent Oil Life Remaining</th>
<th>Distance Traveled [miles]</th>
<th>Date Changed</th>
<th>Days Since Oil Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 FMTV-A1</td>
<td>C65</td>
<td>133.42</td>
<td>242.32</td>
<td>51.54%</td>
<td>354.58</td>
<td>1/28/13</td>
<td>95</td>
</tr>
<tr>
<td>2 FMTV-A1</td>
<td>C66</td>
<td>77.76</td>
<td>170.95</td>
<td>65.81%</td>
<td>424.70</td>
<td>2/11/13</td>
<td>81</td>
</tr>
<tr>
<td>3 FMTV-A1</td>
<td>C67</td>
<td>117.61</td>
<td>254.02</td>
<td>49.20%</td>
<td>286.97</td>
<td>1/29/13</td>
<td>94</td>
</tr>
<tr>
<td>4 FMTV-A1</td>
<td>C68</td>
<td>123.98</td>
<td>288.15</td>
<td>42.37%</td>
<td>927.04</td>
<td>1/7/13</td>
<td>116</td>
</tr>
<tr>
<td>5 FMTV-A1</td>
<td>C69</td>
<td>114.91</td>
<td>216.11</td>
<td>56.78%</td>
<td>779.66</td>
<td>2/15/13</td>
<td>77</td>
</tr>
<tr>
<td>6 FMTV-A1</td>
<td>C70</td>
<td>10.25</td>
<td>30.91</td>
<td>93.82%</td>
<td>53.94</td>
<td>1/30/13</td>
<td>93</td>
</tr>
<tr>
<td>7 FMTV-A1</td>
<td>C71</td>
<td>50.30</td>
<td>108.24</td>
<td>78.35%</td>
<td>325.71</td>
<td>1/28/13</td>
<td>95</td>
</tr>
<tr>
<td>8 FMTV-A1</td>
<td>C72</td>
<td>22.56</td>
<td>71.26</td>
<td>85.75%</td>
<td>124.65</td>
<td>1/14/13</td>
<td>109</td>
</tr>
<tr>
<td>9 FMTV-A1</td>
<td>C73</td>
<td>0.14</td>
<td>0.89</td>
<td>99.82%</td>
<td>0.00</td>
<td>4/16/13</td>
<td>17</td>
</tr>
<tr>
<td>10 FMTV-A1</td>
<td>C74</td>
<td>48.51</td>
<td>216.52</td>
<td>56.70%</td>
<td>249.72</td>
<td>1/17/13</td>
<td>106</td>
</tr>
<tr>
<td>11 FMTV-A1</td>
<td>C75</td>
<td>43.80</td>
<td>139.29</td>
<td>72.14%</td>
<td>252.80</td>
<td>2/10/13</td>
<td>82</td>
</tr>
<tr>
<td>12 FMTV-A1</td>
<td>C76</td>
<td>27.73</td>
<td>107.88</td>
<td>78.42%</td>
<td>82.60</td>
<td>1/3/13</td>
<td>120</td>
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<tr>
<td>13 FMTV-A1</td>
<td>C77</td>
<td>85.91</td>
<td>231.64</td>
<td>53.67%</td>
<td>539.09</td>
<td>2/1/13</td>
<td>91</td>
</tr>
<tr>
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<td>C78</td>
<td>46.18</td>
<td>159.18</td>
<td>68.16%</td>
<td>159.94</td>
<td>1/9/13</td>
<td>114</td>
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<tr>
<td>15 FMTV-A1</td>
<td>C79</td>
<td>40.76</td>
<td>122.52</td>
<td>75.50%</td>
<td>197.47</td>
<td>1/27/13</td>
<td>96</td>
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<td>16 FMTV-A1</td>
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<td>255.83</td>
<td>48.83%</td>
<td>451.39</td>
<td>1/27/13</td>
<td>96</td>
</tr>
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<td></td>
<td>FMTV-A1</td>
<td>C81</td>
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</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td>53.81</td>
<td>150.57</td>
<td>69.89%</td>
<td>469.32</td>
<td>2/14/13</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td>56.74</td>
<td>122.76</td>
<td>75.45%</td>
<td>196.42</td>
<td>1/29/13</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td>79.42</td>
<td>141.43</td>
<td>71.71%</td>
<td>418.41</td>
<td>1/15/13</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td>68.23</td>
<td>135.61</td>
<td>72.88%</td>
<td>338.37</td>
<td>1/13/13</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
<td>61.16</td>
<td>146.76</td>
<td>70.65%</td>
<td>332.75</td>
<td>1/29/13</td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
<td>85.16</td>
<td>143.59</td>
<td>71.28%</td>
<td>486.14</td>
<td>1/7/13</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td>438.22</td>
<td>599.87</td>
<td>-19.97%</td>
<td>2474.20</td>
<td>1/14/13</td>
</tr>
<tr>
<td>24</td>
<td></td>
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<td>307.00</td>
<td>481.76</td>
<td>3.65%</td>
<td>1602.79</td>
<td>2/4/13</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td>209.85</td>
<td>305.66</td>
<td>38.87%</td>
<td>1114.52</td>
<td>1/13/13</td>
</tr>
<tr>
<td>26</td>
<td></td>
<td></td>
<td>34.08</td>
<td>63.04</td>
<td>87.39%</td>
<td>276.37</td>
<td>2/24/13</td>
</tr>
<tr>
<td>27</td>
<td></td>
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<td>17.55</td>
<td>33.39</td>
<td>93.32%</td>
<td>130.18</td>
<td>3/2/13</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td>24.57</td>
<td>50.55</td>
<td>89.89%</td>
<td>156.85</td>
<td>2/26/13</td>
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</table>
Figure B-1: Percent Oil Life Remaining for FMTV Vehicles
Figure B-2: Percent Oil Life Remaining for FMTV Vehicles Including Standard Deviations
Figure B-3: Days vs. Distance Traveled Since Oil Change for FMTVs
Figure B-4: Days vs. Distance Traveled Since Oil Change Cluster 1 for FMTVs
Figure B-5: Days vs. Distance Traveled Since Oil Change Cluster 2 for FMTVs
Figure B-6: Engine Hours vs. Distance Traveled Since Oil Change for FMTVs
Figure B-7: Engine Hours vs. Distance Traveled Since Oil Change Bottom Cluster for FMTVs
## Appendix C

### Visualizations for HEMTTs

Table C-1: Data Spreadsheet for HEMTTs

<table>
<thead>
<tr>
<th>Model</th>
<th>Bumper Number</th>
<th>Engine Time [hrs]</th>
<th>Equivalent Engine Time [hrs]</th>
<th>Percent Oil Life Remaining</th>
<th>Distance Traveled [miles]</th>
<th>Date Changed</th>
<th>Days Since Oil Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 HEMTT-A2</td>
<td>C37</td>
<td>10.58</td>
<td>43.94</td>
<td>91.21%</td>
<td>13.65</td>
<td>1/7/13</td>
<td>116</td>
</tr>
<tr>
<td>2 HEMTT-A4</td>
<td>C38</td>
<td>82.35</td>
<td>117.84</td>
<td>76.43%</td>
<td>535.81</td>
<td>2/15/13</td>
<td>77</td>
</tr>
<tr>
<td>3 HEMTT-A4</td>
<td>C39</td>
<td>166.93</td>
<td>291.66</td>
<td>41.67%</td>
<td>924.13</td>
<td>1/19/13</td>
<td>104</td>
</tr>
<tr>
<td>4 HEMTT-A4</td>
<td>C40</td>
<td>13.58</td>
<td>41.20</td>
<td>91.76%</td>
<td>14.43</td>
<td>2/14/13</td>
<td>78</td>
</tr>
<tr>
<td>5 HEMTT-A4</td>
<td>C41</td>
<td>8.32</td>
<td>39.31</td>
<td>92.14%</td>
<td>5.13</td>
<td>2/19/13</td>
<td>73</td>
</tr>
<tr>
<td>6 HEMTT-A4</td>
<td>C42</td>
<td>15.06</td>
<td>38.49</td>
<td>92.30%</td>
<td>30.53</td>
<td>2/20/13</td>
<td>72</td>
</tr>
<tr>
<td>7 HEMTT-A4</td>
<td>C43</td>
<td>2.56</td>
<td>10.42</td>
<td>97.92%</td>
<td>4.46</td>
<td>2/17/13</td>
<td>75</td>
</tr>
<tr>
<td>8 HEMTT-A4</td>
<td>C44</td>
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<td>14.80</td>
<td>97.04%</td>
<td>8.66</td>
<td>2/9/13</td>
<td>83</td>
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<td>C45</td>
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<td>80.67</td>
<td>83.87%</td>
<td>37.43</td>
<td>4/1/13</td>
<td>32</td>
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<tr>
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<td>C46</td>
<td>76.86</td>
<td>142.94</td>
<td>71.41%</td>
<td>700.30</td>
<td>1/25/13</td>
<td>98</td>
</tr>
<tr>
<td>11 HEMTT-A4</td>
<td>C47</td>
<td>45.70</td>
<td>101.83</td>
<td>79.63%</td>
<td>275.67</td>
<td>2/11/13</td>
<td>81</td>
</tr>
<tr>
<td>12 HEMTT-A4</td>
<td>C48</td>
<td>4.73</td>
<td>17.41</td>
<td>96.52%</td>
<td>1.25</td>
<td>1/27/13</td>
<td>96</td>
</tr>
<tr>
<td>13 HEMTT-A4</td>
<td>C49</td>
<td>6.10</td>
<td>23.14</td>
<td>95.37%</td>
<td>1.65</td>
<td>1/25/13</td>
<td>98</td>
</tr>
<tr>
<td>14 HEMTT-A4</td>
<td>C50</td>
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<td>174.85</td>
<td>65.03%</td>
<td>46.56</td>
<td>1/25/13</td>
<td>98</td>
</tr>
<tr>
<td>15 HEMTT-A4</td>
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<td>15.52</td>
<td>31.22</td>
<td>93.76%</td>
<td>27.26</td>
<td>2/5/13</td>
<td>87</td>
</tr>
<tr>
<td>16 HEMTT-A4</td>
<td>C52</td>
<td>6.75</td>
<td>19.72</td>
<td>96.06%</td>
<td>0.85</td>
<td>1/23/13</td>
<td>100</td>
</tr>
<tr>
<td>17 HEMTT-A4</td>
<td>C53</td>
<td>135.47</td>
<td>231.70</td>
<td>53.66%</td>
<td>825.43</td>
<td>1/18/13</td>
<td>105</td>
</tr>
<tr>
<td>18 HEMTT-A4</td>
<td>C54</td>
<td>1.29</td>
<td>3.61</td>
<td>99.28%</td>
<td>0.00</td>
<td>2/22/13</td>
<td>70</td>
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</table>
Figure C-1: Percent Oil Life Remaining for HEMTT Vehicles
Figure C-2: Percent Oil Life Remaining for HEMTT Vehicles Including Standard Deviations
Figure C-3: Days vs. Distance Traveled Since Oil Change for HEMTTs
Figure C-4: Engine Hours vs. Distance Traveled Since Oil Change for HEMTTs
Figure C-5: Engine Hours vs. Distance Traveled Since Oil Change Bottom Cluster for HEMTTs
Table D-1: Data Spreadsheet for LHSs

<table>
<thead>
<tr>
<th></th>
<th>Model</th>
<th>Bumper Number</th>
<th>Engine Time [hrs]</th>
<th>Equivalent Engine Time [hrs]</th>
<th>Percent Oil Life Remaining</th>
<th>Distance Traveled [miles]</th>
<th>Date Changed</th>
<th>Days Since Oil Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LHS-A4</td>
<td>C58</td>
<td>45.48</td>
<td>94.96</td>
<td>81.01%</td>
<td>70.12</td>
<td>2/22/13</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>LHS-A4</td>
<td>C59</td>
<td>42.13</td>
<td>105.41</td>
<td>78.92%</td>
<td>204.69</td>
<td>1/30/13</td>
<td>93</td>
</tr>
<tr>
<td>3</td>
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<td>421.29</td>
<td>15.74%</td>
<td>1443.35</td>
<td>1/31/13</td>
<td>92</td>
</tr>
<tr>
<td>4</td>
<td>LHS-A4</td>
<td>C61</td>
<td>2.30</td>
<td>8.51</td>
<td>98.30%</td>
<td>2.57</td>
<td>1/31/13</td>
<td>92</td>
</tr>
<tr>
<td>5</td>
<td>LHS-A4</td>
<td>C62</td>
<td>107.48</td>
<td>209.82</td>
<td>58.04%</td>
<td>697.06</td>
<td>2/20/13</td>
<td>72</td>
</tr>
<tr>
<td>6</td>
<td>LHS-A4</td>
<td>C63</td>
<td>70.30</td>
<td>175.84</td>
<td>64.83%</td>
<td>304.08</td>
<td>2/20/13</td>
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</tr>
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<td>7</td>
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<td>C64</td>
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<td>13.26%</td>
<td>382.76</td>
<td>3/1/13</td>
<td>63</td>
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Figure D-1: Percent Oil Life Remaining for LHS Vehicles
Figure D-2: Percent Oil Life Remaining for LHS Vehicles Including Standard Deviations
Figure D-3: Days vs. Distance Traveled Since Oil Change for LHSs
Figure D-4: Engine Hours vs. Distance Traveled Since Oil Change for LHSs
Appendix E

Visualizations for Line Hauls

Table E-1: Data Spreadsheet for Line Hauls

<table>
<thead>
<tr>
<th>Model</th>
<th>Bumper Number</th>
<th>Engine Time [hrs]</th>
<th>Equivalent Engine Time [hrs]</th>
<th>Percent Oil Life Remaining</th>
<th>Distance Traveled [miles]</th>
<th>Date Changed</th>
<th>Days Since Oil Change</th>
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<tbody>
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<td>1 Line-Haul-A3</td>
<td>C55</td>
<td>45.48</td>
<td>130.85</td>
<td>73.83%</td>
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<td>C56</td>
<td>26.76</td>
<td>88.92</td>
<td>82.22%</td>
<td>84.38</td>
<td>1/6/13</td>
<td>117</td>
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<td>C57</td>
<td>114.98</td>
<td>247.74</td>
<td>50.45%</td>
<td>292.53</td>
<td>1/16/13</td>
<td>107</td>
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</table>
Figure E-1: Percent Oil Life Remaining for Line Haul Vehicles
Figure E-2: Days vs. Distance Traveled Since Oil Change for Line Hauls
Figure E-3: Engine Hours vs. Distance Traveled Since Oil Change for Line Hauls
Appendix F
Visualizations for PLSs

Table F-1: Data Spreadsheet for PLSs

<table>
<thead>
<tr>
<th>Model</th>
<th>Bumber Number</th>
<th>Engine Time [hrs]</th>
<th>Equivalent Engine Time [hrs]</th>
<th>Percent Oil Life Remaining</th>
<th>Distance Traveled [miles]</th>
<th>Date Changed</th>
<th>Days Since Oil Change</th>
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<td>50.46</td>
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<td>80.61</td>
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<td>67.87%</td>
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<td>2/11/13</td>
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<td>1557.98</td>
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<td>97.77%</td>
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<td>2/12/13</td>
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<tr>
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<td>64.15%</td>
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<tr>
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<td>47.87%</td>
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<td>96.49%</td>
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<td>1/31/13</td>
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<td>143.59</td>
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</tr>
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<td>24</td>
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<td>25</td>
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Figure F-1: Percent Oil Life Remaining for PLS Vehicles
Figure F-2: Percent Oil Life Remaining for PLS Vehicles Including Standard Deviations
Figure F-3: Days vs. Distance Traveled Since Oil Change for PLSs
Figure F-4: Days vs. Distance Traveled Since Oil Change Cluster 1 for PLSs
Figure F-5: Days vs. Distance Traveled Since Oil Change Cluster 2 for PLSs
Figure F-6: Days vs. Distance Traveled Since Oil Change Cluster 3 for PLs
Figure F-7: Engine Hours vs. Distance Traveled Since Oil Change for PLS
Appendix G

User Jury Script

Get permission to record the interview. Names will be kept out of recording & files. No classified information will be discussed. First, I want to get to know your background. In the next 2 minutes, can you tell me about your position (i.e. how many vehicles you oversee, basics on your responsibilities, specifics on dealing with oil changes, etc.)?

Do you use the oil analysis program?

What is your role in keeping track of oil changes?

What are the differences when you are in a forward environment?

The data you are about to see is from Bagram Air Base. It includes data from 5 types of vehicles, and they will represent your unit that you are in charge of. Here is a scenario that I would like you to look over, and using the reports I give you, talk about the decisions you would make concerning oil changes.

[Scenario]

Your unit consists of:

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<thead>
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<th>Number</th>
<th>Type</th>
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<tbody>
<tr>
<td>36</td>
<td>PLS-A0</td>
</tr>
<tr>
<td>18</td>
<td>HEMTT-A2 &amp; A4</td>
</tr>
<tr>
<td>3</td>
<td>Line Haul-A3</td>
</tr>
<tr>
<td>7</td>
<td>LHS-A4</td>
</tr>
<tr>
<td>28</td>
<td>FMTV-A1</td>
</tr>
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</table>
Your mission is to send supplies to another FOB. The mission will be a total of 6 days (3 days each day), and the destination FOB is 90 miles away. In order to complete the mission, you need to send:

- 6 PLS-A0
- 2 HEMTT-A2 & A4
- 3 Line Haul-A3
- 3 LHS-A4
- 12 FMTV-A1

[End Scenario]

[Explain each column of spreadsheet]

Engine Time [hrs]: the cumulative engine hours since last oil change

Equivalent Engine Time [hrs]: cumulative equivalent engine hours calculated by algorithm (takes into account nominal engine life, engine oil temperature, coolant temperature, engine load, engine speed, engine cranking, oil aging, and climate)

Percent Oil Life Remaining: estimated oil life remaining based off algorithm

Distance Traveled [miles]: cumulative distance traveled since last oil change

Days Since Oil Change: number of days since oil was changed

[End Explanation]

(1) What other information would you need to make decisions (only regarding oil)?

(2) Given the information you have, what vehicles would you send (in terms of engine oil)? Why?

(a) Explain your decision process.
(3) In regards to your fleet of vehicles, what oil change decisions would you make?
   (a) Both in general and before the mission

(4) Discuss your thoughts on the visualizations.
   (a) Between these two options, which visualization did you prefer when making the decisions?
   (b) What did you find helpful or not helpful about each one?
   (c) Compare advantages and disadvantages of each visualization.
   (d) Between the two visualizations (no statistics vs. statistics), which do you prefer?

(5) Again, what additional information would you need to help with these decisions? Why?
   (a) How important is this information you need?

(6) What could you use these visualizations for?