3-2005

Air Force JP-8 Fuel Distribution System: A Statistical Analysis to Determine Where and When to Sample

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AIR FORCE JP-8 FUEL DISTRIBUTION SYSTEM: A STATISTICAL ANALYSIS TO DETERMINE WHERE AND WHEN TO SAMPLE

THESIS

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AFIT/GLM/ENS/05-09

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AFIT/GLM/ENS/05-09

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THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

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4 March 2005

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Abstract

The Air Force Petroleum Office at Wright-Patterson Air Force Base, Ohio collects JP-8 fuel testing data, but this data doesn't undergo analysis to determine the health of the base-level JP-8 fuel distribution system. The objective of this research is to assess Air Force base-level fuel sampling data to determine where each base should focus their sampling efforts. Also, this research seeks to identify how often correlation/aircraft servicing sampling of JP-8 should take place. Currently, Air Force bases send these fuel samples to an area lab for testing every 45 days. Sample test pass rates are analyzed from three locations (receipt, storage, and vehicles/aircraft) at seven different worldwide bases in this study.

The results of this research indicate that the receipt location should be the focus of sampling efforts at base-level. Due to high pass rate variability, lower pass rates, lower sample sizes, less filtration, and a lack of complete control over the JP-8 that arrives at each base, Air Force base-level fuels management should focus sampling efforts at receipt. This attention at receipt will help ensure a healthy fuel flow process through to the aircraft. The Bernoulli CUSUM statistical process control (SPC) chart is introduced as a way of quickly identifying when the base-level JP-8 fuel flow process signals out-of-control. Lastly, a comparison of area and base lab sampling results show that the current 45-day correlation/aircraft servicing sampling requirement is sufficient and reflects the health of the base-level JP-8 fuel distribution system at the point where fuel gets loaded into the aircraft.

Acknowledgements

First and foremost, I would like to thank my thesis advisor, Major Bradley Anderson. Without his knowledge, guidance, and leadership, this research effort wouldn't have been the best that it could be. I appreciate the countless hours reviewing my work and holding meetings to complete this thesis work on-time. I couldn't possibly thank him enough. I would also like to thank my reader, Lieutenant Colonel Marvin Arostegui, for his expertise and all the time spent on this project. I would also like to express my gratitude to other AFIT faculty who helped with my understanding of statistics and other disciplines vital to the quality of this thesis. Major Timothy Webb and Dr. Marcus Perry unselfishly added their time and expertise to any questions I had. Professor Dan Reynolds also taught me a lot about statistics, and his enthusiasm in teaching can be compared to only one other professor that I have ever come across. The biggest impact on my academic career was the late Professor Robert H. Brunell, a teacher, mentor, and confidant. After completing the winter semester in late 2004, he passed on after 57 ½ years in the State University of New York (SUNY) school system. I miss him and always will. Dr. Rosemary Avery and Dr. William Rosen at Cornell University continue to have interest and support my academic career.

To my family, I must thank them for their support along the way. Without my parents, and their never-ending love and support, I would never have completed any college nor had any success. I would also like to thank my wife, who currently resides in Thailand, for her patience and concern while we waited for her visa. My sister, brother, and best friends Jay and Tom deserve recognition for their moral support since this project began. Eric J. Heath

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Air Force JP-8 Fuel Distribution System: A Statistical Analysis to Determine Where and When to Sample

I. Introduction

Background

This research focuses on the health of JP-8 fuel for jet aircraft at U.S. Air Force installations worldwide. JP-8 fuel is essentially commercial Jet-A kerosene-based fuel, with Fuel System Icing Inhibitor (FSII), Corrosion Inhibitor/ Lubricity Improver (CI), and Static Dissipater Additive (SDA) added (SW L6ONU21R1 003-III, 1-4, 5). JP-8 replaces another kerosene-based fuel, JP-4, to improve combat survivability and ground handling safety (SW L6ONU21R1 003-III, 1-4, 5). JP-4 proved too volatile for use in today's high-performance aircraft. Thus, the Air Force prefers the use of JP-8, and this study serves to investigate the health of the JP-8 base-level fuel distribution system that serves the majority of Air Force aircraft customers.

At base-level, the main customers of JP-8 are Wing commanders, aircraft commanders, and ground fuels personnel. Wing commanders at each base desire a high level of confidence that fuel being distributed to their base-level facility meets or exceeds safety of flight use limits. Aircraft commanders want confidence that the JP-8 fuel pumped into their aircraft meets or exceeds standards for safe and effective mission accomplishment. Ground fuels personnel want to ensure that each aircraft gets a healthy dose of JP-8 for a safe flight.

The Defense Energy Support Center (DESC) plays a vital role in the coordination and supply of quality fuel products around the world. Their mission is "to provide the Department of Defense and other customers comprehensive energy solutions in the most effective and economic manner possible" (Fuel Line, 3). DESC-B, the bulk fuel division, maintains aviation fuel specifications and standards for military aircraft, and this specific guidance is covered in Chapter 2 Literature Review. Worldwide DoD contracted agencies deliver refined JP-8 fuel to military installations. The refined JP-8 must contain the previously mentioned SDA, FSII, and CI additives (MIL-DTL-83133E, 1). JP-8+100 is the same kerosene-type turbine fuel, but it adds a thermal stability improver (MIL-DTL-83133E, 1). JP-8 primarily arrives at worldwide bases via tanker barge, pipeline, or tanker trucks (Pittman & Toner, 2004).

Once the fuel arrives on base, this marks the beginning of sample testing before the fuel gets pumped into bulk fuel storage facilities. Regardless of fuel arrival mode, JP-8 samples are taken, analyzed, and recorded by fuels personnel at the time of receipt. DESC and the Air Force have regulations that outline turbine fuel sampling and testing requirements that base personnel must follow, and Chapter 2 presents these requirements. JP-8 flows through fixed filter separators at the base fuel loading and unloading facility receipt location to remove water and sediment that may still exist in the fuel (Pittman & Toner, 2004). After fuel flows through filter separators, it flows through pipes to get to either an underground or above ground storage tank. When a requirement for JP-8 exists on the flight line, JP-8 gets pumped through another set of filter separators before it gets dispensed into an awaiting R-11 or R-9 fuel service truck. Hose carts are another means of transporting fuel to awaiting aircraft. Hose carts connect directly to underground storage tanks (hydrants) beneath the flight line close to the aircraft needing the fuel. When JP-8 flows from a fuel service truck or hose cart to an aircraft, the fuel passes through another set of filter separators. Figure 1.1 below outlines this process.

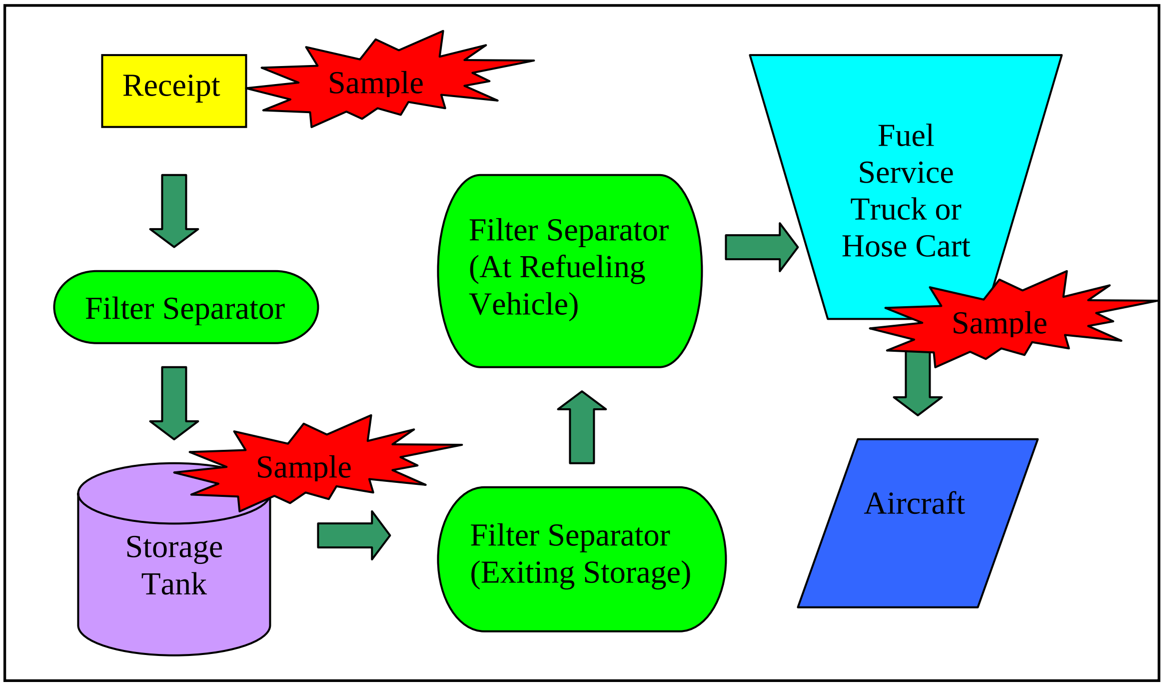


Figure 1.1 Common JP-8 Fuel Flow from Receipt to Aircraft

Fuel filter separators are the key to ensuring that safe grades of JP-8 get placed into military aircraft. These separators help eliminate three main classifications of contamination (SW L6ONU21R1 003 III):

- Chemical: this contamination happens when two different types of fuel get mixed together (1-8),
- Biological: this contamination is due to growth of bacteria or fungi because of the presence of water or especially sea water (1-9), and
- Material: this contamination is the most common and occurs when water or sediment gets into the fuel supply (1-9).

Chemical, biological, and material contaminants can degrade fuel to a point where aircraft using it aren't safe to operate. Also, damage to fuel storage tanks, fuel service trucks, hose carts, and aircraft fuel lines and cells can cost DoD millions of dollars in repair or replacement costs. Complete fuel contamination elimination isn't currently attainable. However, with JP-8 sampling and high filtration frequency, base-level customers at all levels should sense a high level of confidence that their fuel distribution system provides safe JP-8 to the aircraft.

JP-8 samples undergo a battery of tests to determine whether or not collected samples throughout the fuel distribution system pass or fail healthy fuel system requirements (Pittman & Toner, 2004). These tests will be described in greater detail in the following Chapter 2 Literature Review. Each base-level fuels unit conducts these multiple tests on each sample taken on base. If just one test from one sample fails, the entire sample fails and must be retested for validity (Pittman & Toner, 2004). If the sample fails again, further investigation is needed to pinpoint the problem area. Also, every 45 days, each worldwide base sends a sample to one of seven area labs, listed in Chapter 2. This is known as a correlation/aircraft servicing sample (PTO 42B-1-1, 4-2). The area labs perform their own battery of tests to determine if a sample either passes or fails. If samples fail at area labs, base level and area level fuels specialists coordinate to investigate problem areas and to ensure a healthy JP-8 product. This adds another level of checks and balances to safeguard against bad fuel being pumped into aircraft.

Refined JP-8 samples are collected at different points within the DESC fuel distribution system. However, for the purposes of this study, three base-level sampling locations are of primary interest to base and aircraft commanders in determining acceptable levels of quality fuel that enters Air Force and other Department of Defense (DoD) aircraft:

(1) at receipt prior to entering the Air Force storage facility,
(2) at each base-level storage facility,
(3) at aircraft refueling vehicles and at the aircraft.

The samples taken at the refueling vehicles and at the aircraft are of the same quality after the JP-8 passes through the filter separator located on the refueling vehicles. Figure 1.1 above shows the sample locations. Each sampling location has the potential to degrade or contaminate the jet fuel which could result in a test failure. Although test failures are relatively rare, they do happen and are of primary concern to commanders and the flying community (Pittman & Toner, 2004).

Problem Statement and Research Objective

AFPET (Detachment 3 WR-ALC/AFT) at Wright-Patterson Air Force Base, Ohio collects JP-8 sampling data from seven areas of responsibility around the world, and each base provides their sampling data to these areas (Pittman & Toner, 2004). This aggregate data, however, doesn't undergo analysis to determine the health of the base-level jet fuel (JP-8 for this study) distribution system. There is no known confidence level when assessing base-level JP-8 fuel health. Therefore, the objective of this research is to assess Air Force base-level fuel sampling data to identify the base-level sampling location where each base can effectively focus on their sampling efforts. Also, this research seeks to identify how often correlation/aircraft servicing sampling, currently a 45-day requirement at area labs, should take place. The base- and area-level JP-8 tests determine if the fuel sample is healthy (Pittman & Toner, 2004). This study's results may give commanders and pilots the information they need to perform missions and utilize assets with confidence, and the results would also allow AFPET to utilize and apply meaning to the fuel sampling data they collect.

Research Question

This research seeks to answer the question: What base-level JP-8 sampling location should each base focus their sampling efforts and how often should correlation JP-8 samples be taken in order to ensure a healthy fuel product to base-level customers?

Investigative Questions

The following questions are addressed in order to support and defend the overall research question:

(1) What are the probabilities (pass rates) at each base-level sampling point that JP-8 fuel samples will pass testing?

(2) Are the pass rates at base-level receipt, storage, and vehicles/aircraft statistically the same or different?

(3) What procedures could enhance the JP-8 fuel flow process to make the base-level fuel distribution system more responsive and healthy?

(4) How often should area lab samples (45-day correlation/aircraft servicing samples) be taken to ensure a healthy JP-8 fuel distribution system?

Research Methodology

This study is broken into five different phases to help give answers to the research and associated investigative questions. The first three phases attempt to identify which sampling location on base to focus sampling efforts. In Phase 1, descriptive statistics will show the pass rates from the three locations at each of the seven bases selected for this research. Lower pass rates indicate possible locations to focus sampling efforts. The contingency table analysis attempts to show if there is a difference between the three sampling locations on base. If the locations are statistically different, sampling efforts can't be focused on one location. If the three locations are statistically the same, sampling efforts can be focused at any one of the three locations of the fuels manager's choosing. The third phase combines the above two phases in order to attempt to identify one location for sampling. After a base-level location is identified, the fourth phase presents a tool, the Bernoulli CUSUM Control Chart, which quickly identifies when the JP-8 fuel flow process becomes out of control. The final phase compares the base and area lab pass rates using contingency table analysis in order to help determine how often the area labs should sample. The information gained from these five research phases should help give base and aircraft commanders confidence that the JP-8 loaded at their bases and in their aircraft is healthy and safe for flight.

Results and Analysis Overview

Phases 1 through 3 collectively identify the sampling location where future efforts should be focused to ensure quality JP-8 from receipt to the aircraft. In Phase 1, pass rates are analyzed, and the receipt location has the lowest average pass rate, the greatest variability, and the lowest average sample size among the three sampling locations on base. Phase 2 compares the base-level pass rates in order to determine if the pass rates suggest either a difference or no difference among the three sampling locations. The results for Phase 2 are mixed, with three bases having equal pass rates and four bases having unequal pass rates. More investigation is needed to determine the focus for sampling efforts, and Phase 3 helps identify the base-level location.

In Phase 3, information from both phases is gathered and analyzed. Because less attention is paid to the receipt location and due to a lack of control of what enters the JP-8 base-level system, the receipt location is identified as the location for the focus of base-level sampling efforts. Phase 4 provides an example of the Bernoulli CUSUM control chart using Cannon AFB sampling data. This chart could be used at Air Force bases to more closely monitor their JP-8 fuel distribution system. Phase 5 analyzes the 45-day correlation/aircraft servicing requirement. Area- and base-level pass rates are compared to evaluate the effectiveness of the 45-day requirement. Despite the very low sample sizes, the area and base lab pass rates are statistically equal. However, with just one failure at area labs, the results would be different.

Thesis Outline

This thesis is divided into five chapters: Introduction, Literature Review, Methodology, Results and Analysis, and Conclusions and Recommendations.

Chapter 1. Introduction

This chapter covers the background, research objectives, research and investigative questions, and methodology outline of this study.

Chapter 2. Literature Review

This chapter describes the terminology used, outlines the base-level JP-8 sampling locations, and lists the seven bases involved in this study. The tests performed on each JP-8 sample are discussed, and relevant research is covered. Also, the publications, technical orders, and standards that the fuels community uses are included.

Chapter 3. Methodology

This chapter describes the five-phase process used to help answer the research and associated investigative questions. Sample test pass rates help explain the health of the base-level JP-8 fuel distribution system. The statistical process control (SPC) procedure called the Bernoulli CUSUM control chart is also introduced.

Chapter 4. Results and Analysis

This chapter presents the results of the five research phases. An example of the Bernoulli CUSUM control chart using sample data from this study is shown.

Chapter 5. Conclusions and Recommendations

This chapter describes the conclusions from each of the five phases and offers recommendations for future research and future Air Force operational procedures.

II. Literature Review

Introduction

This chapter describes the terminology contained in this study and existing literature to support this research effort. To start, a brief description of this research in collaboration with the Air Force Petroleum Office (AFPET) Program Management team is presented. Next, the data sources from the seven worldwide bases and AFPET (45-day correlation/ aircraft servicing sample data) are presented and discussed. A base-level sampling location description follows, and all the tests conducted on each sample are shown and described. The instructions and technical orders that stipulate sampling points and times are covered. The civil aviation industry is investigated, and this industry is explored to see if their procedures can benefit the Air Force base-level fuel distribution system. Lastly, the search for JP-8 or other aviation fuel-related literature is covered, along with other related research.

JP-8 Fuel Sampling Research Collaboration

In April 2004 and on behalf of AFPET, Maj Andrew Pittman approached the Air Force Institute of Technology (AFIT) with this fuels research opportunity. AFPET wants to ensure a healthy JP-8 fuel distribution system in part by better utilizing sample data. Specifically and as presented in the overall research question, AFPET wants to know at which of the three sampling points on base (aircraft/refueling vehicles, storage facilities, and receipt) should they focus their sampling efforts and how often should sampling take place at the seven area labs. Currently, the Air Force fuels community (AFPET, base-level fuels management and personnel, and base commanders) don't possess a base-level system that accurately monitors a process that is under statistical control. Each base collects their own sampling data from JP-8 sampling tests, and they report sample test failures to AFPET when these test failures can't be fixed on base (Pittman & Toner, 2004). However, there is no statistical analysis completed with their data, and statistical analysis can give base-level fuels customers a better idea of JP-8 fuel distribution system health. AFPET recognizes the opportunity to utilize this collected data in order to provide base-level fuels managers and personnel a standardized and reactive process that helps ensure a healthy JP-8 fuel flow process from receipt to the aircraft.

An initial meeting between AFPET Program Management team and AFIT representatives was held on May 25, 2004. This was the initial meeting to gather information and discuss the research problem for feasibility purposes and to familiarize the participants with this collaborative effort. Limitations (covered in Chapter 5) were also discussed, and JP-8 fuel sampling information was passed to AFIT representatives to familiarize them with the terms and intricacies of JP-8 fuel sampling techniques and the fuel distribution system. The collaboration continued throughout the research project with several meetings attended to coordinate progress.

Data Sources

This section describes the data sources from the seven worldwide bases. Twelve different bases around the world were contacted to participate in this research by sending their JP-8 fuel sampling data to AFIT. These bases were selected to represent geographically and climatologically diverse areas in order to get representative data from assorted fuel refineries and from bases with different weather conditions. Of these twelve bases, seven bases and their accompanying data represent the content for this study. Each base provided data to cover the exact same time frame over a 444-day period from August 1, 2003 to October 18, 2004. The five bases not included in this study either did not meet the November 1, 2004 deadline for submission or could not provide enough data from the approximate 15-month request.

Each Air Force Base maintains JP-8 sampling data in their Fuels Automated System (FAS), and this study uses data extracted from each base-level FAS. Among other functions, such as fuels receipt and other fuels account information, FAS contains fuel sampling data. Base fuels lab personnel keep track of all JP-8 sampling data with FAS, and the following Air Force and Air Bases worldwide supplied this data for this research through electronic database transfer:

- Wright-Patterson Air Force Base, Ohio (Toner, 2004),
- Kadena Air Base, Okinawa/Japan (Boseman, 2004),
- Misawa Air Base, Japan (Larsen, 2004),
- Cannon Air Force Base, New Mexico (Sonnenberg, 2004),
- Hill Air Force Base, Utah (Newton, 2004),
- Mildenhall Air Base, United Kingdom (Duran, 2004), and
- Osan Air Base, Korea (Smith, 2004).

Specifically, and more importantly for this study, this data contains all the vital components needed to analyze the fuel sampling results. Each sample taken is listed according to the:

- date,
- location of each sample taken (from refueling vehicle/aircraft, storage, or time of receipt),
- tests performed on each sample (varies), and
- result of each test (pass or fail).

This data collectively provides the researcher with information to help describe JP-8 fuel sampling test results at the three different sampling points from the seven different worldwide bases.

Base-Level Sampling Location Description

Refined JP-8 samples are collected at three different locations within the base-level fuel distribution system. These three base-level sampling locations are of prime interest to commanders in determining the quality of fuel that enters Air Force and other Department of Defense (DoD) aircraft are (See Figure 2.1 below):

(1) at receipt prior to entering the Air Force storage facility,
(2) at each base-level storage facility,
(3) at the refueling vehicles/at the aircraft.

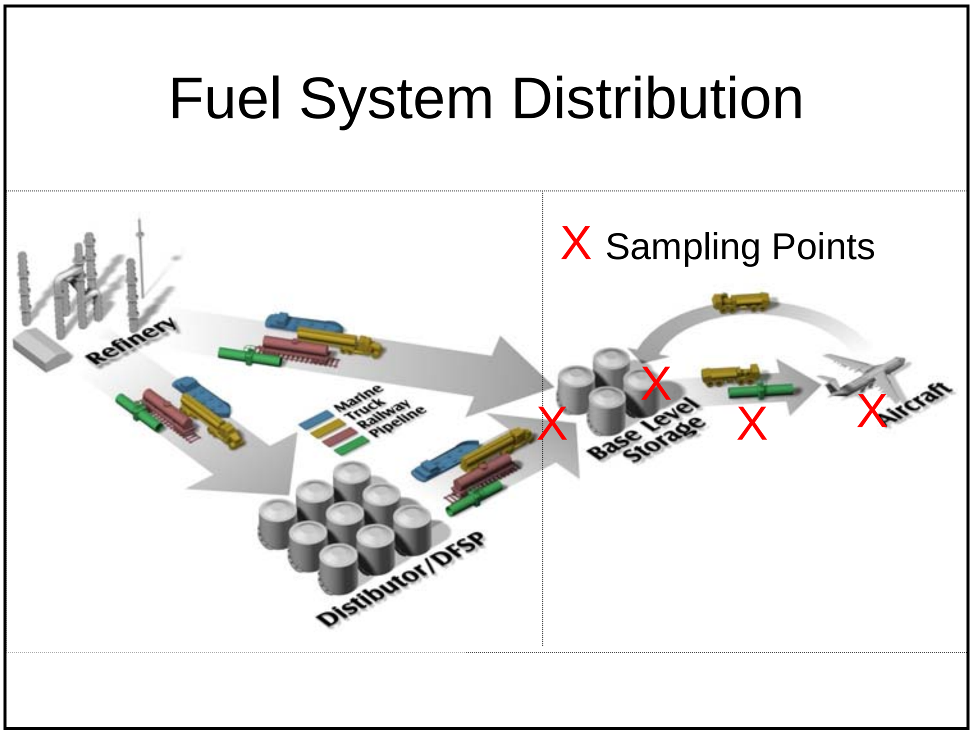


Figure 2.1 JP-8 Fuel System Distribution Sampling Points (Pittman & Toner, 2004)

Base fuels personnel draw JP-8 samples primarily from over the road tanker trucks and pipelines that directly supply fuel to the base. To a lesser extent, a base could possibly receive JP-8 from a railcar, a barge vessel, or from a tanker aircraft, but the data provided didn't include such occurrences. After receipt, JP-8 passes through filter separators to reduce any water or sediments in the fuel, and the next sampling of interest occurs at the storage tanks, either above or underground. Fuels personnel take samples from storage tanks at regular bi-weekly and monthly intervals (PTO 42B-1-1, 5-19). This attention helps fuels personnel identify problems quickly before contamination spreads to other sampling points. JP-8 then passes through a set of filter separators before getting pumped to the refueling vehicle. Fuels personnel take samples from refueling trucks (R-11 or R-9, typically) or from hydrant fueling equipment (HSV-12 vehicle or MH-2 hose cart) after the fuel gets filtered again by the refueling vehicle itself (SW L6ONU21R1 003 II, 1-3). The R-11 tank truck is the newest aircraft refueling vehicle with a 6,000-gallon capacity, a refueling rate of 600 gallons-per-minute (GPM), and a de-fueling rate of 175 gallons per minute (SW L6ONU21R1 003 II, 1-5). This vehicle has a filter separator that is rated at 600 GPM and has 30 filter elements that are double stacked within 15 canisters inside the filter separator housing (SW L6ONU21R1 003 II, 1-5). The older R-9 truck performs the same functions but has a 5,000-gallon capacity, a 600 GPM refueling rate (the same as the R-11), and a 200 GPM de-fueling rate (SW L6ONU21R1 003 II, 1-4). The other typical refueling equipment pieces, the HSV-12 servicing vehicle or MH-2 hose cart, are used in conjunction with underground hydrant systems located on the flight line (SW L6ONU21R1 003 II, 1-7). The HSV-12 is a motorized hose cart with a refueling rate of up to 1,200 GPM and a de-fueling rate of 300 GPM (SW L6ONU21R1 003 II, 1-7). The MH-2 performs the same operations but is not motorized, and each vehicle performs the necessary filtering operation where fuels personnel gather samples (SW L6ONU21R1 003 II, 1-7). Again, personnel can identify problems quickly when the fuels lab detects a failure of one of many tests conducted for each sample. The samples from either HSV-12 or the MH-2 are representative of what gets pumped into the aircraft, referred to as "sampling at the aircraft" in this study (PTO 42-B-1-1, 4-2).

Each sampling point has the potential to degrade or contaminate the jet fuel which can result in a test failure. Although test failures are relatively rare, they do happen and are of primary concern to commanders and the flying community (Pittman & Toner, 2004). As mentioned previously in Chapter 1, chemical, biological, and material contaminants can degrade fuel to a point where aircraft aren't safe to operate. Another form of contamination, microbial, "may cause or contribute to a variety of problems including corrosion, odor, filter plugging, decreased (JP-8) stability, and deterioration of fuel/water separation characteristics. In addition to system component damage, off-specification fuel (fuel that does not maintain JP-8 quality characteristics) can result" (Standard Specification for Aviation Turbine Fuels, 2004). Contamination of fuel is minimized with filtration before fuel enters storage tanks, trucks, and aircraft.

Tests Conducted on JP-8 Fuel Samples

The following tests at base-level help determine if one sample of JP-8 either passes or fails and if just one test from one sample fails, the entire sample fails and needs to be retested for validity (numbers in parentheses show the limits that the test result values must fall between) (Pittman & Toner, 2004). A brief explanation follows each test.

- American Petroleum Institute (API) Density: for product density in API units (from 39.0 to 51)
    - Density is the weight of JP-8 per unit volume (SW L60NU21R1 003-I-2, 2-2). If the test results show API units outside of the limitations above, a test failure results.
- Flashpoint: (minimum acceptable is 100° Fahrenheit)
    - This is the indication of the lowest point at which flammable liquids (JP-8) gives off enough vapors, when mixed with air, to ignite on application of an ignition source (SW L60NU21R1 003-I-2, 2-2). Tested flashpoints below 100° Fahrenheit will result in a failure.
- Allowance Equipage List (AEL): free water in parts per million (ppm) (maximum of 10) (Specification for Aviation Turbine Fuels, 2004)
    - The amount of water in JP-8 can not exceed 10 ppm.
- Color: color of filtration membrane (maximum A4, B4, and G4 color codes)
    - Base or contracted fuels lab personnel filter JP-8 through a filter to detect contamination and compare the filtration membrane to the above codes to determine passes and failures (Toner, 2004).
    - JP-8 in compliance with standards ranges in color from "water white (colorless) to a straw/pale yellow" (Standard Specification for Aviation Turbine Fuels, 2004).
- Polyacryalmide Gel (PAG): visual assessment of filtration membrane (pass or fail)
    - PAG is a type of filtration membrane is used by passing JP-8 through it, and then fuels personnel visually assess the membrane for pass/fail results (Chan, 2003).
- CONCU: conductivity of fuel in conductivity units (CU) (50-700 pS/m)
    - This test measures for static electricity in JP-8 (Specification for Aviation Turbine Fuels, 2004).
- FILMIN: filtration time in minutes (maximum of 15 minutes)
    - Base fuels lab personnel will test one quart samples for filtration time (PTO 42B-1-1, 4-2).
- Fuel System Icing Inhibitor (FSII): FSII content (.07-.20)
    - The FSII additive (diethylene glycol monomethyl) inhibits moisture from entering fuel systems and subsequently freezing in cold temperatures at high altitude, and the content in JP-8 should fall between the limitations above (Specification for Aviation Turbine Fuels, 2004).
- MG/ GAL: particulate filtration results (limit varies for reason sampled)
- MG/ QT: particulate filtration results (maximum of 4)
    - The above (2) particulate filtration tests detect the presence of adventitious solid particulate contaminants such as dirt and rust, and the contaminants may be detected via filtered JP-8 through membrane filters (Specification for Aviation Turbine Fuels, 2004).

The above list is from the Wright-Patterson AFB fuels lab at Wright Patterson AFB, OH (Toner, 2004). In addition to these tests at base level, JP-8 undergoes the following tests at one of seven area labs (listed below) around the world. These correlation/aircraft servicing sample tests are performed every 45 days (PTO 42B-1-1, 4-2):

- Distillation (temperature, maximum 300° Celsius)
    - This is a test for fuel volatility (ease at which a liquid will vaporize or evaporate) at different temperatures (Specification for Aviation Turbine Fuels, 2004).
- Copper Strip Corrosion (2 hours at 100° Celsius, to be reported only)
    - This test ensures that the fuel will not corrode copper or any copper-based alloys present in various parts of a fuel system (Specification for Aviation Turbine Fuels, 2004).
- Freezing Point (-47° Celsius/ -58° F maximum)
    - For JP-8 and other fuels used in high altitude, this measure is important to ensure fuel flow through filter screens to aircraft engines at low temperatures and high altitudes (Specification for Aviation Turbine Fuels, 2004).
- Existent Gum (milligram/ 100 milliliters, maximum 7 per 100 ml)
    - This gum is non-volatile residue left on evaporation of fuel (Specification for Aviation Turbine Fuels, 2004). The lower the presence of this gum the better.
- Water reaction (interface rating, maximum 1 pound)
    - This test determines the presence of materials that react with water and form an insoluble scum at the fuel/water interface (Specification for Aviation Turbine Fuels, 2004).
- Acid Number (in milligrams KOH/ gram, maximum .015)
    - This test checks for residual mineral acid or caustic left over from the refining process, and any amount is not desirable (Specification for Aviation Turbine Fuels, 2004).
- Jet Fuel Thermal Oxidation Test (JFTOT)
    - This test measures the fuel stability at high temperatures (such as 245° or 275° C for example, and the higher the temperature that JP-8 can maintain the better the result (Specification for Aviation Turbine Fuels, 2004).
- BOCLE.
    - BOLCE is a test for a fuel's lubricity.

These area-lab tests are above and beyond the tests performed by the base-level labs (Toner, 2004). The following tests are mentioned in the base-level section above, but they are also performed at the area labs to correlate the sampling test results every 45 days:

- Fuel System Icing Inhibitor (FSII): FSII content (.07-.20)
- MG/ GAL: particulate filtration results (limit varies for reason sampled)
- MG/ QT: particulate filtration results (maximum of 4)
- Flashpoint: (minimum acceptable is 100° Fahrenheit)

The limitations (in parentheses) for these tests were extracted from MIL-DTL-83133E (1999, 6). The following list consists of the seven area labs where the above tests are conducted:

- Wright-Patterson AFB, Ohio
- Searsport, Maine
- Vandenberg AFB, California
- Patrick/Cape Canaveral, Florida
- Kadena AB, Okinawa/Japan
- Mildenhall AB, United Kingdom
- Al Udeid, Qatar

For 45-day correlation/aircraft servicing samples, the base and area labs perform their tests from a representative source of fuel that is provided to the aircraft (PTO 42B-1-1, 4-2). Specifically, these filtered samples come from refueling trucks (R-11 or R-9), MH-2 hose carts, HSV-12 motorized hose carts, and filter meter pits (a fixed refueling device). Also, pantographs, a mobile or fixed refueling/de-fueling unit connected to an underground hydrant or above ground fuel storage system, filter representative samples (CLA-VAL, 2003). This correlation/aircraft servicing test amounts to a one-quart and three one-gallon JP-8 samples to be distributed as follows: one quart and one gallon to the base lab for testing, and two one-gallon samples to the area lab for testing (PTO 42B-1-1, 4-2). If a sample fails a test at base level, personnel execute another round of tests with the unused portion of the original correlation/aircraft servicing sample (PTO 42-B-1-1, 4-2). If a sample fails at an area lab, the area lab contacts the base from which the sample originated, and the base fuels personnel perform an additional test on the retained sample (42-B-1-1, 4-2). The base agency compares their results again with the area lab results, and they will contact AFPET/AFTT if excessive variances can't be reconciled (PTO 42-B-1-1, 4-2). In the event of a definite test failure, bases, area labs, and AFPET further investigate the problem to identify the source of the failure. Depending on the specific sampling test, some failures are "remediatable," which means that problems can be fixed at base level through additization or blending (Toner, 2004). Through the additization remedy, antioxidants and metal deactivators are added to prevent the formation of oxidation deposits and to improve the oxidation stability of fuels in storage (Specification for Aviation Turbine Fuels, 2004). Blending is mixing in Fuel System Icing Inhibitor (FSII), Corrosion Inhibitor/Lubricity Improver (CI), and Static Dissipater Additive (SDA) or other JP-8 uncontaminated fuel portions into contaminated fuel that fails one of the tests described above (Toner, 2004). While some of these tests are remediatable, other test failures lead to "mission failure," which means that problems can't be fixed at base level and need further investigation before dispensing the JP-8 product from the storage or refueling vehicle (Toner, 2004). Table 2.1 below shows examples of remediatable and mission failure tests.

Instructions, Standards, and Technical Orders

This section describes the instructions, standards, and technical orders that are used in the field for conducting JP-8 fuel sampling tests. Preliminary Technical Order 42B-1-1, *Quality Control of Fuel and Lubricants,* prescribes the procedures for assuring quality of Air Force fuels and lubricants. It applies to all seven area labs around the world that submit sampling data to AFPET. Specifically, this T.O. outlines procedures and instructions for receiving, storing, handling, testing, and dispensing fuels and

Table 2.1 Remediatable vs. Mission Failure Tests (Toner, 2004)

	Remediatable	Mission Failure
Acid Number		X
Copper Strip Corrosion		X
Distillation		X
Existent Gum		X
API Gravity (Density)	X	
Appearance (Color, PAG)	X	
Particulate	X	
BOCLE	X	
Conductivity	X	
Filtration Time	X	
Flash Point	X	
Freeze Point	X	
FSII	X	
Thermal Stability (JFTOT)	X	
Total Solids	X	
Water Reaction/ Visual	X	

lubricants at Air Force installations. For this study, the T.O. is used primarily to extract the minimum sampling requirements at each of the three locations of interest: receipt, storage, and vehicles/aircraft. These procedures can be used to ensure that the data collected conforms to prescribed methods. The following Table 2.2 lists the sampling points of concern in this study, the tests performed at each sampling point at a minimum, and the sampling frequency at each location (42-B-1-1, 5-2). The information in Table 2.2 is extracted from PTO 42-B-1-1, 5-18-5-22. In addition to these minimum tests required, base and area labs perform the tests as described in the "Tests Conducted on JP-8 Fuel Samples" section above.

Military Standard (MIL-STD) 3004A, *Quality Surveillance for Fuels, Lubricants, and Related Products*, provides general instructions and minimum procedures to be used by military services and the Defense Energy Support Center (DESC) in quality surveillance of United States government-owned fuels, lubricants, and related products worldwide. These standards can also be used to ensure that the data collected conforms to prescribed methods. Table 2.3 below describes the sampling locations, minimum tests required, and the sampling frequencies as required by DESC (MIL-STD-3004A, 90-96).

Table 2.2 JP-8 Fuel Minimum Sampling Requirements at Air Force Installations (PTO 42-B-1-1, 5-18-5-22)

Sampling Location	Minimum Tests Required	Sample Frequency
Pipeline Receipt	Flash point, visual for color, solids,	Each receipt, 1 hour after
	FSII, conductivity, filtration time	start, after line displacement,
		4-hour intervals thereafter
Tank Truck Receipt	Solids, FSII, conductivity,	One sample daily from each
	filtration time, flash point	supplier
Storage Tanks	FSII, conductivity	Every 14 days, also sample
		at first truck fill (after filtration)
Hydrant Storage Tanks	FSII, conductivity	Monthly from each hydrant
		system operating tank
Vehicles (refuelers and	Solids, water	Weekly, after filter separator
hose carts)		changes, after vehicle
		maintenance that may affect
		fuel quality, after fuel grade
		changes
	Fibers	After filter separator changes,
		prior to or during first servicing
		operation
	Conductivity	Weekly from one vehicle on
		base, assure all units tested
		within 30 days

ASTM International Designation D 1655-04, *Standard Specification for Aviation Turbine Fuels*, outlines test methods for aviation fuels. This document is meant primarily for commercial Jet-A fuel types, but the test methods cited are the same for JP-8 fuel types. These standards can also be used to ensure that the data collected conforms to

Table 2.3 DESC JP-8 Fuel Minimum Sampling Requirements (MIL-STD-3004A, 90-96)

Sampling Location	Minimum Tests Required	Sample Frequency
Pipeline Receipt	Appearance, Color, API density/	Immediately after start of
	gravity	shipment or loading, hourly
		after each shipment
Tank Truck Receipt	Appearance, Color, API density/	One sample daily from each
	gravity	supplier
Storage Tanks	Appearance, API gravity, color,	After establishment of new
	flash point, filtration time, FSII,	batches
	water reaction	
Vehicles (refuelers and	Visual check for appearance,	Daily
hose carts)	water, sediment	
	Lab analysis for appearance,	Monthly
	water, sediment	

prescribed methods. The information that describes the test methods in the "Tests Conducted on JP-8 Fuel Samples" section above is from this aviation industry standard. Air Force area and base-level lab personnel use the tests described in the above section to determine JP-8 sampling results, either pass or fail. The commercial industry also uses this standard when performing sample testing of their Jet-A fuel (Franklin, 2005).

Military Detail 83133E, *Detail Specification: Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8), NATO F-35, and JP-8+100* is used in this study to extract the limitations of the JP-8 sampling test results described in the "Tests Conducted on JP-8

Fuel Samples" section above (1999). The limitations for each test are the numbers or ranges in parentheses following the different tests previously described in this chapter. If the results of the JP-8 sampling don't fall within these ranges or values, the test is considered a failure, and a re-test is performed to confirm the results (Toner, 2004). If a failure is from one of the tests that are remediatable, the source of the failure can be fixed on base (Toner, 2004). If the failure isn't remediatable, it's labeled as "mission failures" as described in Table 2.1 above (Toner, 2004).

Civil Aviation Industry Procedures

On January 31, 2005, Kevin Franklin, Vice President of Operations for Wright Brothers Air at Dayton International Airport, Ohio, was interviewed to explore their Jet-A fuel sampling procedures. Mr. Franklin was primarily interviewed to determine if the health of Air Force base-level fuel system could benefit from their procedures. All information in this section is from the interview unless otherwise cited (Franklin, 2005). Even though only the Dayton airport is covered in this study, the procedures are the same for all commercial airports. First, the oversight of their sampling procedures was investigated. The commercial airport fuels lab workers don't send their samples to area labs for correlation of results like the Air Force does every 45 days (PTO 42-B-1-1, 4-2). They handle any problems with jet fuel quality directly with their suppliers. If they get contaminated fuel that leads to sample failures, they isolate the source of contaminated fuel until it gets fixed through additization in the same manner as the Air Force. The only oversight is from their customers (the airlines), and they also follow ASTM International Designation D 1655-04, *Standard Specification for Aviation Turbine Fuels*, for testing their Jet-A fuels (2004). For the Dayton International Airport, Wright Brothers Air gets visits from quality assurance (QA) inspectors once per year from each of the 25 different airlines they serve. The inspectors ensure that ASTM testing standards are followed, and they don't correlate sample results as the Air Force does with their area labs.

Next, the sampling frequencies at commercial airports were investigated to observe their process. Table 2.4 below summarizes their procedures. Wright Brothers Air doesn't perform as many tests as the Air Force. Notice that they have only monthly requirements instead of daily and weekly requirements. The commercial industry does most of their sampling at receipt, and they rely on their storage and vehicle filter separators to separate contaminants from their Jet-A fuel. They perform more tests for the monthly samples to ensure conformance to ASTM standards, and the result of these tests lets them know the health of their facility fuel distribution system.

Table 2.4 Typical Commercial Airport Sampling Procedures (Franklin, 2005)

Sampling Location	Minimum Tests Required	Sample Frequency
Tank Truck Receipt	Appearance, water, sediment	One sample from each
		truck
Storage Tanks	Density, distillation, flash point,	Monthly
	freezing point, viscosity, corrosion,	
	total acidity, sulfer,water reaction,	
	net heat of combustion	
Vehicles (refuelers and	Density, distillation, flash point,	Monthly
hose carts)	freezing point, viscosity, corrosion,	
	total acidity, sulfer,water reaction,	
	net heat of combustion	

Ultimately, Wright Brothers Air doesn't monitor their pass rates from each sampling location, and they handle sample test failures on a case-by-case basis. This type of system is reactive to individual sample test failures, but the fuels workers don't know the current status of the health of their fuel distribution system. This study strives to find a specific sampling location (receipt, storage, or vehicles/aircraft) so that the Air Force can quickly know the status of their JP-8 base-level fuel distribution systems.

JP-8 or other Aviation Fuel-Related Studies

The Air Force Petroleum Office at Wright-Patterson Air Force Base, Ohio hasn't encountered a JP-8 fuels-based or other aviation fuels-based study that examines the health of the base-level fuel distribution system. This is one reason they seek Air Force Institute of Technology assistance. They want a current study accomplished in order to improve their current system or ensure the system they have is a process that yields a healthy JP-8 product to the end-users: the aircraft and associated aircrew. After an exhaustive search of educational and professional literature, there appear to be no studies of this kind that analyzes the fuel flow process through a distribution system.

The Defense Energy Support Center Product Technology and Standardization Division (DESC-BP) compiles statistical summary data on the quality of aviation fuels, such as JP-8, from refineries all around the world, and DESC assembles this information annually in the publication *Petroleum Quality Information System (PQIS) 2003* (for the most current version). PQIS originated due to a need to form a comprehensive system that tracks fuel quality trends, and the first PQIS report came out in 1998, though the PQIS database itself dates back to 1990 (PQIS 2003, 3). The data is from refineries from nine regions worldwide (PQIS 2003, 1). Regions 1 – 5 represent fuel procured from the United States, while regions 6 (Middle East), 7 (Europe), 8 (Pacific), and 9 (Caribbean) procure fuel from outside the U.S. (PQIS 2003, 1). This publication includes the same sample testing information included in this study, such as Acid Number, Filtration Time, Distillation, Flash Point, and Freezing Point to name several, but this is all refinery data (PQIS, 2003). This study focuses on base-level sample testing, so the statistics reflected in PQIS don't support the objective of this research, which addresses the health of the base-level JP-8 fuel distribution system. Future research comparing refinery data with base-level data would be useful. However, the data from PQIS isn't used in this study.

The Bernoulli CUSUM Control Chart

In Phase 4 of the Methodology, the Bernoulli cumulative sum (CUSUM) control chart is explained in detail (Chapter 3) and executed (Chapter 4). This section introduces the chart from the research of Reynolds and Stoumbos (1999). This chart is a form of statistical process control (SPC) that monitors a process to detect changes in proportions p (Reynolds and Stoumbos, 87). Because this study investigates pass rates at the base-level sampling locations, these rates are based on JP-8 sampling test passes and failures. These sample test passes and failures are Bernoulli trials. Bernoulli trials are samples that have only two possible outcomes, success or failure (Montgomery and Runger, 123).

To detect increases in p, this study examines the increase in JP-8 sample test failures. Although this chart can also be constructed to detect decreases in p (increases in JP-8 sample test pass results for example), monitoring and detecting a process that improves over time isn't a goal in this research. Phase 4 is therefore designed to improve the health of the JP-8 fuel flow process in order to quickly detect an increase in p, which is the detection of too many failures over a (moving) period of time. The estimated

Bernoulli CUSUM control chart parameters in Phase 4 determine the amount of failures it takes over time to signal the fuel flow process as "out-of-control," and these parameters are based on the research from Reynolds and Stoumbos. No known SPC procedure is in place at Air Force bases around the world, and this research in Phase 4 presents a way that base-level Air Force fuels management can monitor their fuel flow process. With this SPC tool in place, these managers will know the health of their process quickly after samples are analyzed and recorded.

Literature Review Summary

To summarize, this chapter described the terminology used in this study and existing literature to support this research effort. This research collaboration with the Air Force Petroleum Office (AFPET) Program Management team was covered. Next, the data sources from the seven worldwide bases and AFPET (45-day correlation/ aircraft servicing sample data) were presented and discussed. The base-level sampling locations were described, and all the tests conducted on each sample were explained. The instructions and technical orders that list sampling points and times were covered. Mr. Kevin Franklin in civil aviation industry was interviewed, and this industry was explored to see if their procedures can benefit the Air Force base-level fuel distribution system. Lastly, the search for JP-8 or other aviation fuel-related literature was covered with the PQIS annual publication, and the Bernoulli CUSUM research by Reynolds and Stoumbos introduced the SPC procedure used in this study.

III. Methodology

Research Objective

The objective of this research is to try and determine where to focus JP-8 sampling efforts at any given Air Force base. Also, this research attempts to determine if the 45-day correlation/aircraft servicing sampling is sufficient in order to help ensure a quality and healthy fuel product at the aircraft. Air Force base- and area-level JP-8 sampling data is used to support these objectives. This study seeks to give base-level commanders, aircrew, and fuels personnel the information they need in order to perform missions and utilize assets with confidence and safety.

Research Paradigm

This study is broken into five phases to help determine where to focus JP-8 base-level sampling efforts and to help determine if area-level correlation/aircraft servicing sampling is sufficient: (1) multiple case study design, (2) contingency table analysis for pass rate differences, (3) a combination of the multiple case study approach and contingency table analysis, (4) statistical process control procedures, and (5) contingency table analysis for correlation sampling frequency.

The first phase addresses the first investigative question of "What are the probabilities at each base-level sampling point that JP-8 fuel samples will pass testing?" Observing these probabilities (pass rates) may show which of the three base-level sampling locations need more attention if the pass rates at one location are lower than the other two. The second phase seeks to help answer the second investigative question, "Are the pass rates at base-level receipt, storage, and vehicles/aircraft statistically the same or different?" A statistical comparison will be made to investigate the independence of the three sampling locations at each of the seven bases using contingency table analysis. If the three sampling locations on base are statistically equal, the base-level JP-8 fuels personnel can focus their sampling efforts at a location of their choosing. If the locations are statistically independent, each sampling location is different, and individual focus at each location is required. The third phase is a combination of the above two approaches to address the research question, "What base-level JP-8 sampling location should each base focus their sampling efforts?" Utilizing pass rate data together with the results from the contingency table analysis, a clear focus of where to sample at base-level may emerge. If a clear sampling location emerges, a statistical process control tool (Phase 4) can be used to quickly monitor the JP-8 base-level fuel flow process. The fourth phase seeks an answer to the third investigative question, "What procedures could enhance the JP-8 fuel flow process to make the base-level fuel distribution system more responsive and healthy?" The Bernoulli CUSUM control chart is explained and introduced as the best fit to monitor the JP-8 fuel flow process. The final phase seeks to answer the fourth investigative question, "How often should area lab samples (45-day correlation/aircraft servicing samples) be taken to ensure a healthy JP-8 fuel distribution system?" Another contingency table analysis will be performed comparing the 45-day correlation sample pass rates collected at AFPET/area labs against the vehicles/aircraft base-level sampling location. Since these samples both represent the quality of JP-8 that gets pumped into aircraft, a comparison between these samples could reveal that the 45-day requirement is either too much, too little, or sufficient. Addressing the investigative questions through these five phases, this study seeks to reveal the answer to the overall research question, “at what base-level JP-8 sampling location should each base focus their sampling efforts and how often should correlation JP-8 samples be taken in order to ensure a healthy fuel product to base-level customers?”

Phase 1. Multiple Case Study for Descriptive Statistics

The first phase addresses the first investigative question, “What are the probabilities at each base-level sampling point that JP-8 fuel samples will pass testing?” Observing these probabilities (pass rates) may show which of the three base-level sampling locations need more attention if the pass rates are low. A multiple case study approach helps describe JP-8 fuel sampling test results at three different base-level sampling locations:

- at the time of receipt
- at fuel storage facilities
- at refueling vehicles and at the aircraft (these locations are synonymous)

The seven locations included in this study are from geographically and climatologically diverse areas around the world in order to observe JP-8 fuel sampling test results at the three locations on base. The data on test results comes from these seven worldwide bases:

- Wright-Patterson Air Force Base, Ohio
- Kadena Air Base, Okinawa/Japan
- Misawa Air Base, Japan
- Cannon Air Force Base, New Mexico
- Hill Air Force Base, Utah
- Mildenhall Air Base, United Kingdom
- Osan Air Base, Korea

Each base provides JP-8 sample test data to cover the same period of time: from August

1, 2003 to October 18, 2004, which amounts to a 444-day timeframe. This data is extracted from the Fuels Automated System (FAS) at each of the seven bases. Certified fuels personnel track all of the JP-8 sampling conducted and enter this data into their base-level FAS. The tests performed on JP-8 are listed in detail in Chapter 2.

Next, the JP-8 sampling data gets placed into three separate categories specific to each base, which correspond to the three different base-level sampling locations listed above. From here, test results that pass and test results that fail are collected to give an effective success rate at each sampling location on base. For example, Wright-Patterson Air Force Base has three categories (receipt, storage, and refuelers/aircraft); each with a success rate that is the ratio of number of sampling result passes over the total sampling results in a particular category. Observing these rates can help point managers in the direction of where problems are more likely to occur and where to focus sampling efforts. Using JMP 5.1.2 Statistical Discovery Software, the following equation describes the pass rates P at each location on each base:

$P = \frac{\# successes(x)}{n}$, where the number of successes x are the amount of sample test passes out of a particular sample size n. The following Table 3.1 provides an example of how these pass rates are presented in the Chapter 4 Results and Analysis section of this study.

These pass rates and accompanying sample size data will help in the following phases to reveal which of the three sampling locations bases should focus their sampling efforts. To compute these pass rates in JMP 5.1.2 for large sample sizes, the passes and failures are divided into nominal categories “1” for sample test passes and “0” for sample

Table 3.1 Pass Rates for Each Base and Sampling Location Example

	Base-level Sampling Location		
Air Force Bases	Receipt	Storage	Vehicles/Aircraft
Cannon AFB	x/n	x/n	x/n
Kadena AB	x/n	x/n	x/n
Misawa AB	x/n	x/n	x/n
Wright-Patterson AFB	x/n	x/n	x/n
Hill AFB	x/n	x/n	x/n
Mildenhall AB	x/n	x/n	x/n
Osan AB	x/n	x/n	x/n

test failures. Therefore, the distribution of "1" and "0" values takes on a discrete binomial distribution. Appendix A shows the distributions and associated pass rates displayed in Chapter 4. There are seven bases with three pass rates each (receipt, storage and vehicles/aircraft) for a total of 21 pass rates and 21 binomial distributions.

Phase 2. Contingency Table Analysis for Pass Rate Differences

The second phase seeks to help answer the second investigative question, "Are the pass rates at base-level receipt, storage, and vehicles/aircraft statistically the same or different?" This phase of the study requires a quantitative approach in order to discover evidence from the pass rates on each base that suggests either a difference or no difference in the sampling locations on base. If there is a statistically significant difference in the pass rates between the three locations on base, this means that it matters where base personnel sample their JP-8 and further experimental research may be required to determine sources of variability. Each sampling location would have to be managed separately. If the results yield no statistically significant difference in pass rates, base-level fuels management can focus their sampling efforts at any one of the three locations (receipt, storage, or vehicles/aircraft). Based on this research, the purpose is to take this a step further and identify which sampling location to focus JP-8 sampling efforts in order to ensure a healthy base-level system.

In order to compare the pass rates on base, the pass rates at the three sampling locations are separated into the following nominal categories:

- “1” for sampling passes, and
- “0” for sampling failures.

These categories are analyzed using contingency table analysis, which tests for independence among the three pass rates *p* which correspond with the three base-level sampling locations (McClave et al, 950). Using contingency table analysis, data gets classified into two or more qualitative variables, such as the three location classifications on base (Everitt, 2). These classifications are then compared in a chi-square (χ^2) test for independence using the equations described below. Assuming that the observed frequencies have a multinomial distribution and assuming that expected frequencies aren’t too small, the χ^2 statistic may be shown to have approximately a χ^2 distribution (Everitt, 7). The discrete binomial distribution of “1” and “0” values in this study meet the first criterion, and the results and analysis section in Chapter 4 addresses the latter. Table 3.2 below is an example of what this contingency table analysis looks like in 2 X 3 matrix form. The sample frequency or count n_{ij} is separated into six cells, and each cell corresponds to the pass or fail sampling results and one of the three base sampling locations. The letter *i* represents the rows and *j* represents the columns.

Table 3.2 Contingency Table for Base-level Analysis Example

	Base Sampling Location		
	Receipt	Storage	Vehicles/ AC
Fail (0)	n_{11}	n_{12}	n_{13}
Pass (1)	n_{21}	n_{22}	n_{23}

The following hypothesis test for independence helps to see differences in sampling locations at base:

H_O: $p_1 = p_2 = p_3$
H_A: at least one pass rate differs

- where p_1 = pass rate at receipt, p_2 = pass rate at storage, and p_3 = pass rate at vehicles/ aircraft
- the rejection region is $\chi^2 > \chi^2$ (α = .05), where χ^2 (α = .05) has (r – 1)(c – 1) degrees of freedom (df) (where r = row and c = column) (McClave et al, 950)
- JMP 5.1 Statistical Discovery Software will be used to compute the test statistics
  - JMP uses the following likelihood ratio to compute the approximate (χ^2) test statistic (JMP 5.1.2):

$$\chi^2 = 2\sum_{ij} n_{ij}\left[\ln \frac{p_{ij}}{p_j}\right], \text{ where } p_{ij} = \frac{n_{ij}}{N} \text{ and } p_j = \frac{N_j}{N}$$

  - JMP 5.1.2 also uses the following chi square (χ^2) test statistic (Pearson, 1904):

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{(n_{ij} - E_{ij})^2}{E_{ij}}$$, where E_{ij} is the expected frequency in the ij^{th} cell of the contingency table if the two variables are independent (Everitt, 6-7).

"Large χ^2 values imply that the observed cell counts (n_{ij}) do not closely agree and hence that the hypothesis for independence is false" (McClave et al, 947).

This paragraph discusses the terms used above. E_{ij} is the *expected* count (frequency) in the ij^{th} cell, where the ij^{th} cell corresponds to the i^{th} row (r) and j^{th} column (c), and this expected count E_{ij} is the number of multinomial trials n times the cell probability p (McClave et al, 946). The n_{ij} statistic represents the *observed* cell count in the i^{th} row and j^{th} column (McClave et al, 946). The p_{ij} (n_{ij}/N) statistic is the probability associated with the i^{th} row and j^{th} column, where the p_j statistic (N_j/N) is the j^{th} column probability. N is the total sample size (frequency) and N_j is the sample size (frequency) from the j^{th} column only. For this study, N is the number of total JP-8 samples taken from the three locations at a particular Air Force Base. As an example of how to read the Pearson statistic, the summation (∑) notation with associated i = 1 and j = 1 means “the sum of the measurements to the right of the (∑) notations, beginning with the first (i and j =1) measurement and ending with the last row (r) and column (c) measurements.” For the likelihood ratio, this statistic reads, “two times the sum of the observed cell counts in the i^{th} rows and j^{th} columns times the natural log of the probability associated with the i^{th} row and j^{th} column divided by the probability associated with the j^{th} column only.” The likelihood ratio is an approximate χ^2 test when the sample size is large (Everitt, 79). The likelihood ratio and the Pearson χ^2 statistic will have similar values for many tables, but Ku and Kullback (1974), Williams (1976), and others show that the likelihood ratio is generally preferred to χ^2 (Everitt, 79). However, this study presents both results in Chapter 4. Appendix B shows the contingency tables used in this study, and Phase 2 in Chapter 4 analyzes the results.

There are a total of seven hypothesis tests that represent the seven bases in this study. Observing the results of these hypothesis tests can help determine whether or not there is a difference in sampling at the three locations on base, and thus, these results may help discover at which base sampling point fuel managers may want to focus their sampling efforts. If the pass rate comparisons at each base don’t produce useful information, the next phase can give base-level fuels managers a clear choice about where to focus sampling efforts.

Phase 3. Combination of Multiple Case Study and Contingency Table Approach

Phase three combines the above two phases to help answer the part of the research question addressing the portion, "What base-level JP-8 sampling location should each base focus their sampling efforts?" In this phase, a combination of Phase 1 and Phase 2 approaches is used to help determine at which of the three locations on base a fuels manager should closely monitor the fuel flow process. Since JP-8 at base-level flows from receipt to storage locations to vehicles and eventually to aircraft, the JP-8 fuel flow process through the three location stages is the same for every base. Figure 1.1, the Common JP-8 Fuel Flow from Receipt to Aircraft, outlines this process, but the following is a brief explanation. Fuel enters the base-level process at receipt, and then it passes through filter separators that remove water, sediment, and other contaminants. Next, fuel flows to the storage systems on base. When a requirement for JP-8 is needed on the flight line, the fuel flows through more filtration before it gets pumped inside the refueling vehicle. After one more round of filtration at the refueling vehicle, fuel flows into the aircraft. The receipt, storage, and vehicles/aircraft sampling locations will be analyzed as separate parts of the fuel flow process

This third phase is a transition from the first two phases and into the fourth. If one of the three sampling locations gets identified through these first three stages, the fourth stage offers a tool to manage and monitor the JP-8 fuel flow process. After gathering the results from the descriptive and inferential statistics presented in the first two phases, these statistics will be used and applied to real-world situations and conditions to determine the best location to focus JP-8 sampling efforts. Each sampling location (receipt, storage, and vehicles/ aircraft) is analyzed using the information gained in the first two phases and also analyzed using Air Force operational procedures. Using the results of this analysis, this phase strives to give Air Force JP-8 base-level fuels managers the most feasible location to set up fuel flow monitoring procedures.

Phase 4. Statistical Process Control for Monitoring

Phase four addresses the third investigative question, "What procedures could enhance the JP-8 fuel flow process to make the base-level fuel distribution system more responsive and healthy?" This phase of the study describes the use of Statistical Process Control (SPC) to monitor the sampling of fuel at the right location. This location is either at receipt, storage, or vehicles/aircraft. Phases 1 – 3 in Chapter 4 attempt to identify the location to focus sampling efforts. This phase defines and explains SPC, offers a monitoring technique called the Bernoulli CUSUM control chart, and estimates the Bernoulli CUSUM control chart parameters.

Statistical Process Control (SPC) Description and Decision

"Statistical Process Control is the process of monitoring and eliminating variation in order to keep a process in a state of statistical control or to bring a process under statistical control" (McClave et al, 688). When monitoring a process such as JP-8 flow from receipt to the aircraft, the eventual goal of SPC is the elimination of variability in the process (Montgomery, 156). To control this variability from the start, the logical place to establish control procedures is at the beginning of the process. For this study, the time that the Air Force receives JP-8 on base is the start of the process or at the time of "receipt." However, this sampling location may or may not always be the best place to focus sampling efforts. Controlling what goes into your system (at receipt) is the logical way to ensure a healthy JP-8 fuel product downstream. Logic may indicate that fuel quality won't improve along the way. But this isn't necessarily the case. Fuel that arrives contaminated can simply have too much moisture or sediment in the fuel, and this gets filtered out before entering the base-level fuel system (Pittman & Toner, 2004). Then again, there could be other harmful contaminants that may not get filtered out, and implementing SPC at receipt can assist in identifying contaminated JP-8 before this fuel gets into other areas of the base-level system. If the data reflects that variability at receipt isn't the greatest source, a base may not want to begin SPC at the receipt location—unless a base wants to control JP-8 flow at multiple locations. If sampling data reflects minimal variability between sampling locations, implementing control procedures at multiple locations would be unnecessary. Multiple SPC execution also adds costs through performing this operation and increased personnel utilization dedicated to monitoring, which may require additional staffing just to maintain the same level of fuel customer service effectiveness.

An ideal situation for the Air Force would be to implement SPC procedures at one location to keep the process uniform across every worldwide base. Air Force Instructions, technical orders, and other relevant publications can easily be updated to reflect consistent control procedures for every fuels unit to follow. If the pass rates at each location are high and consistent, this may provide evidence that sampling at one location is sufficient in order to control the JP-8 flow process. Air Force or any other military aircraft that consumes JP-8 won't be able to fly as much if pass rates aren't high. Every aircraft commander would want their fuel sampled and analyzed, and they wouldn't be able to depart until they know the pass or fail result. This simply isn't feasible, cost-effective, or necessary with high pass rates. Sampling itself is a form of controlling a particular process. Out of the three locations on base that personnel (or contractors) sample (receipt, storage, and vehicles/ aircraft), the Air Force may be able to implement SPC at one location only, and the subsequent locations are already "monitoring" using existing sampling procedures described in Chapter 2.

So why should SPC be required at all? The Air Force Petroleum Office (AFPET) at Wright-Patterson Air Force Base wants to know where they should focus their sampling efforts (Pittman & Toner, 2004). There is currently no standard in place that allows AFPET to gain any useful information from the data they collect (from aircraft servicing samples) about the health of the JP-8 fuel flow process at each base (Pittman & Toner, 2004). Also, aircraft and base commanders don't possess any identifiable or mandated level of confidence about the JP-8 pumped into aircraft for which they are responsible. There currently is no baseline in place for a process that is either in- or out-of-control (Pittman & Toner, 2004). The instructions, standards, and technical orders mentioned in Chapter 2 also don't specify acceptable pass rates or a statistical level of a process out-of-control. How do AFPET, base and aircraft commanders, and fuels leadership know the status of their process with some level of certainty? They don't know the status, but they do rely on an effective monitoring system through mandated sampling alone (Pittman & Toner, 2004). These mandated sampling frequencies are listed in Chapter 2 Tables 2.2 and 2.3 and are extracted from PTO 42B-1-1 and MIL-

STD-3004A, respectively. Currently, AFPET fuels specialists and base fuels personnel collaborate if problems arise with multiple failures at any location on base. However, the Air Force community can benefit from a JP-8 monitoring system that responds quickly to an out-of-control process. This is where SPC can assist the base level fuels community.

There are different types of SPC procedures that can help fuels personnel monitor the health of their fuel flow process. Because the nature of the data is either pass or fail, any SPC procedure that allows for proportions to be monitored could work. For example, the popular Shewhart p-chart plots the number of defective items (or sampling failures) in a random sample of n units (Montgomery, 285). P-charts are used extensively in the manufacturing sector to monitor their production processes. P-charts are easy to set up, maintain, and interpret. However, this chart has several disadvantages. The p-chart is usually set up with three standard deviations (3σ) control limits, and this can result in an unwanted false alarm rate (Reynolds and Stoumbos, 88). The false alarm rate is the average number of observations or samples to signal the process as out-of-control when p, defective or failure rate, equals some predefined in-control value p_0 (Reynolds and Stoumbos, 88). The distribution of the number of defectives (JP-8 sample failures for example) in n items is the discrete binomial distribution (Reynolds and Stoumbos, 88). When failure rate p is close to zero and sample size n is relatively small, the binomial distribution can't be approximated effectively with a normal distribution (Reynolds and Stoumbos, 88). In this case, the (binomial) false alarm rate can differ from using 3σ limits with a normal distribution (Reynolds and Stoumbos, 88). Also, another disadvantage of the p-chart is that it isn't effective for detecting changes in p unless n is very large, due to the discreteness of the binomial distribution causing difficulties if standard runs rules are based on the normal distribution (Reynolds and Stoumbos, 88). The other major disadvantage using p-charts is the use of sample groupings when in fact the process flow is continuous. If there are variations in flow rate through the process, which is the case for JP-8 through the base-level fuel system, or when samples are typically collected at the end of some specified period, fixed time period sampling may not represent a process that shows continuous characteristics (Reynolds and Stoumbos, 88). Therefore, an SPC procedure that can overcome these disadvantages will perform better and could give the Air Force more accurate procedures in monitoring a healthy JP-8 fuel flow process.

The control chart used for this study is a cumulative sum (CUSUM) chart. This is a better alternative because it overcomes the p-chart's insensitivity to small shifts in p (Reynolds and Stoumbos, 88). When fixed samples are collected to determine changes in p as is the case with the p-chart, the p-chart is slower to react or may not react at all to significant process changes. A CUSUM chart can be based on the binomial distribution when samples of n items (or n individual JP-8 samples) are present (Reynolds and Stoumbos, 88). Each individual JP-8 failure can trigger a change in the process, and each failure can therefore make the process exceed the in-control limit p_0. The use of the CUSUM chart for monitoring a proportion when sampling continuously is preferred over charts that reflect process changes only after a fixed period of collected samples (Reynolds and Stoumbos, 88). Since data in this study takes on only pass or fail characteristics, the individual item (observations) can be represented as Bernoulli observations or trials, and the specific name of the chart used is the Bernoulli CUSUM chart. This chart plots a point after each observation, and there is no need to wait until a complete sample grouping is gathered before a summary statistic gets plotted and a process control or out of control decision is made (Reynolds and Stoumbos, 89).

The Bernoulli CUSUM Control Chart

This section expands on and outlines notation, equations, and properties used to execute the Bernoulli CUSUM chart. To begin, the results of the i^{th} observation is represented as a Bernoulli observation X_i, which is 1 if the i^{th} JP-8 sample fails and 0 if it passes; then p (defective or failure rate) corresponds to $P(X_i = 1)$ (Reynolds and Stoumbos, 89). The Bernoulli CUSUM chart in this study is set up to detect *increases* in p. For example, if p increases past a specified in-control value P_0, this chart detects an out-of-control value of p, which is P_1. To detect this increase in p, the Bernoulli CUSUM control statistic B_k is:

$$B_k = \max(0, B_{k-1}) + (X_k - r), k = 1,2.......\text{(Reynolds and Stoumbos, 90).}$$

This CUSUM chart will signal an increase in p if $B_k \geq h_b$, where h_b is the specified control limit (Reynolds and Stoumbos, 90). The h_b parameter determines the false alarm rate and the speed with which the chart detects an increase in p (Reynolds and Stoumbos, 91). For this study, h_b is used to detect an increase in JP-8 sampling failures. When the Bernoulli CUSUM control statistic B_k exceeds the false alarm rate h_b, the chart detects an increase in p. The equation and methodology used to determine h_b is covered in the next section "Estimating the Bernoulli CUSUM Control Chart Parameters."

In order to compute r "reference value" (the chart parameter $r > 0$) in the above control statistic, two more values are needed (Reynolds et al, 90). For a given in-control value p_0 and out-of-control value p_1, the constants r_1 and r_2 need to be defined:

$$r_1 = -\log\left(\frac{1-p_1}{1-p_0}\right) \text{ and } r_2 = \log\left(\frac{p_1(1-p_0)}{p_0(1-p_1)}\right)$$

The chart parameter $r > 0$ is the ratio of r_1 and r_2: $r = \frac{r_1}{r_2}$ (Reynolds and Stoumbos, 90).

To plot the CUSUM chart conveniently, an adjustment to this parameter can be made with no practical consequence (Reynolds et al, 90). If $r = 1/m$ where m is an integer, the chart can be plotted with small adjustments to P_1 (Reynolds and Stoumbos, 90). For example, if $r_1/ r_2 = 1/61.05$, a small adjustment (increase) to p_1 will make $r = 1/61$. If $r = 1/61$, possible values of B_k will be integer multiples of 1/61, which enables the chart to be plotted conveniently (Reynolds and Stoumbos, 90). This technique is desirable when plotting the chart manually, but Microsoft Excel (used to plot the Bernoulli CUSUM examples in this study) can plot the chart without the need for this conversion. However, to keep with the precedent set by Reynolds and Stoumbos, the examples presented in this study use the adjusted 1/*m* approximation for *r*.

Estimating the Bernoulli CUSUM Control Chart Parameters

This section provides an example of how to estimate the Bernoulli CUSUM control chart parameters. The pass rate data in this study feeds the parameters needed to execute the control chart. Specifically, the in-control value of P_0 is the observed pass rate. For example, if the pass rate at a given base is 95%, the in-control value P_0 is 1 – the pass rate, and the value of P_0 is 1 - .95 = .05. Next, P_1 or the specified "out-of-control" value is chosen to observe effects of an increase in *p* (sampling test failure rate). To detect increases in *p*, this value must be less than P_0 to detect increases in sample test failures. Because the researched technical orders don't reveal a known level of acceptable pass rates, Reynolds and Stoumbos suggest approximating P_1 as a small multiple of P_0, such as 1.5(P_0) or 2(P_0) (1999, 92). With an observed in-control P_0 value of .05, the suggested ranges of P_1 would fall between .075 and .10. This P_1 value effectively acts as a level of confidence. For example, if a base wants a level of confidence based on the in-control value P_0 of .05, they can achieve a confidence level of no more than 95%. However, the chart would detect an out-of-control process too quickly if P_0 equals P_1. With a pass rate of 95%, bases should choose the suggestions for P_1 provided above (.075 and .10). These values would correspond to confidence levels between 92.5% (1 - .075) and 90% (1 - .10).

The next parameter to estimate is h_b. This parameter determines the false alarm rate and the speed with which the chart detects an increase in p (Reynolds and Stoumbos, 91). For this study, h_b is used to detect an increase in JP-8 sampling failures. When the Bernoulli CUSUM control statistic B_k exceeds the false alarm rate, the chart detects an increase in p. If a relatively large h_b value is chosen, a low false alarm rate results, and the statistical process control monitor/fuels personnel will detect increases in p slower than they would with a smaller h_b value (Reynolds and Stoumbos, 91). Choosing a small false alarm rate allows the monitor to detect shifts in p sooner and with greater frequency. This study uses an adjusted value of h_b called h_b*, and this value is determined through the coefficient of determination (CD) approximation of the Average Number of Observations to Signal (ANOS) of the Bernoulli CUSUM (Reynolds and Stoumbos, 91). The ANOS is the expected number of individual observations X_k required for the Bernoulli CUSUM chart to signal an out-of-control process (Reynolds and Stoumbos, 90). This study uses the following CD approximation to the ANOS when $p = p_1$ to determine how fast a shift from p_0 to p_1 will be detected:

$$\text{ANOS } (p_1) \approx \frac{\exp\left(-h_b^* r_2\right) + h_b^* r_2 - 1}{\left|r_2 p_1 - r_1\right|} \text{ (Reynolds and Stoumbos, 92).}$$

Another way of arriving at h_b* is to select an integer h_b value or false alarm rate that the fuels personnel can approximate based on experience of sampling test failures. Comparing the results from different false alarm rates will allow the fuels personnel/monitors to select the rate that reflects typical data from base-level receipt locations. Once an h_b rate is selected, this can be inserted into the following formula to determine the adjusted false alarm rate h_b*:

$$h_b{*} = h_b + \varepsilon\left(p_0\right)\sqrt{p_0 q_0}\text{, where } \varepsilon\left(p\right) = .410 - .0842\left(\log\left(p\right)\right) -$$

$$.0391\left(\log\left(p\right)\right)^3 - .00376\left(\log\left(p\right)\right)^4 - .000008\left(\log\left(p\right)\right)^7, \mathit{if}\ .01 \leq p \leq .5\text{, and}$$

$$q_0 = \left(1 - p_0\right) \text{ (Reynolds and Stoumbos, 91).}$$

The results and analysis section for Phase 4 will show and compare these adjusted and chosen false alarm rates to help determine where to set h_b, given the observed pass rates/in-control-value P_0 and out-of-control value P_1. All of the parameters covered in this section can be altered so that monitors can select rates or values that will quickly identify a process that gets out-of-control. The Bernoulli CUSUM chart sends an out-of-control signal when $B_k > h_b$*. This signal is the detection of a process that is not in control.

Phase 5. Contingency Table Analysis for Sampling Frequency

The final phase seeks to answer the fourth investigative question, “How often should area lab samples be taken to ensure a healthy JP-8 fuel distribution system?”

Each base sends an aircraft/correlation servicing sample to one of seven area labs located around the world every 45 days (PTO 42-B-1-1, 4-2). This sample is described in Chapter 2 under the "Tests Conducted on JP-8 Fuel Samples" section. This JP-8 sample is representative of what gets pumped into aircraft, and its purpose is to correlate the sampling results at the base-level lab with the results at the area labs. AFPET wants to know if the 45-day requirement is sufficient to help ensure a healthy JP-8 fuel flow system (Pittman & Toner, 2004). If the area labs sample more frequently than 45 days, this could reflect a redundant requirement and add costs to perform additional tests. However, samples sent to the area lab more frequently can detect problems at base-level sooner than 45-day samples. If the area labs sample less frequently than 45 days, this less stringent requirement could fail to detect problems in the system at base level, and as a worst-case scenario contaminated JP-8 could get pumped into aircraft more frequently. Comparing the pass rate data collected at base-level vehicles/aircraft against the pass rates collected at area labs could reveal that the 45-day requirement is either too stringent or too lenient. Therefore either less or more sampling at area labs would ensure a healthy system, respectively. Finally, if the comparisons show that the pass rates are statistically equal, this suggests that sampling every 45 days at the area labs may be sufficient to detect sample failures with the same frequency as base-level labs.

The pass rates at base-level and at the area labs are from samples taken at the vehicles/aircraft location during the same 444-day period, and the pass rates from base-level labs and area labs will be compared in order to help determine if the 45-day requirement is ideal. These samples from both labs are representative of JP-8 that gets loaded into aircraft, and thus the pass rates at the vehicle/aircraft location are vital in determining a healthy JP-8 fuel flow system because this is the same fuel that gets loaded into aircraft. However, simply dividing the 444 day period by the 45 day requirement, the average sample size at each base is around 10. With such a low sample size, just one failure at an area lab will significantly impact the outcomes of this phase.

The pass rate comparison uses the same contingency table method as described in Phase 2 of this study. Table 3.3 below shows an example of this 2 X 2 matrix that compares the area lab's 45-day correlation sample results against the base-level lab's vehicle/aircraft results. The sample frequency n_{ij} is separated into four cells, and each cell corresponds to the pass or fail sampling result and the area or base lab samples. The letter *i* represents the rows and *j* represents the columns.

Table 3.3 Contingency Table for Base-level vs. Area Lab Analysis Example

	Area Lab Samples vs. Base Lab Vehicles/Aircraft Samples	
	45-Day Requirement at Area Lab	Vehicles/Aircraft on Base
Fail (0)	n_{11}	n_{12}
Pass (1)	n_{21}	n_{22}

The following hypothesis test helps to detect differences between pass rates *p* at base-level labs and pass rates at area labs:

H_O: $p_1 = p_2$
H_A: the pass rates differ

- where p_1 = pass rate from base-level labs and p_2 = pass rate from area labs
- the rejection region is $\chi^2 > \chi^2$ ($\alpha = .05$), where χ^2 ($\alpha = .05$) has $(r - 1)(c - 1)$ degrees of freedom (df) (where r = row and c = column) (McClave et al, 950)
- JMP 5.1.2 Statistical Discovery Software will be used to compute the test statistics—using the likelihood ratio and Pearson method for the chi-square (χ^2) test statistic as mentioned in Phase 2 above (Everitt, 6-7).

There are a total of seven hypothesis tests that represent the seven bases in this study. Observing the results of these hypothesis tests can help determine if there is a difference between pass rates at base-level and at area labs. If the results show that pass rates are not equal, comparing area- and base-level pass rates to observe which rates are higher or lower will provide information about which area labs detect pass rates more effectively. If the area labs show lower pass rates, the area lab may want to sample more frequently than 45 days in order to detect JP-8 failures sooner in order to ensure a healthy system. If area labs show statistically higher pass rates, this suggests that they may wish to sample less frequently than 45 days. However, with the expected low average sample size of 10 at the area labs as previously mentioned, just one area lab sample failure significantly impacts the results in this section. This expected low sample size isn't desirable to generalize the results of this phase, but the data from area- and base-labs covers the same 444-day period for a desirable comparison. If pass rates between base-level and area labs are statistically equal, this suggests that sampling every 45 days at the area labs is enough to detect sample failures with the same frequency as base-level labs.

Methodology Phase Summary

The first three phases attempt to identify which sampling location on base to focus sampling efforts. In the first phase, descriptive statistics show the pass rates from the three locations at each of the seven bases. Lower pass rates will indicate possible locations to focus sampling efforts. The phase two contingency table analysis attempts to show if there is a difference between the three sampling locations on base. If the locations are statistically different, sampling efforts can't be focused on one location. If the three locations are statistically the same, sampling efforts can be focused at any one of the three base-level locations. The third phase combines the first two phases in order to attempt identification of one sampling location for focus. If a base-level location gets identified, the fourth phase presents a tool (Bernoulli CUSUM Control Chart) to quickly identify when the JP-8 fuel flow process gets out of control. The final phase compares the base and area lab pass rates using contingency table analysis in order to help determine how often the area labs should sample. The information gained and results from all of these phases together attempts to give base and aircraft commanders confidence that the JP-8 loaded at their bases and in their aircraft is healthy and safe for flight.

IV. Results and Analysis

Overview

The objective of this research is to determine where Air Force base-level JP-8 sampling efforts should be focused and how often correlation JP-8 samples should be taken in order to ensure a healthy fuel product to base-level customers. Up to this point, the first chapter provides an introduction into the JP-8 fuels distribution system, and it also outlines the research and investigative questions that help to determine the objective of this research. The second chapter reflects the terminology contained in this study and existing literature to support this research effort. In Chapter 3, the five phases of this study are introduced and described, and these phases lay a path to help solve the objective of this research. To summarize briefly, the first three phases attempt to identify which sampling location on base to focus sampling efforts. In the first phase, descriptive statistics show the pass rates from the three sampling locations at each of the seven bases. The phase two contingency table analysis attempts to determine if there is a difference between the three sampling locations on base. The third phase combines the first two phases in order to identify a base sampling location for focus. When a base-level location is identified, the fourth phase presents a tool (Bernoulli CUSUM Control Chart) to quickly identify when the JP-8 fuel flow process gets out of control. The final phase compares the base and area lab pass rates using contingency table analysis in order to help determine how often the area labs should sample. This chapter presents the results from each of these five phases, and the results are analyzed according to how the findings help answer the research and accompanying investigative questions.

Phase 1. Descriptive Statistics Results and Analysis

The first phase addresses the first investigative question, "What are the probabilities at each base-level sampling point that JP-8 fuel samples will pass testing?" Observing these probabilities (pass rates) may show which of the three base-level sampling locations need more attention if the pass rates at one location are lower than the other two. This multiple case study approach helps describe JP-8 fuel sampling test results at three different sampling points from the seven bases in this study: (1) at the time of receipt, (2) at fuel storage facilities, and (3) at refueling vehicles and at the aircraft (these locations are synonymous). The seven locations included data from the following bases: (1) Cannon AFB, NM, (2) Kadena AB, Okinawa, (3) Misawa AB, Japan, (4) Wright-Patterson AFB, OH, (5) Hill AFB, UT, (6) Mildenhall AB, United Kingdom, and (7) Osan AB, Korea. The pass rates p [the number of successes (x)/ the sample size (n)] reflect pass rates at each location at each different base. Therefore, there are a total of 21 pass rates, and these rates are observed according to sampling point location on base. Seven pass rates are thus observed for each sampling point location in order to detect observable differences in p. For statistical differences in pass rates p, the contingency table analysis in the next phase compares pass rates at the three sampling locations on base. If sampling point pass rates are noticeably and consistently different from the other two sampling point pass rates, these observations can yield clues of where to focus base-level sampling efforts. The 21 binomial distributions of pass rates are shown in Appendix A. With the use of JMP 5.1.2 software, these distributions with pass rates reflect data collected from each base and sampling location. The following Table 4.1 summarizes these pass rates.

Table 4.1 Pass Rates at Each Base and Sampling Location

	Receipt	Storage	Vehicles/Aircraft
Cannon AFB	96.61%	99.45%	99.70%
Kadena AB	96.83%	98.00%	99.12%
Misawa AB	100.00%	99.19%	99.27%
Wright-Patterson AFB	100.00%	98.48%	98.90%
Hill AFB	95.28%	99.78%	99.29%
Mildenhall AB	93.10%	98.50%	99.46%
Osan AB	99.24%	99.77%	99.37%

After observing the pass rates in Table 4.1 above, the striking difference between pass rates is the higher degree of variability at the receipt sampling location. The range from the highest and lowest pass rates *p* also confirm that there may be differences in pass rates among the three locations:

- Receipt = 6.9% difference between high and low pass rate
- Storage = 1.78% difference
- Vehicles & Aircraft = .8% difference

Thus, the storage and vehicles/aircraft sampling locations show a tighter pass rate range, and they also show evidence of parts of the fuel flow process that is in control because of higher overall pass rates with less variability between pass rates at the seven different bases.

Even though these pass rates appear much different, these differences could be attributed to the differences in sample size *n*. The sample size at receipt is much lower than the other two sampling locations. Table 4.2 below shows the sample sizes for each sampling point at each base. As the above Table 4.1 also shows, the total and average sample size for the receipt location is much lower than the storage or vehicles/aircraft sampling location. This also gives base-level fuels leadership good information about their current sampling requirements (covered in Chapter 2 in Tables 2.2 and 2.3). Since this data shows that sampling at receipt occurs less frequently, this may be due to infrequent JP-8 reception in large bulk quantities and therefore fewer opportunities

Table 4.2 Sample Size at Each Sampling Point

	Receipt	Storage	Vehicles/Aircraft
Cannon AFB	413	543	665
Kadena AB	126	1,453	1,131
Misawa AB	36	615	818
Wright-Patterson AFB	201	855	908
Hill AFB	233	455	988
Mildenhall AB	58	1,000	742
Osan AB	132	862	1,118
Total	1,199	5,783	6,370
Average	171	826	910

for sampling. Sampling occurs more at the other two locations due to sampling requirements at regularly scheduled and smaller (and thus more frequent) intervals. Also, there are multiple refueling trucks and storage facilities on base, and the required sampling at these multiple locations (Tables 2.2 and 2.3) will outweigh the sampling required at receipt, which represents only one location at each base. Regardless of reason for the sample size difference, the data shows considerable differences in sample size between receipt and the other two sampling locations. The statistical significance of sample size is built within the contingency tables, and Phase 2 covers this analysis. However, observing the data on pass rates and sample size alone suggests that base-level fuels managers and personnel should establish stricter monitoring procedures at the earliest point in the process: at the time of receipt.

Phase 2. Contingency Table Results and Analysis

The second phase seeks to help answer the second investigative question, “Are the pass rates at base-level receipt, storage, and vehicles/aircraft statistically the same or different?” This phase compares pass rates (proportions) in order to determine whether or not there is a significant difference in the sampling locations on base. If there is a statistically significant difference in the pass rates between the three locations on base, this would suggest that where base personnel sample their JP-8 matters and further experimental research may be required to determine sources of variability. If the results show no statistically significant difference in pass rates, where fuel gets sampled doesn’t matter. If the results show that it doesn’t matter where fuel gets sampled, base-level fuels managers may be able to focus their sampling efforts at the location identified in this study.

There are seven hypothesis tests for independence (one for each base) that show that the pass rates (proportions) from the three locations on base are either different or not. If pass rates are the same, fail to reject the null hypothesis (H_O: $p_1 = p_2 = p_3$) that the pass rates don’t differ at $\alpha = .05$. If at least one pass rate differs, reject the null hypothesis at $\alpha = .05$. In order to detect the proper results, the decision to either reject or fail to reject is accomplished in the two following ways:

- First, the observed chi-square (χ^2) statistic must exceed the χ^2 critical value of 5.99147 at $\alpha = .05$ and $(r – 1)(c – 1) = (2 – 1)(3 – 1) = 2$ degrees of freedom (df) in order to reject the null hypothesis that the proportions don’t differ (McClave et al, 991)
- Also, if the p-value is less than $\alpha = .05$, this can provide further evidence to reject the null hypothesis that the proportions do not differ

Thus, if the observed χ^2 statistic is greater than the χ^2 test statistic of 5.99147 (at $\alpha = .05$ and 2 degrees of freedom) and the p-value is less than $\alpha = .05$, this suggests that the three pass rates on base do in fact differ significantly. This result would suggest that there are sources of variability that can't be explained by analyzing pass rates alone. For fuels professionals, this result means that they can't focus on one location for sampling.

The results of the seven hypothesis tests are mixed. Appendix B shows all of the contingency tables, mosaic plots (a visual chart that shows sample size division among the three locations on base), and relevant statistics using JMP 5.1.2 software. Table 4.3 below summarizes the results of the Likelihood Ratio (χ^2 approximation) and Pearson χ^2 tests with associated p-values from all seven bases. Also, the last column reflects the "Reject" or "Fail to Reject" decision rule based on the χ^2 critical value and p-value previously mentioned.

Table 4.3 Contingency Table (2 X 3) Hypothesis Test Results (α = .05)

	Likelihood Ratio	P-value Likelihood	χ2 Pearson	P-value Pearson	Hypothesis Result
Cannon AFB	20.098	<.0001	23.765	<.0001	Reject
Kadena AB	7.273	0.0264	7.167	0.0278	Reject
Misawa AB	0.577	0.7494	0.308	0.8571	Fail to Reject*
Wright-Patterson AFB	5.599	0.0608	3.322	0.1900	Fail to Reject
Hill AFB	21.886	<.0001	31.737	<.0001	Reject
Mildenhall AB	11.628	0.0030	18.117	0.0001	Reject
Osan AB	2.007	0.3665	1.845	0.3975	Fail to Reject*
*** 20% of cells have expected count less than 5: chi-square statistic suspect**					

The JP-8 fuels data from Cannon AFB, Kadena AB, Hill AFB, and Mildenhall AB suggest that the pass rates across the three base-level sampling locations do in fact differ. The JP-8 data from Misawa AB, Wright-Patterson AFB, and Osan AB suggest that the pass rates don't differ. However, as the note at the bottom of Table 4.3 shows, the chi-square statistic may not reflect the correct value because 20% of the cells in the contingency table have an expected count (the number of samples in a given contingency table cell) of less than five (5). For this phase, there are a total of 2 (rows) times 3 (columns) equals six cells that make up the contingency table. Because there are few or sometimes zero sample test failures in the failure ("0") row of contingency table, the cells with the expected cell count problem are from those cells that contain sample test failures (represented by the binomial "0" in the contingency tables). For example, if two of the six cells in the contingency table have zero or fewer than five failures, this means that 2/6 = 33% of the cells in the contingency table have a cell count of less than five. Accurate chi-square statistics are difficult to obtain in these instances. The two bases where this problem occurs are investigated further in the next paragraph. See Appendix B for all seven contingency tables.

Cell Count Investigation at Misawa and Osan Air Bases

There are two separate reasons why 20% of the cells have less than five samples in them: low sample size and too few sample test failures. Misawa and Osan Air Bases have the cell count difficulty as indicated (*) in Table 4.3. For the Misawa Air Base contingency table, the sample size at receipt is the lowest of the seven bases in this study. For the other six bases, it appears that sample size is sufficient. However, at Misawa, because of such a low sample size at receipt *and* because there were no sampling test failures (36 passes and zero failures), the row of zeros (sample test failures) under the "receipt" column combined with low sampling test failures at the storage and vehicles/aircraft locations account for more than 20% of the cells in the contingency table. These two reasons can make the results inaccurate because the expected cell count for all cells in a contingency table should be five or greater in order to achieve reliable results. A larger sample size at receipt would likely remedy this problem. To support this claim, another contingency table that tests the pass rate independence of Misawa storage and Misawa vehicles/aircraft (minus the receipt location) shows that storage and vehicles pass rates don't differ, and there isn't a cell count warning. Because this is now a 2 X 2 contingency table, the critical chi-square statistic for these tables is 3.84146 at α = .05 and $(r - 1)(c - 1) = (2 - 1)(2 - 1) = 1$ degree of freedom. The following Table 4.4 shows the Misawa and Osan Air Base 2 X 2 contingency tables comparing every base-level location combination. The hypothesis tests are: $H_0 = p_1 = p_2$, and H_A = the two base-level pass rates differ.

Table 4.4 Contingency Table (2 X 2) Results Comparing Two Base-level Locations

	Likelihood Ratio	P-value Likelihood	$\chi 2$ Pearson	P-value Pearson	Hypothesis Result
Misawa Storage/Vehicles	0.029	0.8648	0.029	0.8645	Fail to Reject
Misawa Receipt/Storage	0.571	0.4498	0.295	0.5871	Fail to Reject
Misawa Receipt/Vehicles	0.519	0.4714	0.266	0.6061	Fail to Reject
Osan Storage/Vehicles	1.801	0.1796	1.671	0.1962	Fail to Reject
Osan Receipt/Storage	0.792	0.3735	1.051	0.3053	Fail to Reject
Osan Receipt/Vehicles	0.031	0.8613	0.032	0.8578	Fail to Reject

For the Misawa storage and vehicles/aircraft location comparison, these locations are statistically equal. The hypothesis result is to "Fail to Reject" the null hypothesis that the two base-level locations are equal. Two additional 2-way contingency tables that compare receipt and storage pass rates (minus vehicles/aircraft) and receipt and aircraft pass rates alone also show that these pass rates don't differ at Misawa Air Base. See Appendix B for the full contingency tables and results. Because the pass rates don't differ when comparing the three sampling locations with each other, the problem likely rests with the receipt location and lack of receipt data at Misawa Air Base.

The Osan Air Base fuel flow process appears to reflect a system that is under control with high (above 99%) pass rates at each of the three sampling locations on base. It appears that sample sizes are enough for all three locations on base, but the expected cell count problem rests with too high of a pass rate at each base-level location. Indeed, this is desirable for base and aircraft commanders to have such high pass rates. But with contingency table analysis, the extremely low count of failures (zeros) at each location leaves the results to be suspect or inaccurate (the expected cell count of the binomial "0" in the contingency table is too low). However, the pass rate data suggests a process that is under control and likely equal. Refer to Table 4.1 where the pass rates for Osan Air Base receipt, storage, and vehicles/aircraft are 99.24%, 99.77%, and 99.37%, respectively. What these high pass rates suggest is that these locations should be equal, and the contingency table analysis confirms that they are statistically equal. To further investigate the equality of all three locations at Osan Air Base, the same 2 X 2 contingency table analysis as described with the Misawa Air Base is utilized. The hypothesis test for comparing the Osan Air Base locations is the same as the Misawa Air Base 2 X 2 case: $H_0 = p_1 = p_2$, and H_A = these base-level pass rates differ. Table 4.4 above and Appendix B show that pass rates don't differ when each base-level location is compared with the other. Since all hypothesis tests result in a failure to reject the null hypothesis, the pass rates when comparing each location individually (instead of comprehensively as the 2 X 3 contingency table analysis does) are statistically the same. Thus, the expected cell count problem likely rests with too few counts (sample test failures) at each of the three base-level sampling locations.

If the results from Misawa and Osan Air Bases show that the pass rates are equal, there are three bases with equal pass rates and four bases with pass rates not equal. The results from the four bases with unequal pass rates suggest that there are different sources of variability that can't be explained by comparing the pass rates alone. For example, each base could experience different contamination levels at storage tanks, or some bases may get more receipt of JP-8 of lesser quality. For the latter case, this is more reflective of what is shown in the data. The receipt location (refer to Table 4.1) shows the greatest variability. This could be due to the small sample sizes *n* at these locations, but more importantly could be due to the variability of the quality of JP-8 entering the process. The contingency table analysis section alone leaves inconclusive results, but combined with the previous phase of descriptive statistics, this information suggests to base-level fuels managers that they need to focus on controlling the fuel that enters their base-level system.

Phase 3. Combination of Case Study and Contingency Tables Analysis

The third phase is a combination of the above two approaches to help answer the part of the research question addressing the portion, "What base-level JP-8 sampling location should each base focus their sampling efforts?" Utilizing pass rate data together with the results from the contingency table analysis, a clear focus for sampling at base-level emerges. Taking this one step further, a statistical process control (SPC) monitoring tool (Phase 4) can be used by base-level fuels personnel to quickly monitor the JP-8 base-level fuel flow process. Base-level fuels management would then have a better idea of the health of their system in real-time.

Each of the three sampling locations is analyzed using a combination of the descriptive and inferential statistics from the first two phases, as well as using current Air Force operational procedures in order to help determine the base-level location to focus sampling efforts. Also, this phase analyzes the three base-level sampling locations as separate parts of the JP-8 base-level fuels flow process, and the location that is identified as the focal point for sampling efforts is the place to set up SPC monitoring procedures (Phase 4).

Vehicles/Aircraft Location.

Beginning with the vehicles/aircraft location, the descriptive statistics reveal a part of the base-level fuel flow process that is in control. All seven bases show pass rates at or above 98.9%, and the range is tight at only a .8% difference between high and low pass rates from the seven bases. This means that variability among the seven base-level vehicles/aircraft locations is the lowest of the three, but it is ideal to set up SPC monitoring at a place where the variability is the greatest (Montgomery, 156). Using the contingency tables, the vehicles/aircraft average sample size is the highest among the three sampling locations, and thus the problems with insufficient cell counts are not attributed to the sample size at this location. The highest average sample size of 910 also suggests that bases pay the most attention to this area due to the more frequent sampling requirements at this location. Even though it's important to sample JP-8 at the refueling vehicles and at the aircraft, the results of base-level sampling tests aren't realized until after the aircraft has departed on a mission (Toner, 2004). It's too late at that point in the process to focus most of your sampling efforts if the aircraft don't wait to depart until they receive the sampling results. Sampling at refueling vehicles and at the aircraft is no doubt very important. Fuels managers can detect problems with these vehicles if they track the pass rates at this location on base, but this location should not be the focal point for sampling efforts—especially considering that fuels managers can identify problems with JP-8 much earlier in the process. Also, the descriptive statistics in Phase 1 show that the average base-level JP-8 pass rates steadily improve from receipt to storage to vehicles/aircraft. These respective average pass rates across all seven bases are 97.29%, 99.03%, and 99.30%. Since fuel gets filtered between every location in the fuel flow process, these results aren't surprising.

Storage Location.

The descriptive statistics for the storage location reveal a part of the process that is under control. Although the range of the differences between high and low pass rates is slightly larger at a 1.78% difference, the high pass rates, at or above 98% and two of the highest pass rates in this study (99.78 and 99.77%), show that this location doesn't have enough variability to warrant statistical process control (SPC). The decision on how much variability it would take to warrant SPC is ultimately up to the base-level fuels manager, as there are no standards in place in the publications covered in Chapter 2. For this study and as a basis of comparison, however, the variability at the storage location across all seven bases is almost four times lower than it is at the receipt location (6.9% between low and high pass rates at receipt versus 1.78% for storage pass rates). Using the contingency tables, the overall hypothesis tests are inconclusive. Four bases (Cannon AFB, Kadena AB, Hill AFB, and Mildenhall AB) show significant differences between locations, while three others (Misawa AB, Wright-Patterson AFB, and Osan AB) reveal that all three locations are the same. The high average sample size at the storage location of 826 didn't contribute to the problems discussed with cell counts (too few sample test failures) at Misawa and Osan Air Bases. This amount of sampling also shows that fuels managers and personnel already pay a great deal of attention to the storage location, and the statistics confirm effective management at this location. Sampling at JP-8 storage tank systems could reveal potential problems with contaminated JP-8, and these problems occur because there are sample test failures that need to be addressed. The sample test failures are remedied quickly with either a re-test or remediation (additization or blending procedures as discussed in Chapter two's "Tests Conducted on JP-8 Fuel Samples" section) when possible (Toner, 2004). If the sample test failure is a "mission failure" classification, this means that problems can't be fixed at base-level and need further investigation before dispensing the JP-8 product from storage (or refueling vehicle) (Toner, 2004). Contaminated fuel in storage tanks will typically not make it to the aircraft because fuels personnel will not pump contaminated fuel into refueling vehicles. But there is a chance that JP-8 from storage tanks may not get tested before the same fuel gets loaded onto an aircraft, and the aircraft subsequently departs without the aircraft commanders knowing the results. In fact, aircraft commanders aren't briefed about base-level lab tests from storage tanks. They only know the quality of the fuel that comes from the refueling vehicle. However, before this same fuel from storage gets pumped into aircraft, the JP-8 flows through at least two sets of filter separators. (See Figure 1.1 for a typical JP-8 fuel flow process.) Therefore, aircraft commanders should feel that they receive a healthy dose of JP-8 product due to the filtration used and the frequent sampling required (which varies from tank to tank and vehicle to different vehicle type) according to PTO 42-B-1-1. For the vehicles/aircraft location, fuels managers can detect problems at storage facilities if they track the sample test pass rates at this location on base. The storage location shouldn't be the focal point for sampling efforts due to low variability, frequent filtration and testing, and statistics that reflect a part of the process that is already under control.

Receipt Location.

The descriptive statistics for the receipt location reveal a part of the process that is less in control, due to greater variability, than the other two sampling locations by a wide margin. The range of the differences between high and low sample test pass rates at the receipt location for all seven bases is the highest among the three sampling locations at a 6.9% difference. The variability between sample test pass rates at the receipt location for all seven bases is also the greatest, with none of pass rates hovering around the mean pass rate for receipt (97.29%). The location with the greatest variability makes it the strongest candidate for SPC (Montgomery, 156), and the receipt location fits this description. Using contingency table results, the receipt location should be a primary focus for a few reasons. First, the sample size isn't enough to effectively compare this location with the other two. This reflects a part of the process with the least amount of attention or a part of the process that is under-reported. Also, the pass rates at receipt are lower or significantly different than the other two locations. Operationally, different bases get JP-8 from different sources around the world. Low pass rates at the receipt location could be due to water (or condensation from the delivery vehicle or pipeline) or other solid contaminants, but most of these contaminants are removed from the fuel before it enters the storage tanks by the filter separators. Fuels managers and personnel know that most contaminants are removed after filtration, but they are not sure of other contaminants that may pass through filter separators undetected, at least until a full battery of tests described in Chapter 2 is performed on the receipt sample (Toner, 2004). Also, as Table 2.2 shows, the Air Force tanker truck receipt requirement specifies that only one sample is required per day from each supplier (PTO 42-B-1-1, 5-18). If a supplier brings more than one truckload of JP-8, the bases aren't required to sample the subsequent truckloads from the same supplier. Because less attention is paid to the receipt location (fewer sample sizes as compared with the other locations and fewer sampling requirements), there is not enough data submitted from each base to determine if the pass rates at receipt in this study accurately reflect this part of the process. Due to the higher degree of variability among pass rates, the small sample sizes reported, and the lack of control of what enters the JP-8 base-level system, the only remaining location to focus sampling efforts is at the time of receipt. The receipt location would therefore be the ideal location to set up SPC procedures. The next phase of this study presents examples of a specific type of SPC: the Bernoulli CUSUM control chart.

Phase 4. Statistical Process Control Using Bernoulli CUSUM Chart

The fourth phase seeks an answer to the third investigative question, "What procedures could enhance the JP-8 fuel flow process to make the base-level fuel distribution system more responsive and healthy?" The Bernoulli CUSUM control chart is selected to monitor the JP-8 fuel flow process. Based on the results and analyses in the above three phases, the receipt location is identified as the base-level location where SPC monitoring should take place. Lower average pass rates, higher pass rate variation, and small sample sizes from this location draw more attention to the receipt location. This phase of the study presents an example of a Bernoulli CUSUM chart with data collected from the receipt location at the base where the sample size is greatest and the pass rate is reasonably close to the average for all seven bases (97.16%): Cannon AFB.

Cannon AFB Descriptive Statistics for Estimating Bernoulli CUSUM Parameters

Because Cannon AFB has the largest sample size at receipt (413) and a pass rate that closely resembles the average (97.16%) pass rate at receipt (96.61%), this base's data is used for this example of the Bernoulli CUSUM control chart. Cannon AFB pass rate data feeds the parameters needed to execute the control chart. Specifically, the in-control value of P_0 is the observed pass rate. To review, the following estimated parameters are used to execute the Bernoulli CUSUM control chart:

- P_0 = .034 is the observed in-control value from Cannon AFB's pass rate (100 – 96.6%)
- P_1 = .05 and .068 or the specified out-of-control values to detect increases in p (sampling test failure rate)
- h_b* = 4.0997 at P_1 = .05 and 5.142 a P_1 = .068 to determine the false alarm rate and the speed with which the chart detects an increase in p (Reynolds and Stoumbos, 91)

Observing the data from Cannon AFB, there are a total of 413 sampling tests. Looking closer at the data, there are three groupings of sample test failures that would concern SPC monitors. For this Cannon AFB example, these three areas could be possible signals that detect an increase or shift from P_0 to P_1. The approximate ANOS for this case alone is the sample size n divided by the suspected number of observations to signal (3). Dividing the sample size (413) by ANOS (3) equals 138 rounded up. Using ANOS (P_1) = 138 and solving for h_b*, h_b* equals 4.0997 at P_0 = .05, and h_b* equals 5.142 at P_0 = .068. Another way of arriving at h_b* is to select an integer h_b value or false alarm rate that the fuels personnel can approximate based on experience of sampling test failures. This section offers three more alternate h_b* values as a basis of comparison. Comparing the results from different false alarm rates will allow the fuels personnel/monitors to select the rate that reflects typical data from base-level receipt locations. All of the parameters covered on this section can be altered so that monitors can quickly identify rates or values that will detect a process that gets out-of-control.

Example of a Bernoulli CUSUM Control Chart

There are a total of eight separate Bernoulli CUSUM control charts executed in this phase. Table 4.5 below summarizes the results. The objective for all JP-8 fuels monitors/mangers is the same with this control chart: to detect significant increases in p (sampling test failure rate). Based on the parameters specified above, these increases in p in Table 4.5 are the amount of signals detected if this representative sample size (413) from Cannon AFB's receipt location had a Bernoulli CUSUM control chart in place. If the Bernoulli CUSUM control statistic exceeds the h_b* parameter, a signal is quickly detected, and the process is deemed out-of-control. Every base would have different parameters, though. Base-levels fuels managers could set their own control values based on their own observed pass rates P_0 from their respective and different fuel sources.

Once the chart detects a process out of control, the fuels manager can then decide the appropriate actions to take. They may re-sample to confirm or dispute the control

Table 4.5 Bernoulli CUSUM Signals Detected from Cannon AFB Data

Chosen h_b	(Adjusted) h_b*	P_1	P_0	Signals Detected
3	3.1159	0.050	0.034	3
3	3.1159	0.068	0.034	3
4	4.1159	0.050	0.034	1
4	4.1159	0.068	0.034	1
N/A	4.0997	0.050	0.034	1
N/A	5.1420	0.068	0.034	1
7	7.1159	0.050	0.034	1
7	7.1159	0.068	0.034	0

chart results, or they can fix the problem with fuel remediation. If remediation isn't possible, the managers can contact AFPET, and they can send a team to investigate the problem. The key here is instant awareness that a process may be out of control. There is no lag or uncertainty of knowing the instantaneous health of the JP-8 base-level system. Without a control system in place, the fuels responsible personnel don't have a good idea of knowing whether or not their JP-8 fuel flow process is either under or out-of-control.

To give managers an indication of the health status of their fuel distribution system, the following Bernoulli CUSUM control chart sample in Figure 4.1 shows the Cannon data from the 190th to the 413th sample (as there were no sample test failures prior to the 190th sample). The chart detects one signal where the process is out-of-control based on the parameters P_1 = .05 and h_b* = 4.0997 (the horizontal constant). The P_0 = .034 parameter is the same for every chart in this study, as this is the pass rate from the 413 samples collected at Cannon AFB. The chart control statistic B_k fluctuates as the sample test failures either add up or decrease over time.

As the chart below shows, when sample test failures are closely grouped together, the control statistic B_k spikes and could possibly signal an out-of-control process if enough failures are detected over a short period. In the ANOS section described previously, observe the three locations in the chart where there are closely packed sample test failures. There are three distinctive peaks where a signal could occur, based on the parameters. However, the chart detected the significant increase or shift in p which led to a signal only one time over the entire sample of 413 observations. Changing the

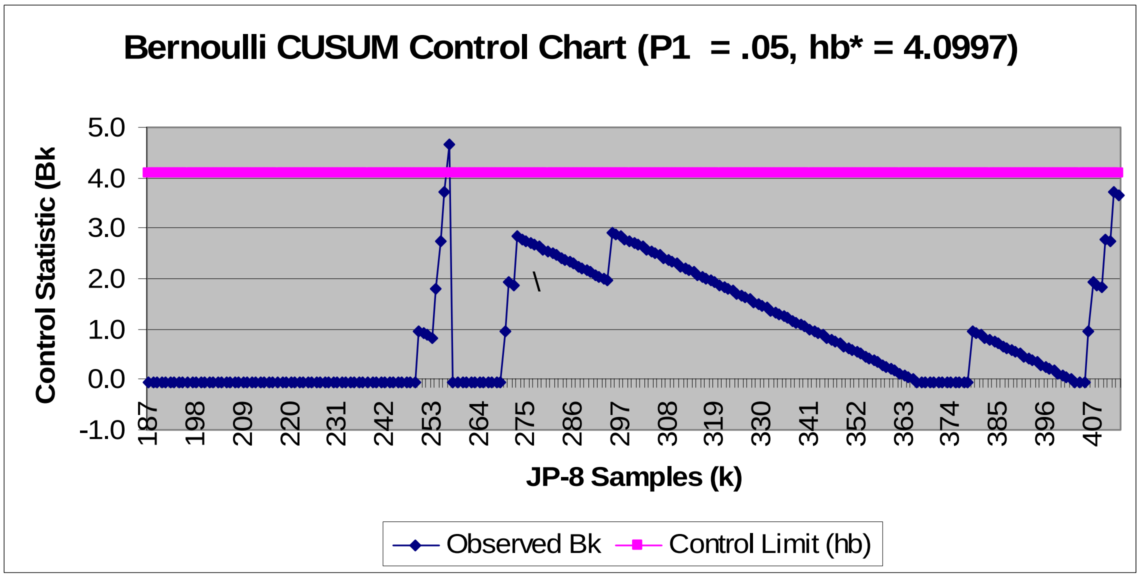


Figure 4.1 Bernoulli CUSUM Control Chart Example

parameters yields different results as Table 4.5 shows. Lower h_b* values signal the chart more often, while changing the P_1 out-of-control values has less of an effect, given the same h_b* values. Three of the four comparisons between P_1 = .05 and P_1 = .068 show identical signal amounts (at the same level of h_b*). The remaining seven Bernoulli CUSUM charts are located in Appendix E for further (visual) comparisons.

The above Bernoulli CUSUM chart in Figure 4.1 comes from a Microsoft Excel spreadsheet that is set up like the excerpt in Figure 4.2 below. The *k* column represents the sample number. For this Cannon AFB data, *k* goes from 1 to 413, the sample size amount. For the next column, X_k shows either a "1" or "0." Zero means that the sample test *k* passes, and the number one means that the sample fails. The $X_k - r$ column subtracts the control value $r = .0417$ from either 1 or zero. This is the second part of the Bernoulli CUSUM control statistic as described in Chapter 3 Methodology. The next $X_k - r\ (m)$ column is the fraction of the previous column, and it's meant for convenience when plotting this chart manually. It also serves as the computational approximation for $X_k - r$ in this example. The Bernoulli CUSUM control statistic B_k column is next, and this is the first part of the B_k statistic where the Excel cell is the maximum of either zero or the previous sample control statistic B_k. The false alarm rate h_b* column is next. If the

k	X_k	X_k - r	X_k - r (*m*)	B_k	h_b*	Action
246	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
247	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
248	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
249	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
250	1	0.9583	23 / 24	0.9583	4.0997	*
251	0	-0.0417	- 1 / 24	0.9167	4.0997	*
252	0	-0.0417	- 1 / 24	0.8750	4.0997	*
253	0	-0.0417	- 1 / 24	0.8333	4.0997	*
254	1	0.9583	23 / 24	1.7917	4.0997	*
255	1	0.9583	23 / 24	2.7500	4.0997	*
256	1	0.9583	23 / 24	3.7083	4.0997	*
257	1	0.9583	23 / 24	4.6667	4.0997	Signal
258	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
259	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset

Figure 4.2. Excerpt from Bernoulli CUSUM Control Chart Spreadsheet

B_k statistic exceeds the false alarm rate, this signals that the JP-8 fuel flow process is out of control, based on the P_0, P_1, and h_b* parameters specified above. This column also shows a "Reset" command, and this happens when the B_k statistic falls below zero. Additionally, this column also shows an asterisk (*). This identifies that the B_k statistic is above zero but hasn't set off a signal because the B_k value is less than the false alarm rate h_b*. A full example of the Bernoulli CUSUM control chart spreadsheet is included in Appendix F. Both the chart and spreadsheet are useful tools in quickly determining a process that is either in or out of control

Phase 5. Results and Analysis.

This final phase seeks to answer the fourth investigative question, "How often should area lab samples (45-day correlation/aircraft servicing samples) be taken to ensure a healthy JP-8 fuel distribution system?" AFPET wants to know if the current 45-day requirement for area lab sampling of JP-8 is the right amount in order to help ensure a healthy JP-8 fuel system. This phase shows results of the aircraft/correlation servicing sample pass rates from the each of the seven bases and their respective area labs. The pass rates from each of the seven base's vehicles/aircraft sample location are presented again in this section in order to statistically compare the area lab results against the base-level results using contingency table analysis. The time frame for the area and base-level lab pass rates is the same 444-day period. If the area labs show lower pass rates, the area lab may want to sample more frequently than 45 days in order to detect JP-8 failures sooner. If area labs show higher pass rates, this suggests that they may wish to sample less frequently than 45 days. If pass rates between base-level and area labs are statistically equal, this suggests that sampling every 45 days at the area labs is sufficient to detect sample failures with the same frequency as base-level labs.

The pass rates and associated distributions for the base-level vehicle/aircraft location samples are in Appendix A, and the area lab pass rates and distributions are in Appendix C. The pass rates and corresponding sample sizes are summarized in Table 4.6 below. Observing the pass rates alone, the area lab rates are all 100%, while the base-level results are between 98.9% and 99.7%. Based on these statistics alone and since area labs show slightly higher pass rates, this suggests that area labs may wish to sample less frequently than 45 days. However, these pass rates are so close that they may be statistically equal, which would suggest that the area labs should keep their 45-day sampling requirement. This comparison alone doesn't show if these pass rates are the same or different, but the pass rates appear to be close. The contingency table analysis comparing the area and base-level lab pass rates shows the comparison that AFPET is looking for.

Table 4.6 Sample Sizes and Pass Rates at Area Lab and Base-level

	Area Lab Sample Size	Area Lab Pass Rate Correlation (45-day)	Base-level Lab Sample Size	Base-level Lab Pass Rate Vehicles & Aircraft
Cannon AFB	11	100.00%	665	99.70%
Kadena AB	9	100.00%	1,131	99.12%
Misawa AB	11	100.00%	818	99.27%
Wright-Patterson AFB	11	100.00%	908	98.90%
Hill	11	100.00%	988	99.29%
Mildenhall AB	14	100.00%	742	99.46%
Osan AB	11	100.00%	1,118	99.37%

Because the 45-day sample requirement for area lab samples are very low compared with the amount of samples collected over the same period at base-level, the area lab pass rates results could be misleading. Just one failure at an area lab could result in a significantly lower pass rate. For example, one failure at Cannon Air Force Base's area lab would result in a pass rate of 10/11 = 90.9%. This pass rate would not match up well with the 99.7% pass rate at Cannon's base-level lab. Based on the data collected, however, there is no evidence to suggest that the area lab would get one or more failures over an extended period such as the 444-day time-frame of this study. Of the 78 total samples from the area labs, the labs detected no failures. To show the statistical significance between the area and base-level lab pass rates, a contingency table analysis compares the lab pass rates with $\alpha = .05$ confidence. Table 4.7 below shows the results of the likelihood ratio and Pearson χ^2 statistic, both described in Chapter 3 Methodology.

Table 4.7 Contingency Table Analysis Comparing Correlation vs. Vehicle Samples

	Likelihood Ratio	P-value Likelihood	χ2 Pearson	P-value Pearson	Hypothesis Result
Cannon AFB	0.066	0.7977	0.033	0.8555	Fail to Reject
Kadena AB	0.159	0.6899	0.080	0.7769	Fail to Reject
Misawa AB	0.161	0.6883	0.081	0.7756	Fail to Reject
Wright-Patterson AFB	0.242	0.6226	0.122	0.7264	Fail to Reject
Hill AFB	0.156	0.6933	0.078	0.7794	Fail to Reject
Mildenhall AB	0.150	0.6986	0.076	0.7830	Fail to Reject
Osan AB	0.138	0.7108	0.069	0.7924	Fail to Reject

The results reflect that each base has an observed χ^2 statistic less than the χ^2 test statistic of 3.84146 at $\alpha = .05$ and $(r - 1)(c - 1) = (2 - 1)(2 - 1) = 1$ degree of freedom. Also, the high p-values well exceed $\alpha = .05$. Both observed statistics, the likelihood ratio and Pearson χ^2 statistic, agree with the p-value, and the hypothesis result is to fail to reject the null hypothesis that the pass rates *p* are equal at every one of the seven bases in this study.

For AFPET, these results provide evidence that area and base-level pass rates are equal. Therefore, the area lab 45-day sampling requirement is sufficient and adequately reflects the health of the base-level JP-8 fuel system at the point where fuel gets loaded into the aircraft. Observing just the pass rates in Table 4.6, the results of the contingency table analysis agree with the very close pass rates between the area and base-level labs. Due to the very low sample size at the area labs, however, these results would be different with just one failure at an area lab. Then again, one failure would have to occur at every area lab that corresponds to each base in order to possibly suggest a significant difference in pass rates. Ultimately, there isn't evidence to suggest a difference in pass rates based on the data collected in this study. Despite the low sample sizes, each of the seven area and corresponding base-level labs reveal data that suggest pass rates are equal. AFPET should be confident that the 45-day correlation/aircraft servicing sampling requirement is enough to ensure a healthy JP-8 product at the aircraft.

Summary for Results and Analysis: Phases 1 Through 5

To recap the results and analysis chapter, Phases 1 through 3 collectively identify the sampling location where future efforts should be focused to ensure quality JP-8 from receipt to the aircraft. In Phase 1, pass rates are analyzed, and the receipt location has the lowest average pass rate, the greatest variability, and the lowest average sample size among the three sampling locations on base. Phase 2 statistically compares the pass rates in order to determine if the pass rates on each base suggest either a difference or no difference among the three sampling locations. Statistically equal pass rates are desirable for focusing on only one sampling location per base. Statistically unequal pass rates suggest that there are sources of variability that can't be explained by the pass rate comparisons alone. The results for Phase 2 are mixed, with three bases having equal pass rates and four bases having unequal pass rates. More investigation is needed to determine the focus for sampling efforts, and Phase 3 provides more evidence.

In Phase 3, information from both phases is gathered and analyzed. In addition to the results gathered in Phase 1, less attention is paid to the receipt location as a result of fewer sampling opportunities. Also, there is the lack of control of what enters the JP-8 base-level system, and JP-8 passes through the least amount of filtration at receipt. Because of this evidence, the receipt location is identified as the location for the focus of base-level sampling efforts. Phase 4 provides an example of the Bernoulli CUSUM control chart using Cannon AFB sampling data. This chart could be used at Air Force bases to closely monitor their JP-8 fuel distribution system. Phase 5 analyzes the 45-day correlation/aircraft servicing requirement. AFPET wants to know if this requirement is sufficient in determining the health of the fuel distribution system. Area- and base-level pass rates are compared to evaluate the effectiveness of the 45-day requirement. Despite the very low sample sizes, the area and base lab pass rates are statistically equal. However, with just one failure at area labs, the results would be different. A larger sample size would be desirable in order to strengthen the results of Phase 5. Though with high pass rates at over 99%, there is no evidence to suggest that the pass rates aren't equal, and the 45-day requirement is determined to be sufficient in detecting JP-8 fuel distribution health.

V. Conclusions and Recommendations

Research Overview

The objective of this research is to assess Air Force base-level fuel sampling data to determine the base-level sampling location to focus on that ensures a quality and healthy product at the aircraft. Also, this research seeks to identify how often correlation/aircraft servicing sampling (the 45-day sample) should take place at Air Force area labs. This study seeks to give base-level commanders and pilots the information they need in order to perform missions and utilize assets with confidence and safety.

The first three phases collectively identify which sampling location on base to focus sampling efforts. In the first phase, descriptive statistics show the pass rates from the three locations at each of the seven bases. The phase two contingency table analysis shows if there is a difference between the three sampling locations on base. The third phase combines the first two phases in order to identify one sampling location for focus. The fourth phase presents a tool (Bernoulli CUSUM Control Chart) that instantly identifies when the JP-8 fuel flow process gets out of control. The final phase compares the base and area lab pass rates using contingency table analysis in order to determine how often the area labs should sample. This research assists the Air Force Petroleum Office (AFPET), the office responsible for assuring JP-8 fuel quality for the Air Force, by helping to ensure a healthy base-level JP-8 fuel distribution system.

Research Conclusions and Recommendations

In Phase 1, pass rates are compared to observe the sampling locations that need more attention. Due to higher variability and lower pass rate averages than the storage and vehicles/aircraft locations, fuels managers and decision makers may want to focus more sampling efforts toward the receipt location to control this higher variability and to increase the pass rate average. The data also shows considerable differences in sample size between receipt and the other two sampling locations, so more sampling at receipt may help to more closely monitor the JP-8 that enters the system. There are additional opportunities to sample at receipt. For example, instead of sampling just the first truck from a supplier in a given day, bases could sample all of the trucks from that same supplier if the supplier delivers more than one truck of JP-8 in a single day.

In Phase 2, the results of the seven hypothesis tests are mixed. Even if the results from Misawa and Osan Air Bases show that the pass rates are equal, because of the cell count problem (too few failures and low sample sizes at receipt), three bases have equal pass rates and four bases have pass rates not equal. Thus, the results from the four bases with unequal pass rates suggest that there are different sources of variability that can't be explained by analyzing the pass rates alone. Fuels managers may wish to further investigate the inherent differences between the sampling locations in order to ensure a healthy JP-8 fuel flow system on base.

For Phase 3, the receipt, storage, and vehicles/aircraft locations are analyzed as separate parts of the fuel flow process. Combining the data and information from the first two phases and addressing operational sampling procedures, the receipt location is identified as the focal point for sampling efforts. Therefore, the receipt location is the place to set up SPC monitoring procedures. Fuels personnel and management can better monitor the JP-8 that enters their system with more focus at this location and less sampling at the storage and vehicles/aircraft location. In Phase 4, the Bernoulli CUSUM control chart was presented as a tool to monitor the JP-8 fuel flow process, and Cannon AFB data was used to execute the chart. Both the chart and spreadsheet are useful tools in quickly determining a process that is either in- or out-of-control, and the health of any base-level fuel system can be improved with these tools. Because this chart has a built-in confidence level, base fuels personnel know the status of their JP-8 fuel flow system after each sample is tested.

In Phase 5, ultimately, there is no evidence to suggest a difference in pass rates based on the data collected in this study. Despite the low sample sizes, each of the seven area and corresponding base-level labs reveal data that suggest pass rates are equal. Based on the data in this study, AFPET should be confident that the 45-day correlation/aircraft servicing sampling requirement is sufficient to ensure a healthy JP-8 product at the aircraft. However, the results would be different with just one failure at the area labs because of the low average sample sizes. More samples from area labs are statistically desirable to strengthen Phase 5 results, but with the data provided the 45-day requirement is enough to correlate base- and area-level sampling results.

Research and Operational Limitations

The following information in this section identifies research limitations encountered during the course of this thesis. When compiling data for this study, each of the twelve total Air Force bases solicited to submit sampling data needed to be contacted individually. With seven bases responding with the required data by the deadline, this left five bases whose data wasn't included in this study. The conclusions from the seven bases in this study represent a typical base-level JP-8 fuel flow process, but data from all bases should be available to those with a "need-to-know." Specifically, AFPET should have ready access to summary data from each base's Fuels Automated System (FAS), but this currently isn't the case (Pittman & Toner, 2004). AFPET should be able to "drill" sampling data so that they can see the status of all base-level fuel sampling locations in real-time. At the very least, the area labs should be able to electronically drill the data needed so that they can reconcile the 45-day correlation/aircraft servicing samples with base-level data easily and quickly. AFPET and the Air Force fuels community are currently working to electronically connect fuels information systems and databases to improve visibility over the entire JP-8 distribution system (Pittman & Toner, 2004).

Also, of the seven bases included in this study, none are Air Mobility Command (AMC) bases. It would have been desirable to have different command representation in this study, but there were no data responses from the AMC bases solicited. However, the bases in this study represent installations from around the world and from different climates. The seven representative bases receive their JP-8 from different sources, and the fuel facilities at each base endure differing weather conditions. Both of these conditions contribute to making the results more generalizable. Including more bases from more commands may or may not have strengthened the results of the study, but more data is desirable.

The scope of this study isn't large enough to identify every variable that influence testing results. However, with such high pass rates, especially at the point where fuel gets loaded into the aircraft, the return or benefit from knowing every variable won't necessarily improve the health of the base-level JP-8 fuel flow process. Additionally, JP-8 fuel samples that have failed at base level get dumped back into storage tanks (Pittman

& Toner, 2004). Dumping will have a negligible effect if the rest of fuel in the storage tank passes testing, but this drawback should be addressed (Pittman & Toner, 2004). Blending and additization (remediation) techniques help to restore a healthy JP-8 fuel quality (Toner, 2004).

As a monitoring process, the 45-day correlation/aircraft servicing sample conducted at the area labs works, as the results from phase five of this study indicate. Because of 99% pass rates at the vehicles/aircraft sampling location, there shouldn't be many (or any) failures at the area labs. Area lab sampling adds value to the monitoring process by verifying base-level sampling test credibility and calibration of testing equipment (Toner, 2004). These area lab samples could thus detect a personnel training deficiency if the base-level tests aren't being performed correctly. Multiple differences in sampling test results between area- and base-level labs could identify such deficiencies. The area lab samples also endure additional tests, as Chapter 2 describes in detail. Thus, area lab sampling doesn't detect contaminated fuel before the fuel from that same sample gets loaded into aircraft, but area lab sampling adds value by verifying base-level results, verifying testing equipment calibration, and administering additional sample tests.

Lastly, there are a lack of relevant aviation fuels-based studies that effectively support the objective of this research. There are studies that address the different sampling tests mentioned in Chapter 2 of this study, but these studies would have no impact on the direction of this research and aren't included in this study. Despite this lack of directly or indirectly relevant fuels-based research, the Bernoulli CUSUM control chart research by Reynolds and Stoumbos (1999) is a relevant and potentially useful tool in tracking the base-level fuels distribution system health.

Future Research

There are at least four future research opportunities that come from or are related to this study. After conducting Phase 2 contingency table results, a research opportunity emerges after observing that four bases (Cannon AFB, Kadena AB, Hill AFB, and Mildenhall AB) show pass rates that are different. These differences mean that something else that can't be explained with pass rate comparisons is occurring. These pass rate differences suggest that there are different sources of variability that contribute to the different results in Phase 2. To investigate these differences, an experimental research design to identify the inherent differences between sampling locations could help identify sources of variability, and a healthier fuel flow system could result if more is known about each location in the process. As mentioned previously in the research limitations section, the return from knowing all sources of variability (from contaminated fuel) may not be worth the cost. With high JP-8 sampling pass rates at the aircraft location and because JP-8 passes through several rounds of filtration, the Air Force may not benefit from attempting to isolate sources of contaminated fuel on base.

Another research project could involve the use of PQIS data mentioned in Chapter 2. Because the sampling data included in PQIS is refinery data, this database doesn't help assess the health of the Air Force base-level JP-8 distribution system. However, this data could be used to compare sampling results with results achieved at the Air Force receipt location in order to determine the effects on JP-8 fuel quality from refinery to base-level receipt. If there are significant differences in quality of JP-8 between these two locations, DESC and the Air Force may want to assess the quality effects of long-term storage and transportation of JP-8.

The third future research suggestion is to install statistical process control (SPC) procedures at test bases worldwide at the fuels management team level. The Bernoulli CUSUM chart in Phase 4 would be the tool that these managers could use, and they would need the proper training to be able to execute this SPC procedure. The purpose would be to evaluate the effectiveness of monitoring JP-8 as it enters an Air Force base at receipt. If the monitoring procedures help to improve the quality of JP-8, all bases could use SPC, and the appropriate fuels technical orders, such as PTO 42-B-1-1, could be updated to reflect the use of SPC for monitoring the JP-8 fuel flow process.

The final research opportunity could come from identifying specific modes of sample test failures. This study observes sample tests on a pass or fail basis, regardless of which of the individual sample tests failed. However, a study could be to observe the individual sample tests conducted on each JP-8 sample. The researcher could identify which specific sample test yields the most or least amount of failure results. This may give the Air Force valuable information on where to pinpoint problems with JP-8 quality. For example, if there are repeat failures due to Fuel System Icing Inhibitor (FSII) content falling outside of the limitations specified in Chapter 2, AFPET and base-levels fuels personnel could focus their sampling efforts more closely on JP-8 FSII content. If problems are identified by analyzing specific sample test modes, the health of the base-level JP-8 fuel distribution system could be improved.

Final Notes

This chapter presents the research overview, conclusions, recommendations, and limitations, as well as future research suggestions. There are high pass rates that average to over 99% at the vehicles/aircraft location from the bases in this study. This JP-8 represents the quality of fuel that enters Air Force and other military aircraft. Also, frequent filtration on base ensures these high pass rates, but these rates aren't 100%. Attaining a 100% pass rate at the aircraft isn't a stated goal or currently achievable, but cost-effective improvements that ensure aircrew safety and equipment functionality are worthwhile.

There currently aren't frequent Air Force aircraft crashes due to contaminated JP-8, but just one would be too much. If a plane does crash, the investigators are certain to sample the fuel source of the JP-8 that was pumped into the aircraft. They could potentially eliminate or confirm the role of JP-8 quality in the accident, so bases should do all they can to constantly improve the fuel flow process where possible. What could be more costly in the long run is aircraft fuel system, ground equipment, and facility damage due to contaminated fuel. This potential damage could shorten the system or product life-cycle and therefore increase operating costs. At the very least, this research can help improve upon the current JP-8 distribution system and add a level of confidence to ensure the healthiest possible JP-8 product at the aircraft.

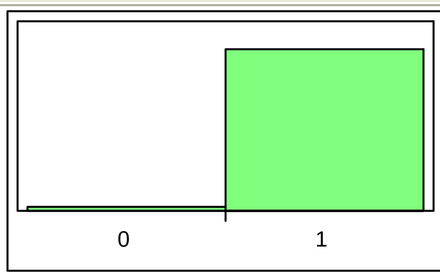
Appendix A. Distributions and Pass Rates (Phase 1)

The following JMP 5.1 output shows the binomial distributions from each of the three sampling locations (receipt, storage, and vehicles and aircraft) at each of the seven representative bases. The "1" levels are the sampling test passes, and the "0" levels are the sampling test failures. The pass rates p are the number of successes x (sampling test passes) divided by the sample size n, and these pass rates are located under the "Prob" column. Disregard the "N Missing" count, as this only represents blank cells in a single spreadsheet that includes different combinations of sample sizes from bases in this study.

Cannon AFB Distributions and Pass Rates

Distributions

Receipt

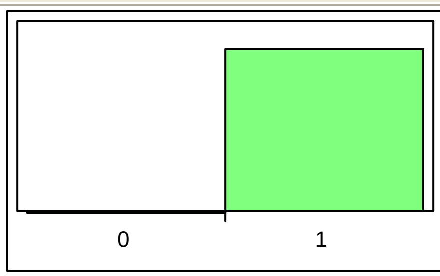


Frequencies

Level	Count	Prob
0	14	0.03390
1	399	0.96610
Total	413	1.00000

N Missing 1548
2 Levels

Storage

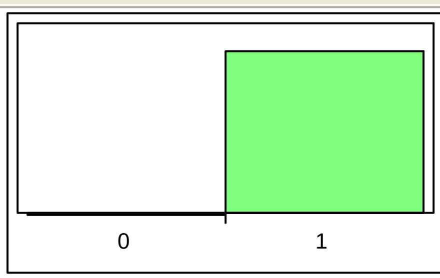


Frequencies

Level	Count	Prob
0	3	0.00549
1	543	0.99451
Total	546	1.00000

N Missing 1415
2 Levels

Vehicles A/C



Frequencies

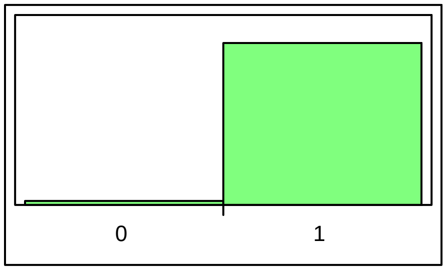
Level	Count	Prob
0	2	0.00301
1	663	0.99699
Total	665	1.00000

N Missing 1296
2 Levels

Kadena AB Distributions and Pass Rates

Distributions

Receipt

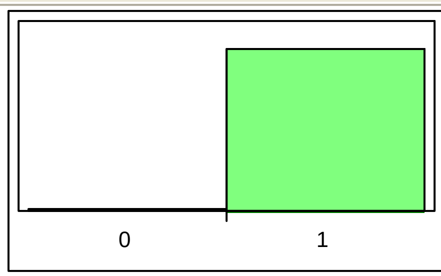


Frequencies

Level	Count	Prob
0	4	0.03175
1	122	0.96825
Total	126	1.00000

N Missing 4233
2 Levels

Storage

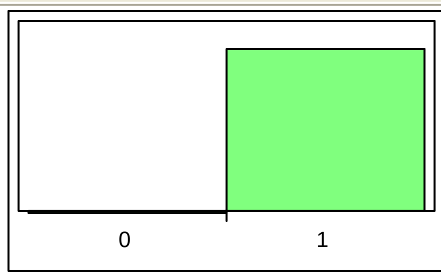


Frequencies

Level	Count	Prob
0	29	0.01996
1	1424	0.98004
Total	1453	1.00000

N Missing 2906
2 Levels

Vehicles A/C



Frequencies

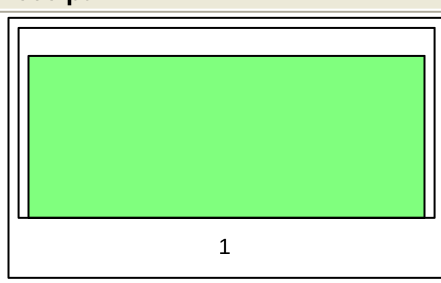
Level	Count	Prob
0	10	0.00884
1	1121	0.99116
Total	1131	1.00000

N Missing 3228
2 Levels

Misawa AB Distributions and Pass Rates

Distributions

Receipt



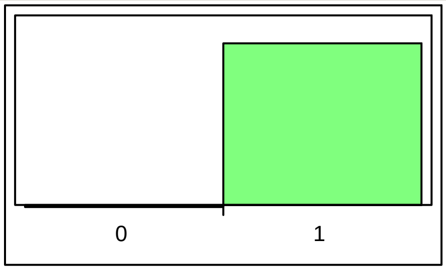
Frequencies

Level	Count	Prob
1	36	1.00000
Total	36	1.00000

N Missing 2397
1 Levels

Distributions

Storage

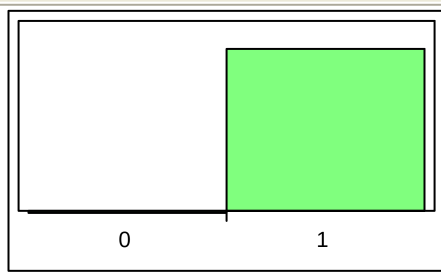


Frequencies

Level	Count	Prob
0	5	0.00813
1	610	0.99187
Total	615	1.00000

N Missing 1818
2 Levels

Vehicles A/C



Frequencies

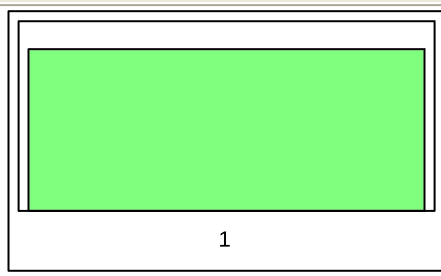
Level	Count	Prob
0	6	0.00733
1	812	0.99267
Total	818	1.00000

N Missing 1615
2 Levels

Wright-Patterson AFB (WPAFB) Distributions and Pass Rates

Distributions

Receipt

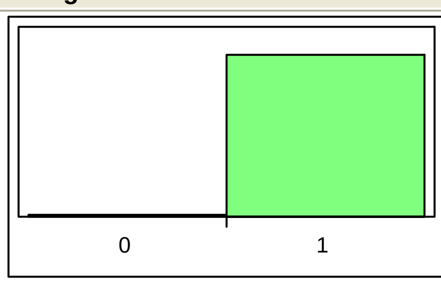


Frequencies

Level	Count	Prob
1	201	1.00000
Total	201	1.00000

N Missing 2364
1 Levels

Storage



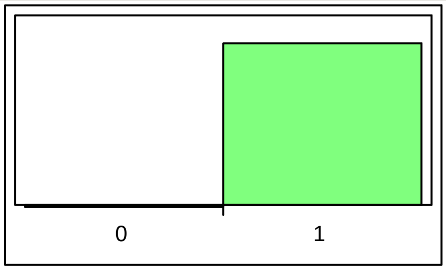
Frequencies

Level	Count	Prob
0	13	0.01520
1	842	0.98480
Total	855	1.00000

N Missing 1710
2 Levels

Distributions

Vehicles A/C



Frequencies

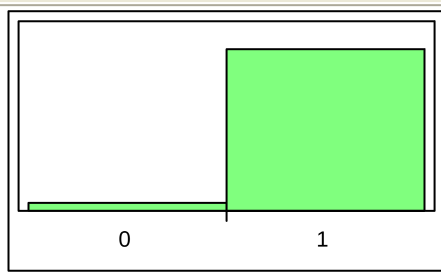
Level	Count	Prob
0	10	0.01101
1	898	0.98899
Total	908	1.00000

N Missing 1657
2 Levels

Hill AFB Distributions and Pass Rates

Distributions

Receipt

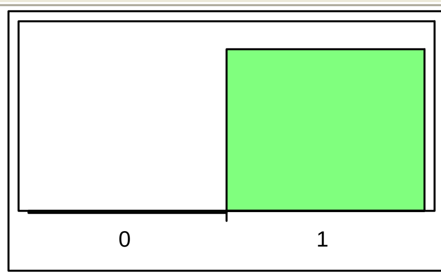


Frequencies

Level	Count	Prob
0	11	0.04721
1	222	0.95279
Total	233	1.00000

N Missing 2575
2 Levels

Storage

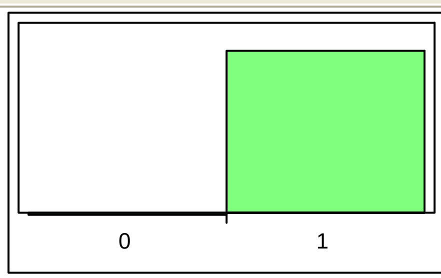


Frequencies

Level	Count	Prob
0	1	0.00220
1	454	0.99780
Total	455	1.00000

N Missing 2353
2 Levels

Vehicles A/C



Frequencies

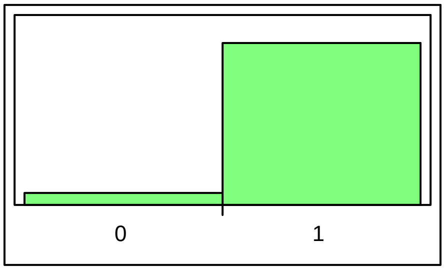
Level	Count	Prob
0	7	0.00709
1	981	0.99291
Total	988	1.00000

N Missing 1820
2 Levels

Mildenhall AB Distributions and Pass Rates

Distributions

Receipt

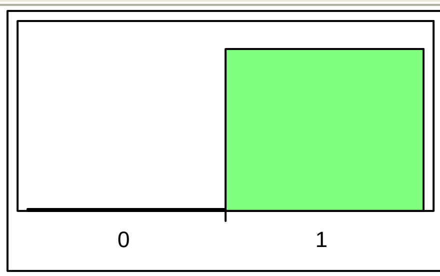


Frequencies

Level	Count	Prob
0	4	0.06897
1	54	0.93103
Total	58	1.00000

N Missing 2942
2 Levels

Storage

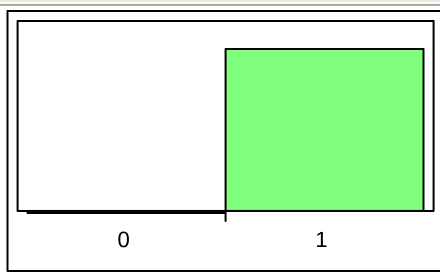


Frequencies

Level	Count	Prob
0	15	0.01500
1	985	0.98500
Total	1000	1.00000

N Missing 2000
2 Levels

Vehicles A/C



Frequencies

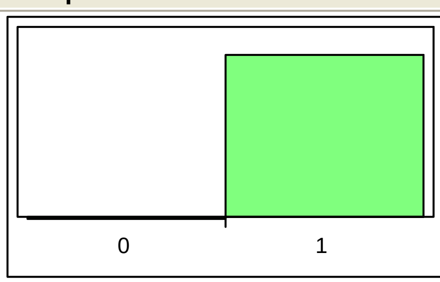
Level	Count	Prob
0	4	0.00539
1	738	0.99461
Total	742	1.00000

N Missing 2258
2 Levels

Osan AB Distributions and Pass Rates

Distributions

Receipt



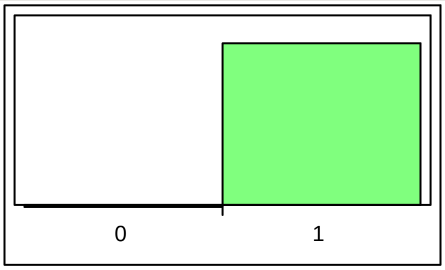
Frequencies

Level	Count	Prob
0	1	0.00758
1	131	0.99242
Total	132	1.00000

N Missing 3006
2 Levels

Distributions

Storage

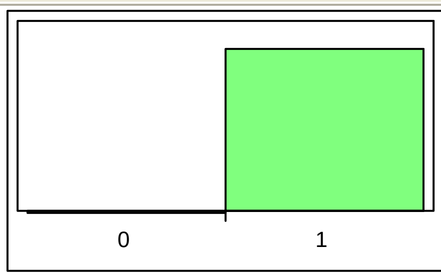


Frequencies

Level	Count	Prob
0	2	0.00232
1	860	0.99768
Total	862	1.00000

N Missing 2276
2 Levels

Vehicles A/C



Frequencies

Level	Count	Prob
0	7	0.00626
1	1111	0.99374
Total	1118	1.00000

N Missing 2020
2 Levels

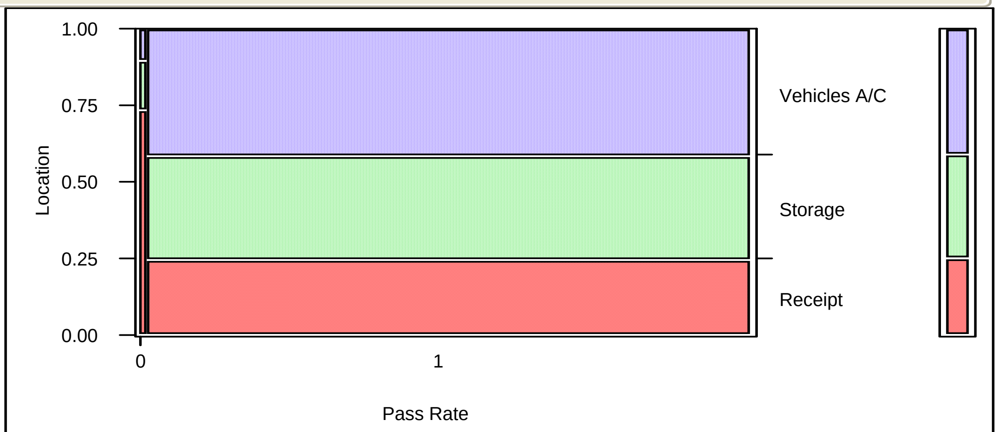
Appendix B. Contingency Tables and Chi-square Test Results (Phase 2)

Cannon AFB Results

There are six "cells" in this 2 X 3 matrix below in the "Contingency Table." The "Count" is the cell frequency (number of JP-8 samples in each cell), Total % is the percent of cells counts to the grand total *N*, Col % is the percent of each cell count to its column total, and the Row % is the percent of each cell count to its row total.

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Location

Pass Rate: Count / Total % / Col % / Row %	Receipt	Storage	Vehicles A/C	
0	14 0.86 3.39 73.68	3 0.18 0.55 15.79	2 0.12 0.30 10.53	19 1.17
1	399 24.57 96.61 24.86	543 33.44 99.45 33.83	663 40.83 99.70 41.31	1605 98.83
	413 25.43	546 33.62	665 40.95	1624

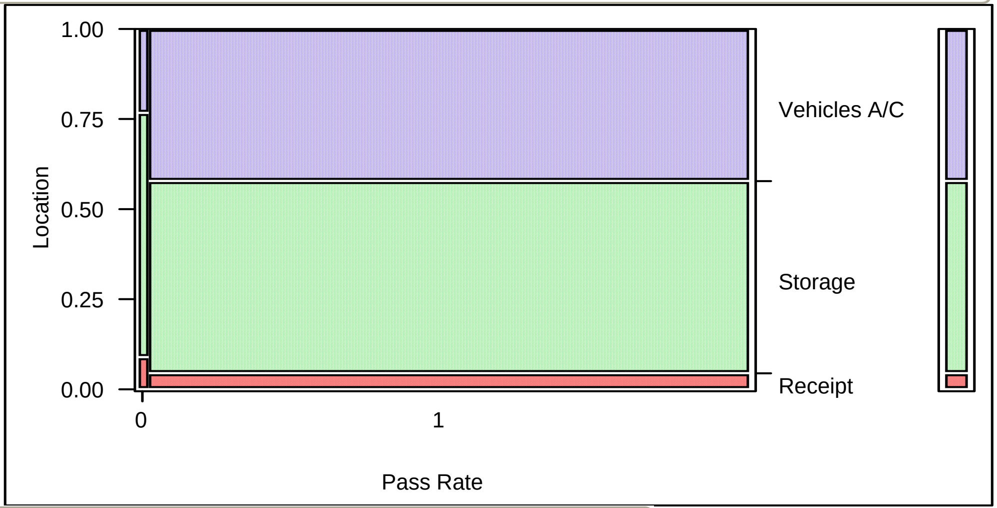
Tests

Source	DF	-LogLike	RSquare (U)
Model	2	10.0489	0.0057
Error	1620	1744.3385	
C. Total	1622	1754.3874	
N	1624		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	20.098	<.0001
Pearson	23.765	<.0001

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count / Total % / Col % / Row %	Location: Receipt	Storage	Vehicles A/C	
	0	4 0.15 3.17 9.30	29 1.07 2.00 67.44	10 0.37 0.88 23.26	43 1.59
	1	122 4.50 96.83 4.57	1424 52.55 98.00 53.39	1121 41.37 99.12 42.03	2667 98.41
		126 4.65	1453 53.62	1131 41.73	2710

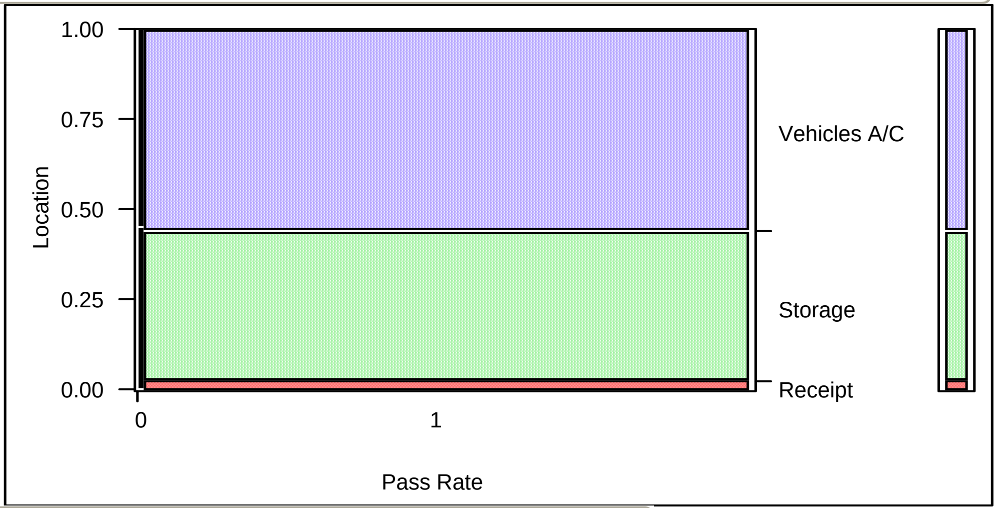
Tests

Source	DF	-LogLike	RSquare (U)
Model	2	3.6363	0.0016
Error	2706	2276.9866	
C. Total	2708	2280.6229	
N	2710		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	7.273	0.0264
Pearson	7.167	0.0278

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count / Total % / Col % / Row %	Location: Receipt	Storage	Vehicles A/C	
	0	0 0.00 0.00 0.00	5 0.34 0.81 45.45	6 0.41 0.73 54.55	11 0.75
	1	36 2.45 100.00 2.47	610 41.52 99.19 41.84	812 55.28 99.27 55.69	1458 99.25
		36 2.45	615 41.87	818 55.68	1469

Tests

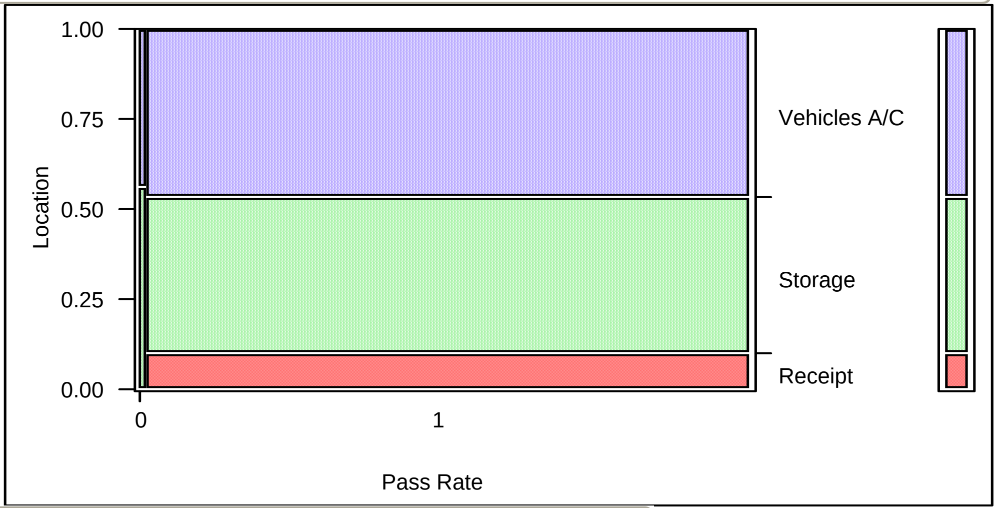
Source	DF	-LogLike	RSquare (U)
Model	2	0.2885	0.0003
Error	1465	1147.6371	
C. Total	1467	1147.9255	
N	1469		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.577	0.7494
Pearson	0.308	0.8571

Warning: 20% of cells have expected count less than 5, ChiSquare suspect

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count / Total % / Col % / Row %	Location: Receipt	Storage	Vehicles A/C	
	0	0 0.00 0.00 0.00	13 0.66 1.52 56.52	10 0.51 1.10 43.48	23 1.17
	1	201 10.23 100.00 10.36	842 42.87 98.48 43.38	898 45.72 98.90 46.26	1941 98.83
		201 10.23	855 43.53	908 46.23	1964

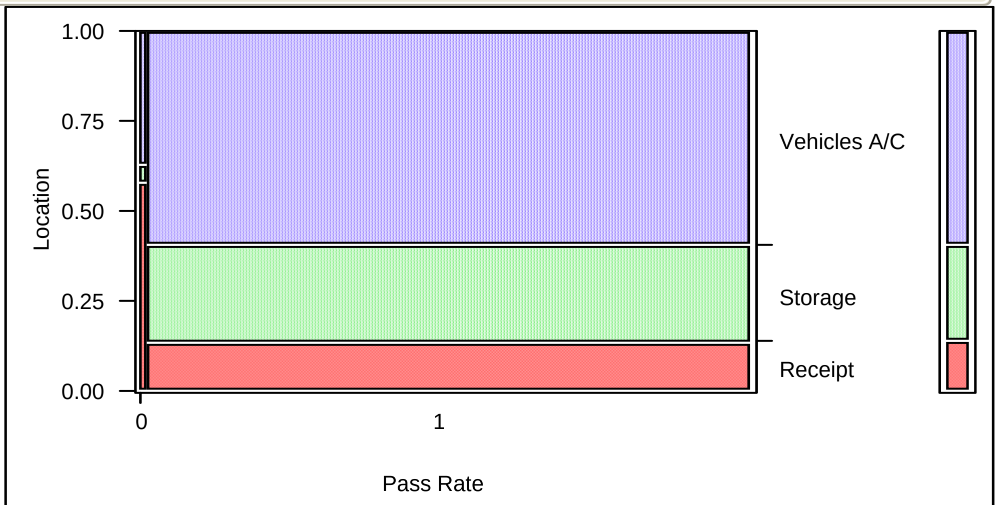
Tests

Source	DF	-LogLike	RSquare (U)
Model	2	2.7994	0.0015
Error	1960	1866.9330	
C. Total	1962	1869.7325	
N	1964		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	5.599	0.0608
Pearson	3.322	0.1900

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count / Total % / Col % / Row %	Receipt	Storage	Vehicles A/C	
	0	11 0.66 4.72 57.89	1 0.06 0.22 5.26	7 0.42 0.71 36.84	19 1.13
	1	222 13.25 95.28 13.40	454 27.09 99.78 27.40	981 58.53 99.29 59.20	1657 98.87
		233 13.90	455 27.15	988 58.95	1676

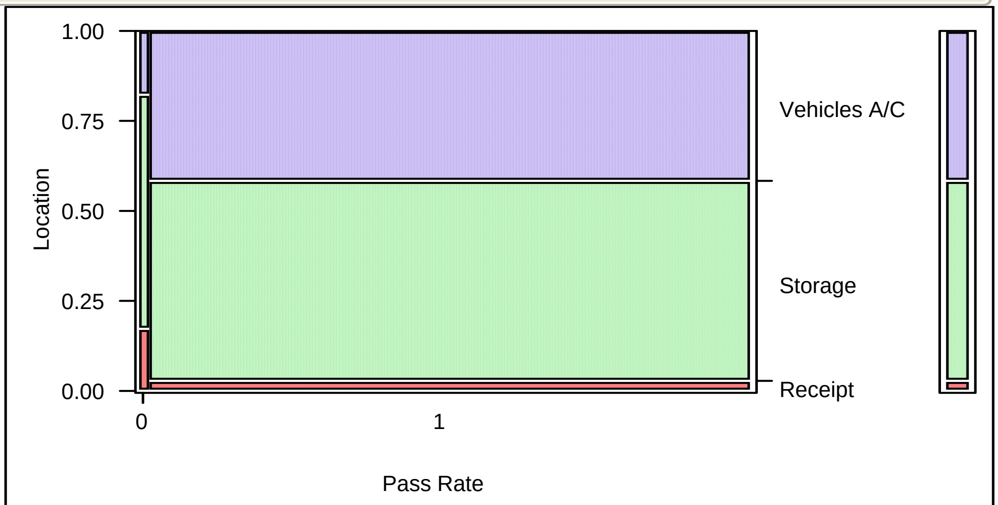
Tests

Source	DF	-LogLike	RSquare (U)
Model	2	10.9432	0.0069
Error	1672	1564.1960	
C. Total	1674	1575.1392	
N	1676		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	21.886	<.0001
Pearson	31.737	<.0001

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Location; rows: Pass Rate

Count Total % Col % Row %	Receipt	Storage	Vehicles A/C	
0	4 0.22 6.90 17.39	15 0.83 1.50 65.22	4 0.22 0.54 17.39	23 1.28
1	54 3.00 93.10 3.04	985 54.72 98.50 55.43	738 41.00 99.46 41.53	1777 98.72
	58 3.22	1000 55.56	742 41.22	1800

Tests

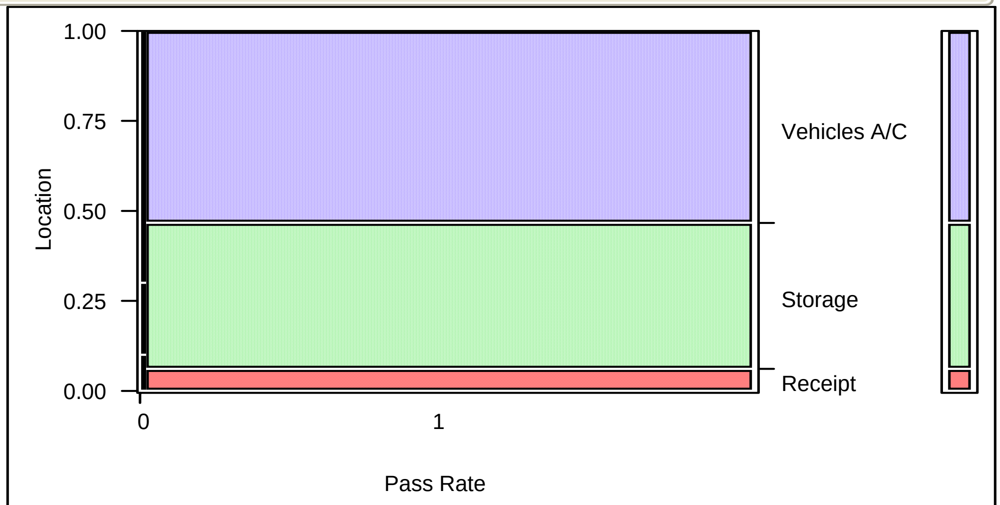
Source	DF	-LogLike	RSquare (U)
Model	2	5.8142	0.0040
Error	1796	1438.7632	
C. Total	1798	1444.5774	
N	1800		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	11.628	0.0030
Pearson	18.117	0.0001

Osan AB Results

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Location (columns) by Pass Rate (rows)

Count Total % Col % Row %	Receipt	Storage	Vehicles A/C	
0	1 0.05 0.76 10.00	2 0.09 0.23 20.00	7 0.33 0.63 70.00	10 0.47
1	131 6.20 99.24 6.23	860 40.72 99.77 40.91	1111 52.60 99.37 52.85	2102 99.53
	132 6.25	862 40.81	1118 52.94	2112

Tests

Source	DF	-LogLike	RSquare (U)
Model	2	1.0037	0.0005
Error	2108	1848.5998	
C. Total	2110	1849.6035	
N	2112		

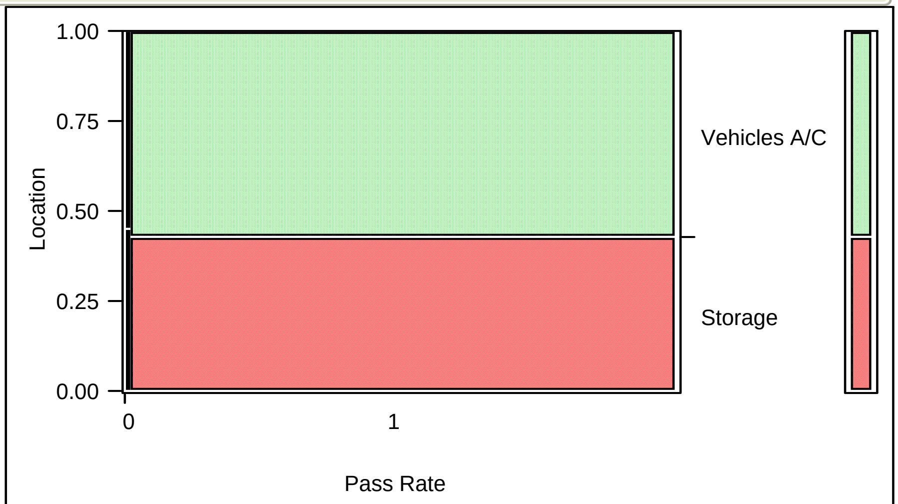
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	2.007	0.3665
Pearson	1.845	0.3975

Warning: 20% of cells have expected count less than 5, ChiSquare suspect

Misawa AB Results from Storage and Vehicles/ Aircraft Only

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Location

Pass Rate

Count Total % Col % Row %	Storage	Vehicles A/C	
0	5 0.35 0.81 45.45	6 0.42 0.73 54.55	11 0.77
1	610 42.57 99.19 42.90	812 56.66 99.27 57.10	1422 99.23
	615 42.92	818 57.08	1433

Tests

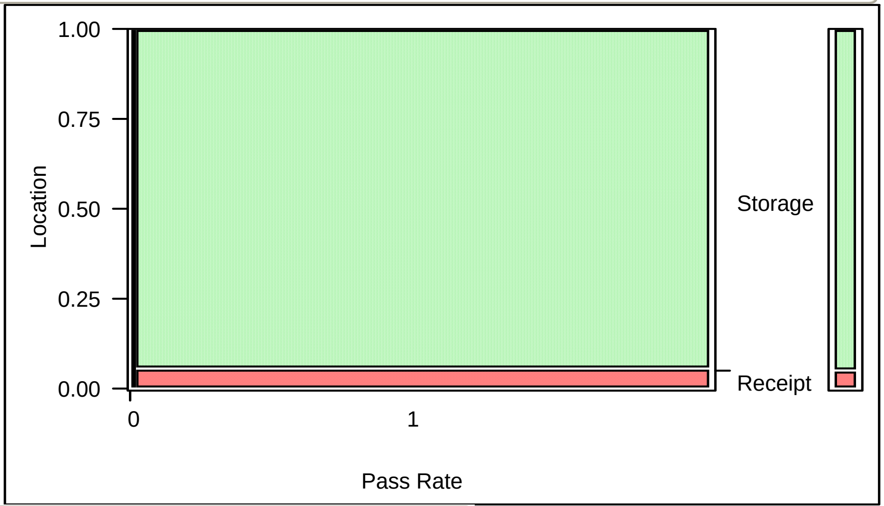
Source	DF	-LogLike	RSquare (U)
Model	1	0.01450	0.0000
Error	1431	978.83835	
C. Total	1432	978.85285	
N	1433		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.029	0.8648
Pearson	0.029	0.8645

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.6861	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	0.5475	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Vehicles A/C) is different across Pass Rate

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count Total % Col % Row %	Location: Receipt	Storage	
	0	0 0.00 0.00 0.00	5 0.77 0.81 100.00	5 0.77
	1	36 5.53 100.00 5.57	610 93.70 99.19 94.43	646 99.23
		36 5.53	615 94.47	651

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.28557	0.0021
Error	649	138.91983	
C. Total	650	139.20540	
N	651		

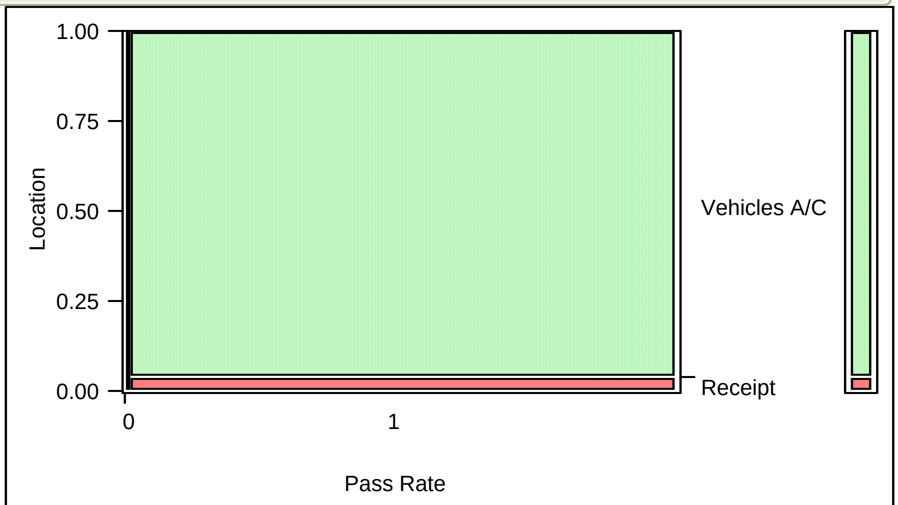
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.571	0.4498
Pearson	0.295	0.5871

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.7518	Prob(Location=Storage) is greater for Pass Rate=0 than 1
Right	1.0000	Prob(Location=Storage) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Storage) is different across Pass Rate

Misawa AB Results from Receipt and Vehicles/ Aircraft Only

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count Total % Col % Row %	Location: Receipt	Location: Vehicles A/C	
	0	0 0.00 0.00 0.00	6 0.70 0.73 100.00	6 0.70
	1	36 4.22 100.00 4.25	812 95.08 99.27 95.75	848 99.30
		36 4.22	818 95.78	854

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.25935	0.0017
Error	852	148.96182	
C. Total	853	149.22117	
N	854		

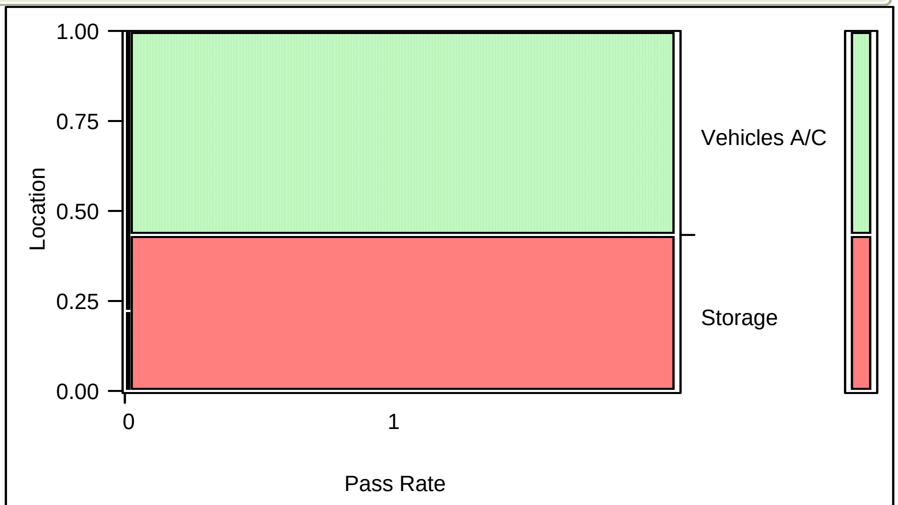
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.519	0.4714
Pearson	0.266	0.6061

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.7717	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	1.0000	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Vehicles A/C) is different across Pass Rate

Osan AB Results from Storage and Vehicles/ Aircraft Only

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count / Total % / Col % / Row %	Location: Storage	Vehicles A/C	
	0	2 0.10 0.23 22.22	7 0.35 0.63 77.78	9 0.45
	1	860 43.43 99.77 43.63	1111 56.11 99.37 56.37	1971 99.55
		862 43.54	1118 56.46	1980

Tests

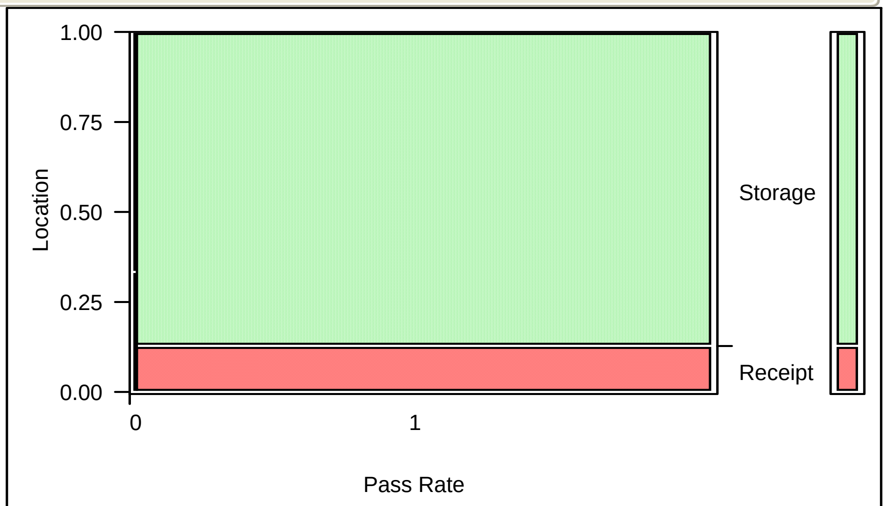
Source	DF	-LogLike	RSquare (U)
Model	1	0.9005	0.0007
Error	1978	1354.9350	
C. Total	1979	1355.8355	
N	1980		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	1.801	0.1796
Pearson	1.671	0.1962

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.1706	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	0.9540	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	0.3142	Prob(Location=Vehicles A/C) is different across Pass Rate

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Location

Pass Rate: Count Total % Col % Row %	Receipt	Storage	
0	1 0.10 0.76 33.33	2 0.20 0.23 66.67	3 0.30
1	131 13.18 99.24 13.22	860 86.52 99.77 86.78	991 99.70
	132 13.28	862 86.72	994

Tests

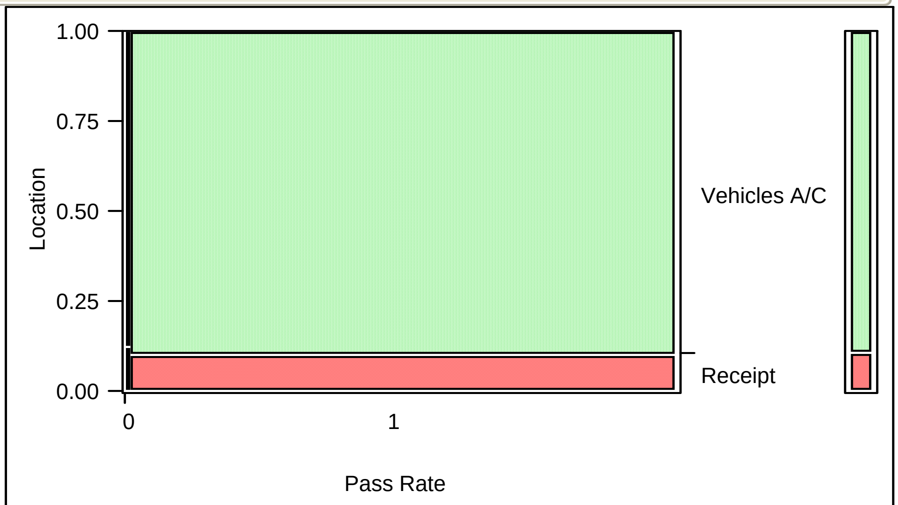
Source	DF	-LogLike	RSquare (U)
Model	1	0.39594	0.0010
Error	992	388.92294	
C. Total	993	389.31889	
N	994		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.792	0.3735
Pearson	1.051	0.3053

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.9520	Prob(Location=Storage) is greater for Pass Rate=0 than 1
Right	0.3481	Prob(Location=Storage) is greater for Pass Rate=1 than 0
2-Tail	0.3481	Prob(Location=Storage) is different across Pass Rate

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Location

Pass Rate	Count / Total % / Col % / Row %	Receipt	Vehicles A/C	
	0	1 0.08 0.76 12.50	7 0.56 0.63 87.50	8 0.64
	1	131 10.48 99.24 10.55	1111 88.88 99.37 89.45	1242 99.36
		132 10.56	1118 89.44	1250

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.01525	0.0000
Error	1248	421.50477	
C. Total	1249	421.52003	
N	1250		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.031	0.8613
Pearson	0.032	0.8578

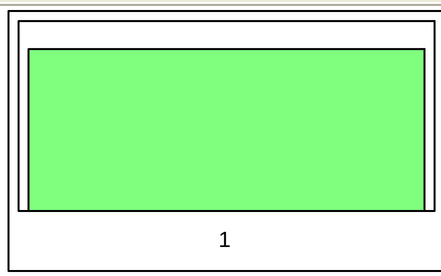
Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.7966	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	0.5916	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	0.5916	Prob(Location=Vehicles A/C) is different across Pass Rate

Appendix C. Distributions and Pass Rates (Phase 5)

Distributions and Pass Rates (Frequencies) for Correlation (45-Day) Samples from all Seven Locations

Distributions

Cannon 45-Day

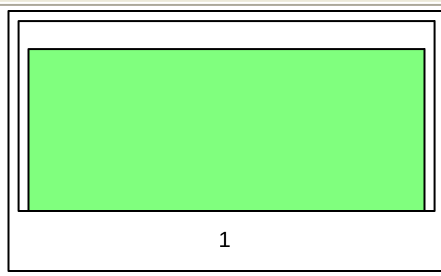


Frequencies

Level	Count	Prob
1	11	1.00000
Total	11	1.00000

N Missing 3
1 Levels

Kadena 45-Day

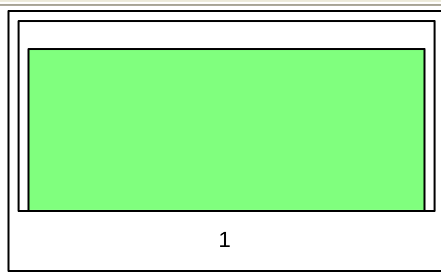


Frequencies

Level	Count	Prob
1	9	1.00000
Total	9	1.00000

N Missing 5
1 Levels

Misawa 45-Day

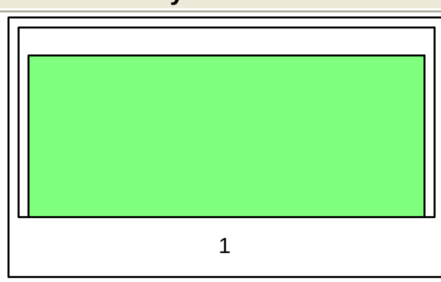


Frequencies

Level	Count	Prob
1	11	1.00000
Total	11	1.00000

N Missing 3
1 Levels

WPAFB 45-Day



Frequencies

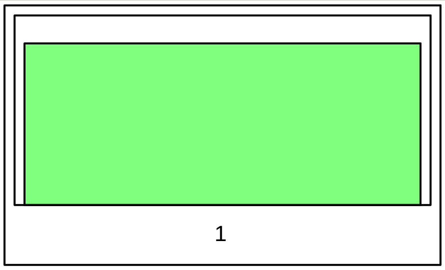
Level	Count	Prob
1	11	1.00000
Total	11	1.00000

N Missing 3
1 Levels

Distributions and Pass Rates (Frequencies) for Correlation (45-Day) Samples from all Seven Locations (Continued)

Distributions

Hill 45-Day

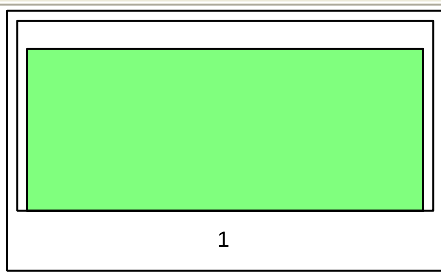


Frequencies

Level	Count	Prob
1	11	1.00000
Total	11	1.00000

N Missing 3
1 Levels

Mildenhall 45-Day

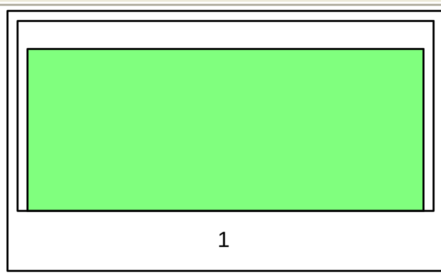


Frequencies

Level	Count	Prob
1	14	1.00000
Total	14	1.00000

N Missing 0
1 Levels

Osan 45-Day



Frequencies

Level	Count	Prob
1	11	1.00000
Total	11	1.00000

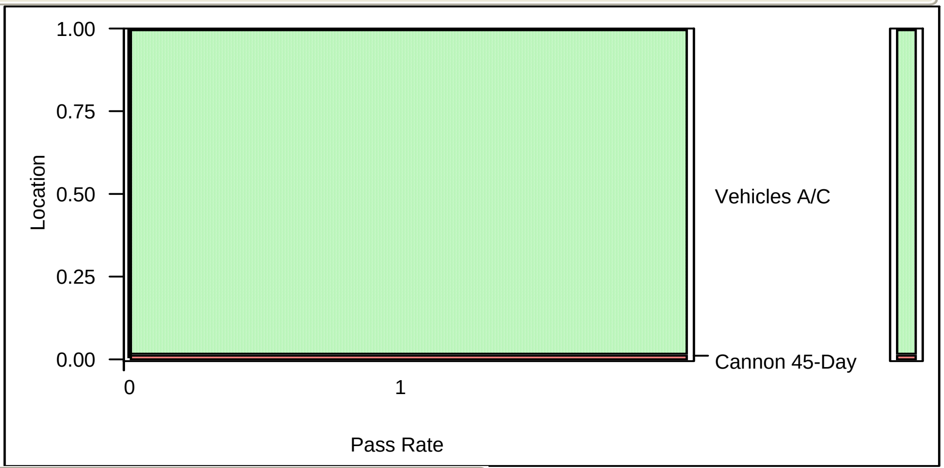
N Missing 3
1 Levels

Appendix D. Contingency Tables and Hypothesis Test Results (Phase 5) for Correlation (45-Day) vs. Vehicles/Aircraft Samples

Cannon AFB Results from Correlation vs. Vehicles/Aircraft Samples

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count Total % Col % Row %	Location: Cannon 45-Day	Location: Vehicles A/C	
	0	0 0.00 0.00 0.00	2 0.30 0.30 100.00	2 0.30
	1	11 1.63 100.00 1.63	663 98.08 99.70 98.37	674 99.70
		11 1.63	665 98.37	676

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.032861	0.0006
Error	674	56.178428	
C. Total	675	56.211289	
N	676		

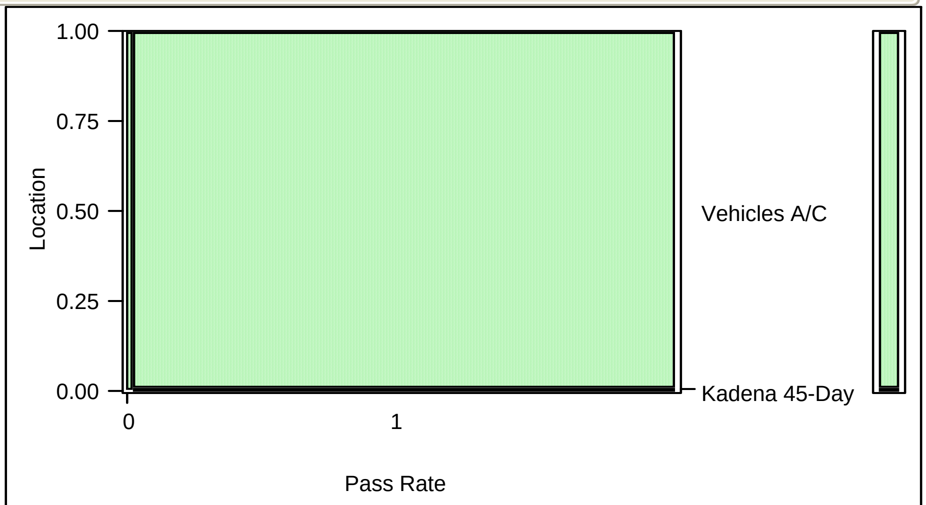
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.066	0.7977
Pearson	0.033	0.8555

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.9677	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	1.0000	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Vehicles A/C) is different across Pass Rate

Kadena AB Results from Correlation vs. Vehicles/Aircraft Samples

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count Total % Col % Row %	Location: Kadena 45-Day	Location: Vehicles A/C	
	0	0 0.00 0.00 0.00	10 0.88 0.88 100.00	10 0.88
	1	9 0.79 100.00 0.80	1121 98.33 99.12 99.20	1130 99.12
		9 0.79	1131 99.21	1140

Tests

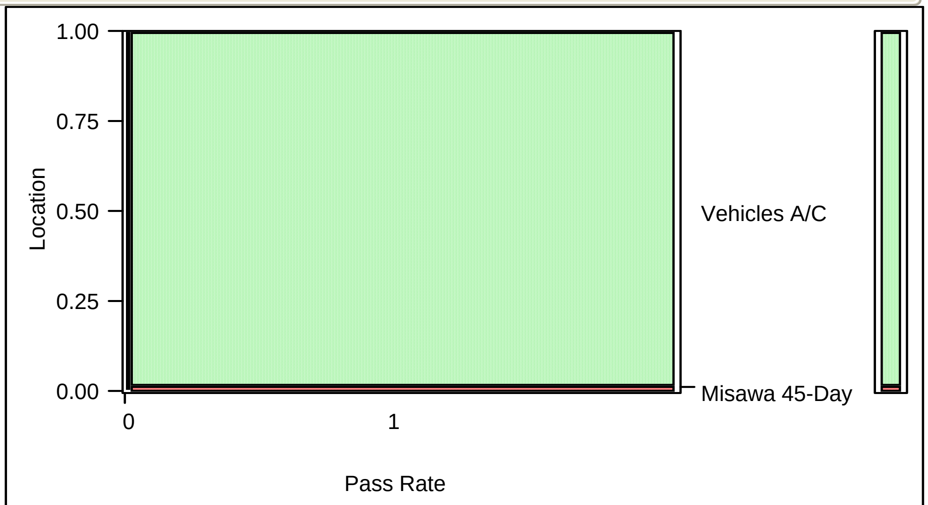
Source	DF	-LogLike	RSquare (U)
Model	1	0.079612	0.0015
Error	1138	52.458799	
C. Total	1139	52.538410	
N	1140		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.159	0.6899
Pearson	0.080	0.7769

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.9235	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	1.0000	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Vehicles A/C) is different across Pass Rate

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate / Location: Count, Total %, Col %, Row %	Misawa 45-Day	Vehicles A/C	
0	0 0.00 0.00 0.00	6 0.72 0.73 100.00	6 0.72
1	11 1.33 100.00 1.34	812 97.95 99.27 98.66	823 99.28
	11 1.33	818 98.67	829

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.080440	0.0014
Error	827	58.391829	
C. Total	828	58.472269	
N	829		

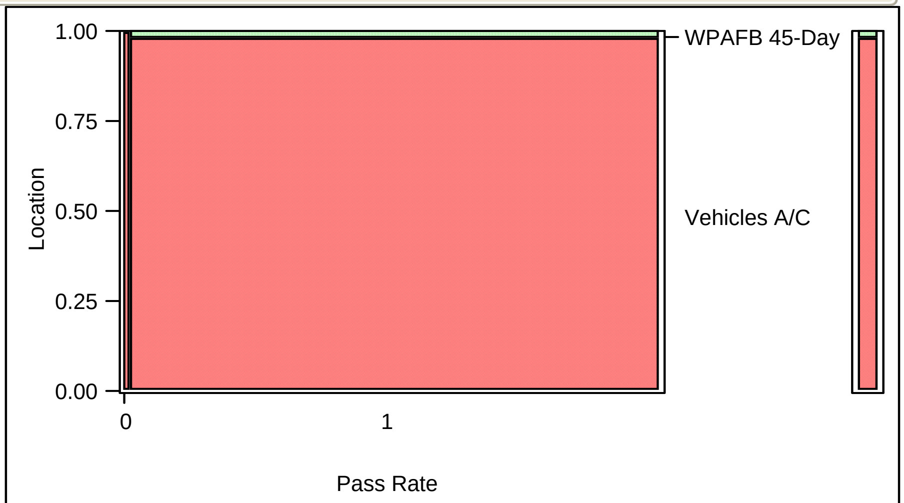
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.161	0.6883
Pearson	0.081	0.7756

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.9228	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	1.0000	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Vehicles A/C) is different across Pass Rate

WPAFB Results from Correlation vs. Vehicles/Aircraft Samples

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count Total % Col % Row %	Location: Vehicles A/C	Location: WPAFB 45-Day	
	0	10 1.09 1.10 100.00	0 0.00 0.00 0.00	10 1.09
	1	898 97.71 98.90 98.79	11 1.20 100.00 1.21	909 98.91
		908 98.80	11 1.20	919

Tests

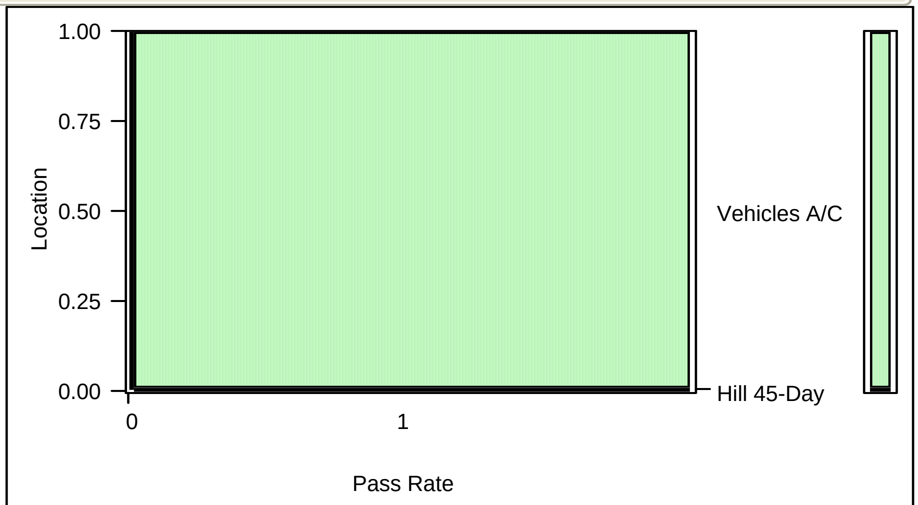
Source	DF	-LogLike	RSquare (U)
Model	1	0.121081	0.0020
Error	917	59.492121	
C. Total	918	59.613203	
N	919		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.242	0.6226
Pearson	0.122	0.7264

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	1.0000	Prob(Location=WPAFB 45-Day) is greater for Pass Rate=0 than 1
Right	0.8860	Prob(Location=WPAFB 45-Day) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=WPAFB 45-Day) is different across Pass Rate

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Location

Pass Rate	Count Total % Col % Row %	Hill 45-Da y	Vehicles A/C	
	0	0 0.00 0.00 0.00	7 0.70 0.71 100.00	7 0.70
	1	11 1.10 100.00 1.11	981 98.20 99.29 98.89	992 99.30
		11 1.10	988 98.90	999

Tests

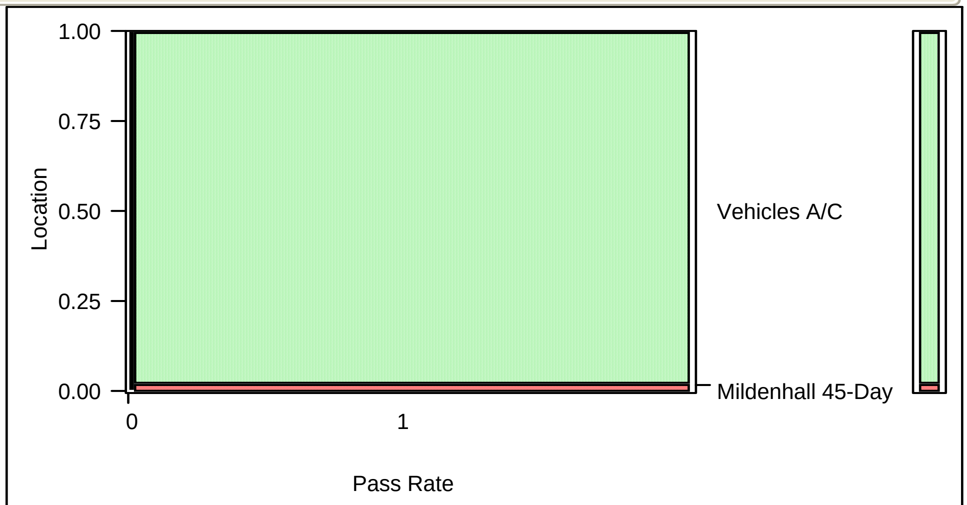
Source	DF	-LogLike	RSquare (U)
Model	1	0.077779	0.0013
Error	997	60.458892	
C. Total	998	60.536670	
N	999		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.156	0.6933
Pearson	0.078	0.7794

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.9252	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	1.0000	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Vehicles A/C) is different across Pass Rate

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Pass Rate	Count / Total % / Col % / Row %	Location: Mildenhall 45-Day	Location: Vehicles A/C	
	0	0 0.00 0.00 0.00	4 0.53 0.54 100.00	4 0.53
	1	14 1.85 100.00 1.86	738 97.62 99.46 98.14	752 99.47
		14 1.85	742 98.15	756

Tests

Source	DF	-LogLike	RSquare (U)
Model	1	0.074969	0.0011
Error	754	69.640370	
C. Total	755	69.715339	
N	756		

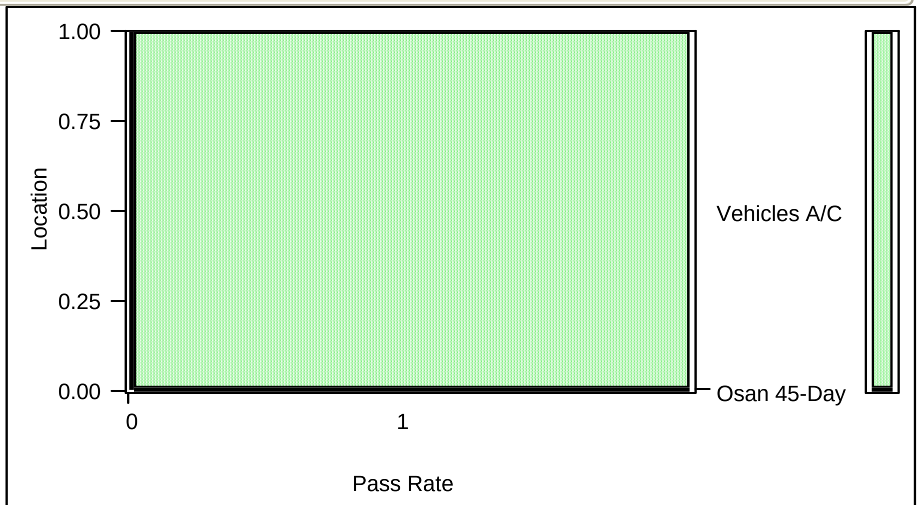
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.150	0.6986
Pearson	0.076	0.7830

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.9278	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	1.0000	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Vehicles A/C) is different across Pass Rate

Osan AB Results from Correlation vs. Vehicles/Aircraft Samples

Contingency Analysis of Location By Pass Rate

Mosaic Plot



Contingency Table

Location

Count Total % Col % Row %	Osan 45-Day	Vehicles A/C	
Pass Rate 0	0 0.00 0.00 0.00	7 0.62 0.63 100.00	7 0.62
Pass Rate 1	11 0.97 100.00 0.98	1111 98.41 99.37 99.02	1122 99.38
	11 0.97	1118 99.03	1129

Tests

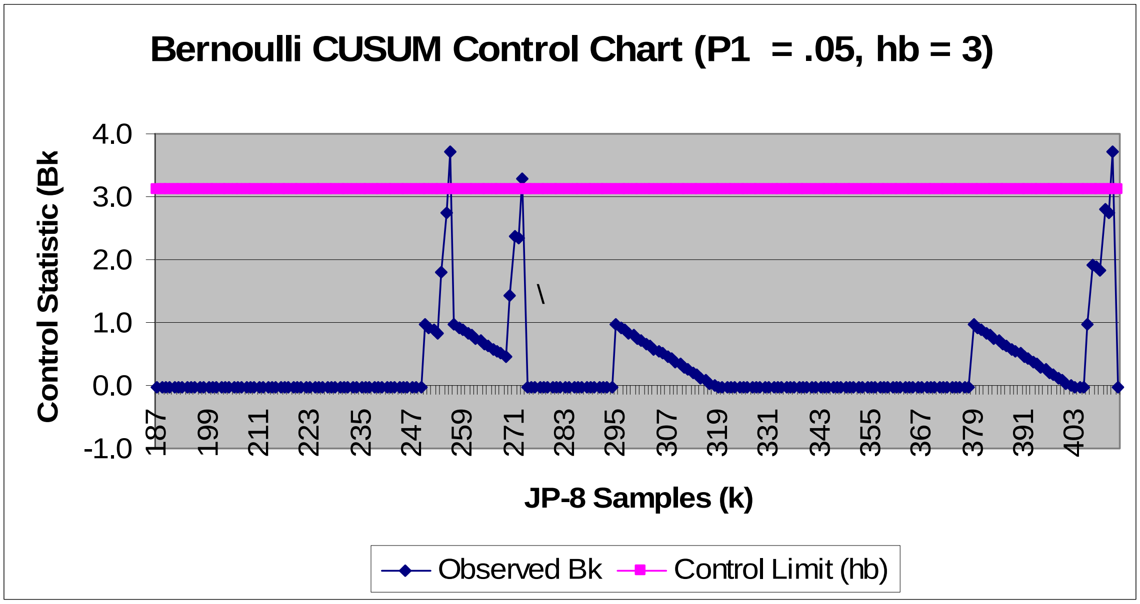
Source	DF	-LogLike	RSquare (U)
Model	1	0.068751	0.0011
Error	1127	61.820602	
C. Total	1128	61.889353	
N	1129		

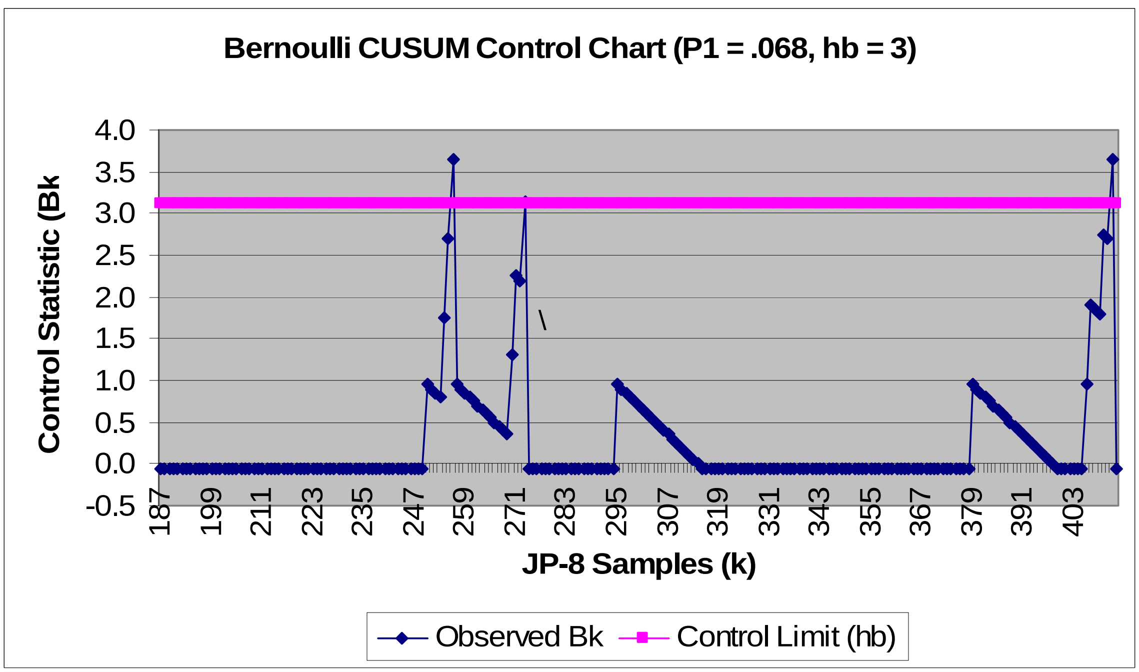
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.138	0.7108
Pearson	0.069	0.7924

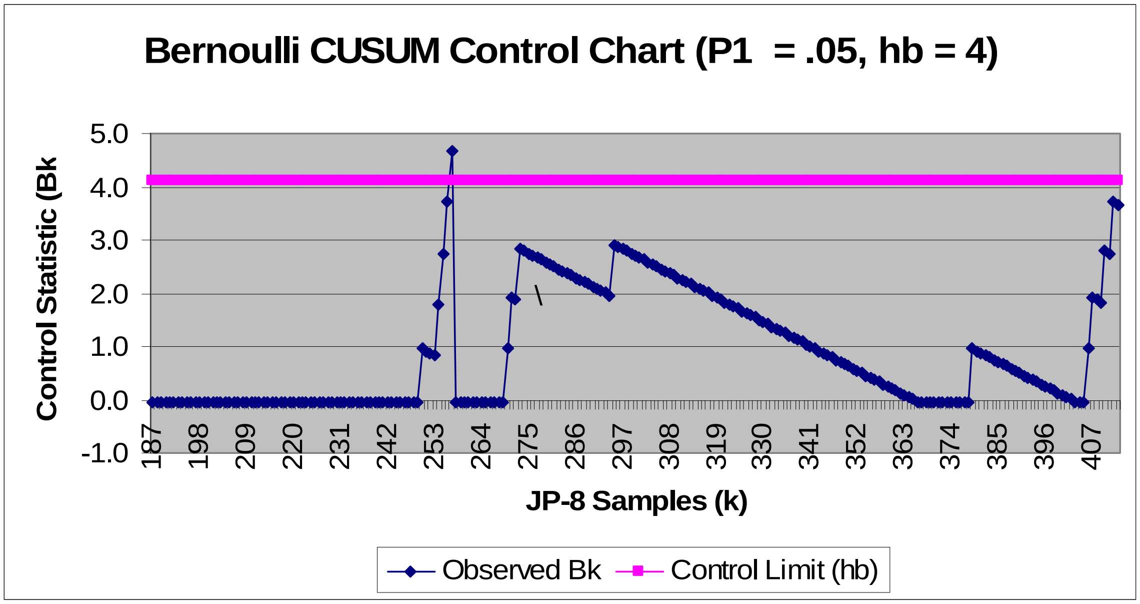
Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.9336	Prob(Location=Vehicles A/C) is greater for Pass Rate=0 than 1
Right	1.0000	Prob(Location=Vehicles A/C) is greater for Pass Rate=1 than 0
2-Tail	1.0000	Prob(Location=Vehicles A/C) is different across Pass Rate

Appendix E. Bernoulli CUSUM Control Charts (Phase 4)

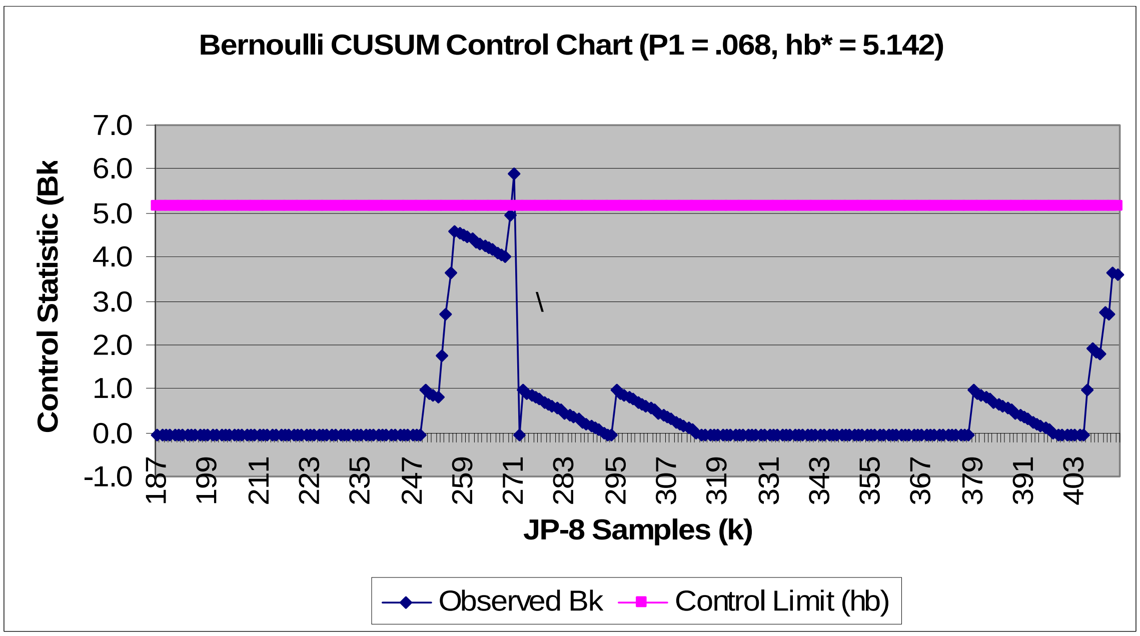
The different chart parameters are each labeled at the top, while the P_0 = .034 in-control value is the same .034 for every chart because this statistic is the pass rate for the Cannon AFB receipt location.



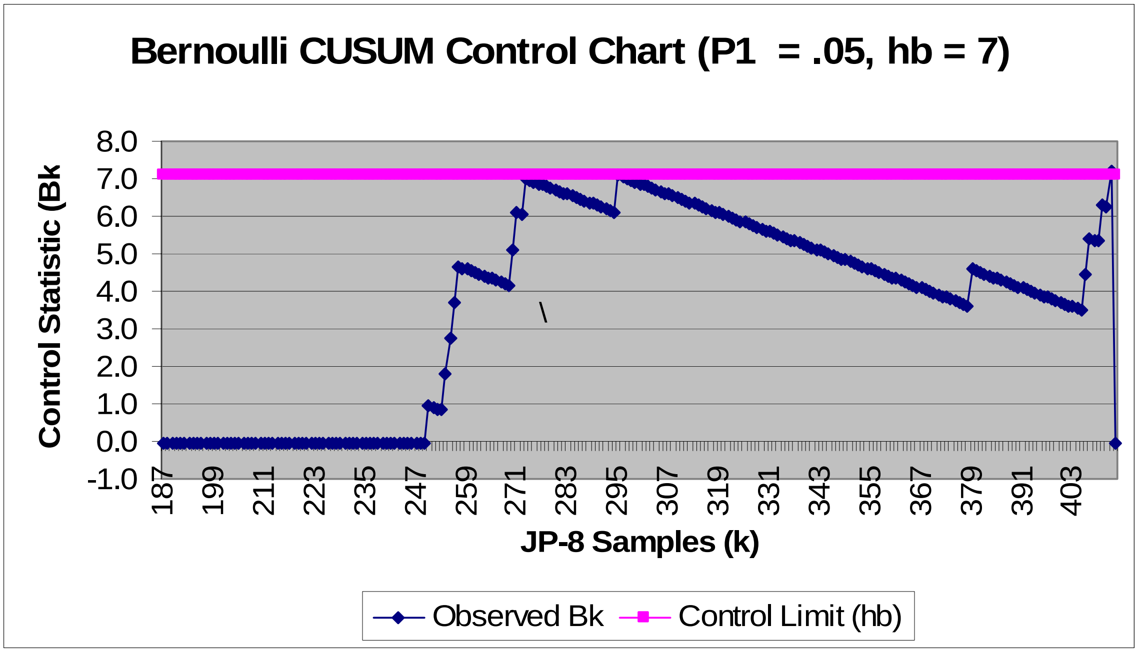


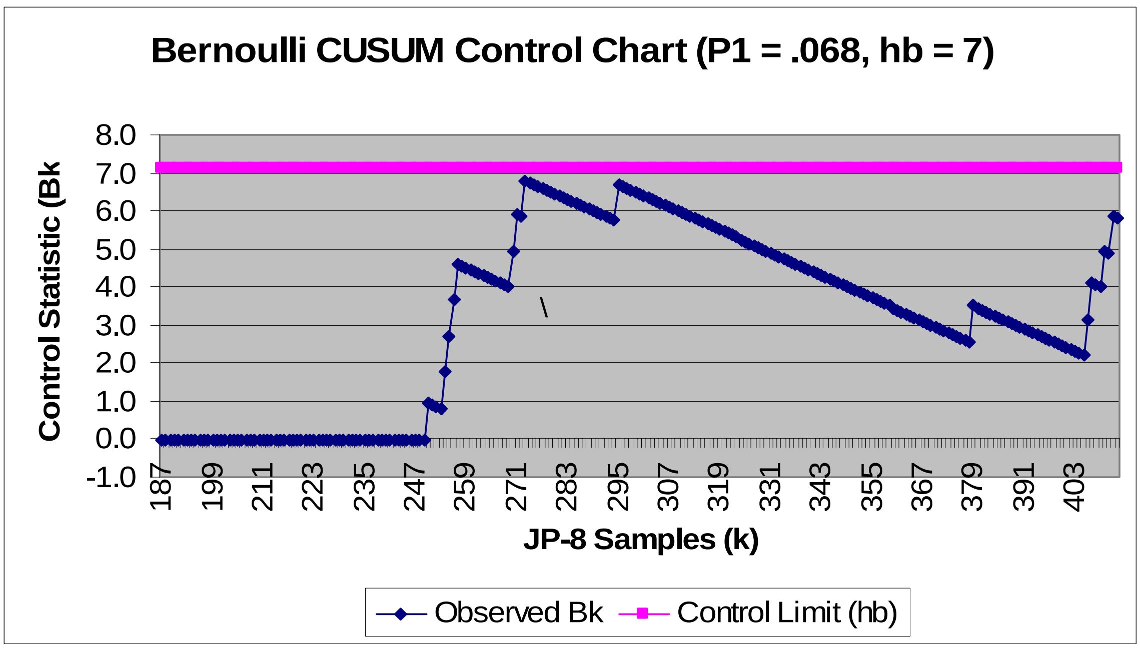


Bernoulli CUSUM Control Chart (P1 = .05, hb = 4)
Control Statistic (Bk
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
187
198
209
220
231
242
253
264
275
286
297
308
319
330
341
352
363
374
385
396
407
JP-8 Samples (k)
Observed Bk
Control Limit (hb)



Bernoulli CUSUM Control Chart (P1 = .068, hb* = 5.142)
Control Statistic (Bk
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
187
199
211
223
235
247
259
271
283
295
307
319
331
343
355
367
379
391
403
JP-8 Samples (k)
Observed Bk
Control Limit (hb)


Bernoulli CUSUM Control Chart (P1 = .05, hb = 7)
Control Statistic (Bk
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
187
199
211
223
235
247
259
271
283
295
307
319
331
343
355
367
379
391
403
JP-8 Samples (k)
Observed Bk
Control Limit (hb)


Bernoulli CUSUM Control Chart (P1 = .068, hb = 7)
Control Statistic (Bk
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
187
199
211
223
235
247
259
271
283
295
307
319
331
343
355
367
379
391
403
JP-8 Samples (k)
Observed Bk
Control Limit (hb)

Appendix F. Bernoulli CUSUM Control Chart Spreadsheet Sample

k	X_k	X_k - r	X_k - r (m)	B_k	h_b*	Action
1	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
2	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
3	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
4	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
5	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
6	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
7	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
8	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
9	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
10	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
11	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
12	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
13	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
14	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
15	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
16	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
17	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
18	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
19	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
20	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
21	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
22	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
23	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
24	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
25	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
26	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
27	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
28	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
29	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
30	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
31	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
32	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
33	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
34	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
35	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
36	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
37	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
38	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset

39	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
40	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
41	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
42	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
43	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
44	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
45	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
46	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
47	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
48	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
49	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
50	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
51	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
52	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
53	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
54	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
55	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
56	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
57	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
58	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
59	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
60	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
61	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
62	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
63	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
64	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
65	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
66	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
67	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
68	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
69	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
70	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
71	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
72	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
73	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
74	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
75	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
76	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
77	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
78	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
79	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
80	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset

81	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
82	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
83	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
84	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
85	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
86	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
87	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
88	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
89	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
90	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
91	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
92	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
93	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
94	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
95	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
96	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
97	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
98	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
99	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
100	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
101	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
102	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
103	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
104	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
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106	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
107	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
108	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
109	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
110	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
111	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
112	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
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122	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset

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157	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
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163	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
164	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset

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185	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
186	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
187	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
188	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
189	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
190	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
191	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
192	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
193	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
194	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
195	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
196	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
197	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
198	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
199	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
200	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
201	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
202	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
203	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
204	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
205	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
206	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset

207	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
208	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
209	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
210	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
211	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
212	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
213	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
214	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
215	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
216	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
217	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
218	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
219	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
220	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
221	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
222	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
223	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
224	0	-0.0417	- 1 / 24	-0.0417	4.0997	Reset
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252	0	-0.0417	- 1 / 24	0.8750	4.0997	*
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255	1	0.9583	23 / 24	2.7500	4.0997	*
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407	1	0.9583	23 / 24	1.9167	4.0997	*
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413	0	-0.0417	- 1 / 24	3.6667	4.0997	*

Bibliography

ASTM International Designation D 1655-04. *Standard Specification for Aviation Turbine Fuels*. 1 June 2004.

Boseman, Brian, J. 2d Lt. Fuels Management Flight Commander, 18 LRS. *Fuels Automated System (FAS).* Kadena AB, Okinawa. Electronic Database Transfer. 20 October 2004.

Chan, Wei-seng. 2003. *The Development of Novel Nanoporous Membrane for Bioanalytical Chemistry*. Web site: http://inac.purdue.edu/inac/suri2003/Chan_slides.pdf Accessed 19 January 2005.

CLA-VAL Refueling/De-fueling Pantograph. 2003. Web site: http://www.milleniumsystemsintl.com/Cla-Val/ClaVal_850GF_Refuel_Defuel_Specs.pdf Accessed 20 January 2005.

Colson, Jeremy. *Fuels Automated System (FAS).* Wright-Patterson AFB, OH. Electronic Database Transfer. 24 January 2005.

Defense Energy Support Center Product Technology Standardization Division (DESC-BP). 2003. *Petroleum Quality Information System (PQIS)*. CD-ROM version. Fort Belvoir, VA.

Duran, Gregory, M. SSgt. NCOIC, Base Fuels Laboratory, 100 LRS/LGSF. *Fuels Automated System (FAS).* Mildenhall AB, U.K.. Electronic Database Transfer. 20 October 2004.

Everitt, B.S.. 1977. *The Analysis of Contingency Tables*. Chapman and Hall, London.

Franklin, Kevin, Vice President of Operations for Wright Brothers Air at Dayton International Airport. Personal interview. 31 January 2005.

From The Editor: Defense Energy Support Center. Spring/Summer, vol. 2. 2004. From *Fuel Line.*

JMP 5.1.2 Statistical Discovery Software. 2004. Air Force Institute of Technology Campus-Wide License. Site ID: 03357024.

Ku, H.H. & Kullback, S. 1974. Log-linear Models in Contingency Table Analysis. *Amer. Statistician*, 28, 115-122.

Larsen, Carl, B. MSgt. Fuels Information Service Center Superintendent, 35 LRS/LGRFI. *Fuels Automated System (FAS).* Misawa AB, Japan. Electronic Database Transfer. 24 October 2004.

Leedy, Paul D. & Ormrod, Jeanne E. 2001. Practical Research: Planning and Design. (7th). Merrill Prentice Hall. Upper Saddle River, NJ.

McClave, James T., Benson, George P., & Sincich, Terry. 2001. *Statistics for Business and Economics*, 8th ed. Prentice Hall. Upper Saddle River, NJ.

Military Detail 83133E. *Detail Specification: Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8), NATO F-35, and JP-8+100*. 1 April 1999.

Military Standard 3004A. *Department of Defense Standard Practice: Quality Surveillance for Fuels, Lubricants, and Related Products*. 15 April 2004.

Montgomery, Douglas C. 2001. *Introduction to Statistical Quality Control*, 4th ed. John Wiley & Sons, Inc. New York, NY.

Montgomery, Douglas C. & Runger, George C. 1994. *Applied Statistics and Probability for Engineers*. John Wiley & Sons, Inc. New York, NY.

Newton, Todd, A. Capt. Fuels Flight Commander, 75 LRS/LGRF. *Fuels Automated System (FAS).* Hill AFB, UT. Electronic Database Transfer. 20 October 2004.

Pearson, K. 1904. *On the Theory of Contingency and Its Relation to Association and Normal Correlation*. Drapers' Co. Memoirs, Biometric Series No. 1, London.

Pittman, Andrew Maj. & Toner, RuthAnne. Program Management, AFPET, Wright-Patterson AFB, OH. Personal meeting. 25 May 2004.

Preliminary Technical Order 42B-1-1 (Draft Copy). *Quality Control of Fuel and Lubricants.* 2004.

Reynolds, Marion R., & Stoumbos, Zachary G. A CUSUM Chart for Monitoring a Proportion When Inspecting Continuously. *Journal of Quality Technology*. January 1999; 31(1), 87-108.

Smith, Donna, L. SSgt. NCOIC, Base Fuels Laboratory, 51 LRS/LGRFIC. *Fuels Automated System (FAS).* Osan AB, Korea. Electronic Database Transfer. 17 October 2004.

Sonnenberg, Robert, A. 1d Lt. Fuels Management Operations Officer, 27 LRS/LGRF. *Fuels Automated System (FAS).* Cannon AFB, NM. Electronic Database Transfer. 25 October 2004.

SW L6ONU21R1 003 I. *Logistics Readiness Officer Exportable Training Course: Fuels Block 1*. Logistics Readiness Officer Training Flight. Lackland AFB, TX. June 2002.

SW L6ONU21R1 003 II. *Logistics Readiness Officer Exportable Training Course: Fuels Block 2*. Logistics Readiness Officer Training Flight. Lackland AFB, TX. June 2002.

SW L6ONU21R1 003 III. *Logistics Readiness Officer Exportable Training Course: Fuels Block 3*. Logistics Readiness Officer Training Flight. Lackland AFB, TX. June 2002.

Toner, RuthAnne, Program Manager. 2004. *Fuels Automated System (FAS).* Wright-Patterson AFB, OH. Electronic Database Transfer. 2 June 2004.

Toner, RuthAnne, Program Manager. 2004. *Lab Manager*. Wright-Patterson AFB, OH. Electronic Database Transfer. 2 June 2004.

Toner, RuthAnne, Program Management, AFPET. Personal Meeting with Wright-Patterson Air Force Base Fuels Lab Personnel. 2 June 2004.

Williams, K. 1976. The Failure of Pearson's Goodness of Fit Statistic. *The Statistician*, 25, 49.

Vita

Captain Eric J. Heath graduated from Auburn High School in Auburn, New York in 1987. He enlisted into the U.S. Air Force a year later in 1988. His first assignment as an air transportation specialist was at RAF Mildenhall, U.K.. From there, then Airman First Class Heath moved to Dyess Air Force Base in Abilene, Texas in 1990 where he served in a mobile aerial port unit during Operation Desert Storm. After just a year tour in Texas, then Airman First Class Heath moved to Kadena Air Base in Okinawa, Japan in 1991. He served there as an air passenger service representative for two years before separating from the Air Force in 1993 as a Senior Airman.

In 1994, Captain Heath enrolled in Cayuga Community College in Auburn, New York. In 1995, Capt Heath graduated with an Associates degree in Liberal Arts; Humanities and Social Sciences. During this period, Capt Heath worked full-time with emotionally disturbed children in Sennett, New York. In 1996 and after taking one year away from school, Capt Heath enrolled into Cornell University. Two years later and fulfilling a life-long dream in 1998, Capt Heath graduated from Cornell, which was his proudest achievement up to that point. Capt Heath worked for two more years with children in Auburn, New York before going back into the Air Force.

Capt Heath entered Air Force Officer Training School in 2000 and was commissioned a Second Lieutenant in 2001. From there, he moved to Travis Air Force Base, California to work as an Air Transportation and Operations Officer. Capt Heath then moved to his current assignment at the Air Force Institute of Technology as a graduate student in Logistics Management, and then he will go to Langley Air Force Base in Virginia for three years to Headquarters Air Combat Command.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
01-03-2005	**Master's Thesis**	Apr 2004 - Mar 2005

4. TITLE AND SUBTITLE

AIR FORCE JP-8 FUEL DISTRIBUTION SYSTEM: A STATISTICAL ANALYSIS TO DETERMINE WHERE AND WHEN TO SAMPLE

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Heath, Eric, J., Captain, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Street, Building 642
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GLM/ENS/05-09

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Det 3 WR-ALC/AFT
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10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Air Force Petroleum Office at Wright-Patterson Air Force Base, Ohio collects JP-8 sampling data, but this data doesn't undergo analysis to determine the health of the base-level JP-8 fuel distribution system. Commanders possess no known confidence level when assessing base-level fuel health. Therefore, the objective of this research is to assess Air Force base-level fuel sampling data to determine the base-level sampling point that ensures a quality and healthy product at the aircraft. Also, this research seeks to identify how often correlation sampling should take place. Sample test pass rates are analyzed from three locations, receipt, storage, and vehicles/aircraft, at seven different worldwide bases. The research results indicate that the receipt location should be the focus of sampling efforts at base-level. Due to high pass rate variability, lower pass rates, low sampling requirements, low sample sizes, and a lack of complete control of the JP-8 that arrives on base, Air Force base-level fuels management should focus sampling efforts at receipt to ensure a healthy fuel flow process. Also, a Bernoulli CUSUM statistical process control (SPC) chart is introduced as a way of instantly identifying when a base-level JP-8 fuel flow process signals out-of-control. Lastly, a comparison of area and base lab sampling results show the current 45-day correlation sampling requirement ensures a healthy base-level JP-8 fuel system.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
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Prescribed by ANSI Std. Z39-18