FORECASTING FUELS SUPPORT EQUIPMENT REQUISITIONS

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Abstract

Within the past two years the Air Force has begun transitioning management of equipment from regionalized management at Command Equipment Management Offices (CEMOs) to centralized enterprise management offices. The fuels support equipment (FSE) inventory is a subcategory of Air Force equipment, the management of which has recently transferred from CEMOs to the Air Force Petroleum Agency (AFPA). Because FSE inventory was previously managed regionally, there is a gap in descriptive data for the enterprise FSE inventory. This study attempts to close this information gap through describing the current inventory position, defining historical FSE demand, and using this knowledge to forecast 2015's anticipated FSE demand using time and unit aggregation in conjunction with simple exponential smoothing. The results are useful to AFPA as the enterprise manager of FSE and to Air Force Item Managers as the acquisition managers for FSE. Lastly, this research is intended as a stepping stone into more detail study of the AF FSE inventory and supply chain.

Dedicated to

My Wife and Children for sacrificing so much to give me this opportunity!

Mom & Dad for giving me every opportunity possible!

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Justin P. D'Agostino

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I. Introduction

The Strategic Picture

Since 2010, public concern over government spending has leveraged political pressure on Congress and the President of the United States to seek, and adopt, changes in federal spending behavior. Since 2010, one of these changes in federal spending has been to reduce annual budgetary allocations across the Federal Government. The Department of Defense, one such agency of the Federal Government, has felt the results of these public pressures and subsequent changes in federal spending. In fact, in 2002 the defense budget was $345.1B. It doubled over the next eight years, reaching a peak of $691B in 2010 (Office of the Undersecretary of Defense/Chief Financial Officer, 2014). Since then, however, the defense budget has declined by nearly twenty percent. The 2015 Defense Budget is $575B, a seventeen percent reduction from the 2010 Defense Budget. Furthermore, in 2013, Secretary of Defense, Chuck Hagel, announced the Department of Defense will also reduce "major headquarters budgets by 20 percent" as part of an effort to cut costs within the Department of Defense (Department of Defense, 2014, p. 17). This decline in Defense Budget allocations is expected to continue over the next five years. Indeed, the Department of Defense anticipates the 2019 Fiscal Year Defense Budget to be $559B despite the need to build sustainment capabilities for new acquisitions such as the F-22 and F-35, and the growing age of mobility and bomber aircraft, such as the C-5, C-130, KC-10, KC-135, and B-52 (Office of the Undersecretary of Defense/Chief Financial Officer, 2014).

In response to political pressure, and a declining budget for the foreseeable future, the Department of Defense is moving strategically to maintain national security capabilities while at the same time operate with a smaller budget. In 2012, the President of the United States and the Secretary of Defense published Sustaining U.S. Global Leadership: Priorities for 21st Century Defense, where both jointly outline strategic priorities and objectives for the Department of Defense into the next decade (Department of Defense, 2012). One such priority is Rebalancing the Defense Institution (Department of Defense, 2014). This priority institutes several significant reforms such as improving buying power and financial management, implementing efficiencies, managing the Total Force, and Base Realignment and Closure. The first two reforms are of fundamental importance to this research. First, Better Buying Power directly affects Air Force acquisitions and logistics management through achieving affordable programs and controlling costs throughout the product life cycle. Second, implementing efficiencies within the department of defense, incorporates reducing headquarter budgets and reducing direct reporting units (i.e. consolidating these units within existing organizations). As will be described later, one way the Air Force is implementing this directive is by consolidating direct reporting units into existing organizations.

As part of its strategic response to a shrinking budget, the Department of Defense has developed and implemented an initiative called “Better Buying Power.” Two fundamental principles of this initiative is to "achieve greater efficiencies through affordability, [and] cost control" (Department of Defense, 2014, p. 1). This Better Buying Power initiative and these two principles attempt to rein-in Department of Defense acquisition spending. Successful institution of this initiative, under these two principles, will allow the Department of Defense, and the Air Force, to increase their value despite fiscal constraints.

The Operational Picture

The Air Force is one of the largest organizations in the United States. In fact, the Fiscal Year 2015 (FY2015) budget is $138B (USAF, 2014). Part of this budget constitutes appropriations for supporting specific mission activities, such as supply management, which procures and manages inventories of consumable and reparable spare parts required to keep all force structure elements mission ready (USAF, 2014, p. 28). These appropriations operate through the Air Force Working Capital Fund (AFWCF), which the FY2015 AFWCF is $23.7B (USAF, 2014). Part of establishing annual AFWCF is through historical procurements and through forecasted procurement needs. One aspect of the AFWCF is determining forecasted procurement requirements for service items, such as fuels support equipment (FSE).

As part of its effort to implement efficiencies in overhead, the Air Force has integrated direct reporting units and responsibilities into existing organizational structures. One such way the Air Force is implementing these efficiencies is through consolidation of functions such as enterprise management of supply functions. In 2014, responsibility of managing enterprise FSE was centralized at the Air Force Petroleum

Agency (AFPA) for the purposes of managing fuels requirements, equipment allowances, prioritization plans, and fueling equipment authorization validation (Program Action Direct 12-02, 2013). One of AFPA's new responsibilities is to manage the enterprise inventory of FSE. Management, in this context, is very specific. AFPA manages FSE to ensure the operational Air Force (i.e. Air Force bases) have on-hand the authorized equipment needed to support Air Force missions. AFPA is also responsible for meeting strategic goals and priorities, such as spending every dollar to its maximum utilization value as possible.

The AFPA, in response to these new responsibilities, is searching for techniques to better manage FSE inventory. Specifically, AFPA is looking at the expected useful life of inventory items to make decisions on whether to replace individual items or extend their life, thereby delaying new requisitions. Data enabling this decision-making is unavailable though. One reason for this lack of data is because service items, such as FSE, have a low-frequency, highly erratic demand, which feeds into the lack of data needed (Fogarty, Blackstone, & Hoffmann, 1991).

Problem Statement

Which forecasting method is most appropriate to forecast fuels support equipment requisitions?

Investigative Questions

To determine if the aggregated demand of FSE can be used in lieu of the expected useful life of inventory, several questions must be answered.

Investigative Question 1. Can FSE requisitions be described using a theoretical probability distribution?

Investigative Question 2. What type of demand does FSE requisitions exhibit and which forecasting method is most appropriate given this demand type?

Investigative Question 3. Using the identified forecasting method, what are next year's forecasted FSE requisitions?

Investigative Question 4. What are the associated costs with next year's forecasted FSE requisitions?

Methodology

To answer the above investigative questions this research will employ statistical analysis of FSE historical demand to describe FSE demand, followed by employing simple exponential smoothing techniques to forecast next year's anticipated demand and associated costs.

Motivation

If FSE demand and associated requisition costs can be forecasted and successfully applied to improve FSE inventory performance, then AFPA gains a technique it can employ to better meet its responsibility as manager of enterprise FSE inventory. This improved management has secondary effects because improved inventory performance means operational units have more authorized FSE on-hand to support Air Force missions.

II. Literature Review

Chapter Overview

The purpose of this literature review is to develop relevant background information to build context around this study. In an effort to do so, this chapter first summarizes current Air Force supply management which directly impacts the FSE inventory system. This background provides the institutional environment in which the FSE inventory exists in. Second, a theoretical background on inventory management is reviewed to provide the reader with traditional inventory concepts by which to compare the FSE inventory system. Lastly, this chapter presents important findings from previous demand forecasting research, providing a precedent for this research in areas where it deviates from common forecasting methods.

Air Force Impetus

In 2013, the United States Air Force published Program Action Directive 12-02, Implementation of the Secretary of the United States Air Force and Air Force Chief of Staff Direction to Implement the Air Force Installation Support Centralization (ISC) Vehicle and Fuels Management Initiative, hereafter referred to as HAF PAD 12-02. As it relates to this research, HAF PAD 12-02 transfers major command (MAJCOM) management of fuels management to AFPA. The objective of transferring fuels management from MAJCOMs to AFPA is "to achieve rapid decision-making and enable the most cost effective use of Air Force resources while increasing combat capability" (Program Action Direct 12-02, 2013, p. 2). With respect to FSE, under the ISC construct AFPA is responsible for coordinating all equipment, refueling vehicles, and FSE authorization requirements as well as to develop and oversee FSE replacement programs, such as items reaching or extended past their life cycle expectancy (Program Action Direct 12-02, 2013). Additionally, AFPA provides technical and product quality guidance along with management of fuels requirements, equipment allowances, prioritization plans, and fueling equipment authorization validation (Program Action Direct 12-02, 2013).

AFPA has taken on the responsibility of coordinating FSE authorization requirements and replacement programs. Currently, this enterprise management is in its infancy. As such, much research is needed to identify best management practices, performance metrics, and inventory controls. Within the Air Force, however, enterprise management of items is not new. In fact, enterprise management of aircraft spare parts has been practiced for well over a decade.

Air Force Policy Directive 23-1, *Materiel Management*.

The Air Force conducts materiel management under an acquisition-to-disposition paradigm: from the time an asset enters to the time an asset exits the Air Force inventory system. Air Force Policy Direct 23-1, Materiel Management, outlines direction to conduct activities within this paradigm: ordering, receiving, storing, issuing, demilitarization and disposal. As such, the Air Force is required to determine requirements and stock sufficient supplies and equipment to meet global operational needs. Additionally, the Air Force must "establish provisioning and replenishment objectives that include costs, control of surpluses, and minimizing impact on the environment while optimizing availability of materiel when and where needed" (AF/A4/7, 2011, p. 2)

Air Force Pamphlet 23-221, *Fuels Logistics Planning.*

One of the key areas AFPA supports are Combatant Commanders (CCDRs). CCDRs are responsible for arranging the movement of fuel and related products, to include FSE. Coordination with the Joint Petroleum Office (JPO), and Sub-Area Petroleum Offices (SAPOs) is critical (AF/A4L, 2013). FSE is defined as "fuels and cryogenic related support equipment required to support/sustain base operations. This includes Fuels Operational Readiness Capability Equipment (FORCE), Legacy Fuels Management Support Equipment (FMSE), and support assets such as cryogenics, bladders, lab, etc." (AF/A4L, 2013, p. 32). AFPA is also responsible for keeping abreast of technology advances in FSE for the FSE Working Group. Additionally, AFPA is responsible for total asset accountability in the Air Force Equipment Management System (AFEMS).

Air Force Instruction 23-201, *Fuels Management*.

AFPA has several responsibilities related to FSE. The Mission Support Directorate Infrastructure Division is to provide subject matter expert (SME) assistance and technical review during FSE and vehicle contract source selection (AF/A4L, 2014). AFPA coordinates FSE requirements with the War Reserve Materiel Global Manager (WRM GM), the Major Command Equipment Office (CEMO), and item managers as applicable. Additionally, AFPA assists Fuel Management Teams (FMTs) with validating FSE requirements utilizing the FSE calculator for peacetime authorizations and with the requisition process. Related to this responsibility, AFPA must work with item managers (IMs) to develop and oversee fuels equipment lifecycle replacement programs (AF/A4L, 2014). Lastly, the Technical Assistance Division provides technical expertise for FSE.

Inventory Management

The academic field of inventory management began in the 1920s, as noted by Harvey Wagner (2002, p. 217), "the lot size (square root EOQ) model is the most notable example", but did not begin to make serious headway until the 1950s when probabilistic inventory models, statistical processes, statistical decision theory, microeconomics, multi-period optimization and feedback systems were explored, however, the ability to empirically test these models was limited. Even though the models were limited, the research of the 1950s identified specific principles of inventory. Such principles include enhancing inventory management through replenishment rules, the usefulness of discrete and continuous time modeling, the interdependence between reorder points and reorder quantities, identification of certain demand distributions for describing inventory, and optimality as the goal of inventory management (Wagner, 2002).

To come from the 1950s is the dynamic lot-size model which defines several criteria needed when solving an inventory management problem. For instance, the planning horizon is of critical importance as it defines the scope of the problem.

Additionally, treating inventory and lead time as a queuing system where the demand distribution over the lead time is important when solving for a specified customer service level (Wagner, 2002). These factors are important because it allows a manager to refill what has been demanded, which allows for a pull-inventory system.

By the 1960s, inventory management problems were being solved using linear programs. The insights gained from these programs allow one to address multi-item, multi-location, and multi-period inventory problems in-light of specified constraints. This method, however, did not handle aggregated demand very well. According to Wagner (2002, p. 219), using aggregated demand distributions tend to lead to infeasible production schedules as well as periods with excess capacity." During this time, it was assumed that once accurate and timely historical data could be gathered, it would be a matter of developing and applying replenishment formulas using statistical methods (Wagner, 2002). With the creation of exponential smoothing, however, long time frame historical data was no longer needed. Indeed, if long time frame historical data is missing for calculating a statistical demand, then a short time frame suffices.

The Inventory Problem

The general concept behind the inventory problem is to determine what goods and in what quantities to stock in anticipation of future demand (Dvoretzky, Kiefer, & Wolfowitz, 1952). As defined by Dvoretzky et al. (1952), the inventory problem is framed in terms of economic loss. The goal of solving this problem is to minimize this economic loss, which can occur in two ways. First, by not having enough supply to meet demand or, second, by stocking items for which there is no demand. Dvoretzky et al. (1952), put forth that an optimum policy must strike a balance between overstocking and under stocking in order to minimize loss. To find this optimum balance, Dvoretzky et al. (1952) use four principal assumptions when solving the inventory problem. First, the authors assume the amounts demanded are chance variables with known distribution functions. That is, demand is random but follows a known distribution. Second, it is assumed the agency in charge of inventories can only order or not order goods. That is, their influence on the problem is strictly limited to ordering. Third, the ordering agency must place a single order for all commodities involved at every time point. That is, all needed quantities for each commodity is ordered only once per time-period. Lastly, it is assumed the initial stock at the beginning of the first interval is given and not within the control of the ordering agency, which ties back to the first assumption.

With these four assumptions in mind Dvoretzky et al. (1952), piecemeal a solution to the inventory problem. First, the authors look at a one-time interval where the initial stock starts, x. As this one-time interval elapses the initial stock is depleted by demand, D, which is uncertain but has a known distribution. The remaining stock, if there is any, is starting stock, y, for the next time interval. If, over the course of this time interval, demand is less than initial stock, then an economic loss is faced, W, because more inventory was purchased than sold. If, however, demand is less than initial stock, then there is an economic gain, -W. Therefore, at the end of the time interval the starting stock will be in one of two conditions. Starting stock will either be positive, meaning inventory was greater than demand, and there is an economic loss; or starting stock will be zero or negative, meaning demand equal to or greater than inventory, in which case there is an economic gain. Second, the authors solve the inventory problem for finitely many time intervals. In this special case, it is assumed that orders are filled simultaneously. That is, there is no lag-time between order and order fulfillment. Intuitively this assumption is known to be false, but this characteristic will be addressed later. The insight provided from this special case is that it is beneficial to order more than demanded from the current demand interval in preparation for the next demand interval. Third, the authors solve for an infinite number of time intervals. In this special case the authors find there are tradeoffs between ordering costs and demand losses. In essence there is an optimal point where one can minimize total loss between both. Fourth, the authors add complexity by solving for a lag in delivery of order while demand continues. Similar to the third case, there is a balance point between carrying costs and demand losses. Lastly, they solve for several commodities, consumers, and sources of supply.

As explained by Laderman and Littauer (1953), the inventory problem is important for all organizations because all inventories are at the cost of something else; just as the purchase of something else will be at the sacrifice of inventory. As a brief example, the purchase of an F-35 aircraft by the Air Force has an estimated per unit cost of $98M (Lockheed Martin Corporation, 2014). As mentioned earlier, the current FSE inventory is $53.2M. To purchase one F-35, the Air Force foregoes the opportunity to double its FSE inventory, if it wished to. This example is a bit exaggerated, but it illustrates the fundamental principle of the inventory problem: how much to buy in anticipation of future demand while minimizing losses.

Sergey Rumyantsev and Serguei Netessine explore how companies utilize classical inventory models from an enterprise level rather than a product level. Their purpose in this research was to determine if classical inventory models sync with traditional macroeconomics.

Definition

There are several types of inventory. There is production inventory, inventory that goes towards a product production, which consists of raw materials, work in progress, and finished goods. There is also functional inventory, such as consumables and service, repair, replacement, and spare items, commonly referred to as S&R (Muller, 2003). Service items within an organization are items, such as equipment, used for the production of goods and services and so constitute a separate class of inventory. Inventory management of S&R is the organizing, planning, directing, and execution of maintaining operationally appropriate inventory levels of all S&R items.

Purpose

Traditionally, inventory is viewed as money but in a different form. To have S&R inventory is to invest in the acquisition, maintenance, replacement, and disposal of items. Therefore, the purpose of inventory management is to "optimize" the use of financial resources. That is, to find the balance between adequately supporting operations without over allocating financial resources.

Characteristics

According to Fogarty, Blackstone, and Hoffman (1991), service, repair, replacement, and spare items are a separate class of inventory item for three reasons. First, S&R items typically have low and erratic demand. Second, the cost of a stockout is extremely high. Third, the customer is reliant upon the item's producer for production of the item. That is, a customer will not stand up operations to build required S&R items, but instead purchase them from a producer.

Inventory Problem Classifications

Richard Tersine (1982) uses a classification system to break-down inventory problems. There are five categories, each with its own subcategories. Table 1lists these categories. Under this classification scheme, FSE is considered repeat order items with external supply sources, under variable demand, with variable lead times, under a perpetually reviewed inventory system.

Repetitiveness:	Single Order	Repeat Order
Supply Source:	Outside Supply	Inside Supply
Knowledge of Future Demand:	Constant Demand	Variable Demand
Knowledge of Lead Time:	Constant Lead Time	Variable Lead Time
Inventory System:	Perpetual Material Requirements Planning	Period

Table 1 Categories of Inventory Problems

What is FSE?

FSE is one category of Air Force service items. It is, however, specifically intended for use in ground-based aircraft refueling operations and support operations. Because FSE fits into the broader system of Air Force equipment inventory but is segregated in use it is also segregated in how it is managed. This isolation from the broader AF equipment inventory system enables it to be researched separately from other Air Force equipment items. To conduct this research a review of statistical and forecasting techniques is needed.

Probability Distributions of Demand

As will be seen later, the first investigative question asks if FSE demand can be described using a theoretical probability distribution. In essence, what this question is asking is if observed demand values follow a mathematically derived distribution function (a theoretical probability distribution). As will be shortly revealed, this is an important question answer before this research can move forward because in open systems, such as the FSE inventory system, external factors are able to influence the system. Therefore; if a theoretical probability distribution can be used to describe the system, it greatly reduces complexity and increases understanding.

In statistics, a probability distribution describes the likelihood of the value a random variable will. Random variables can take on two forms: discrete or continuous. Discrete random variables consist of whole, countable, units. A very common discrete random variable is the binomial random variable in which only two outcomes can occur: success or failure. FSE demand can be viewed in this manner, if desired. A simple way to do this is to ask, "Was there demand on this day?" to which there are only two possible outcomes, yes or no. This line of questioning, however, will only get a researcher so far. Instead, a better question to ask is, "how much demand was there on this day?" With this question more fidelity and understanding of demand for the FSE inventory system is gained. McClave et al. (2011, p. 178), define the probability distribution for discrete random variables (such as FSE demand) as "a graph, table, or formula that specifies the probability associated with each possible value the random variable can assume." For the purposes of this research, a discrete probability distribution specifies the probability associated with each possible value that FSE demand can assume. Some common discrete probability distributions are the binomial distribution, as previously stated, and the Poisson distribution, which are useful in describing rare events (McClave, Benson, & Sincich, 2011).

Continuous probability distributions specify the likelihood of a continuous random variable, such as monetary value, to assume a possible value. Common continuous probability distributions are the normal distribution, uniform distribution, and exponential distribution. Another continuous probability distribution that does not provide the detail as the ones just listed is the triangular distribution. This is a non-parametric distribution that is useful when the data does not fit a theoretical continuous probability distribution because it provides point estimates for mean and mode as well as the lowest assumed value and the highest assumed value. Lastly, regardless if the data analyzed fit a theoretical probability distribution or not, descriptive statistics are also useful for identifying patterns in a data set as well as to summarize estimation parameters of a data set (McClave, Benson, & Sincich, 2011).

It is not uncommon, however, for demand to exhibit a probability distribution that does not follow a theoretical probability distribution (Babiloni, Cardos, Albarracin, & Palmer, 2010). In these instances a common method for describing the data and its underlying probability distribution is to use re-sampling methods, such as bootstrapping and Monte Carlo. In these methods, samples are taken at random from the data set and the values annotated. Taking the same number of samples as in the sample data set gives each data point an equal opportunity. These methods allow greater confidence in the sample parameters. A third method is the use of quartiles. Another non-parametric distribution, quartiles use divide the number of observations in the sample data into four equal parts. Thus, the four increments each represent 25% of the data.

Intermittent Demand

It is assumed that intermittent demand appears randomly, but with many periods without demand. When demand does occur it tends to be for more than one unit (Babiloni, Cardos, Albarracin, & Palmer, 2010). Because of this intermittent demand inventory policies and forecasts tend to perform poorly. Therefore, Babiloni et al. (2010), set out to produce a methodology for categorizing demand patterns, to forecast intermittent demand, and inventory control methods for items with intermittent demand patterns. One method used to determine if demand is intermittent is via the demand shape. Babiloni et al. (2010) found the more positively skewed the distribution (i.e. the longer the right tail is) the more intermittent the demand is likely to be.

There are four demand categories for inter-demand intervals: erratic, lumpy, smooth, and intermittent (Babiloni, Cardos, Albarracin, & Palmer, 2010). These categories are based on inter-demand intervals and coefficients of variation. Erratic demand has high squared coefficient of variation of the demand size but lower inter-demand intervals.

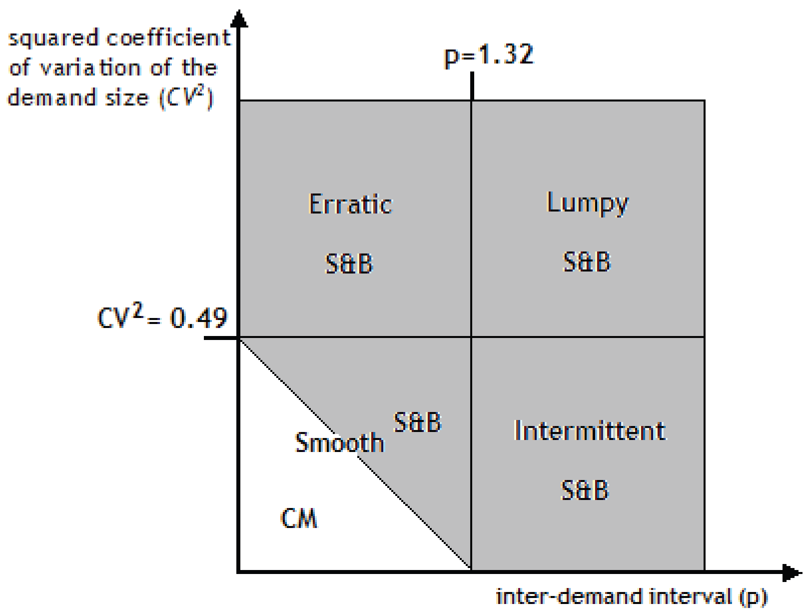


Figure 1. Categorization of demand pattern based on the accuracy of forecasting procedures (Babiloni, Cardos, Albarracin, & Palmer, 2010)

Figure 1Figure 1. Categorization of demand pattern based on the accuracy of forecasting procedures shows the four categories of intermittent demand, where squared coefficient of variance and the average inter-demand interval (p) are the criteria used to define these categories. The annotation CM indicates Croston's method, while S&B indicates Syntetos and Boylan's technique which uses Croston's method but with a correction for estimator bias. Both techniques will be discussed later. Coefficient of Variance is the ratio between standard deviation of the observed demand, σ, and the mean of the observed demand, μ. Typically, this ratio is expressed as follows

$$Coefficient\ of\ Variance\ (CV) = \frac{\sigma}{\mu} \quad (1)$$

Inter-demand interval (p) also the mean of the observed demand and is calculated as follows

$$Mean\ (\mu) = \frac{\sum_{i=1}^{n} x_i}{n} \quad (2)$$

$$Standard\ Deviation\ (\sigma) = \sqrt{\frac{\sum(x-\overline{x})^2}{n-1}} \quad (3)$$

Forecasting

Management of inventory has significant economic consequences for businesses and the Air Force is no different. For example, the Air Force currently has $53.2M of FSE in its inventory. A decision to reduce this by five percent would equal $2.66M in deferred costs that can be used elsewhere. In this example, though, the decision to reduce FSE should not be made arbitrarily, but instead in an informed manner with insight into how the FSE inventory system behaves. To gain insight to make informed decisions there are several tools an inventory manager and decision maker can use. One such tool is forecasting. Forecasting employs many different techniques all with the goal of making a prediction about a future state with a greater degree of confidence then what you currently have. Forecasting also relies heavily on, but is not dependent upon, historical records to make these predictions. This section will expand on what forecasting is and give a general overview of quantitative techniques. Additionally, specific techniques used in inventory management to forecast demand will be covered, specifically when intermittent demand is being forecasted.

There are two general forecasting methods: qualitative and quantitative (Bowerman, O'Connell, & Koehler, 2005). Qualitative forecasting methods utilize subject matter experts to make informed opinions on what to expect in the future; however, because of their subjectivity, these methods are highly variable and lack precision. Because of this, quantitative methods are preferred when feasible because they provide an expected mathematical outcome based on patterns observed in the historical data. Additionally, quantitative methods assign a value to the apparent random or unexplained observations of the historical data as well. This takes on the general form below from Chase (2013).

$$\textit{Forecast} = \textit{Pattern(s)} + \textit{Randomness} \tag{4}$$

Randomness is also known as unexplained variance or irregular fluctuations. Patterns, or explained variance, can consist of trends, seasonality, or known cycles. Trends are the general increase or decrease of data over time. For example, consider the hypothetical data in Figure 2.

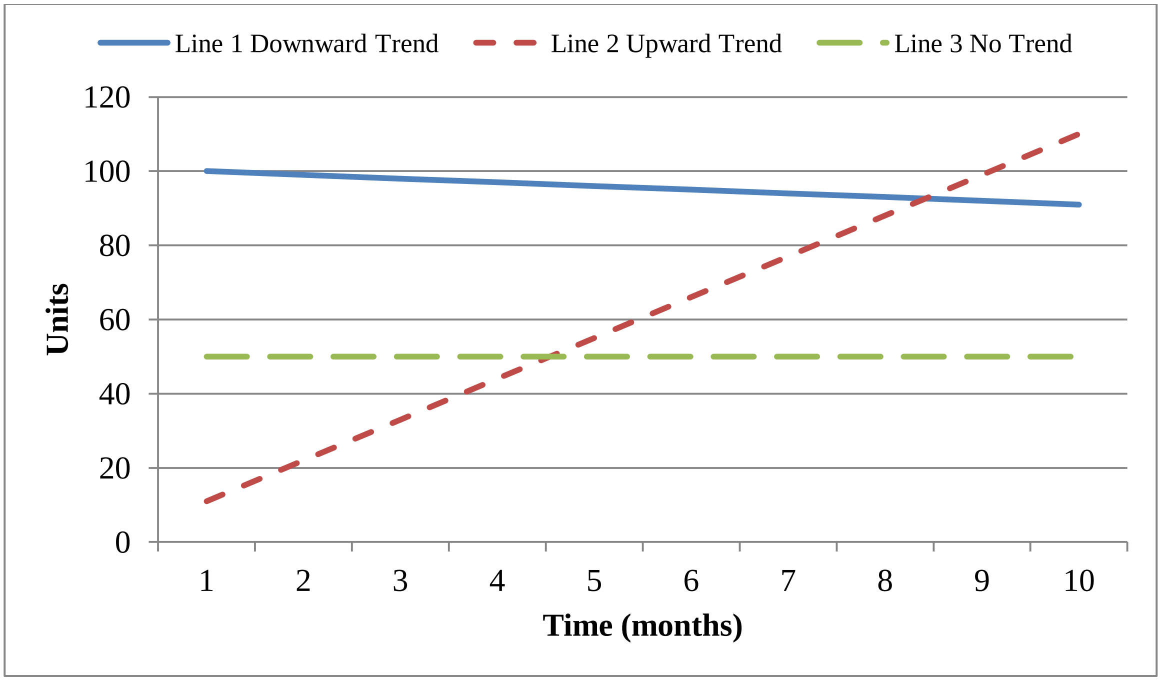


Figure 2. Example of Trends

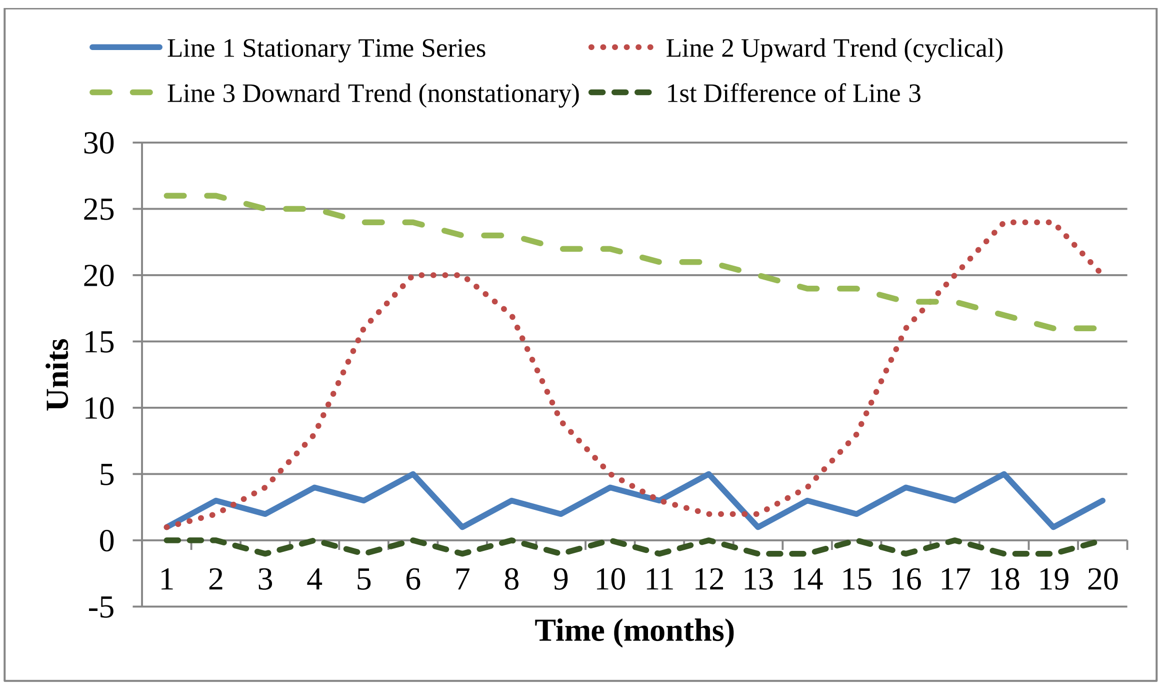


Figure 3. Example of Trends with Variation

In this example, there are three trend lines, a downward trend over time, an upward trend over time, and no trend over time. As is evident in this example, trends will vary in magnitude. Furthermore, trends of some time series data will vary in both direction and magnitude over time. In Figure 3 above, there are three sets of time series data. Line 1 represents a time series data set with no significant change in mean or variation over time. This is known as a stationary time series (Bowerman, O'Connell, & Koehler, 2005). If the time series is found to be nonstationary, as Line 3 is, a common method to induce stationarity is by taking the first differences of the time series values (Bowerman, O'Connell, & Koehler, 2005). Taking the first difference is calculating the difference between time t and time t_{t-1}. This typically reduces the trend and variation of the time series and can be seen in the fourth line in Figure 3. Line 2 represents data that exhibits a cyclical nature. If time is in months, then one would expect data values to increase between one and six months and to decrease between six and twelve months in the future. The added complexity in this time series example is the values twelve months apart (also known as lag) are non-stationary. Month six has a value of 20 and month eighteen has a value of 24. Based on this historical data, if a forecast of the subsequent year were to be predicted, it is reasonable to expect month 36 to have the highest value and quite possibly have a value greater than 24. If the frequency of a cycle consistently coincides with the calendar year, then it can be considered a seasonal affect (Bowerman, O'Connell, & Koehler, 2005). Lastly, once trend, cycle, and seasonal variation are mathematically accounted for, any variation that is left is unexplained and is commonly annotated as ε. With this in mind, the forecast model can now be rewritten to include these elements.

$$Forecast = Trend + Seasonality + Cyclical + \varepsilon \quad (5)$$

The hypothetical data illustrated in Figure 2 and Figure 3 represents ideal cases where values are continuous over time and clearly identify each component of the model. FSE, however, is unique in the field of inventory management because, while FSE assets are always in demand, FSE replacement demand is not. Because of this, FSE requisitions have an intermittent, or irregular, demand. In other words, there are long periods of no demand for specific FSE items. Because of this characteristic, specialized forecasting methods have been developed over the years to handle intermittent demand.

Simple Exponential Smoothing & Intermittent Demand

Simple exponential smoothing (SES) is a forecasting method for when a time series shows no trend or seasonal pattern and the mean slowly changes over time (Bowerman, O'Connell, & Koehler, 2005). To account for the slow change of the mean over time, the SES method gives more weight to recent observations and continuously less weight to older observations. By doing this, an observation twenty time periods ago has less influence on the forecast then an observation one time period ago. Below is the basic simple exponential smoothing equation where ℓ_T is the estimated mean at time T, α is the smoothing constant (which takes on a value between 0 and 1), and ℓ_{T-1} is the previous mean at time T-1 (Bowerman, O'Connell, & Koehler, 2005).

$$\ell_T = \alpha y_T + (1 - \alpha)\ell_{T-1} \quad (6)$$

Because this is a relatively simple equation it has a tendency to consistently over estimate or under estimate predicted values compared to the observed values. This is known as bias. Therefore, this equation has been adapted over time to take bias into consideration. One of the first well-known and commonly used methods for forecasting intermittent demand was developed in 1972 by J.D. Croston and is known in the field as Croston's method. This method improves upon the simple exponential smoothing technique by handling demand size and inter-demand intervals separately (Croston, 1972). Croston's method independently applies single exponential smoothing (SES) to demand size, y, and inter-demand intervals, τ. This allows a forecaster to smooth demand and inter-demand intervals independently. Despite this effort, it was found that this method still exhibits bias. Croston's method is expressed in equation 7 below.

$$Y_t' = \frac{z_t'}{p_t'}, \tag{7}$$

where Y_t' is the demand estimate, p_t' is the exponentially smoothed inter-demand interval that is updated only when there is demand, and z_t' is the exponentially smoothed size of demand (Syntetos & Boylan, 2006).

To correct the bias in Croston's method, several modifications have been developed. First, A. Vijaya Rao identified that Croston's method approximates variance. To improve upon the method, Rao reduced the approximation giving a better estimate (Syntetos & Boylan, 2010). However, Syntetos and Boylan (2010) revealed that the updated method is still not appropriate because of continued bias when α is above .15 and when the two separate estimates of demand and inter-demand interval are used as a ratio and applied to the inventory system. To correct for this bias, they proposed a new method.

$$Y_t' = \left(1 - \frac{\alpha}{2}\right)\frac{z_t'}{p_t'}, \tag{8}$$

where α is the smoothing constant value used for updating the inter-demand intervals (Syntetos & Boylan, 2005). A new method to handle forecasting bias was developed by Prestwich, Tarim, Rossi and Hnich (2014). In this method, the authors developed a hybrid of Croston's method and Bayesian inference called Hyperbolic-Exponential smoothing.

To this point, these SES models are addressing forecast demand for individual items. There is support for aggregating the demand across several items to produce a continuous demand at the supply chain level. Viswanathan, Widiarta and Piplani (2008) evaluated top-down and bottom-up forecasting methods. The top-down involves aggregating historical data across individual unit demand to reduce variability and produce a forecast. The bottom-up approach involves forecasting each individual demand item. The authors found that forecasting aggregate demand using SES is superior to forecasting the sub-aggregate demand using Croston's method, when there were many sub-aggregate units aggregated together and when the inter-demand intervals and demand sizes for the sub-aggregate units are highly variable (Viswanathan, Widiarta, & Piplani, 2008). This research was corroborated by Babai, Ali, and Nikolopoulos (2012). Babai et al. looked into the impact temporal aggregation has on stock control performance. The results confirmed that aggregating demand and using SES provide greater stock control and customer service level performance (Babai, Ali, & Nikolopoulos, 2012).

Measuring Forecast Accuracy

To measure accuracy of a forecasts prediction there are several measures that can be used. Mean Absolute Scaled Error (MASE), Root Mean Squared Error (RMSE), and Mean Absolute Deviation (MAD) has been used in the relevant research (Prestwich, Tarim, Rossi, & Hnich, 2014). Absolute percentage error (APE) and mean absolute percentage error (MAPE) are also recommended to compare across different time series (Bowerman, O'Connell, & Koehler, 2005). However, it has been recommended that Mean Squared Error (MSE) is the only measure that can be used across methodologies and compared directly (Syntetos & Boylan, 2010).

This chapter summarizes three important areas to this research. First, current Air Force supply management practices were outlined providing the institutional environment in which the FSE inventory exists. Second, a review of inventory management provided the theoretical and conceptual background which provided the foundations for Air Force inventory management. Lastly, important works in forecasting were discussed, providing the conceptual precedent for the applied research methodology.

III. METHODOLOGY

Chapter Overview

This chapter describes the methodologies and assumptions used to analyze FSE requisitions. There are five sections within this chapter; each section corresponds to an Investigative Question posed in this research. The first section discusses the methodology used for Investigative Question 1, identifying if FSE requisitions fit a theoretical probability distribution. In the second section is an explanation on the methodology used for Investigative Question 2, identifying which forecasting method is most appropriate to use. The third section describes the methodology used for Investigative Question 3, forecasting anticipated FSE requisitions in 2015 utilizing the most appropriate forecasting method. In the fourth section, the methodology for Investigative Question 4, calculating associated requisition costs with the anticipated FSE requisitions in 2015, is discussed. Lastly, the fifth section briefly explains assumptions used throughout this research. Therefore, a discussion on the methodology for Investigative Question 1 starts off this chapter.

Investigative Question 1 Methodology

Investigative Question 1. Can FSE requisitions be described using a theoretical probability distribution?

Theoretical probability distributions are important mathematical tools used to simplify calculations. They are especially important when describing demand because they provide probabilities to each possible value the demand can take. Therefore, it is important to first determine if FSE requisitions exhibit a theoretical probability distribution. To answer this investigative question, this research will follow the input analysis method laid out in *Discrete-Event System Simulation*, written by Jerry Banks, Carson, and Nelson (2014).

Input Analysis

The input analysis methodology described by Banks et al. (2014), is an overarching methodology broken down into two parts. First is data collection, which consists of the methodology for determining required data, for gathering data, for data clean up, and data validation. The second part of the input analysis methodology is determining the theoretical probability distributions of a data set. This includes a methodology for building histograms, parameter estimations, and testing goodness of fit. In instances where a theoretical probability distribution does not fit the data set a quartile distribution of the FSE requisition data will be fit.

Data Collection

The first part of the input analysis is data collection. Data collection consists of identifying required data, gathering the identified data, ensuring the data is clean (i.e. identifying missing and correcting wrong data), and validating the data. To determine the required data to meet the needs of the AFPA Equipment Management (AFPA EM) office and this research, this research will inquire within the AFPA EM office for recommended data. The recommended data by the AFPA EM office will then be collected. Once collected, the data set will be scrubbed to identify and correct any missing, incomplete, or incorrect data. Finally, the data collected will be validated to ensure it in fact represents what it is intended to represent and can be used for its intended purpose. Once data collection is complete the second step in the input analysis methodology will be taken.

Theoretical Probability Fitting

The second step to input analysis consists of histogram building to provide a visual cue as to whether the data might fit a theoretical probability distribution, parameter estimations to provide descriptive statistics of the data set, and goodness-of-fit tests to determine how well a theoretical probability distribution fits a data set. To create histograms of the data, guidance given by McClave, Benson, and Sincich (2011) and Hines, Montgomery, Goldsman, and Borrow Banks (2002) as cited by Banks et al. (2014) will be followed. McClave et al. (2011) recommend using 15 to 20 bins when data sets contain over 50 observations. Hines et al. (2002) recommend the number of bins be close to equal square root of the sample size. The use of Microsoft Excel® and JMP® will be used to build histograms. Once histograms are completed parameter estimations are calculated. Parameter estimations will be conducted using Microsoft Excel's® Descriptive Statistics Data Analysis capability. The output of this step will include the data set's mean, standard error, mode, standard deviation, sample variance, kurtosis, skewness, range, minimum value, maximum value, sum value, observation count and confidence level at 95%. Lastly, using JMP's® Distribution Analysis, theoretical probability distributions will tested for goodness-of-fit to the observed FSE requisitions data. Data sets equal to or greater than 30 observations, the Pearson Chi^2 test will be used to test goodness-of-fit. For data sets with less than 30 observations, the Kolmogorov's D test will be used to test goodness-of-fit.

Quartile Distributions

In case it is found theoretical probability distributions do not fit the FSE requisitions data, a quartile distribution will be utilized to describe FSE requisitions. JMP's® Distribution Analyzer capability will provide the output for the quartile distribution; however, the output is calculated using the following equations.

$$Median = \frac{N+1}{2} \tag{9}$$

$$Upper\ Quartile = Median + \frac{N+1}{2} \tag{10}$$

$$Lower\ Quartile = Median - \frac{N+1}{2} \tag{11}$$

$$Interquartile\ Range = UQ - LQ \tag{12}$$

Up to this point, the FSE requisition data will go through the input analysis process to ensure the correct data is collected, that it is clean and valid, and to test if a theoretical probability distribution can be applied. In cases where a theoretical probability distribution cannot be applied, the quartile distribution is fitted. It is important to note at this point that the literature reviewed for this study, Viswanatha et al. (2008) and Babai et al. (2012), indicate temporal demand aggregation is an appropriate method when demand is found to be intermittent. Therefore, the remainder of this study will utilize temporal demand aggregation as well as aggregation across items for historical FSE requisitions. The purpose of these aggregations is to give a system-level view of FSE requisitions. All methodologies laid out will be applied to these aggregations, which include the original data set which is quantity of FSE requisitioned per day, but will also include weekly quantities of FSE requisitioned, monthly quantities of FSE requisitioned, quantity of FSE requisitioned over six-month periods, and annual FSE requisitioned. The next step in this research is to determine which forecasting method is most appropriate to use for this type of data set which leads to Investigative Question 2.

Investigative Question 2 Methodology

Investigative Question 2. What type of demand does FSE requisitions exhibit and which forecasting method is most appropriate given this demand type?

Investigative Question 1 is intended to identify if a theoretical probability distribution fits the historical FSE requisition data set. The purpose of which is to simplify calculations because if FSE requisitions can be described using a theoretical distribution, then the most appropriate method to forecast FSE requisitions is to use a simulation model where the theoretical distribution can be assigned. However, it is suspected that FSE requisitions do not follow a theoretical distribution. In the case this suspicion is confirmed, another method must be used to determine what forecasting method is most appropriate to use. Therefore, the methodology described by Babiloni et al. (2010) will be followed.

The methodology described by Babiloni et al. (2010) describes the type of demand observed in a data set and assigns a forecasting methodology based on the type of demand observed. To determine the type of demand observed, first, the coefficient of variance for FSE requisitions is calculated using equation 1.

Second, the mean inter-demand interval is calculated. These two outputs allow the utilization of Figure 1 to determine if demand is intermittent.

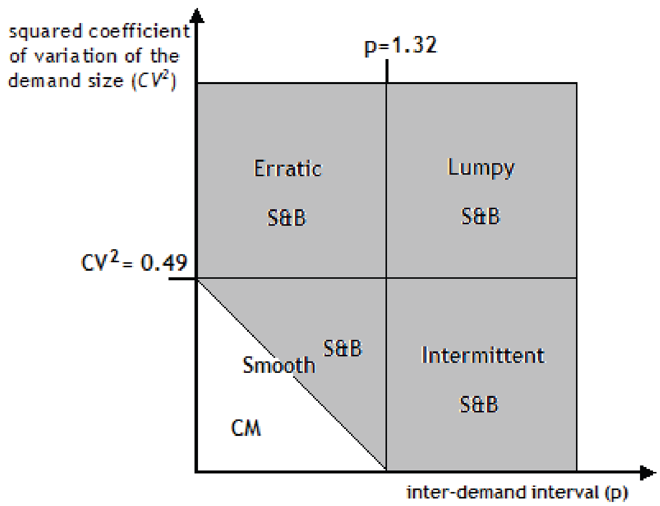


Figure 4. Categorization of demand pattern based on the accuracy of forecasting procedures (Babiloni, Cardos, Albarracin, & Palmer, 2010)

The outcome of this Investigative Question will determine which forecasting method is most appropriate given the type of demand observed in FSE requisitions. This leads the research to Investigative Question 3, forecasting 2015's anticipated demand.

Investigative Question 3 Methodology

Investigative Question 3. Using the identified forecasting method, what are next year's forecasted FSE requisitions?

Investigative Question's 1 and 2 determine if a theoretical distribution fits the FSE requisition data and determine which forecasting method is most appropriate given the observed FSE requisition data, respectively. Investigative Question 3 applies this knowledge to forecast 2015's anticipated FSE requisitions using JMP®. Forecasting 2015's anticipated FSE requisitions is a three step process. First is applying the selected forecast method to each aggregated data set of historical FSE requisitions. Second, is comparing the results these data sets produce utilize the selected forecasting method. The purpose of this comparison is to determine which data set the selected forecasting method produces the least error with. Third, is applying the forecasting method to the best data set to forecast 2015's anticipated FSE requisitions.

Forecasting 2015's anticipated FSE requisitions will utilized the appropriate forecasting method identified in Investigative Question 2. This method will be applied to each of the aggregated historical FSE requisitions data sets from 1/1/2009 to 12/31/2013. Even though the Federal Fiscal Year is from October 1 to September 31, these dates are chosen because they provide four complete years of historical FSE requisitions. To determine which aggregated data set the applied forecasting method works best with, the Sum Squared Errors (SSE) and Mean Squared Errors (MSE) are compared. The lowest SSE and MSE indicate the least amount of error between predicted values and observed values. After the best aggregated data set is determined, the chosen forecasting method will be applied to the entire best aggregated historical FSE data set (1/1/2009 to 9/2/2014) to forecast 2015's anticipated FSE requisitions.

The output of Investigative Question 3 produces 2015's anticipated FSE requisitions. This forecast provides an expectation of how many FSE items will be requisitioned over the course of time in 2015. This does not provide the whole story, though, because each requisition has an associated cost. For this reason, Investigative Question 4 addresses associated costs given the anticipated FSE requisitions forecasted for 2015.

Investigative Question 4 Methodology

Investigative Question 4. What are the associated costs with next year's forecasted FSE requisitions?

A requisition is the equivalent of a purchase. Consequently, all requisitions have an associated cost. The literature review for this study did not bring to light a forecasting method to forecast costs in relation to forecasting demand. Because of this, Investigative Question 4 will utilize the descriptive statistics identified in Investigative Question 1 to quantify 2015's requisition costs. The results will provide an expected requisition cost for 2015.

To calculate 2015's associated requisition costs, the average requisition value per FSE item (mean value per FSE requisition / mean number of FSE requisitioned) identified in the results of Investigative Question 1 will be applied to the forecasted FSE requisitions for 2015. A cumulative cost will be calculated according to the time units applied to the aggregated data set. The end result will be a total anticipated cost of FSE requisitions during 2015.

Assumptions

Assumption 1. This research assumes all authorized FSE is valid and required to support Air Force missions. As such, this research is not aimed at verifying FSE authorizations and allowances.

Assumption 2. Inventory management does not operate independently or in a vacuum. Instead, it relies heavily on corporate resource management (i.e. budgeting) and purchasing management. This research assumes corporate resource management allocates the appropriate level of resources to meet FSE inventory and replacement item requirements. This research also assumes that purchase managers perform as required to requisition inventory and replacement items to meet inventory and replacement requirements. That is, the funds and acquisition management are robust enough that deficiencies in these areas have no effect on inventory and replacement goals.

Assumption 3. This research also assumes acquisition management performs as required to meet inventory and replacement requirements. That is, funding and purchasing management are robust enough that deficiencies in these areas have no effect on FSE inventory and replacement requirements.

Assumption 4. This research also assumes the historical data retrieved and received accurately represent the Air Force's FSE inventory.

Assumption 5. Demand is random.

Assumption 6. Fill-rate is an adequate measure of inventory management performance for this research.

This chapter provides the overarching methodology used to conduct this research as well as methodologies used to answer each investigative question posed. First, each aggregated FSE requisition data set is tested to determine if they fit a theoretical probability distribution. Second, in light of the probability distributions exhibited by the aggregated FSE requisition data sets, a determination is made as to which forecasting method is appropriate for use. Third, the identified forecasting method is applied to each FSE requisition data set where a comparison of results, using MSE and RMSE, will identify which aggregated FSE requisition data set is appropriate to forecast 2015's FSE requisitions. Then 2015's FSE requisitions will be forecast using the selected forecasting method and aggregated FSE requisitions data set. Lastly, the associated costs are calculated for this forecast using the mean FSE value per requisition. The results of this methodology are discussed in Chapter IV.

IV. RESULTS

Chapter Overview

This chapter is a discussion of the results of the study. There are five sections within this chapter. First, is a brief overview of AF FSE requisitions from 1/1/2009 to 9/2/2014. Second, is a discussion of Investigative Question 1 and identifying FSE requisition probability distributions. The third section discusses Investigative Question 2 and the identification of which forecasting method is most appropriate, given the results to Investigative Question 1. Fourth, the results of Investigative Question 3, forecasting 2015's anticipated FSE requisitions, are discussed. Lastly, the results of Investigative Question 4 are presented. Before the results of each Investigative Question are presented a quick discussion on AF FSE requisitions is needed to give an understanding of the system being studied.

Overview of FSE Requisitions

The purpose of this section is to give the reader an over view of FSE inventory system. This overview will provide context for the reader. The current FSE inventory encompasses FSE located at 89 locations across 10 Major Commands. Table 2 is a summary of the FSE inventory system in relation to Major Commands. Current on-hand inventory is 2,492 items valued at $26.5M while the authorized inventory is 2,566 items valued is $33.8M. Despite the current FSE inventory fill-rate of 97%, the remaining shortage of 74 FSE items is valued at $7.3M, representing 21.6% of the authorized budget, no small amount. Table 3 shows how the 3% shortage is spread out across the MAJCOMs.

Table 2 Major Command FSE Inventory Overview

	# of Locations	# of Unique NSNs	# of On-hand FSE Inventory	# of Authorized FSE Inventory	Total On-Hand FSE Inventory Cost	Total Authorized FSE Inventory Cost
Air Combat Command (ACC)	15	116	334	348	$3,458,893.04	$3,879,887.22
Air Education & Training Command (AETC)	10	89	272	289	$3,445,283.65	$4,549,331.03
Air Force Global Strike Command (AFGSC)	5	48	110	106	$495,434.06	$1,134,682.64
Air Force Materiel Command (AFMC)	8	161	370	374	$4,193,357.20	$4,503,251.42
Air Force Research Center (AFRC)	10	65	217	221	$1,679,464.49	$2,740,160.39
Air Force Space Command (AFSPC)	6	156	306	308	$2,816,183.18	$3,351,870.80
Air Force Special Operations Command (AFSOC)	2	38	61	65	$452,926.98	$1,019,879.20
Air Mobility Command (AMC)	12	95	295	312	$2,355,115.19	$3,152,234.98
Pacafic Air Forces Command (PACAF)	10	109	262	263	$4,930,558.53	$5,604,587.84
United States Air Force's Europe Command (USAFE)	11	84	265	280	$2,694,490.42	$3,875,572.53
Totals	**89**	**519***	**2492**	**2566**	**$26,521,706.74**	**$33,811,458.05**

*There are 519 unique items to the Air Force FSE inventory. Some items are required by multiple MAJCOMs and therefore are represented more than once in the '# of Unique NSNs' column.

Table 3 Major Command FSE Inventory Ratios

	Fill-Rate (On-Hand / Authorized)	On-Hand / Authorized Cost Ratio
Air Combat Command (ACC)	0.960	0.891
Air Education & Training Command (AETC)	0.941	0.757
Air Force Global Strike Command (AFGSC)	1.038	0.437
Air Force Materiel Command (AFMC)	0.989	0.931
Air Force Research Center (AFRC)	0.982	0.613
Air Force Space Command (AFSPC)	0.994	0.840
Air Force Special Operations Command (AFSOC)	0.938	0.444
Air Mobility Command (AMC)	0.946	0.747
Pacafic Air Forces Command (PACAF)	0.996	0.880
United States Air Force's Europe Command (USAFE)	0.946	0.695
Totals	**0.971**	**0.784**

Table 3 also shows where the value of these short falls are located. For example, AFSOCs Fill-rate is 0.938 and its On-Hand Value to Authorized Value is 0.44. This indicates the remaining 6% of items represent 55% of AFSOCS authorized cost of equipment. Meaning, AFSOC does not require a lot of FSE to have a 100% fill-rate, but what it does require will cost the Air Force significant sums of money to requisition. The current state of the Air Force's FSE inventory shows. Now, a review of the Air Force's FSE inventory requisition behavior is required.

The Air Force FSE inventory system places a requisition for an FSE item on an as-needed basis. Each requisition for an item is the equivalent of a demand for that item. Therefore, requisition and demand are synonymous in this study. As mentioned in Chapter 3, and supported by Chapter 2, demand for FSE items is assumed to be random. This demand, over time is not continuous and is highly variable. Figure 5 shows how demand within the FSE inventory system changes over time. It is apparent that most days see demand for small quantities of FSE; however, there are many days, at random intervals, where large quantities of FSE are requisitioned.

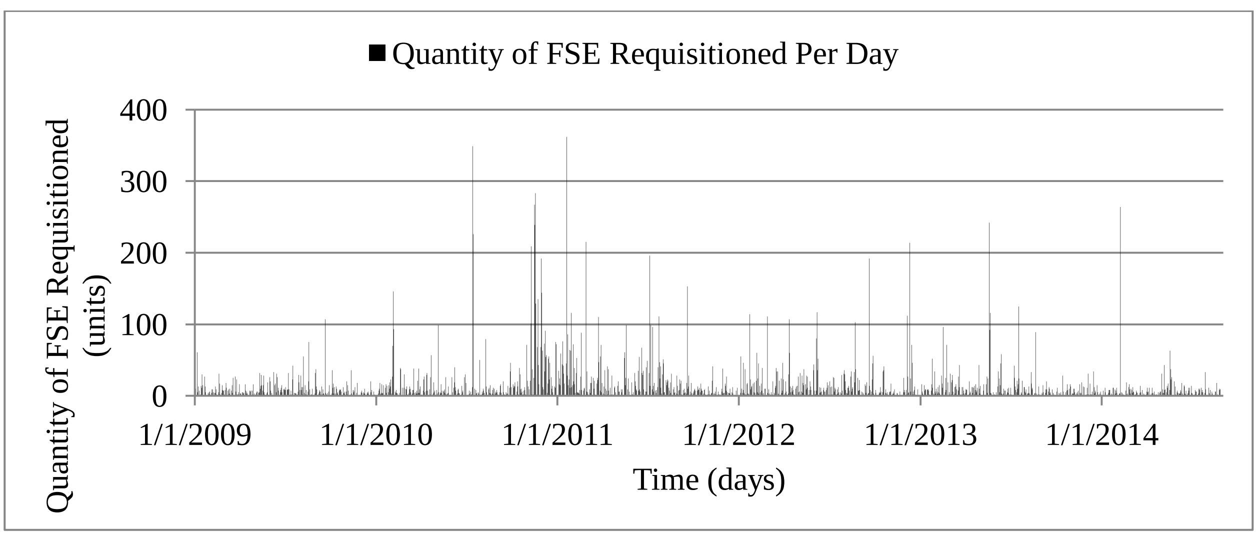


Figure 5 Quantity of FSE Requisitioned per Day (1/1/2009 – 9/2/2014)

Similar to the number of FSE units demanded per day, the number of requisitions per day remains relatively small with random instances of high numbers of requisitions. To provide a more detailed view of how the number of requisitions change over time Figure 6 represents the number of requisitions per day from 1/12009 to 12/31/2009.

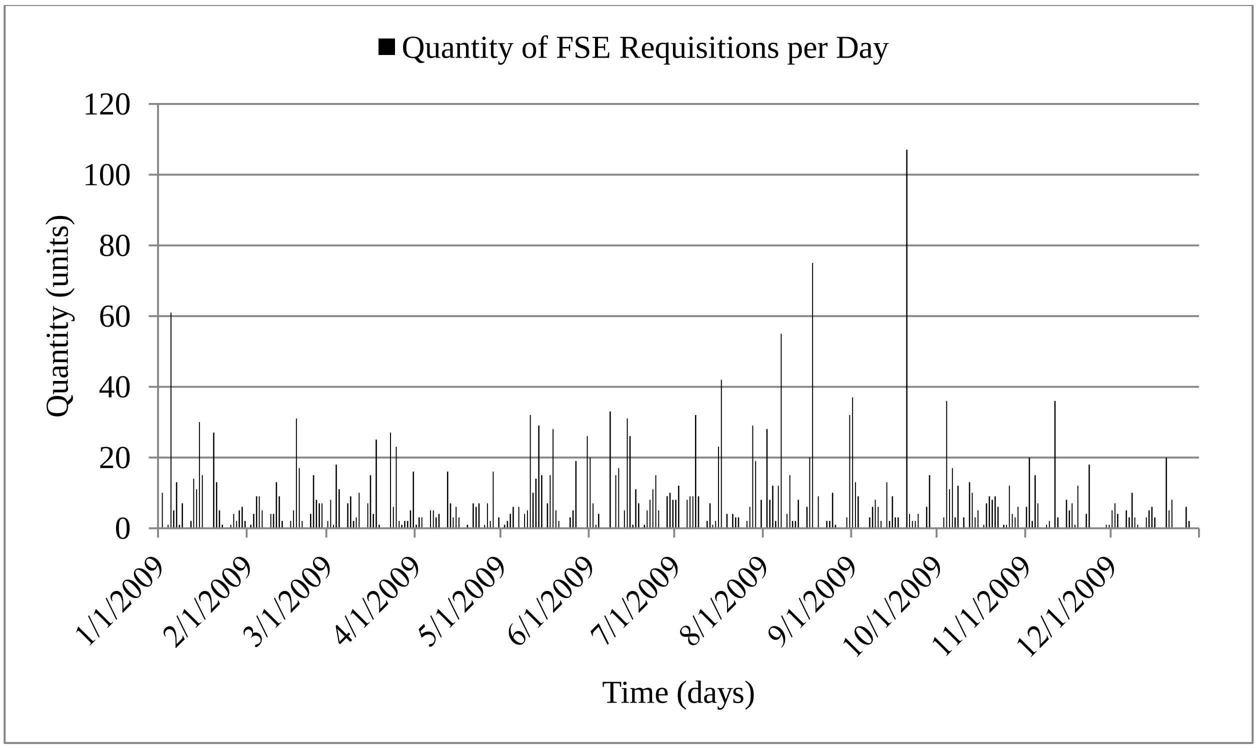


Figure 6 Quantity of FSE Requisitioned per Day (1/1/2009 – 12/31/2009)

This section gave an overview of the current state of the Air Force's FSE inventory system. A comparison was given showing the number of FSE items within the inventory compared to the number of FSE items authorized to be in the inventory. In addition to showing the related costs of on-hand and authorized, the cost of the difference between authorized and on-hand is given. These results show there is a significant amount of money authorized for the system, a significant amount of money residing within the system as on-hand inventory, and a significant amount of money missing from the system (represented as short-falls). This lends credence to the idea, that the Air Force FSE inventory system is important and should be researched for improvement where improvements can be made.

The first step in researching the FSE inventory system is to determine if demand follows a theoretical probability distribution. If demand can be predicted, then the system can be better managed in anticipation of demand. The next section presents the results to Investigative Question 1, which is to identify if FSE requisitions, or demand, follow a theoretical probability distribution.

Investigative Question 1 Results

Investigative Question 1. Can FSE requisitions be described using a theoretical probability distribution?

The first Investigative Question of this research is to determine if FSE requisitions fit a theoretical probability distribution. Using JMP®, this analysis fit two discrete probability distributions, the Poisson and Binomial probability distributions, to five sets of aggregated demand: Daily Requisitions, Weekly Aggregated Requisitions, Monthly Aggregated Requisitions, Bi-annually Aggregated Requisitions, and Annually Aggregated Requisitions. The following are the results of these time-series.

Daily Aggregated FSE Requisitions

The first aggregated data set tested was Daily Aggregated FSE Requisitions. This data set represents the number of FSE items requisitions per each calendar day. In total there are 2,071 days between 1/9/2009 and 9/2/2014 which gives 2,071 days of varying demand. For more detail the Daily Aggregated FSE Requisitions data set see Appendix 3. Using JMP®, the Poisson and Binomial distributions were fitted to this data set with the following results shown in Table 4. Despite the rather large data set, neither the Poisson nor the Binomial fit the Daily Aggregated Requisitions data set very well. Therefore, the next higher level of aggregation is test.

Table 4 Fitted Distributions of Daily Aggregated FSE Requisition Quantities (1/1/2009 – 9/2/2014)

Fitted Poisson				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	λ	11.00	10.86	11.15
-2(Likelihood)= 59252.128				
Goodness-of-Fit Test				
Pearson ChiSquared				
X2	Prob>X2			
1.67E+279	< .0001*			
Note: Ho=The data is from the Poisson distribution. Small p-values reject Ho.				
Fitted Binomial				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	p	1	0.999	1
-2(Likelihood)= 0				
Note: Binomial Distribution options are not available for non-constant sample sizes.				

Weekly Aggregated FSE Requisitions

The second aggregated data set tested is Weekly Aggregated FSE Requisitions. This data set represents the quantity of FSE requisitioned per calendar week. For this study there are 297 weeks between 1/1/2009 and 9/2/2014. For more detail on this data set, see Appendix 3. As expected, aggregating requisitions in this manner did smooth out demand but not enough to eliminate the high variability of demand. The result is both the Poisson or Binomial distributions are poor fits to this data set as shown in Table 5. The higher level of aggregation shows promise in reducing variability, so the next higher level of aggregation is tested.

Table 5 Fitted Distributions of Weekly Aggregated FSE Requisitions (1/12009 – 9/2/2014)

Fitted Poisson				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	λ	76.76	75.77	77.77
-2(Likelihood)= 21732.486				
Goodness-of-Fit Test				
Pearson ChiSquared				
X2	Prob>X2			
4.62E+204	< .0001*			
Note: Ho=The data is from the Poisson distribution. Small p-values reject Ho.				
Fitted Binomial				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	p	1	0.999	1
-2(Likelihood)= 0				
Note: Binomial Distribution options are not available for non-constant sample sizes.				

Monthly Aggregated FSE Requisitions

The third aggregated data set is Monthly Aggregated FSE Requisitions. This data represents the total quantity of FSE requisitioned over a calendar month. For this study there are 69 months of data between 1/1/2009 and 9/2/2014. Because September, 2, 2014 is not a complete month, it is excluded from the analysis, leaving us with 68 months during the time frame between 1/1/2009 and 8/31/2014. For more detail on this data set, see Appendix 3. As anticipated, Monthly Aggregated FSE Requisitions smoothed out the data and reduce variance between observations; however, it was not enough to fit the Poisson and Binomial distributions to the data set. Table 6 shows the results of fitting both distributions to this data set. The fit for Poisson and Binomial distributions are still very poor despite aggregating the data. Therefore, the next high-level aggregation is analyzed.

Table 6 Fitted Distributions of Monthly Aggregated FSE Requisitions (1/1/2009 – 8/31/2014)

Fitted Poisson				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	λ	335	331	340
-2(Likelihood)= 11717				
Goodness-of-Fit Test				
Pearson ChiSquared				
X2	Prob>X2			
3.32E+288	< .0001*			
Note: Ho=The data is from the Poisson distribution. Small p-values reject Ho.				
Fitted Binomial				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	p	1	0.99	1
-2(Likelihood)= 0				
Note: Binomial Distribution options are not available for non-constant sample sizes.				

Semi-Annual Aggregation of FSE Requisitions

To this point, increasing aggregation of requisitions is conducted in an effort to fit a theoretical probability distribution to no avail. The fourth aggregated data set is Semi-annual requisitions. This data set represents the total number of FSE requisitioned over a six month period. Because this data set contains only a portion of 2014, the Semi-Annual Aggregated Requisitions will encompass all requisitions from 1/1/2009 to 6/30/2014. This data set gives us 11 observations over this time frame. For more detail on this data set, refer to Appendix 3. As indicated in Table 7, neither the Poisson nor the Binomial distributions fit the Semi-Annual Aggregation of FSE Requisitions well.

Table 7 Fitted Distributions of Semi-Annual Aggregated FSE Requisitions (1/1/2009 – 6/30/2014)

Fitted Poisson				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	λ	2051	2024	2077
-2(Likelihood)= 4591				
Goodness-of-Fit Test				
Kolmogorov's D				
D	Prob>D			
0.53	< .0015*			
Note: Ho=The data is from the Poisson distribution. Small p-values reject Ho.				
Fitted Binomial				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	p	1	0.999	1
-2(Likelihood)= 0				
Note: Binomial Distribution options are not available for non-constant sample sizes.				

Annual Aggregation of Requisitions

The last aggregation of FSE requisitions is Annual Aggregation. The Annual Aggregation of FSE Requisitions consists of five data points, one for each full calendar year. Because the data set provided for this research contains only a portion of 2014, this year was omitted from this analysis. Therefore, only five years were used in this portion of the analysis. More detail on this data set can be referenced in Appendix 3. The results of this analysis, as seen in Table 8, indicated the Annual Aggregated FSE Requisitions partially fit a Poisson distribution but do not fit a Binomial distribution.

Table 8 Fitted Distributions of Annual FSE Requisitions (1/1/2009 – 12/31/2013)

Fitted Poisson				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	λ	4275	4218	4333
-2(Likelihood)= 2312				
Goodness-of-Fit Test				
Kolmogorov's D				
D	Prob>D			
0.40	< .29*			
Note: Ho=The data is from the Poisson distribution. Small p-values reject Ho.				
Fitted Binomial				
Parameter Estimates				
Type	Parameter	Estimate	Lower 95%	Upper 95%
Scale	p	1	0.999	1
-2(Likelihood)= 0				
Note: Binomial Distribution options are not available for non-constant sample sizes.				

With the exception of Annual Aggregation of FSE Requisitions, the Poisson and Binomial distributions did not fit the aggregated data sets. While the 2009-2013 Annual

Aggregation of FSE Requisitions did fit the Poisson distribution, when 2014 requisitions are added it no longer fits this distribution. Therefore, quartile distributions are fitted to describe these data sets.

Quartile Distributions

In the last part of this section, theoretical probability distributions were fitted to aggregated data sets of FSE requisitions. The purpose of which, is to help describe the FSE inventory system. With the exception of the Annual Aggregation of FSE Requisitions, the distributions analyzed did not fit. Because no theoretical probability distribution fit the aggregated demand series for FSE requisitions, the quartile distributions will be fit to each aggregated data set. These distributions statistically describe demand for the FSE inventory system and are found in Table 9.

Table 9 Quartile Distributions for Each Aggregated Data Series of FSE

Quantile	Daily Aggregate	Weekly Aggregate	Monthly Aggregate	Semi-Annual Aggregate	Annual Aggregate
N	2071	297	68	11	5
100% (Max)	362	853	2028	4292	6006
75%	71	90	383	2307	5763
50% (Median)	4	48	250	1939	4332
25%	0	28	171	1198	2760
0% (Min	0	0	96	1152	2430

This purpose of Investigative Question 1 is to statistically define demand for the FSE inventory system. As the results show, demand for the FSE inventory system do not follow a theoretical probability distribution, therefore, the quartile distribution was fit to each aggregated demand data set. The purpose of which, is to describe demand for the FSE inventory system. Now that demand for the FSE inventory system has been described, the next step is to define the type of demand observed for the FSE inventory system. The results of this step are presented in the next section.

Investigative Question 2 Results

Investigative Question 2. What type of demand does FSE requisitions exhibit and which forecasting method is most appropriate given the demand type?

The previous section described the demand observed for the FSE inventory system over the past five and half years. The results show that a theoretical probability distribution does not adequately describe demand for this system. Because a theoretical distribution cannot be used another method must be used to forecast FSE for 2015. The literature reviewed indicated for demand that doesn't exhibit a theoretical distribution, it is possible the data is exhibiting a non-smooth demand pattern. If demand exhibited is not smooth, then the appropriate forecasting method is Simple Exponential Smoothing. Therefore, Investigative Question 2 is broken down into two parts. First, identifying if the demand observed for the FSE system exhibits non-smooth characteristics. Second, based on these results, the selection of the appropriate forecasting method is made.

<u>Identifying Type of Demand Exhibited</u>

To identify the type of demand exhibited by the FSE system, this research utilized the method laid out by Babiloni et al. (2010). First, the inter-demand mean is calculated and, second, the coefficient of variance for demand size is calculated. The calculated mean for inter-demand of FSE requisitions is 1.39. The calculated coefficient of variance squared for FSE requisition demand size is 0.37.

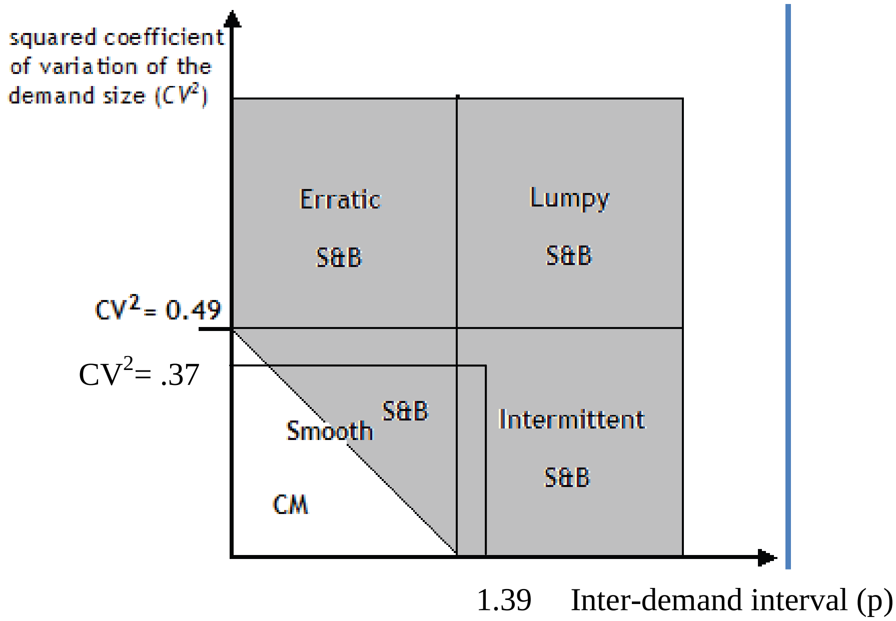


Figure 7 Evaluation of Demand Type for FSE Requisitions

<u>Identifying the Appropriate Forecasting Method</u>

Using the method put forth by Babiloni et al. (2010) Air Force FSE exhibits lumpy intermittent demand, as can be seen in Table 9. Based on this result, on the literature reviewed and the results of Investigative Question 1, this analysis will use Simple Exponential Smoothing as its technique to forecast next year's requisitions.

Investigative Question 3 Results

> *Investigative Question 3: Using the identified forecasting method, what are next year's forecasted FSE requisitions?*

Investigative Question 2 shows Simple Exponential Smoothing is the appropriate method to use to forecast future FSE demand, based on the type of demand exhibited by historical FSE requisitions. Investigative Question 3 takes this forecasting method and applies it to each aggregated FSE data set. Once applied, the output of each is compared to determine which data set is most appropriate for use to forecast 2015 FSE requisitions. The determination of which leads to the application of the SES method to forecast 2015s anticipated FSE requisitions. This section discusses the results of these actions.

Analysis of Applying SES to the Aggregated Data Sets

The SES forecasting technique is applied to each of the five aggregated FSE requisition data sets from the time period starting 1/9/2009 and ending 12/31/2013. The results of this application are summarized in Table 10 below. It is apparent the SES method handled the bi-annually aggregated FSE requisitions better than the other aggregated data sets. For instance, the annual RMSE (which is calculated RMSE multiplied by the number of observations per year for a given level of aggregation) for bi-annual is 2,042 units of FSE. Conversely, the daily prediction for FSE has an annual RMSE of 15,585 units of FSE. This indicates aggregation of units and time works quite will with SES.

Table 10 Summary of Results for SES Applied to Aggregated FSE Requisitions Data Sets

Model Summary	**Daily**	**Weekly**	**Monthly**	**Bi-annually**	**Annual**
N	1826	260	60	10	5
DF	1824	258	58	8	3
SSE	1,266,028	1,907,384	4,811,671	10,427,522	15,975,397
MSE	1,827	7393	80,194	1,042,752	3,195,079
RMSE	42.7	86	286	1,021	1,787
Annual RMSE	15,585	4,472	3,432	2,042	1,787
Variance Estimates	694	7393	82,959	1,303,440	5,325,132
Std Dev	26	85	288	1141	2307
Rsquare	0.056	0.15	0.079	-0.23	-2.13
Rsquare Adj	0.056	0.15	0.079	-0.23	N/A
MAPE	N/A	119	50	31	34
MAE	13	52	160	751	1622
Stable	Yes	Yes	Yes	Yes	Yes
Invertible	Yes	Yes	Yes	Yes	Yes
Parameter Estimates					
Term	Level Smoothing Weight	LSW	LSW	LSW	LSW
Estimate	0.08	0.27	0.31	0.99	1
Std Error	0.01	0.07	0.12	0.56	0.74
t Ratio	5.18	3.77	2.51	1.76	1.34
Prob > t	< .0001	< .0002	0.015	0.12	0.27

2015's Forecasted FSE Requisitions

In the previous section the results indicate the SES method best handled the Bi-Annual Aggregation of FSE Requisitions data set because it produces the smallest annual RMSE. This section discusses the results of applying SES to the Bi-annual Aggregation of FSE Requisitions data set to forecast 2015's FSE requisitions. The SES method was applied to the Bi-annual Aggregation of FSE Requisitions from 1/1/2009 to 6/30/2014, which equates to eleven time periods. Thus, the forecast will predict three time periods. The first time period is 7/1/2014 to 12/31/2014, the second time period is 1/1/2015 to 6/30/2015, and the third time period is 7/1/2015 to 12/31/2015. The results of this application are shown in Figure 8. The SES forecast of bi-annual FSE requisitions predict 1,180 units of FSE to be requisitioned for each bi-annual time period.

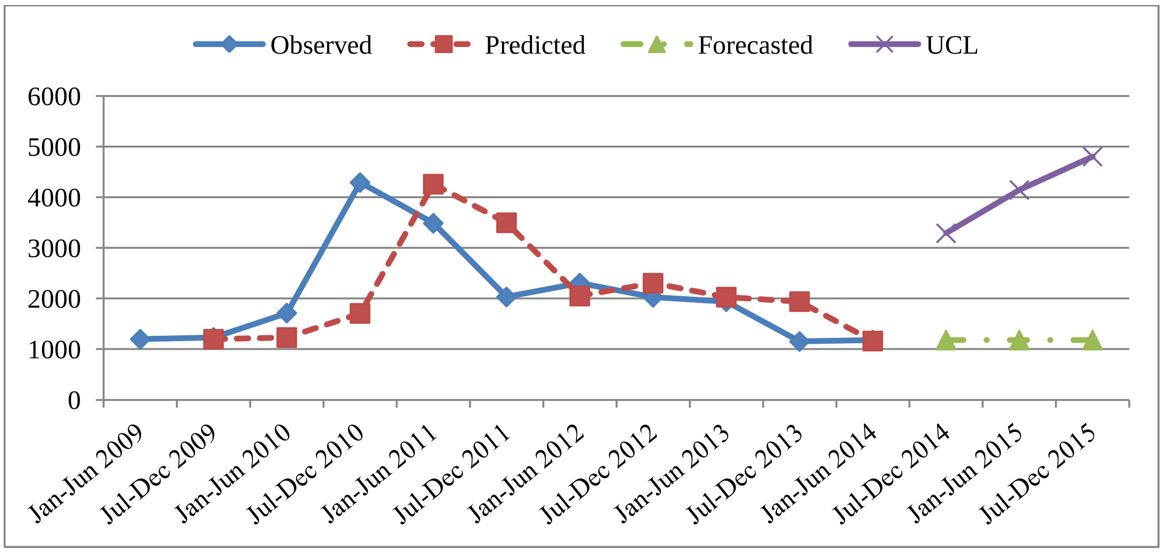


Figure 8 SES forecast of bi-annual FSE requisitions

Figure 8 shows the predicted values, both historical and forecasted. It also shows a one time period lag between observed values and predicted values. Figure 9 below shows the cumulative FSE requisitioned by year. The 2014 and 2015 predicted requisitions follow the downward trend, but do not continue it. Instead it flattens out to 2,361 units of FSE requisitioned for these two years. Additionally, it is apparent that more units of FSE are requisitioned during the first half of the calendar year than during the second half. The forecasted FSE requisitions do not take this trend into account. One possible explanation of this trend, though, is the Federal fiscal year, which begins on the first of October and ends on the last day of September. In light of current fiscal constraints, it is not unusual for funds to be unavailable at the beginning of the fiscal year. It is also not unusual for funds to dry-up towards the end of the fiscal year. Therefore, with the first of October directly in the middle of the Jul – Dec bi-annual time frame, it is no surprise that FSE requisitions are frequently less than FSE requisitions during the Jan – Jun time frame.

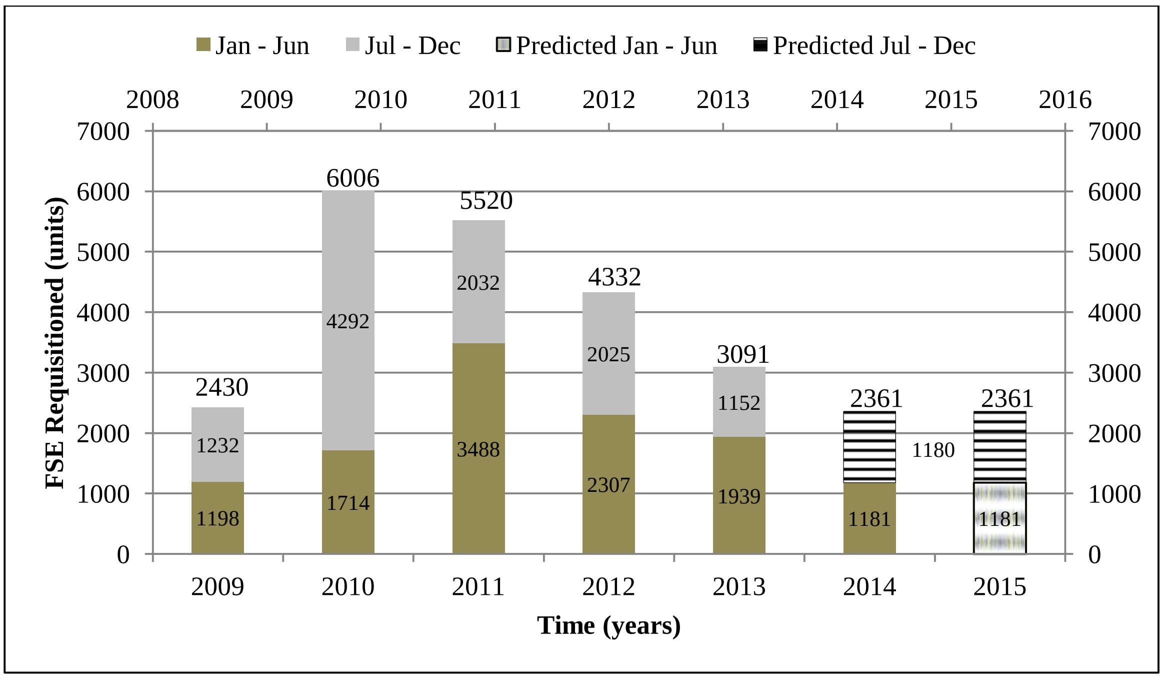


Figure 9 Cumulative FSE Requisitioned by Year

The forecast for 2015 and the comparisons of Cumulative FSE Requisitions by Year show how the forecast compares to years past. An additional way to compare is via daily cumulative FSE requisitions over an annual time period. Figure 10 below shows this comparison. The important result of this analysis is the 2015 prediction of FSE requisitions follows the same cumulative trend as the first half of 2014. This validates the SES forecast for 2015. One limitation of this prediction, though, is the negative annual trend of FSE requisitions is not followed between 2014's forecast and 2015's forecast. This trend, however, is assumed to continue. It may very well not.

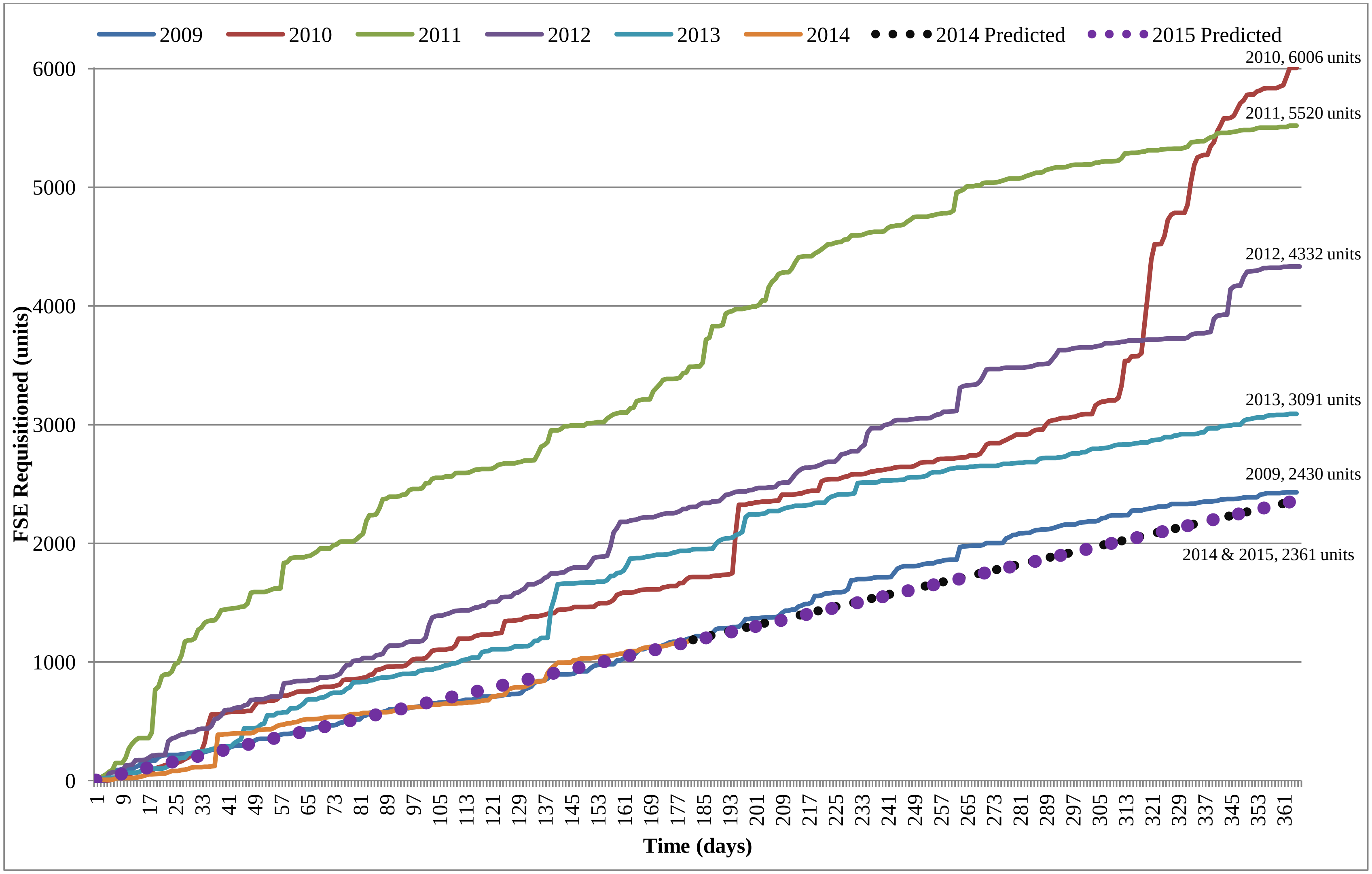


Figure 10 Cumulative Daily FSE Requisitions by Year

The SES forecasting method was also applied to the entire Daily Aggregated FSE Requisitions data set, which encompasses daily demand from 1/9/2009 to 9/2/2014, using the JMP® modeling tool. The forecasted results include the time frame from 9/3/2014 to 12/31/2015. Figure 11 is the output of this forecast. As can be seen, the SES forecast does not provide a good predicted output for historical Daily FSE Requisitions. Additionally, it does not handle the large spikes of demand observed in the historical data sets. As the forecast projects into the future, the SES method produces a flat line with a value of 3 units of FSE requisitioned per day. It is important to note the Upper Confidence Level for this forecast of 2015's FSE requisitions grows significantly large in a short period of time. This indicates a significant limitation when using SES to forecast demand using daily aggregation.

To compare how this forecast fits with historical FSE demand, the cumulative quantity of FSE requisitioned in years' past is compared to the forecasted cumulative quantity of FSE requisitioned. Figure 12 shows this comparison to years past. It is apparent from 2010 to 2014 the cumulative quantity of FSE requisitioned per year is decreasing. The forecasted cumulative quantities requisitioned for 2014 and 2015 continue this trend. Even though the forecast continues this negative trend, it is possible the 2015 prediction is significantly under estimating the cumulative quantity requisitioned. Lastly, the SES forecast handles the step-increases exhibited in historical FSE requisitions; however, this method does not handle these features in future forecasts. This is another limitation to the SES technique when applied to data sets with daily aggregation.

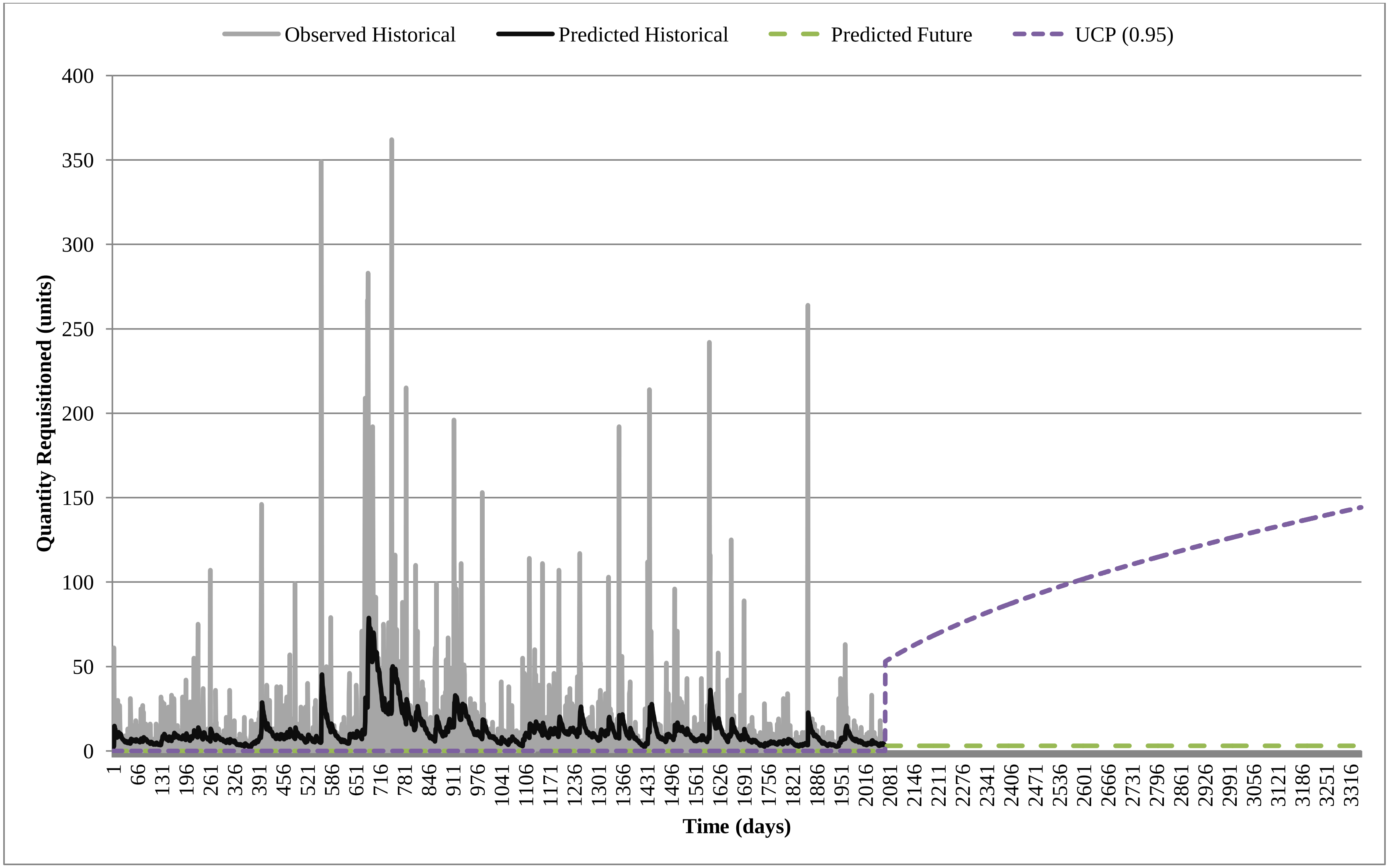


Figure 11 Predicted FSE Requisitions (9/3/2014 – 9/2/2015)

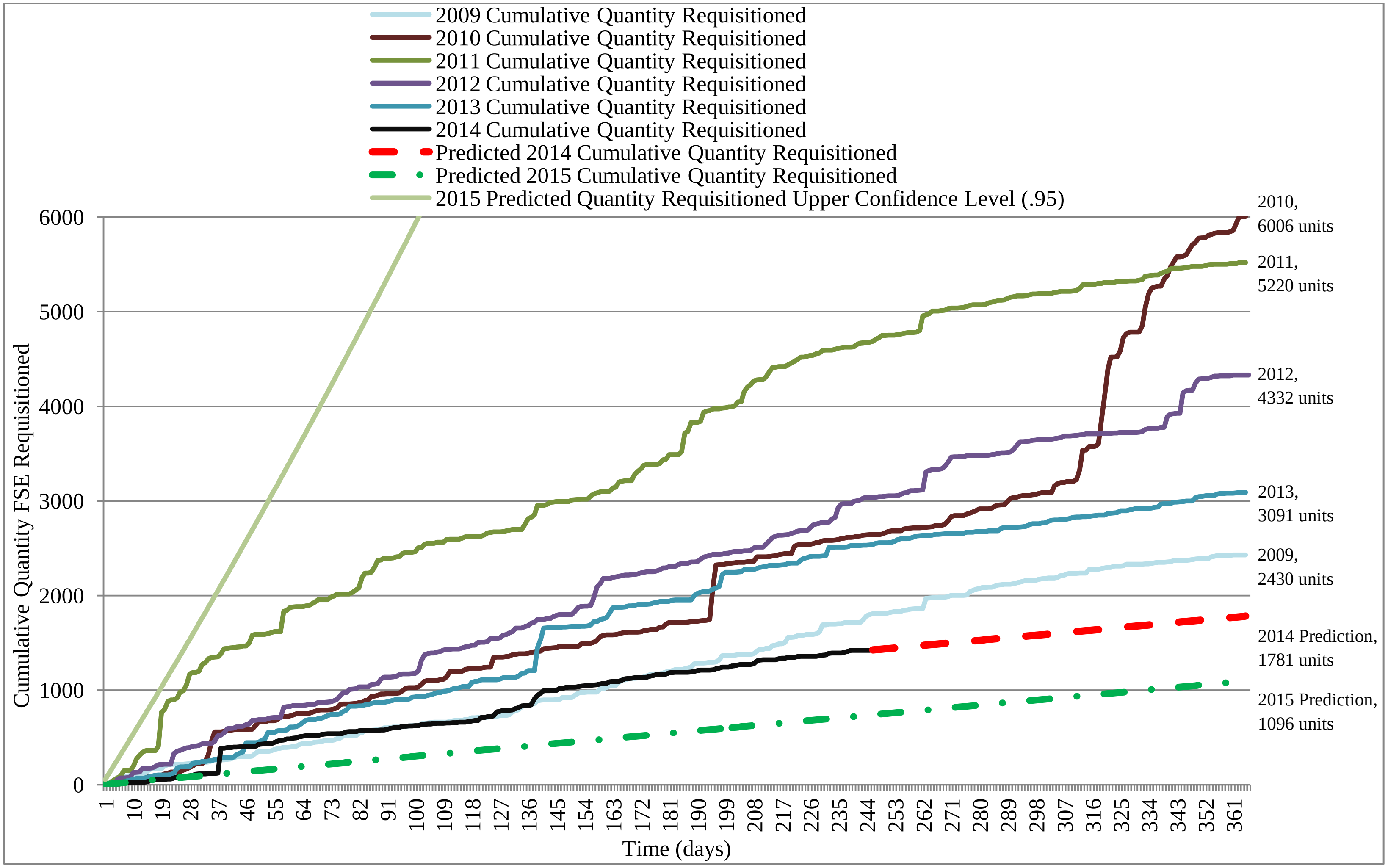


Figure 12 Comparison of Historical By Year Cumulative Quantity Requisitioned & Future Quantity Requisitioned

Investigative Question 4 Results

Investigative Question 4. What are the associated costs to next year's forecasted FSE requisitions?

In the previous section 2015 FSE Requisitions are forecasted using SES on Bi-annual Aggregated FSE Requisitions with the results conforming to historical trends. The next step in this study is applying this knowledge to calculate associated costs with the forecasted 2015 FSE Requisitions. The calculated value of forecasted FSE requisitions for 2015 is $74.2M. Figure 13 is a comparison of cumulative value of FSE requisitioned by year. That is, the total cost of requisitions for each year observed and forecasted. The cumulative cost follows the same pattern as cumulative quantity. The year 2009 saw a relatively smaller quantity requisitioned which corresponds to a lower cost requisitioned. In 2010 and 2011, though, there are significant increases in quantity requisitioned and increases in corresponding costs. After which there is a steady decline in quantity requisitioned and associated costs. If this trend continues, as is predicted by the SES forecast, then 2015 will see the lowest quantity of FSE requisitioned and lowest associated costs in the past seven years.

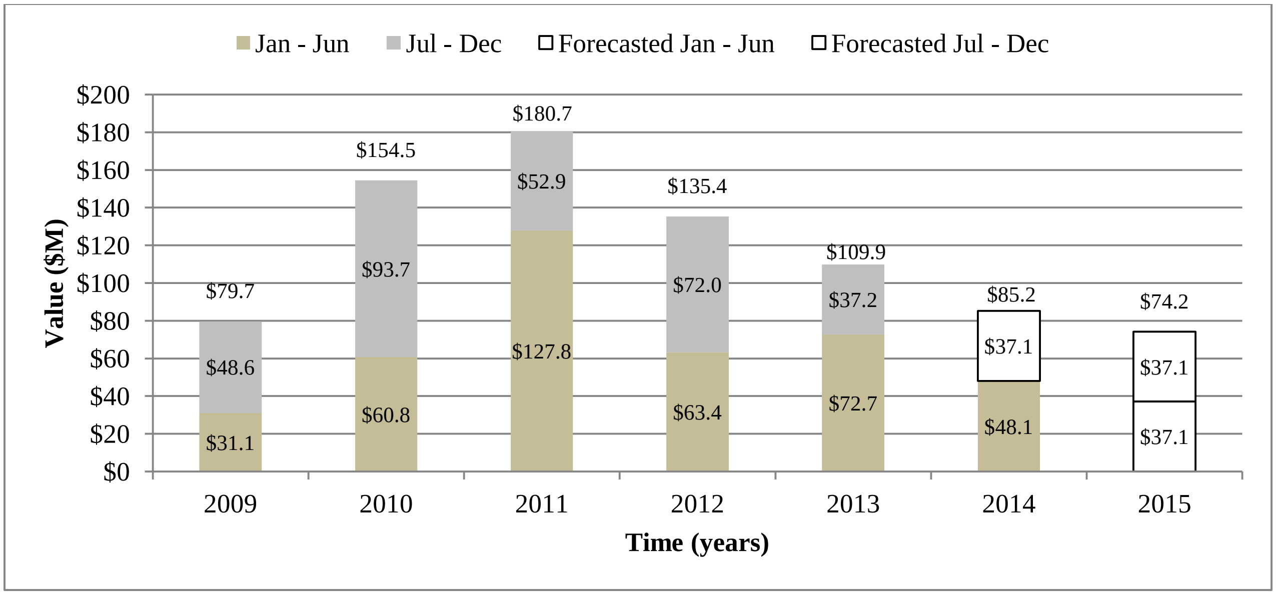


Figure 13 Comparison of Historical Value of Annual Requisitions to Forecasted Values

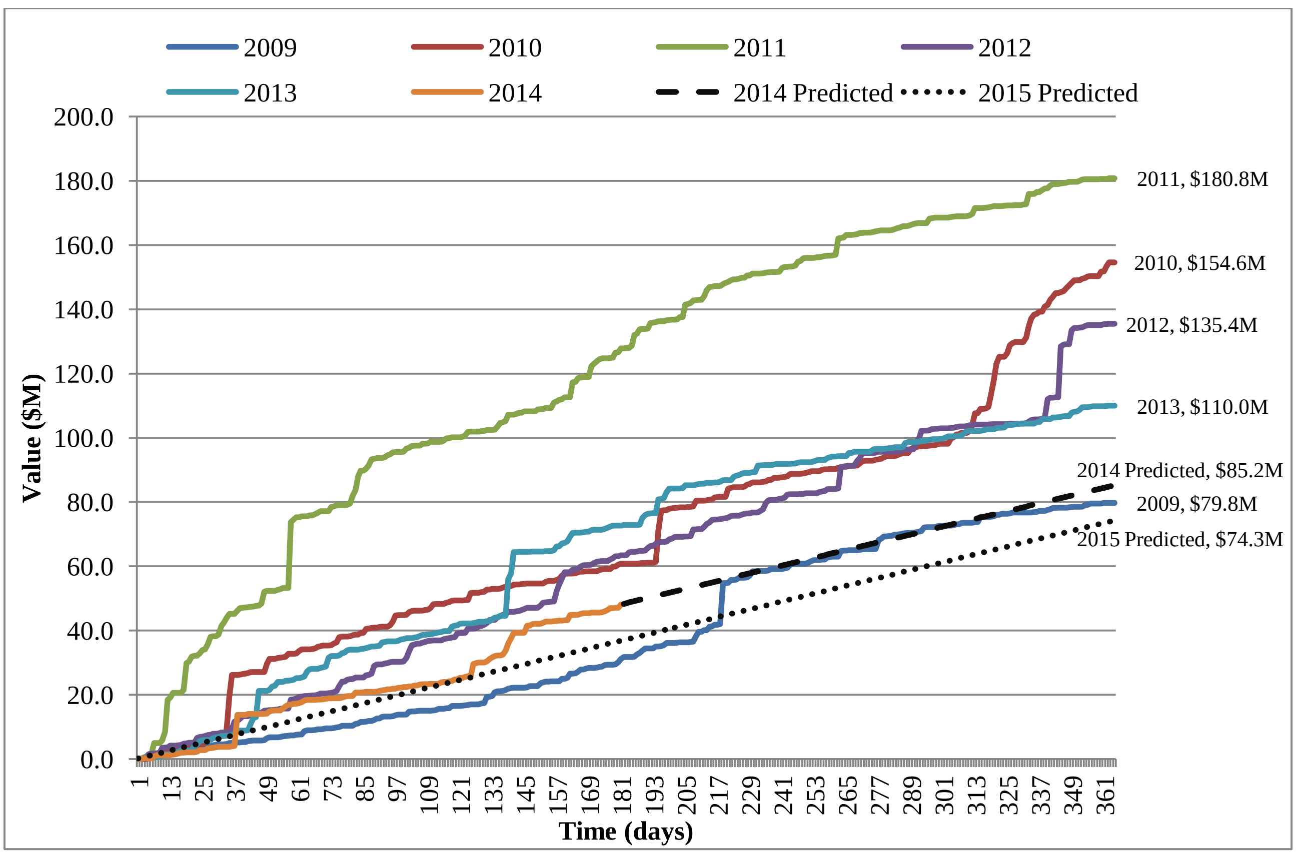


Figure 14 Comparison of Historical Daily Cumulative Values to Forecasted Values

Summary

The results of this research provide several key findings. First, the demand for FSE does not follow a theoretical probability distribution. Because of this, the demand distribution of each aggregation is described using the quartile distribution. This provides a statistical description of FSE demand which can be used for modeling or future research. Second, this research identified the type of demand pattern exhibited by FSE. That is, FSE requisitions are intermittent at the daily level. This is an important finding in terms of further describing the FSE inventory system. Third, the results indicate the usefulness of aggregation across both units and time when using SES to forecast intermittent demand. This result illustrate bi-annual aggregation provides the best forecast because the amount of variance is minimal compared to lower levels of aggregation (e.g. daily or weekly). Fourth, using the forecasted FSE requisitions and the average cost per FSE item, a forecast of expected costs can be made.

V. CONCLUSION

In the field of forecasting, the literature recommends utilizing simple exponential smoothing to forecast items that exhibit intermittent, or non-continuous, demand. This study applies simple exponential smoothing to historical FSE requisitions to forecast Air Force FSE Requisitions for 2015. Additionally, the associated costs of this forecast are calculated. The purpose of this study is to determine if simple exponential smoothing is appropriate for anticipating future FSE requisitions and associated costs, as the literature suggests. The results of this study do not support the literature reviewed. This study found that simple exponential smoothing does not provide enough detail to account for various changes in demand size over time.

Impact

The Air Force's equipment management system does not specifically budget for FSE requisitions. Instead, FSE requisitions are paid for through a pooled fund which is used to acquire all Air Force equipment items. As the system currently works, all requisitions, FSE and non-FSE, are prioritized annually with items requisitioned according to priority and fund availability. The utility of this study is its ability to provide an improved capability to plan for FSE requisitions and associated costs. This forecast can then be integrated into the larger equipment management system to better manage equipment requisitions, funding, and better support the fuels mission.

Future Research

One area of future research is to review the current inventory strategy of the FSE inventory system. At the moment, the FSE inventory system operates under a (Q,S) strategy, where "Q" is continuous review and "S" is an order-up-to-level. It is recommended a traditional inventory analysis be conducted in the future to determine if the current (Q,S) strategy continues to be the appropriate option under current conditions.

This research utilized the simple exponential smoothing to forecast one year into the future. It is recommended a more nuanced approach, such as Autoregressive Integrated Moving Average (ARIMA) be introduced to future research. The use of ARIMA could, quite possibly, account for the rather large step-increases in FSE requisitions observed each year.

A purely statistical approach can also be utilized. Capturing all FSE requisitions throughout one year and grouping like items into categories can provide a relative frequency distribution for each category and item. Capturing historical FSE requisitions in this manner will potentially provide insight into future FSE requisitions; for example, using relative frequency to identify items that are likely to be requisitioned more than others.

Bibliography

AF/A4/7. (2011). *Air Force Policy Directive 23-1: Materiel Management.* Washington, D.C.: HQ USAF.

AF/A4L. (2014). *Air Force Instruction 23-201: Fuels Management.* Washington, D.C.: HQ USAF.

AF/A4L. (2013). *Air Force Pamphlet 23-221: Fuels Logistics Planning.* Washington, D.C: HQ USAF.

Babai, M. Z., Ali, M. M., & Nikolopoulos, K. (2012). Impact of Temporal Aggregation on Stock Control Performance of Intermittent Demand Estimators: Empirical Analysis. *Omega* , 713-721.

Babiloni, E., Cardos, M., Albarracin, J., & Palmer, M. (2010). Demand Categorisation, Forecasting, and Inventory Control for Intermittent Demand Items. *South African Journal of Industrial Engineering* , 115-130.

Banks, J., Carson II, J., Nelson, B. L., & Nicol, D. M. (2014). *Discrete-Event System Simulation.* New Dehli: Dorlin Kindersley.

Bowerman, B. L., O'Connell, R. T., & Koehler, A. B. (2005). *Forecasting, Time Series, and Regression: An Applied Approach.* Belmont: Brooks/Cole.

Chase Jr., C. W. (2013). *Demand-Driven Forecasting: A Structured Approach to Forecasting.* Hoboken: John Wiley & Sons, Inc.

Croston, J. (1972). Forecasting and Stock Control for Intermittent Demand. *Operational Research Quarterly* , 289-303.

Department of Defense. (2014). *Better Buying Power*. Retrieved October 30, 2014, from Defense Acquisitions University: http://bbp.dau.mil/index.html

Department of Defense. (2014, March 4). *Quadrennial Defense Review 2014.* Retrieved October 30, 2014, from Department of Defense: http://www.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf

Department of Defense. (2012, January 5). *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense.* Retrieved October 30, 2014, from Department of Defense: http://www.defense.gov/news/Defense_Strategic_Guidance.pdf

Dvoretzky, A., Kiefer, J., & Wolfowitz, J. (1952). The Inventory Problem: I. Case of Known Distributions of Demand. *Econometrica* , 187-222.

Fogarty, D., Blackstone, J., & Hoffmann, T. (1991). *Production & Inventory Management* (2d ed.). Cincinnati, OH: South-Western Publishing, Co.

Hines, W., Montgomery, D., Goldsman, D., & Borror, C. (2002). *Probability and Statistics in Engineering and Management Science.* New York: Wiley.

Laderman, J., & Littauer, S. (1953). The Inventory Problem. *Journal of the American Statistical Association* , 717-732.

Lockheed Martin Corporation. (2014). *Producing, Operating and Supporting a 5th Generation Fighter*. Retrieved November 20, 2014, from F-35: https://www.f35.com/about/fast-facts/cost

McClave, J. T., Benson, P. G., & Sincich, T. (2011). *Statistics for Business and Economics* (11th ed.). New York: Prentice Hall.

Muller, M. (2003). *Essentials of Inventory Management.* New York, NY: American Management Association.

Office of the Undersecretary of Defense/Chief Financial Officer. (2014, March). *United States Department of Defense Fiscal Year 2015 Budget Request Overview.* Retrieved October 30, 2014, from Department of Defense: http://comptroller.defense.gov/Portals/45/documents/defbudget/fy2015/fy2015_Budget_Request_Overview_Book.pdf

Prestwich, S., Tarim, S., Rossi, R., & Hnich, B. (2014). Forecasting Intermittent Demand by Hyperbolic-Exponential Smoothing. *International Journal of Forecasting* , 928-933.

Program Action Direct 12-02. (2013). *Implementation of the Secretary of the United States Air Force and Air Force Chief of Staff Direction to Implement the Air Force Installation Support Centralization Vehicle and Fuels Management Initiative.* Washington, D.C.: HQ USAF.

SAF/AQX. (2014). *Air Force Instruction 63-101/20-101: Integrated Life Cycle Management.* Washington, D.C.: HQ USAF.

SAS Institute Inc. (2015, January). *Fit Distributions*. Retrieved from JMP Online: http://www.jmp.com/support/help/Fit_Distributions.shtml#273232

Syntetos, A. A., & Boylan, J. E. (2010). On the Variance of Intermittent Demand Estimates. *International Journal of Production Economics* , 546-555.

Syntetos, A., & Boylan, J. (2001). On the Bias of Intermittent Demand Estimates. *International Journal of Production Economics ,* 457-466.

Syntetos, A., & Boylan, J. (2006). On the Stock Control Performance of Intermittent Demand Estimators. *International Journal of Production Economics ,* 36-47.

Syntetos, A., & Boylan, J. (2005). The Accuracy of Intermittent Demand Estimates. *International Journal of Forecasting* , 303-314.

Tersine, R. J. (1982). *Principles of Inventory and Materials Management.* New York: Elsevier North Holland, Inc.

USAF. (2014). *United States Air Force: Fiscal Year 2015 Budget Overview.* Retrieved from http://www.saffm.hq.af.mil/shared/media/document/AFD-140304-039.pdf

Viswanathan, S., Widiarta, H., & Piplani, R. (2008). Forecasting Aggregate Time Series with Intermittent Subaggregate Components: top-down versus bottom-up forecasting. *IMA Journal of Management Mathematics* , 275-287.

Wagner, H. M. (2002). And Then There Were None. *Operations Research , 50* (1), 217-226.

Wagner, H. M. (1962). *Statistical Management of Inventory Systems.* New York: John Wiley & Sons, Inc.

Appendix 1. Listing of FSE Items

NSN	Equipment Type	NOMENCLATURE
1560P03279044	22 TON JACK	TON JACK
1560P03279144	HUSQVARNA PRESSURE	HUSQVARNA PRESSURE
1560P03279244	MULTI METER	MULTI METER
1730002034697	JACK,AIRCRAFT LAND	JACK,AIRCRAFT LAND
1730003952781	MAINT PLAT 48E1691	MAINT PLAT 48E1691
1730013517409	TOWBAR,AIRCRAFT	TOWBAR
173001554366R	MAINTENANCE PLATFO	MAINTENANCE STAND
1730015544187	MAINTENANCE PLATFO	MAINTENANCE STAND
1730015554366	MAINTENANCE PLATFO	MAINTENANCE STAND
1730015554367	MAINTENANCE PLATFO	MAINTENANCE STAND
1940012156801	BOSTON, WHALER	16 FT BOAT; FIBERGLASS
1940012625743	MOTORBOAT	MOTORBOAT
1940PJ1720CC	BOAT,PERSONNEL	16 FT BOAT; FIBERGLASS
2330002948889	SA TLR MAINT 3 TON	UTILITY TRAILER
2330012459458	TRAILER,TANK	BOWSER 400 GAL
2330013004482	TRAILER,TANK	BOWSER 600 GAL
2330013004882	TRAILER, TANK	TRAILER, TANK
2330013010753	TRAILER,TANK	BOWSER 200 GAL
2330014643666	TRAILER,TANK	BOWSER 600 GAL
2330015585335	TRAILER,TANK	BOWSER 400 GAL
2330PKD7X12T2	HAULMARK TRAILER	UTILITY TRAILER
2330PUT612	FAO, UTILITY TRAIL	FAO, UTILITY TRAIL

2340005403900	SCOOTER22HP GED3WH	LOWSPEED VEHICLE
2340005403901	SCOOTER MOTOR	LOWSPEED VEHICLE
2340005857495	SCOOTER, MOTOR	LOWSPEED VEHICLE
234000587495	OGMVC	OGMVC
2805004934754	OUTBOARD MOTOR,GAS	BOAT
2805PF115XB	MOTOR, 115 HP 4 STR	
2835013901807	POWER UNIT,GAS TUR	APU
3120012217854	BEARING,SLEEVE	TOWBAR
3655000180312	TANK,STORAGE,LIQUI	TANK,STORAGE,LIQUI
3655000434062	TANK,STORAGE,LIQUI	TANK,STORAGE,LIQUI
3655004292896	PURGING UNIT,AIR	PURGE UNIT
3655005340564	GENERATING AND CHA	GENERATING AND CHA
3655005402733	TRAILER,COMPRESSED	TRAILER,COMPRESSED
3655009958575	TANK,STORAGE,LIQUI	TANK,STORAGE,LIQUI
3655010865358	TANK STORAGE LIQUI	2K LOX TANK
3655012233313	MULTIPLE SERVICE U	MULTIPLE SERVICE U
3655012458408	TANK, STORAGE, LIQUI	TANK, STORAGE, LIQUI
3655012521257	TANK,STORAGE,LIQUI	5K LIN
3655012637635	TANK STORAGE LIQUI	5K LIN
3655012815438	TANK,STORAGE,LIQUI	2K CRYO TANK
3655012888774	CHARGING GENERATOR	CHARGING GENERATOR
3655013080943	TANK,STORAGE,LIQUI	TANK,STORAGE,LIQUI
3655013536699	TANK,STORAGE,LIQUI	3K LOX
3655013536700	TANK,STORAGE,LIQUI	6K LOX
3655013536701	TANK,STORAGE,LIQUI	3K LIN

3655013536702	TANK,STORAGE,LIQUI	6K LIN
3655014592005	GENERATING PLANT	GENERATING PLANT
3655016012544	TANK,STORAGE,LIQUI	400 LOX
3655016041576	TANK, STORAGE LIQUI	500 LOX
3655P79025400		RECHARGER SYSTEM
3694010031777	WORK STATION CLEAN	WORK STATION CLEAN
3815PBR121DT	BOOM SYSTEM	BOOM SYSTEM
3835P30100022	PORTABLE CLOUD POI	PORTABLE CLOUD POI
3910004053453	CONVEYOR,ROLLER,GR	CONVEYOR,ROLLER,GRAVITY
3990014811162	CART MENDEZ ACCART	INJECTOR
4110PC2RDS454	REFRIGERATOR, ENVIR	REFRIGERATOR, ENVIR
4140003029534	FAN,CENTRIFUGAL	FAN,CENTRIFUGAL
4310000604742	VAC PUMP RECIPROCA	VACUUM PUMP
4310001319187	VACUUM PUMP UNIT,R	VACUUM LAB
4310004493724	VACUUM PUMP UNIT	
4310005401271	VACUUM PUMP UNIT,R	VACUUM LAB
4310005850511	VACUUM PUMP (NO SU	VACUUM LAB
4310006932653	COMPRESSOR UNIT,RE	AIR COMPRESSOR
4310008989959	VACUUM PUMP UNIT	VACUUM PUMP
4310008989960	VACUUM PUMP UNIT,R	VACUUM PUMP
4310008989961	VACUUM PUMP UNIT,	VACUUM PUMP
4310010410006	VACUUM PUMP(REP BY	VACUUM PUMP
4310010652955	COMPRESSOR, AIR	AIR COMPRESSOR
4310011593314	VACUUM PUMP,ROTARY	VACUUM PUMP
4310015428391	VACUUM PUMP UNIT,	VACUUM PUMP

4310015608709	COMPRESSOR UNIT,RO	AIR COMPRESSOR
4310015927565	COMPRESSOR UNIT,RO	COMPRESSOR UNIT,RO
4320000677587	PUMPING ASSEMBLY,F	PMU-27
4320001319185	PUMPING ASSEMBLY,F	R-22
4320010492396	EXTRACTOR,128000	CENTRIFUGAL PUMP
4320011170421	PUMPING ASSEMBLY,F	PMU-27
4320015442959	PUMPING ASSEMBLY,F	R-18
4430000527076	OVEN, THERMAL DRYIN	LAB OVEN
4520014761467	HEATER,DUCT TYPE,P	PORTABLE HEATER
4820009698216	AFEMS UNID STOCK N	TIRE DOLLY
4820P00001330	PRESSURE CONTROL V	PRESSURE CONTROL V
4910000864940	JACK, DOLLY TYPE, HY	20 TON JACK
4910001418966	LIFT,TRANSMISSION	TRANSMISSION JACK
4910002897233	JACK,DOLLY TYPE,HY	HYDRAULIC JACK DOLLY
4910005545983	TRUCK,LIFT,WHEEL	TRUCK,LIFT,WHEEL
4910005853622	LIFT,TRANSMISSION	TRANSMISSION JACK
4910008606587	JACK,DOLLY TYPE,HY	20 TON JACK
4910010092449	TRUCK,LIFT,WHEEL	TIRE JACK
4910011721399	DRAIN CART DO NOT	DRAIN KART HD06018
4910012000870	JACK,VEHICULAR,MUL	20 TON JACK
4910012253708	LIFT MOTOR VEH 130	VEHICLE LIFT
4920007786091	TEST SET,AIRCRAFT	F-15 C-130 TEST KIT
4920009176479	DRAIN KIT,LIQUID O	DRAIN KIT,LIQUID O
4930002221073	PUMP,LUBRICANT TRA	LUB PUMP
4930002878293	DISPENSING PUMP,HA	HAND PUMP

4930002945110	DISPENSING PUMP,HA	HAND PUMP
4930005406956	FUEL SERVICING UNI	HOSE CART
4930009357328	PUMPING ASSEMBLY,F	FFU-15E
4930010894581	FUEL SERVICING UNIT	HOSE CART
4930011392492	FUEL SERVICING UNI	HOSE CART
4930013889490	HYDRANT REFUELING	ABFDS W/ACE
4930013892212	HYDRANT REFUELING	ABFDS
4930013927988	FUEL SERVICING UNI	FUEL SERVICING UNI
4930014182694	INJECTOR,FUEL ADDI	INJECTOR
4930014337063	FILTER-SEPARATOR,L	FFU-15E
4930015219141	TANK UNIT,FUEL DIS	TASS
4930015264592	FUEL SERVICING UNI	FARP CART
4930015434717	SERVICING PLATFORM	R-20
4930015436231	FILTER-SEPARATOR	R-19
4930015439005	PLUMBING ASSEMBLY	R-21
4931007778520	THERMOMETERANSHUTZ	THERMOMETER SET
4940001860027	CLEANER,STEAM,PRES	PRESSURE WASHER
4940003005247	CLEANER,LIQUID HIP	PRESSURE WASHER
4940004068113	TEST BENCH,POP VAL	PRESSURE TEST BENCH
4940008422308	GO IMPAC/CLEANER P	GO IMPAC/CLEANER P
4940010644268	IMPAC CLEANER,PRES	PRESSURE WASHER
4940012438058	CLEANER,STEAM,PRES	PRESSURE WASHER
4940013330997	TESTER,HYDRAULIC H	HYDRAULIC HOSE TESTER
4940013584247	CLEANER, STEAM, PR	CLEANER, STEAM, PR
4940013584847	HYDROBLASTER, TRLR	HYDROBLASTER, TRLR

4940013597624	TESTER,HYDRAULIC H	HYDRAULIC HOSE TESTER
4940P100833	PRESSURE WASHER	PRESSURE WASHER
4940P3Z829	CLEANER,STEAM,PRES	PRESSURE WASHER
4940PHPKV2015	PRESSURE WASHER	PRESSURE WASHER
5130013414504	AFEMS UNID STOCK N	IMPACT GUN
5410013392233	BUILDING, PREFABRIC	BUILDING, PREFABRIC
5410L00000130	PRECAST STORAGE BU	PRECAST STORAGE BU
5410PRUB39.5X	LOGISTICS SHELTER	LOGISTICS SHELTER
5430001069417	TANK,FABRIC,COLLAP	3K BLADDER
5430006638330	TANK ST T1856	PETROLEUM STORAGE AND DISPENSING TANK
5430015178580	TANK, FABRIC COLLA	50K BLADDER
5810013603895	TELEPHONE SECURE U	STE PHONE
5810014596441	TELEPHONE,SECURE U	STE PHONE
5810015068896	PHONE, STE	STE PHONE
5810015293778	TELEPHONE,SECURE U	STE PHONE
5810015474520	ENCRYPTION R/B 581	TACLANE
5905009009174	AFEMS UNID STOCK N	BLACK HAWK HIGH LI
6115004208486	GENERATOR -60	GENERATOR -60
6115012561059	GENERATOR SET DIES	GENERATOR SET DIES
6115012853012	GENERATOR SET,DIESEL ENGINE	GENERATOR SET,DIESEL ENGINE
6115012961462	GENERATOR SET DIES	GENERATOR SET DIES
6115015617532	GENERATOR SET,DIES	GENERATOR SET,DIES
6115L00054050	COLEMAN POWERMATE	COLEMAN POWERMATE

6116P5PORFILT	PORTABLE COLD FILT	PORTABLE COLD FILT
6116PASTD5188	VAPOR PRESSURE TES	VAPOR PRESSURE TES
6150004710749	CABLE ASSEMBLY,SPE	CABLE ASSEMBLY,SPE
6150013886280	LOAD BANK,ELECTRIC	LOAD BANK,ELECTRIC
6230015270631	FLOODLIGHT SET,ELE	FLOODLIGHT SET,ELE
630PFPP5GS	CFPP ANALYZER	CFPP ANALYZER
6440P1305U	OVEN	OVEN
6440P13245615	OVEN, GRAVITY	OVEN, GRAVITY
6625010791762	MULTIMETER	MULTIMETER
6625011476182	MULTIMETER DIGITAL	MULTIMETER
6625012663494	MULTIMETER 8025B	MULTIMETER
6625P420A	MILLIVOLT METER	MILLIVOLT METER
6625P73111	MULTI-METER	MULTI METER
6625PLLHHG420	P/N 89536	
6625PMP329	ANALYZER FLASH POI	FLASH POINT TESTER
6625PSVM3000	VISCOMETER, STABING	VISCOMETER, STABING
6630000916958	TEST KIT,OIL CONDI	TEST KIT,OIL CONDITION
6630002223539	TESTING KIT,PETROL	JET FUEL THERMAL OXIDATION TESTER
6630002421343	TITRATOR/PRIME	TITRATOR
6630002613662	FLASH POINT TESTER	FLASH POINT TESTER
6630002614940	DISTILLATION TEST	DITILLATION TEST
6630003347416	METER	HYDROMETER SET, GRAD
6630003592213	COLORIMETER,COMPAR	COLORIMETER,COMPARATIVE
6630003599772	DISTILLATION TEST	DISTILLATION TEST

6630004042753	BATH, KINEMATIC VI	BATH,KINEMATIC VISCOSITY
6630004715676	METER PH DIG	METER PH DIG
6630005095236	MACHINE,GREASE WOR	MACHINE GREASE
6630005300987	TESTER(MEDICAL SUP	FLASH POINT TESTER
6630007293990	TEST BATH,VISCOSIM	TEST BATH,VISCOSIMETER,OIL
6630008301329	CONTAMINATION KIT	B-2 TEST KIT
6630008572279	CHROMOMETER 13-422	CHROMOMETER
6630010149767	METER,PH	METER,DENSITY,DIGITAL
6630010353921	ANALYZER S3AN22MR	OXYGEN ANALYZER
6630010486361	TESTING KIT,PETROL	CONDUCTIVITY METER
6630010490209	ANALYZER, OXYGEN	ANALYZER, OXYGEN
6630010700316	CHROMOMETER, REFIN	CHROMOMETER,REFINED OILS,SAYBOLT
6630010705774	RATER TUBE TDR200	RATER TUBE TDR200
6630010708876	TESTING KIT, PETRO	JET FUEL THERMAL OXIDATION TESTER
6630010726060	TESTING KIT,PETROL	TESTING KIT,PETROL
6630011152398	TESTING KIT, PETROL	CONDUCTIVITY METER
6630011226286	IN LINE SAMP	CONDUCTIVITY METER
6630011444643	TESTER,GASOLINE	TESTER,GASOLINE
6630011493999	ANALYZER,TRACE HYD	ANALYZER,TRACE HYDROCARBONS
6630011516742	CHROMATOGPH SYS GAS	CHROMATOGPH SYS GAS
6630011532088	MELTING POINT APPA	MELTING POINT APPARATUS,ELECTRIC
6630011565826	TESTING KIT, PETRO	COOLING BATH

6630011657133	TESTING KIT,PETROL	B-2 TEST KIT
6630011676589	AFEMS UNID STOCK N	TEST BATH,OIL OXIDATION STABILITY
6630011874031	SPECTROMETER 4000	SPECTROMETER 4000
6630012259729	AFEMS UNID STOCK N	AFEMS UNID STOCK N
6630012681630	CALORIMETER	CALORIMETER
6630012681670	CHROMATOGRAPH,GAS	CHROMATOGRAPH,GAS
6630012684598	DISTILLATION TEST	DISTILLATION TEST
6630012689610	DETECTOR,AIR,ELECT	DETECTOR,AIR,ELECTROLYTE ANALYZER
6630012764339	TESTING KIT,PETROL	TESTING KIT,PETROL
6630012934324	TITRATOR	TITRATOR
663001296644R	TESTER, FLASH POIN	TESTER, FLASH POIN
6630012976643	TESTER,FLASH POINT	FLASH POINT TESTER
6630012976644	TESTER, FLASH POINT	FLASH POINT TESTER
6630013208789	ANALYZER, OXYGEN	ANALYZER, OXYGEN
6630013581564	TESTING KIT,PETROL	TESTING KIT,PETROL
6630014107374	VAPOR PRESSURE APP	VAPOR PRESSURE APP
6630014402975	TESTING KIT,PETROL	B-2 TEST KIT
6630015581811	TESTER,FLASH POIN	FLASH POINT TESTER
6630015601529	DISTILLATION TEST	DISTILLATION TEST APPARATUS,PETROLEUM
6630016224620	TESTER, FLASH POINT	
6630L00118923	ANALYZER, TRACE SN	
6630P00177648	0741004901 FLASH T	0741004901 FLASH T
6630P01478825	P8802-46-0-20-00-1	P8802-46-0-20-00-1

6630P01500825	P5890A W/OPTANALYZ	P5890A W/OPTANALYZ
6630P01558625	OXY ANAYL 02 READI	OXY ANAYL 02 READI
6630P02400	EVAPORATOR	EVAPORATOR
6630P1112000	PH METER	PH METER
6630P13451	PETRO COLORMETER	PETRO COLORMETER
6630P135428	BATH	BATH
6630P1547425	WATER BATH 10”X12”	WATER BATH 10”X12”
6630P26000	LOW TEMPERATURE VI	
6630P29050010	AUTOTITRATOR	
6630P340000	TESTER,FLASH POINT	FLASH POINT TESTER
6630P350325	ANLYZR SLFR-IN-OIL	ANLYZR SLFR-IN-OIL
6630P6890N	GAS CHROMATOGPH/OP	GAS CHROMATOGPH/OP
6630P7119F25	TESTER FLASHPOINT	
6630P74804	GUM BATH O-600F	GUM BATH
6630P7551	ANALYZER OXYGEN	ANALYZER OXYGEN
6630P7890	GAS CHROMATOGPH	GAS CHROMATOGPH
6630P950FASTQ	ORION 950,TITRATOR	ORION 950,TITRATOR
6630PCPAT30	PORTABLE CLOUD POI	CLOUD POINT TESTER
6630PDMA5000	METER,CONCENTRATIO	METER,CONCENTRATIO
6630PDX500	CHROMATOGRAPH, ION	CHROMATOGRAPH, ION
6630PERASPEC	ANALYZER, FTIR FUEL	
6630PGEN2XR	SPECTROMETER, X-RAY	
6630PHP1050SY	CHROMATOGPH SYS/OP	CHROMATOGPH SYS/OP
6630PHP6890SY	GAS CHROMATOGPH/OP	GAS CHROMATOGPH/OP
6630PK233A	BATH, VISCOSITY	BATH, VISCOSITY

6630PK27100A	CARBON RES APP	CARBON RES APP
6630PK29790	FREEZE POINT BATH,	
6630PK33780	BATH,GUM	TEST GUM BATH
6630PK33800	BATH GUM	
6630PK35100	TEAT BATH, OIL	TEAT BATH, OIL
6630PMKC500	TITRATOR	TITRATOR
6630PMKC510	TITRATOR AUTO ACID	TITRATOR AUTO ACID
6630PRTE111	BATH, REFRIGERATED	BATH, REFRIGERATED
6630PTM1A	ANALYZER,OXYGEN	ANALYZER,OXYGEN
6630PVAP79000	RAPID EVAPORATOR	RAPID EVAPORATOR
6630PX2GPIR	ANALYZER, CO2	ANALYZER, CO2
6635000384323	ANALYZER,PARTICLE	ANALYZER,PARTICLE
6635004616035	X-RAY DIFFRACTOMET	X-RAY DIFFRACTOMET
6635005785286	TESTER,SPRING RESI	SPRING TESTER
6635010446182	TESTER,LUBRICANT	TESTER,LUBRICANT
6635011291046	ANALYZER, SULFUR AN	ANALYZER, SULFUR AN
6635011491436	DETECTOR KIT,WATER	WATER DETECTOR KIT
6635011563927	PROBE,ULTRASONIC	ULTRASONIC PROBE
6635011579173	TESTER, PRESSURE,	LUBRICANT PRESSURE TESTER
6635011679546	TESTER, GREASE, DR	TESTER,GREASE,DROPPING POINT
6635015007182	METER, DENSITY, DIGI	METER, DENSITY, DIGI
6635P400	TESTER, JET THERMAL	
6635PDX300	OVEN,LABORATORY	LAB OVEN
6635PPSA70X	ANALYZER,FREEZE PO	ANALYZER,FREEZE PO
6635PTWINXULS	ANALYZER, SULFUR	ANALYZER, SULFUR

6636004806493	TEST, SET, CORROSI	CHAMBER,ENVIRONMENTAL TESTING
6640000039673	CABINET LAB 973-55	CABINET LAB 973-55
6640000099467	HOOD,FUME,LABORATO	FUME HOOD
6640000702627	VIEWER,FREE WATER	AEL VIEWER
6640000702927	VIEWER, FREE WATER	VIEWER, FREE WATER
6640000899457	HOT PLATE,ELECTRIC	HOT PLATE, ELECTRIC
6640000945582	CABINET,LABORATORY	LAB CABINET
6640001655749	OVEN,LABORATORY	LAB OVEN
6640001843685	TST BATH S67097B	BATH,CONSTANT TEMPERATURE
6640001892557	BATH CORROSON 7503	BATH,CONSTANT TEMPERATURE
6640002260634	CABINET,H18878	LAB CABINET
6640002700763	STEAM WASHER	STEAM WASHER
6640002726484	FUME, EXHAUST HOOD	FUME HOOD
6640002816182	DISH, EVAPORATING	DISH, EVAPORATING
6640003599628	FOAM TEST APPARATU	FOAM TEST APPARATUS,LABORATORY
6640004129008	CENTRIFUGE LAB SZ	CENTRIFUGE LAB SZ
6640004213900	DO NOT B/O MEDICAL	DO NOT B/O MEDICAL
6640004357120	AFEMS UNID STOCK N	AFEMS UNID STOCK N
6640004404916	DISTILLING APPARAT	WATER DISTILER
6640004506563	CABINET, DESICCATIN	CABINET, DESICCATIN
6640004711218	CABINET 35-3/4X35I	CABINET 35-3/4X35I
6640004711232	CUPBOARD 47X35I	CUPBOARD 47X35I
6640004715685	SHAKING MACHINE LA	SHAKING MACHINE LA

6640004715689	FURNACE F-A10500P	FURNACE F-A10500P
6640004767933	CABINET 5DWRS 35I	CABINET 5DWRS 35I
6640004832826	SHAKING MACHINE,LA	SHAKING MACHINE,LABORATORY
6640004886246	CABINET LAB	CABINET LAB
6640004899162	CAB 35-3/4X25-15/1	CAB 35-3/4X25-15/1
6640004903240	TABLE,BALANCE,LABO	LAB TABLE BALANCE
6640004909383	CABINET LAB	CABINET LAB
6640005015496	OVEN, LABORATORY	LAB OVEN
6640008268649	TABLE,BALANCE,LABO	LAB TABLE BALANCE
6640008569588	TOP, LABORATORY TA	TOP, LABORATORY TA
6640008569591	NM DRAWER UNIT	LAB DRAWER
6640008569593	SINK UNIT,LABORATO	LAB SINK
6640009923114	FURNACE, MUFFLE, L	FURNACE, MUFFLE
6640010033087	SINK UNIT	SINK UNIT
6640010110606	GENERATOR,HYDROGEN	GENERATOR,HYDROGEN
6640010235723	OVEN LABORATORY	LAB OVEN
6640010367647	OVEN,LABORATORY	LAB OVEN
6640010374415	HOOD FUME 16-309	FUME HOOD
6640010701425	BATH, CONSTANT TEMP	
6640010701434	BALANCE TABLE	BALANCE TABLE
6640010701477	CABINET 30.75X47X1	LAB CABINET
6640010702307	HOOD FUME 93-470	
6640010785366	BATH,CONSTANT TEMP	BATH,CONSTANT TEMP
6640010803997	COOLER AY	COOLER AY
6640010876776	OVEN, LABORATORY	AIR COMPRESSOR

6640011024284	GENERATOR HYDR 832	GENERATOR HYDR 832
6640011327223	GENERATOR,GAS ENVE	PURE AIR GENERATOR
6640011459569	WATER BATH,ELECTRI	WATER BATH,ELECT
6640011566581	COMBUSTION BOMB, L	COMBUSTION BOMB,LABORATORY
6640011644915	CABINET, CONSTANT	CABINET,CONSTANT TEMPERATURE
6640011837195	BATH,CONSTANT TEMP	BATH,CONSTANT TEMP
6640012122078	METER,DENSITY,DIGI	DIGITAL METER,DENSITY
6640012624475	MAG STIR11-493-310	STIRRER-HOT PLATE,MAGNETIC,LABORATORY
6640012695485	HOOD,FUME,LABORATO	FUME HOOD
6640012695487	HOOD,FUME,LABORATO	HOOD,FUME,LABORATO
6640012695512	ROTARY EXTRACTOR	ROTARY EXTRACTOR
6640012699925	BATH,CONSTANT TEMP	BATH,CONSTANT TEMP
6640014923500	BATH,CONSTANT TEMP	CONSTANT TEMP BATH,
6640P028241	BAROMETER MERCUIA	BAROMETER MERCUIA
6640P03388320	P/N MSD-2777	HOT PLATE, ELECTRIC
6640P1100	HPLC	HPLC
6640P11429AB	CARBON COATER	CARBON COATER
6640P11430	COATER, SPUTTER	COATER, SPUTTER
6640P2804	COPPER, CORROSION B	
6640P2814	COPPER, CORROSION B	
6640P2818	COPPER, CORROSION B	
6640P51220121	OVEN, PRECISION	OVEN, PRECISION
6640P516G	OVEN LAB 120V/50/6	LAB OVEN

6640P6795600D	HOT PLATE MOD	HOT PLATE MOD
6640P7165	CENTRIFUGE 120V IE	CENTRIFUGE 120V IE
6640PAQUAVUL T	HYDROMETER, AUTO	HYDROMETER, AUTO
6640PCT2000	SYSTEM, PCS AUTOMA	
6640PD4641	WATER PURIFIER	WATER PURIFIER
6640PF47925	FURNACE, MUFFEL	FURNACE, MUFFEL
6640PFPP5GS	TESTER, COLD FILTER	
6640PGTV001	MICROSCOPE, AUTO	
6640PHS501	LABORATORY SHAKER	
6640PK27000	LAMP, SMOKE POINT	
6640PMINIAVX	VISCOMETER, AUTOMA	VISCOMETER, AUTOMA
6640PMINIVAPV	TESTER,VAPOR PRESS	VAPOR PRESSURE TESTER
6640PPSA70X	ANALYZER, CP98FP	ANALYZER, CP98FP
6640PQMS100	ANALYZER, TRACE GAS	
6640PSE2ULTRA	BALANCE, MICRO	BALANCE, MICRO
6640PSH10050G	HOOD EXH FUME 5FT	FUME HOOD
6640PSH100606	HOOD EXH FUME	FUME HOOD
6640PSIZE2	INTERNATIONAL EQUI	
6640PTRACESNC	ANALYZER, SONAR	ANALYZER, SONAR
6650000713101	LIGHT,MICROSCOPE	LAMP MICROSCOPE
6650000713102	MICROSCOPE,OPTICAL	MICROSCOPE
6650002293790	MICROSCOPE,OPTICAL	MICROSCOPE
6650002633552	REFRACTOMETER 1007	REFRACTOMETER
6650002963329	MICROSCOPE OPTICAL	MICROSCOPE OPTICAL

6650005300021	MICROSCOPE,OPTICAL	MICROSCOPE
6650005665190	MICROSCOPE, OPTICAL	MICROSCOPE
6650007248258	MICR OPTI TBV8	MICROSCOPE,OPTICAL
6650009736945	MICROSCOPE OPTICAL	MICROSCOPE
6650010795575	MICROSCOPE,OPTICAL	MICROSCOPE,OPTICAL
6650010805483	MICROSCOPE, OPTICAL	
6650011730427	SPECTROMETER INFRA	SPECTROMETER DIFFRACTION GRATING
6650012295751	REFRACTOMETER,HBR1	REFRACTOMETER
6650012689701	SPECTROMETER INFRA	SPECTROMETER DIFFRACTION GRATING
6650012689702	SPECTROMETER,DIFFR	SPECTROMETER,DIFFRACTION GRATING
6650012769404	MICROSCOPE, OPTICA	MICROSCOPE,OPTICAL
6650013080445	SPECTROPHOTOMETER	SPECTROPHOTOMETER SYSTEM
6650013204283	SPECTROMETER,DIFFR	SPECTROMETER,DIFFRACTION GRATING
6650013488147	SPECTROPHOTOMETER	SPECTROPHOTOMETER
6650015198473	AFEMS UNID STOCK N	AFEMS UNID STOCK N
6650L00006246	MICROSCOPE, BINOCUL	MICROSCOPE, BINOCUL
6650L00033546	MICROSCOPE, BINOCUL	MICROSCOPE, BINOCUL
6650P00085455	MICROSCOPE, OPTICA	
6650P420SEM11	SCOPE ELECTRON SCA	SCOPE ELECTRON SCA
6650PFS193001	MICROSCOPE,OPTICAL	MICROSCOPE
6650PNPNBMAX	MICROSCOPE	MICROSCOPE
6650PXL64831	MICROSCOPE	MICROSCOPE

6660PPA70V	CLOUD-POUR-FREEZE	CLOUD-POUR-FREEZE
6665009416554	COMBUSTIBLE GAS IN	COMBUSTIBLE GAS INDICATOR
6665011157666	ALARM GAS AUTO POR	GAS SNIFFER
6665015069002	TESTER,LEAKAGE,PRO	PROTECTIVE MASK
6665P01558225	HYDROCARBON ANYLZR	HYDROCARBON ANYLZR
6670002389765	BALANCE,ANALYTICAL	ANALYTICAL BALANCE
6670002433694	BALANCE,ANALYTICAL	ANALYTICAL BALANCE
6670002832415	BALANCE,ANALYTICAL	ANALYTICAL BALANCE
6670004901569	BALANCE ANALYTICAL	ANALYTICAL BALANCE
6670009889301	ANALYTICAL BALANCE	ANALYTICAL BALANCE
6670010805872	BALANCE,TORSION	BALANCE,TORSION
6670010918923	TORSION BALANCE	BALANCE,TORSION
6670011041773	BALANCE,TORSION	TORSION BALANCE
6670011146067	BALANCE ANALYTICAL	ANALYTICAL BALANCE
6670011571647	BALANCE,TORSION	TORSION BALANCE
6670011960054	ANALYTICAL BALANCE	ANALYTICAL BALANCE
6670011960056	ELECTRONIC BALANCE	ELECTRONIC BALANCE
6670012517858	BALANCE,ANALYTICAL	ANALYTICAL BALANCE
6670013584888	BALANCE ANALYTICAL	BALANCE ANALYTICAL
6670P04157065	ANALYTICAL BALANCE	ANALYTICAL BALANCE
6670P163ELECT	ANALYTICAL BALANCE	ANALYTICAL BALANCE
6670PAE100	BALANCE,ANALYT 115	BALANCE,ANALYT 115
6670PAT201	BALANCE ANAYL 0.20	ANALYTICAL BALANCE
6670PAT261	BALANCE ANAL DUAL	BALANCE ANAL DUAL
6670PB125412	BALANCE,ANALYTICAL	ANALYTICAL BALANCE

6670PHFP329	TESTER, FLAMMABILIT	TESTER, FLAMMABILIT
6670PVP114CN	BALANCE,TORSION	TORSION BALANCE
6680000411161	TANK TESTING PROVI	PROVER TANK
6680009075692	METER,GAS VOLUME,W	METER,GAS VOLUME,WET TEST
6680011179913	METER,FLOW RATE IN	DUAL EFFICIENCY METER
6680013806577	TEST SET,FLOW RATE	MASTER METER
6685001159602	INDICATOR,VACUUM	VACUUM GAGE
6685003245847	HYD PRESS TS MP-1	PRESSURE GAUGE TESTER
6685005575597	MANOMETERFA134	MANOMETER,VERTICAL TUBE
6685007641137	HYGROTHERMOG OBS W	HYGROTHERMOGRAPH
6685010897261	REGULATOR, TEMPERAT	REGULATOR, TEMPERAT
6685013695270	INDICATOR,TEMPERAT	MULTIMETER
6685015490278	HYGROTHERMOMETER, D	HYGROTHERMOMETER, D
6685P1515	GAUGE, THERMOCOPLE	GAUGE, THERMOCOPLE
6685P7391K2	METER,OHM	METER,OHM
6685PK29790	ANALYZER, FREEZE PO	
6685PPSA70XGS	PORTABLE POINT ANA	
6685PSADPTR	DEWPOINT, METER	DEWPOINT, METER
6695011015691	SAMPLER,LIQUID	CRYO SAMPLER
6695PA1036	TESTER, DEW POINT	TESTER, DEW POINT
6910P00006030	400 GALLON TANK	400 LOX
6910P00012430	SA AIRCRAFT FUELS	SA AIRCRAFT FUELS
6910P01096130	SR TNR TFT 85	SR TNR TFT 85
6910P01096230	SR TNR TFT 84	SR TNR TFT 84

6910P20122540	SA TRN R-11 FILTER	SA TRN R-11 FILTER
7050012982515	INTEGRATOR	INTEGRATOR
8145008721285	OBS W/O SHIPPING &	SHIPPING AND STORAGE CONTAINER
8145011189872	SHIPPING AND STORA	MOBILITY BIN
8145011189873	SHIPPING AND STORA	SHIPPING AND STORA
8145011189884	SHIPPING AND STORA	SHIPPING AND STORAGE CONTAINER
8145014654160	SHIPPING & STORAGE	SHIPPING & STORAGE

Appendix 2. Descriptive Statistics of the Aggregated Data Sets

<u>Daily Aggregation of FSE Requisitions</u>

Table 11. Descriptive Statistics Quantity per Requisition

Mean	2.323448487
Standard Error	0.045046128
Median	1
Mode	1
Standard Deviation	4.462295894
Sample Variance	19.91208464
Kurtosis	192.255702
Skewness	11.48269012
Range	126
Minimum	1
Maximum	127
Sum	22800
Count	9813
Largest(1)	127
Smallest(1)	1
Confidence Level(95.0%)	0.088299678

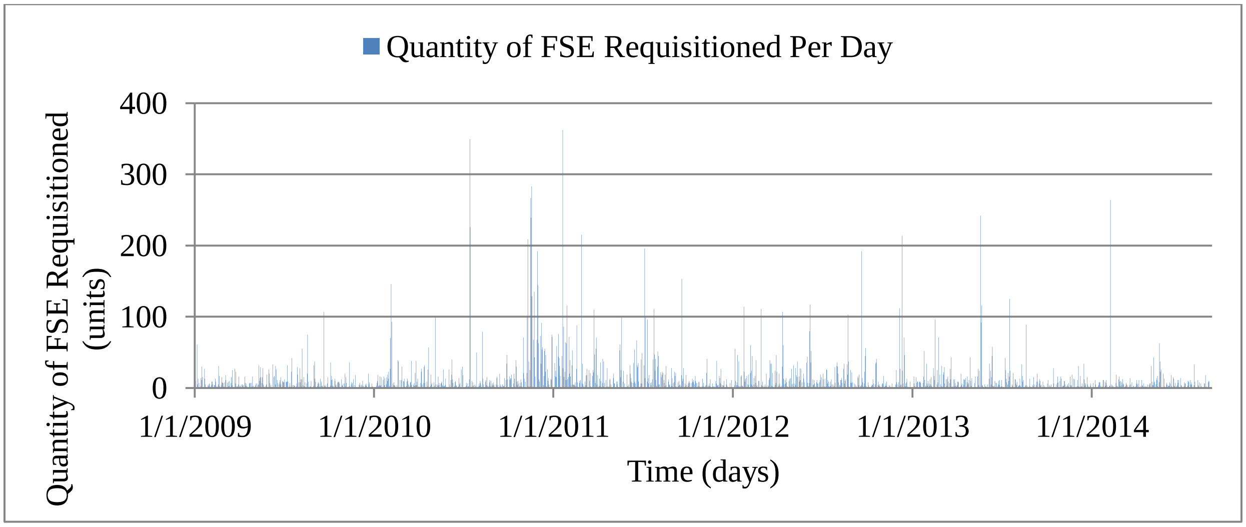


Figure 15. Daily Aggregated FSE Requisitions (1/1/2009 – 9/2/2014)

Table 12. Descriptive Statistics Value per Requisition

Mean	$73,100.60
Standard Error	$2,843.19
Median	$30,000.00
Mode	$17,000.00
Standard Deviation	$281,647.65
Sample Variance	$79,325,401,134.24
Kurtosis	1,825.43
Skewness	33.47
Range	$18,122,842.00
Minimum	$383.00
Maximum	$18,123,225.00
Sum	$717,336,205.34
Count	9813
Largest(1)	$18,123,225.00
Smallest(1)	$383.00
Confidence Level(95.0%)	$5,573.23

Inter-Demand

Table 13. Descriptive Statistics FSE Requisitions Inter-Demand Time

Mean	1.3938
Standard Error	0.02213
Median	1
Mode	1
Standard Deviation	0.85209
Sample Variance	0.72606
Kurtosis	5.87189
Skewness	2.39422
Range	6
Minimum	1
Maximum	7
Sum	2067
Count	1483
Largest(1)	7
Smallest(1)	1
Confidence Level(95.0%)	0.0434

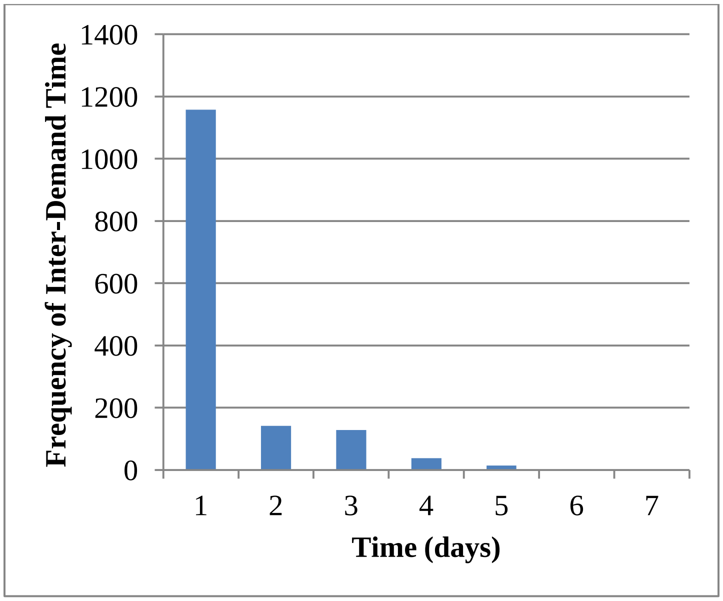


Figure 16. Histogram of FSE Requisitions Inter-Demand Time

Weekly Aggregation of FSE Requisitions

Table 14 Weekly FSE Requisitions Descriptive Statistics

Mean	76.7677
Standard Error	5.23685
Median	48
Mode	35
Standard Deviation	90.2502
Sample Variance	8145.1
Kurtosis	21.7961
Skewness	3.78529
Range	853
Minimum	0
Maximum	853
Sum	22800
Count	297
Largest(1)	853
Smallest(1)	0
Confidence Level(95.0%)	10.3062

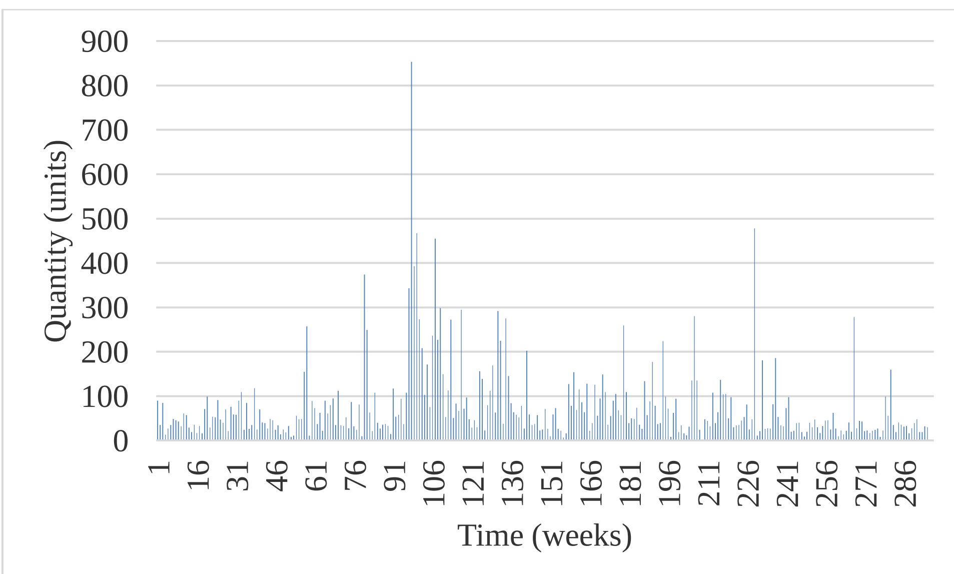


Figure 17 Weekly Aggregated FSE Requisitions (1/1/2009 – 9/2/2014)

Monthly Aggregation of FSE Requisitions

Table 15. Monthly FSE Requisitions Descriptive Statistics

Mean	335.29
Standard Error	34.93
Median	250
Mode	207
Standard Deviation	288.07
Sample Variance	82986.44
Kurtosis	18.07
Skewness	3.64
Range	1932
Minimum	96
Maximum	2028
Sum	22800
Count	68
Largest(1)	2028
Smallest(1)	96
Confidence Level(95.0%)	69.72

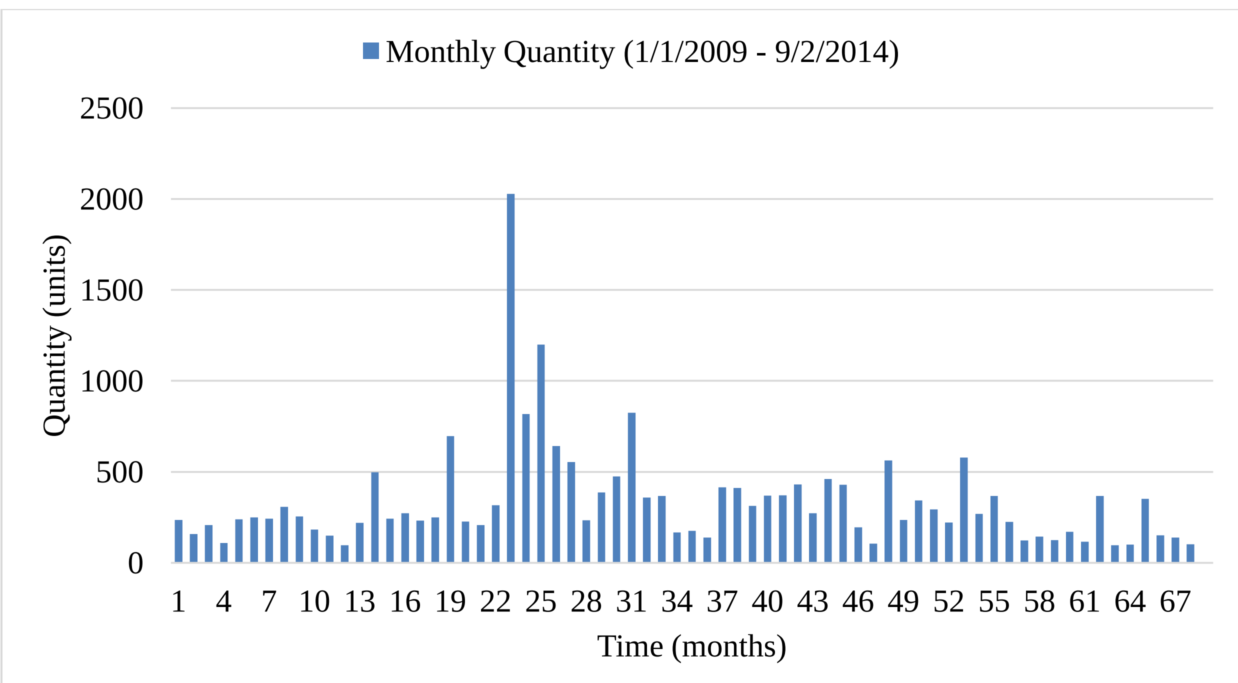


Figure 18. Monthly Aggregated FSE Requisitions (1/1/2009 – 9/2/2014)

Bi-Annual Aggregation of FSE Requisitions

Table 16. Bi-annual FSE Requisitions Descriptive Statistics

Mean	2050.90
Standard Error	305.15
Median	1939
Mode	#N/A
Standard Deviation	1012.08
Sample Variance	1024320.7
Kurtosis	1.37
Skewness	1.37
Range	3140
Minimum	1152
Maximum	4292
Sum	22560
Count	11
Largest(1)	4292
Smallest(1)	1152
Confidence Level(95.0%)	679.92

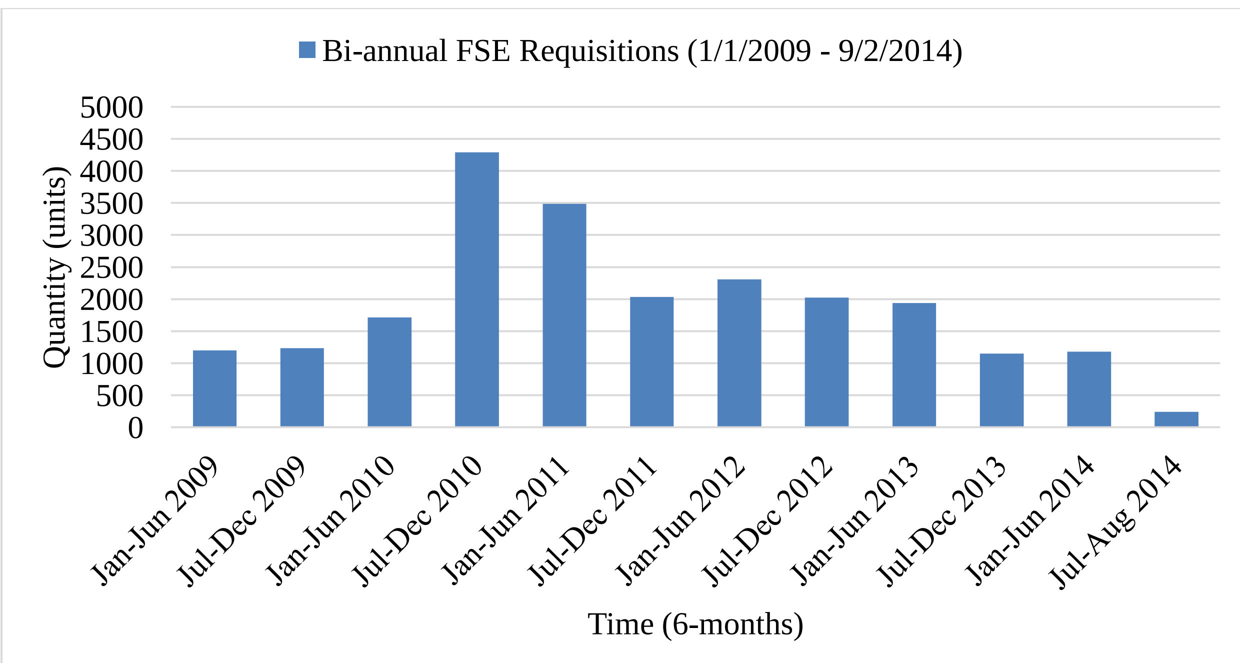


Figure 19. Bi-annual Aggregated FSE Requisitions (1/1/2009 – 9/2/2014)

Annual Aggregation of FSE Requisitions

Table 17. Annual FSE Requisitions Descriptive Statistics

Mean	4275.80
Standard Error	683.94
Median	4332.00
Mode	#N/A
Standard Deviation	1529.34
Sample Variance	2338878.20
Kurtosis	-2.30
Skewness	-0.10
Range	3576.00
Minimum	2430.00
Maximum	6006.00
Sum	21379.00
Count	5.00
Largest(1)	6006.00
Smallest(1)	2430.00
Confidence Level(95.0%)	1898.93

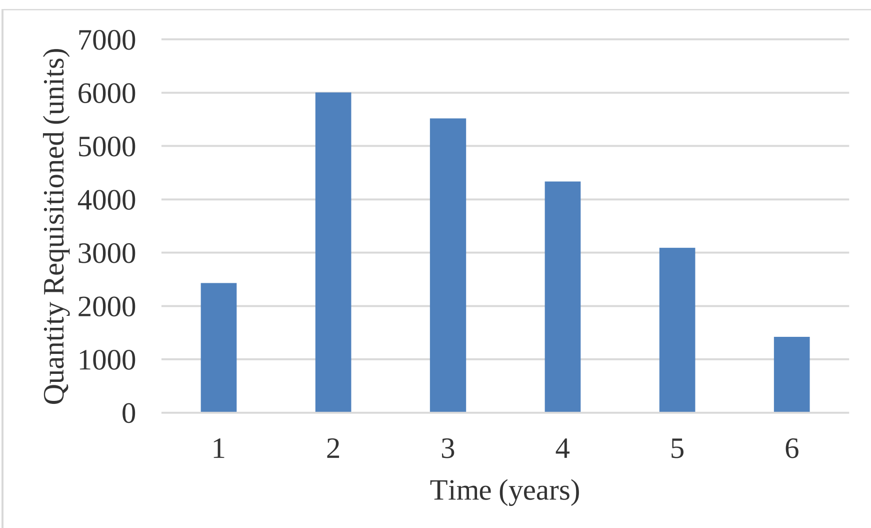


Figure 20. Annual Aggregated FSE Requisitions (1/1/2009 – 9/2/2014)

Appendix 3. Storyboard

Forecasting Fuels Support Equipment Requisitions

Capt Justin D'Agostino
Advisors:
Lt Col Joseph Huscroft
Lt Col Robert Overstreet
Department of Operational Sciences (ENS)

Introduction

The budget of the Department of Defense has been in decline since 2010 and is expected to continue well into the foreseeable future. The DoD is strategically responding to maintain national security capabilities despite this reality. One strategic response is to increase the buying power of DoD budgets used to sustain the force. One way to increase buying power is to improve understanding of the systems being sustained. One such system is the fuels support equipment (FSE) system. Within just CONUS Air Force bases, there are $26.5M worth of FSE in the inventory. A better understanding of how the FSE inventory behaves can help inform decision makers execute their budgets.

Research Question

Which forecasting method is most appropriate for forecasting fuels support equipment requisitions?

Investigative Questions

1. Can aggregated FSE requisitions be described using a theoretical probability distribution?
2. What type of demand does FSE requisitions exhibit and which forecasting method is appropriate given this demand type?
3. Using the identified forecasting method, what are next year's forecasted FSE requisitions?
4. What are the associated costs with next year's forecasted FSE requisitions?

Methodology

IQ 1: Goodness of fit test to discrete theoretical probability distributions

IQ 2: Categorization of Demand Test (developed by Babiloni, Cardos, Albarracin & Palmer, 2010)

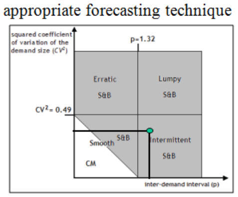
IQ 3: Use appropriate forecasting method based on type of demand identified

IQ 4: Multiply avg FSE cost by results of IQ 3.

Results

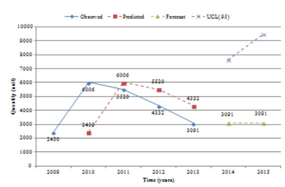
IQ 1: FSE Requisitions, both aggregated and non aggregated, do not follow a theoretical probability distribution

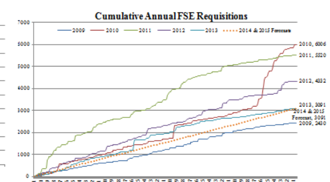
IQ 2: FSE Requisitions have intermittent demand implying simple exponential smoothing is the most appropriate forecasting technique



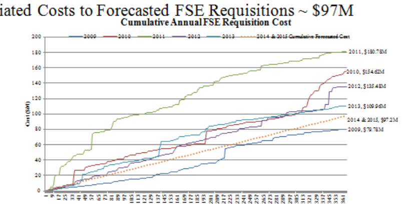
(Babiloni, Cardos, Albarracin & Palmer, 2010)

IQ 3: 2015 Forecasted Requisitions using Simple Exponential Smoothing (SES) ~ 3,091 FSE items requisitioned





IQ 4: Associated Costs to Forecasted FSE Requisitions ~ $97M



Conclusions

This study found that while FSE requisitions appear to be random, they do not follow a theoretical probability distribution. Therefore, the best method of characterizing requisitions is through quartile distributions.

This study found that FSE requisitions exhibit intermittent demand. That is, there are long periods of time with no FSE requisitions and when there is a requisition it is typically for more than one item. The literature recommends using SES for these types of items.

The literature reviewed recommended aggregating across items and time for intermittent demand items. This study tested several aggregations of FSE with SES and found annual aggregation of FSE requisitions provided the least amount of error.

The literature recommends SES to forecast items with intermittent demand. This study found that SES can provide a very simple and high-level forecast but that SES does not take into account cyclical variations in FSE requisitions nor can it handle the large step-increases in requisitions that are frequently seen.

Lastly, the associated costs forecasted fall in-line with the historical trend, but, because it's based on the SES forecast, it only provides us a linear rate of costs over time.

Future Research

Study FSE requisitions using more nuanced forecasting methods such as Autoregressive Integrated Moving Average.

Study the relative frequency of FSE item requisitions over time to develop probabilities for what FSE items a requisition will be for.

Sponsor: Air Force Petroleum Agency March 2015

Department of Operational Sciences

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14. ABSTRACT
Within the past two years the Air Force has begun transitioning management of equipment from regionalized management at Command Equipment Management Offices (CEMOs) to centralized enterprise management offices. The fuels support equipment (FSE) inventory is a subcategory of Air Force equipment, the management of which has recently transferred from CEMOs to the Air Force Petroleum Agency (AFPA). Because FSE inventory was previously managed regionally, there is a gap in descriptive data for the enterprise FSE inventory. This study attempts to close this information gap through describing the current inventory position, defining historical FSE demand, and using this knowledge to forecast 2015's anticipated FSE demand using time and unit aggregation in conjunction with simple exponential smoothing. The results are useful to AFPA as the enterprise manager of FSE and to Air Force Item Managers as the acquisition managers for FSE. Lastly, this research is intended as a stepping stone into more detail study of the AF FSE inventory and supply chain.

15. SUBJECT TERMS
Fuels Support Equipment, Inventory Management, Inventory Forecasting, Forecasting

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