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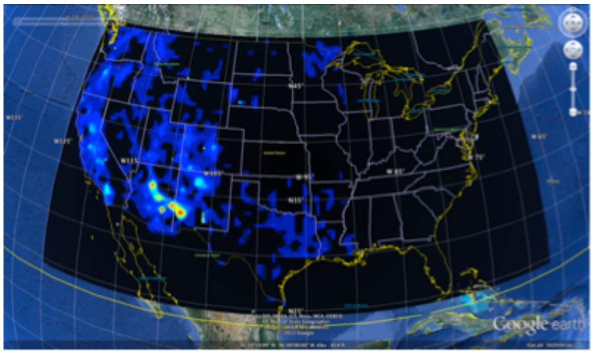
Final Report

Firefighting Aircraft Study (FAS)



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1. Exec Summary

Over the past decade, the fleet of U.S. Forest Service (USFS) firefighting aircraft has changed dramatically. The agency has identified the need to assess the effects of these changes and determine the needs for the future. The purpose of this study is to build analytical data that can be used to estimate the requirement for airtankers in the future. In recent years, the USFS has collected a large amount of data on the usage of aircraft to fight wildfires. By systematically investigating that data, some trends can be identified, and support for future investment can be developed.

As a result of airworthiness, safety and reliability issues with the fleet of aging airtankers, a dramatic reduction in the number of airtankers has taken place over the past decade, while the need for airtankers is projected to continue growing (USDA Forest Service, 2012). This has left an unfulfilled demand for airtankers, which have historically provided firefighters with an effective tool for successfully controlling wildfires. At the same time, there are mounting budget pressures that have forced the USFS to identify both costs and benefits of making significant changes to the firefighting aircraft fleet. It is accepted that the airtanker fleet needs to be modernized, and the firefighting aircraft fleet number and mix needs to be examined. Providing data and analysis that contribute to the case for fleet size is the focus of this report.

Literature reviews of the documents provided by the USFS, and others that we found through our independent research served to develop an understanding of the way in which wildfires are fought utilizing aerial resources. The experience of the firefighting community is developed through the application of a variety of tactics, and the lessons learned are captured. While most of the data that has been documented is anecdotal, this information has obviously shaped the different approaches employed in the use of aviation for firefighting.

The USFS has been fighting wildfires for many years. There have been countless lessons learned from both success and failure. The operational management of firefighting resources has grown out of the fact that the terrain, vegetation and weather patterns are all key factors in how a wildfire can be successfully fought. It is evident that the evolution of firefighting is driven by the resourcefulness of the people who are involved, but there will always be a need for technology advancement as well.

Just like a traditional war between armies, wildfire fire managers know that the battle is won with “boots on the ground” (Plucinski, et al., 2007, USDA Forest Service, 2012). However, they also know that air power is an important component of the speed and risk at which the ground forces can operate. Due to the chaotic and random nature of wildfires, there is currently no accurate data on the “effectiveness” of aerial attack. There is an ongoing study that will begin to assess that information, but it is lagging this study. Since effectiveness data was not available, our approach here has been to assume that the “person in charge” knows what he or she needs to fight a particular wildfire, and the fact that he or she orders air support is significant. This of course assumes a level of efficiency in the incident commander’s request for and allocation of aerial firefighting resources. However, we have not encountered any indication in the literature or available data to counter this assumption.

One of the primary goals of this study is to generate a performance measure that "directly demonstrates cost-impact" (USDA Forest Service, 2009). In theory, this appears to be a straightforward analysis. However, in reality an accurate and rational cost-impact is quite difficult. While the USFS data show that the cost and performance of the aviation portion of this equation is quite well documented, the effectiveness of an aviation asset against wildfires is problematic. Computing the effectiveness of the fleet over a season of fires, and comparing one year to another becomes even more complicated. In this study, our primary focus has been on large airtankers and heavy helicopters.

The data collected on each aircraft during flight is sufficient for finding where and when retardant and water drops are made. While there are some data outages, the amount of data collected is significant. The Operational Loads Monitoring System (OLMS), Automated Flight Following (AFF), Aviation Business System (ABS) and Resource Ordering and Status System (ROSS) databases were all used and to correlated to build useful aviation models in this study.

The precision of wildfire incident location and identification is lower than the precision of the aircraft data. Since there are tens of thousands of fire starts every year, not every fire is immediately given an identifier. Fires grow, merge, separate and jump. Our attempts to identify the specific fire being attacked during each recorded flight, and how effective a retardant or water drop is in fighting that fire, yielded limited success. The process taken by Thompson et al. (2012) in using the US Forest Service's Aviation Business System (ABS) database for flight information and Geospatial Multiple-Agency Coordination (GeoMAC) Group fire data was meticulous and thorough, but was still not able to match flights and fires for about a third of the flights analyzed. The present study used the Fire Program Analysis (FPA) historical fire data in a similar manner. The smaller fires are sometimes given a catchall job code or neglected altogether, which means that the initial attack location data is the most inaccurate. The correlation rate using time and position of the fire is higher in this study, but includes some simplifying assumptions. As remote sensing of fire starts becomes more prevalent and automated, capturing the initial attack fire positions will be more robust and easier to use in effectiveness studies.

The fire behavior elements needed to define effectiveness are much more problematic. The data being collected is always on an invasive basis. There is no available system that defines a fire incident in way that provides the data on location, conditions, and fuels that can accurately determine an expected uncontrolled behavior. If that were available, then the cost reduction in damage could be assessed when firefighting resources are applied.

We investigated the use of fire behavior modeling and simulation to assist in the analysis of effectiveness. However that approach is still developing and is not ready to be used in national scale studies. Chaotic parameters such as weather, fire-induced atmospheric effects and fuel models are far from a point where computational tools can be used for prediction.

The reduced supply of airtankers is skewing the data toward degraded performance, however the USFS uses every available asset, including cooperative airtankers, to contain and control fires. One comparison of the change in IA success rate from 2004 to 2007 neglects that the fire activity of 2004, when measured by acres burned, was significantly less than activity of 2007. This would mean that the preparedness levels, fuel availability, and climate were all significantly different, and while the fleet was similar, the demands on the fleet were much different. The number of fires where the airtanker could not arrive on time, or were completely neglected would necessarily be higher. Aviation request data for 2004 was not part of the current study. However, a similar comparison of 2010 to 2007 shows the reduction in unfilled orders in 2010, which, like 2004, was a year with less fire activity than 2007.

For this study, the order status from the ROSS request database has been used as the fleet performance measure. After investigating other approaches, it was determined that the incident commander has the best understanding of each particular fire, and the strategy for ground and aviation resource usage. If a legitimate request is made, and a resource is applied in a timely manner, then that is considered a success. This assumes that the drop is accurate and works as expected. Furthermore, the type of resource that was assigned to the request is captured in this manner. Resources from the US Forest Service, military, state-operated, and other cooperative resources are all captured in this manner.

An analytical approach to developing data to support decisions about future airtanker fleet size was developed. The data flow diagram in Figure 1 shows how the USFS datasets were processed to achieve the final result. Much of the effort has been to correlate various datasets of airtanker usage and then to construct stochastic models that can be used in predictions. The modeled demand for airtankers is generated from the actual number of orders from incident commanders as recorded in the data. The primary metric for this study has been the annual number of orders that cannot be filled by the US Forest Service contract fleet, also known as "Unable To Fill" (UTF)." This is a step towards the long-term goal of more efficient and effective use of airtankers for firefighting.

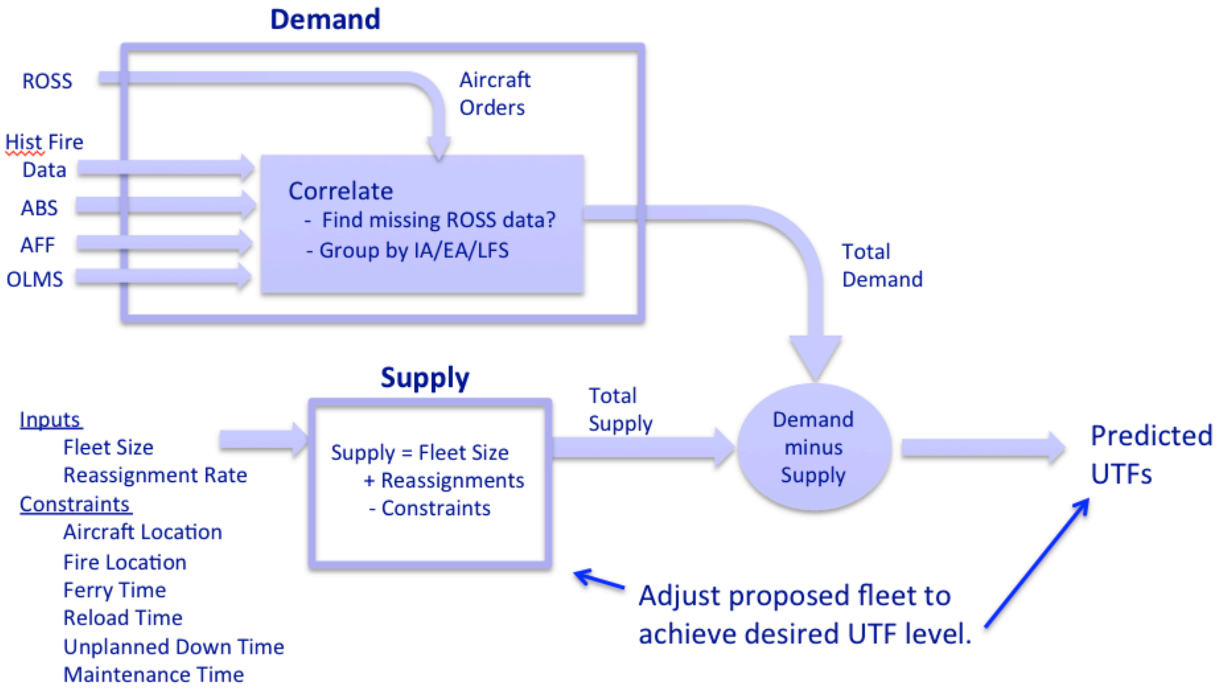

Figure 1 - Data Analysis Flow Diagram

The basic component of the demand model is the request, or "order," for aviation support. The five years of historical ROSS data available to this study have been used to develop the request data that goes into the demand model. The other components of the demand are the fires' locations and report times. The size and type of the fires were investigated. However there is no straightforward way to predict how large a fire will become. Instead, historical fire data were used to develop a probabilistic model of where and when fires are most likely to occur. To determine the locations and times of the fires, the historical fire data was used from the FPA database. The model is then used to "place" the fires around the country. By investigating the historical fire data, we developed a proposed average fire year. Historical fire data from FPA has shown greater variance since 2005 in the number of fire starts and acres burned (see section 3.3). A more detailed description of the model of airtanker demand is given in section 4.1.

The supply model was developed from the number of available airtankers, the reassignment rates, basing and range of the aircraft. The aircraft contracts are used to schedule the availability of airtankers throughout the predicted year. While analyzing the historical supply data, it was found that the USFS relies heavily on outside sources of large airtankers and helicopters. Aircraft from cooperator state resources, the military and Canada are sometimes employed to fight fires. As the USFS airtanker fleet shrank in 2011, the usage of cooperator resources grew. While the use of this surge capacity helped meet the demand for aerial resources, relying on "other aircraft for surge capacity when needed is not a sustainable path for the future" (USDA Forest Service, 2012).

The supply model was tuned using actual data from the existing fleet's capabilities, and is therefore appropriate for predicting capabilities of a similar fleet. The extension to predicting the greater capabilities of a NextGen fleet can be accomplished by stages, with increasing detail. A sensitivity analysis of model parameters was conducted to explore concepts related to increased aircraft capability, without going into the level of detail required to model specific aircraft.

The convergence of the supply and demand models results in a predicted level of orders unable to be filled with USFS contract airtankers (UTFs). The plot in Figure 2 shows the sensitivity of UTFs to the number of available aircraft and the annual fire activity level. This result gives the USFS a tool to help decide the best level of contracted airtanker supply and the resulting level of UTFs. The predicted number of airtankers that will be required can be estimated from the expected level of fire activity for the year and then subtracting the percentage of surge supply from other cooperator sources that the USFS is willing to use. In this way, the total cost of the fleet can be managed by the USFS.

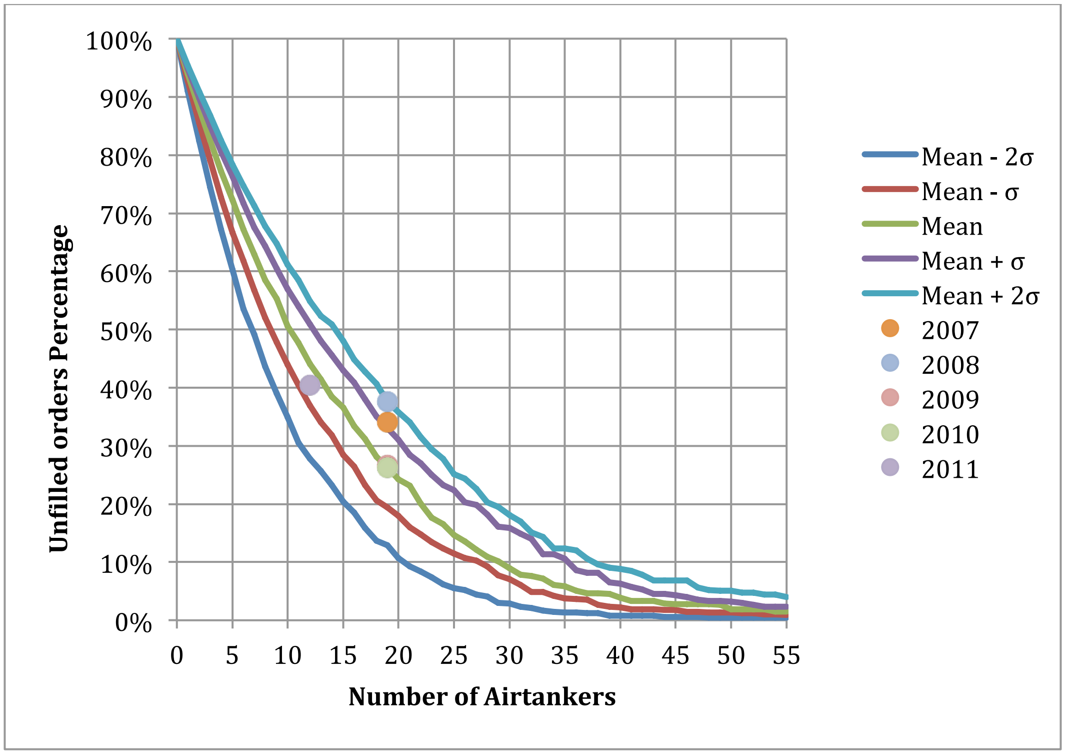

Figure 2 - Modeled and actual percent of unfilled requests vs. number of airtankers for differing relative fire activity

Helicopter supply and demand is a somewhat different problem from the large airtankers. The airtanker demand modeling was in part based on day-by-day assignment of airtankers to requests. The data indicates, however, that helicopters often stay on assignment to a single incident for multiple days, or even weeks. Thus, an additional means of modeling this real-world behavior is needed to adequately model the demand for helicopters. On the supply side, the airtanker modeling is based on a well-defined USFS contract fleet, available full-time over a portion of each year. Helicopters come from a mixed set of exclusive-use and call-when-needed contracts, a concept that would need to be incorporated in the supply modeling. Because of these added complexities, continued study of the use of Type 1 helicopters is necessary to build robust supply and demand models.

Water scoopers are most effective in locations where fires are close to water sources. This means that they are more likely to be used to fight fires similarly to helicopters that drop water, than they are to large airtankers that drop fire retardant (USDA Forest Service, 2012). There are areas of the country where additional scooper aircraft could augment large fire support resources, but to be most effective, scoopers need nearby water sources that are large enough to support approach, landing, takeoff and departure maneuvers. Because of their unique nature, a large change in fleet mix toward scooper type aircraft does not seem logical.

There is a relatively small amount of USFS background data that documents the use of scooper aircraft, making it difficult to come to conclusions regarding their use. While continued analysis of scooper usage is warranted, the focus of the current analysis is primarily on large airtanker usage, followed by heavy helicopter usage.

The data currently collected and managed by the USFS are needed to make investment decisions and to continue to develop policy, procedures and tactics for fighting fires. These datasets are continuing to mature, and the ROSS ordering system is improving each year. However, this effort must be continued to build the relationship between fire starts and the effectiveness of each component of the attack in controlling wildfires. The chaotic nature of the fires and the weather, combined with the fact that there is no easy method to develop a "control" case for comparing an attack method on a similar fire, makes determining a computable effectiveness problematic. Only through continued capture and analysis of the data will effectiveness be understood.

2. Literature Review

2.1. History

As with most of the literature, large quantities of the data are inconsistent, and outdated. While attempting to use 10 years of data collected by the US Forest Service, AVID is only able to use five with any level of accuracy, and only four years were available to correlate across the ROSS and FPA databases. With this in mind, the literature review goes back to 1949 (USDA Forest Service, 1949) for a cost analysis of helicopters versus manpower. Though the 1949 helicopter study is informative, a paper dating back that far is only useful in a period study. Aircraft performance, technology, tactics and labor rates have changed the entire approach that was begun during this period. This gives no useful insight into the cost effectiveness of next generation airtankers. Any economics book, talking about supply versus demand, can glean the relevant material.

Discussion of the history for the US Forest Service using air vehicles does add value to this study. It shows a great need for an accurate study to be conducted to analyze the next generation of airtankers. This study of current US Forest Service airtanker practices creates a model to be used in the discussion going forward for airtankers. Had these historical studies not been read, AVID would have attempted to study efficiency, which has proven futile on many occasions. Only by collecting more data will a study of this magnitude be concluded.

The "Helicopter Rappelling" guide (USDA Forest Service, 1973) also revealed how aircraft can be effective at moving ground forces to key places on the fire. Furthermore, the document reinforces the idea that ground forces are the key to fighting fires, by providing a detailed guide to all smokejumper equipment. For instance, the firefighters are taken to key fire locations by a light helicopter that is fast enough to move them to a safe place should equipment become trapped on their descent. The light helicopter is fast enough to maneuver firefighters to the important part of the fire that would typically be out of reach by normal ground support.

After becoming familiar with the U.S. Forest Service's firefighting history, AVID believes certain firefighting techniques that are currently in place should not be changed, because the U.S. Forest Service utilizes resources well. AVID's role in this study is not to find how best to use the U.S. Fire Service's airtankers, but rather to find how many airtankers it takes to fill all potential requests. AVID understands this role as delivering the airtankers to a fire and not flying them at a fire. Because of the many different airtankers available, AVID chose to model a generalized airtanker. To help define the size of an airtanker, AVID used the "Generic Fire Fighting Aircraft Specifications" document provided by the U.S. Forest Service. AVID used the large airtanker definition of 3,000 gallons of retardant to drop, weighing 9 lbs/gallon. This definition leads to some discrepancy in the modeling, as there are many types of aircraft that can hold and drop this amount. AVID sampled most of the aircraft that can fill this requirement and created a general model based off of all of these.

2.2. Model Discussion

The nature of fighting wildfires is that the first and most important thing is to address the fire safely and effectively. Collecting data along the way is an excellent goal, but is a lower priority than fighting the fire. The US Forest Service is continuing to improve the collection of data. However the existing databases and their connectivity limit AVID's overall ability to develop detailed models within a reasonable scope of effort. This has been recognized in a number of other studies, notably (Thompson et al., 2012). AVID agrees that based on the 3-month study of the data, the quality and reporting standards make it difficult to ascertain the assumptions needed to run an in depth study. Throughout the study, analyzing airtanker use through a lens outside of the US Forest Service allows for a new look at the previous work. A lack of consistency throughout each literature piece is disturbing, as a need for a directed approach is crucial. This makes it difficult to link these resources together, and creating a difficult method for modeling. While AVID successfully links the data sources together, a level of depth is lost in translation from one source to another. This lost depth shifts the goal in the AVID model from dropping gallons to filling unfilled orders.

Number of gallons dropped appears through these separate data sources to be the most viable use of determining supply to wildland fires. Airtanker use at fires can be modeled, but for a specific fire and spread it is very difficult to model. Fire behavior is chaotic and challenging to model, and thus cannot be accurately fought with airtanker models by gallons dropped. "The fundamental unit of analysis is a flight, which is recorded every time an aircraft takes off after reloading. A load can be split into multiple drops depending on mission objectives" (Thompson et al., 2012). While this proves true for fires that are fought with aircraft, it is extremely difficult to model how many gallons were not dropped in cases of unfilled requests for an aircraft. The numbers of flights vary significantly for each individual fire, but with a greater modeling structure of fire spread, a better analysis of unit of measurement can be used.

2.3. Fire Behavior

Previous reports on specific events, such as the OIG report on the Station Fire point to the unpredictable nature of fire behavior. The theories of combustion work well in a controlled environment. The growth of a fire can be modeled with theory that relates to such things as fuel and wind. However, the natural environment for wildfire is much less ordered. Atmospheric turbulence, coupled with simple ground and vegetation variability, makes the prediction of fire behavior at the scale required for the present study out of scope. The Buckhorn Fire Investigation Team Report is another example of how experienced fire fighters can be surprised by fire behavior, sometimes tragically.

To model effectiveness of aircraft accurately, there would need to be advanced modeling of fire behavior, which is out of scope for this study. "We do not explicitly know what processes occur and how they occur at fuel particle ignition scales. A fundamental theory of woodland fire spread is missing. And without theory, the sequence and influences of known combustion and heat transfer processes cannot be reliably applied to fire spread (Finney et al., 2012). Experts on this subject agree that the model behavior of fire is inaccurate. "None of today's models seem to provide an explanation" (Finney et al., 2012). With these findings in a recent paper on wildland fire spread, an appropriate theory needs to be constructed. This theory would need to be applied to AVID's statistical model to model correctly how airtankers can support a large fire (over 300 acres). With no way to model fire expansion, AVID must resort to number of requests.

2.4. Cost

As stated in the 2009 Quadrennial Fire Review (NWCG, 2009), "Fire agency budget resources – federal, tribal, state or local – will be strained by increased demands and rising costs during a period where government budget revenues will be very tight or falling." The cost of firefighting is a major focus of the USFS. The QFR also emphasizes the increasing cost of damage due to the effects of changes in climate and growth of the wild-land urban interface.

Cost effectiveness of firefighting aircraft in the forest service is a major dilemma and has been studied multiple times. In 2008, the "Management Efficiency Assessment on Aviation Activities" report (Management Analysis, Inc., 2008) addressed cost effectiveness in many different ways. "A high percentage of this funding is expended on contract aviation resources. In 2005, of the $178 million spent on aircraft costs $170 million (96%) was paid to contractors" (pg. 24). This creates a substantial market opportunity for the U.S. Forest Service looking toward the future with different aircraft and how they are used and appropriated. Over a period from 2001 – 2004 "Aircraft – Contract aircraft costs averaged $154M per year. They were 17 percent of the total suppression costs for the five-year period (2001–2004), ranging from 14–42 percent on individual large fires. Recommendations affecting this cost center also deserve special emphasis and careful analysis" (System Planning Corp., 2006). With costs continually rising for aircraft for wildfire support, cost effectiveness becomes a critical element to the fire support element of the US Forest Service.

To manage the cost of firefighting and damages caused by wildfires, the government has asked for a reduction of cost, but not effectiveness. "The cost of fighting large wildland fires each year is on the order of $1B. Congress and the Office of Management and Budget (OMB) have asked the FS and other agencies whether the total bill can be reduced" (System Planning Corp., 2006). With this in mind, controlling the cost of air support is an important facet to each fire. One way to minimize cost is to limit the Large Fire Support (LFS) by getting control of the fire during the first 24 hours of at fire or the Initial Attack. "Get to the fire and contain or extinguish it quickly, before it becomes a larger, more expensive fire. Make the most cost-effective management decision on the response to a fire if it escapes, including wildland fire use as well as suppression alternatives" (System Planning Corp., 2006). This initiative to hit the initial attack of each fire has been documented throughout the literature as the key to limiting LFS, which is expensive. With this in mind, "Most investigations into the efficiency of aerial firefighting have focused exclusively on initial attack" (Thompson et al., 2012). This complements the US Forest Service's directive that airtankers should be focused on initial attack. The limits to modeling an extended attack and large fire support are documented throughout many studies. For instance, "Airtanker use for extended attack and large fire support is more complex than initial attack, requiring only consideration of line-building capabilities but also the effectiveness of retardant delivery for point protection and the benefits of buying time by delaying rather than preventing eventual fire spread" (Thompson et al., 2012).

2.5. Airtanker and Type 1 Helicopter Use

The effectiveness of airtankers and helicopters has been studied several times. One Australian study developed an excellent statistical framework for evaluating the effectiveness of aviation usage. However their study did not include Type 1 Airtankers (Plucinski et al., 2007). There are several references that describe differences in tactics between direct attack and indirect attack. The use of water, gel, and retardant is also varied between helicopters, SEATs, scoopers and large airtankers largely based on experience. The attempt to identify the effectiveness of any type of aerial attack on any type of wildfire remains an immature science at this point. An example of a field trial that illustrates this point is described in "Project Fuse Aerial Suppression" (Plucinski, et al., 2008). This science has not yet been verified, making it difficult to utilize in a current study. The need to gain this knowledge is critical to the study of airtankers and helicopter use. Without effectiveness, assumptions of how best to use these aircraft are the best a study can do.

"The relative mix of aircraft on any given day is determined by several factors including: availability, type, location, fire weather, and priority use within the nation. In order to maximize effectiveness and efficiency, Airtankers and Type I Helicopters are centrally controlled and aviation operations are locally executed. Aircraft very seldom work independently of ground based resources and when aviation and ground resources are jointly engaged, the effect will be complementary and serve as a force multiplier. The effect of an aircraft on a fire is directly proportional to its capacity and to the speed with which it engages the fire. Effects of speed and capacity are magnified by proper prioritization, mobilization, positioning and utilization" (NICC, 2012). This mix affects the effectiveness of the air attack against all the fires on any given day, playing into how aircraft are used throughout the fire season every day.

"Although the primary intended use of the airtanker fleet is for initial attack of wildfires, our results indicate that the use of these aircraft tends to occur for extended attack or large fire support, with a significant number of flights associated with very large fires greater than 4047 ha (10,000 acres)" (Thompson, et al., 2012). The need for the airtanker fleet to attack in the initial attack period of the fire is crucial. With the data presented in the Thompson paper, AVID opines that the US Forest Service needs to redouble efforts to control where airtankers are used and how they are used. The deployment shown in many studies like this current study calls for the US Forest Service to adhere to the "National Interagency Mobilization Guide" (NICC, 2012), which states, "The primary mission of federally contracted large fixed-wing airtankers is initial attack operations" (NICC, 2012).

2.6. Previous Fleet Mix Studies

The QFR (NWCG, 2009) has called for a stable National fleet of aircraft on the order of 20 vehicles as well as an improved effectiveness of the airtankers. Obviously, the aging fleet and the difficulty in replacing the airtankers has resulted in a fleet that is significantly smaller than even the fleet called for in the QFR.

There are many different studies covering this topic of fleet mix. The most recent is a RAND report (Keating et al., 2012), which has some flaws. The report tried to model fire behavior accurately. However, modeling fire behavior is unpredictable in the field. Instead, this report should have focused on the fire behavior and spread as it deals strictly with cost. While cost is very important, it assumes a value can be placed on efficiency and potential fire damage. This is inherently wrong in 2012. With very few studies done on the efficiency of air vehicles, the RAND study makes assumptions that cannot be validated at this time.

"Because scoopers cost less and can make multiple water drops per hour when water sources are nearby, we found that the most cost-effective firefighting fleet for the Forest Service will have more scoopers than airtankers for the prevention of large fires," said Edward G. Keating, lead author of the study and a senior economist at RAND, a nonprofit research organization (RAND, 2012). "However, airtankers are important in an ancillary role in initial attack for the minority of wildfires where water sources are not nearby, and possibly for fighting large fires as well" (RAND, 2012). Scoopers do cost less to maintain, but how effective they are at fighting all the fires in the United States has not yet been verified. There is little data to support an entire fleet restructuring. Airtankers have data that show there is a correlation to being on a fire and how the spread can be contained. This could use more data, and a current study is being conducted alongside this firefighting aircraft study. One goal of that "Firefighting Effectiveness Use and Efficiency (AFFEUE) Study" is to provide the US Forest Service with a data set that can be used to create a better model for all aircraft.

Cost has been the focus of all previous studies, and while it is an effective tool to judge most criteria, it cannot be the only factor used to create a model. The key with the fleet mix model is that there are many separate factors, and each plays a role. As previously discussed, fire behavior is chaotic at best and has no current model to predict it accurately. The effects of ground crews, aircrews, support systems, weather models and other factors that play into accurate modeling make it a complex problem.

Efficiency is crucial in a model like this as it can add a common denominator to all the different approaches and attack techniques. However, there is no quantifiable method to determine efficiency right now. There is not enough data to run a 10-year study like this. A simplified method is needed to accomplish the goals of the previous fleet mix studies. Attacking efficiency of aircraft at a fire and fire behavior is a study that will need to be accomplished before determining the correct fleet-mix for the US Forest Service.

To address the current need of the US Forest Service, AVID chose to learn from history by providing the details needed to understand why the model could be used in the short term to minimize the costs of aircraft, while still maintaining that the understanding of this is imperfect.

3. Data and Analysis

Several data sources were used for the analysis portion of this study. Most of the data for this study was obtained from the following.

ROSS: Resource Ordering and Status System

The ROSS system is used by several federal organizations for managing Wildland firefighting resources. While not specifically designed as an analysis dataset, ROSS does contain information such as type of resource requested, status of the request, what resource filled the request, who requested the resource, who filled it, and how long the resource was assigned. This was the primary source for historical demand and supply of aviation firefighting assets for this study, and included ROSS data from 2007 to 2011.

FPA: Fire Program Analysis

FPA is an interagency planning and evaluation system. For purposes of this study, these capabilities were not used. Historical fire data was extracted from FPA and used to determine fire characteristics from 1992 to 2010. Information such as latitude and longitude location of each fire, acreage burned, start cause, and start and containment dates was used.

OLMS: Operational Loads Monitoring System

Data collected by onboard OLMS equipment was used to determine firefighting flight details. Note that OLMS data is only available on federally contracted legacy large airtankers and not the entire fleet.

Contracts

U.S. Forest Service contract information was used to determine historical fleet size and positioning data.

AFF: Automated Flight Following

This data is collected from specially equipped aircraft and includes automatic tracking of position, velocity and heading.

ABS: Aviation Business System

This system is used by the USFS to document and process contract aviation costs.

The data from these sources provide a detailed view into what the demand for aviation resources has been, and how those resources have been used. As also noted by Thompson, et al., (2012) the present study also reveals that there are data inconsistencies and, in some cases, missing data, which can limit the conclusions drawn. Those data inconsistencies are noted in Appendix 7.1.

The data analysis was focused primarily on the demand for, and use of, Type 1 airtankers (more than 3000 gallon retardant capacity) and Type 2 airtankers (from 1800 to 2999 gallon capacity) (NWCG 2011). Additionally, the case where multi-engine Type 3 airtankers (800 to 1799 gallons) were used to fill a request for a Type 1 or Type 2 airtanker. The year of 2010 was used as a focus year because of the relative completeness and maturity of that year's data as compared to other years. Demand and usage data from ROSS for Type 1 (Heavy) helicopters (5,000 lbs. payload and 700 gallons retardant capacity (NIAC, 2009)) and, to a lesser account, water scoopers, were studied and are noted throughout this report.

3.1. Historical Aviation Usage

Unless otherwise noted in this section, a filled airtanker or helicopter order is defined as a ROSS request with a status of "Released," meaning the aircraft assigned to the request completed its assignment and was released for further work. An order is also defined as filled if its status is recorded as "Reassigned," meaning the aircraft was reassigned to a different request at some time before it was released from its original assignment. The distinction between "Released" and "Reassigned" was not studied in the present study. Unfilled orders are those with a ROSS status equal to "Canceled – UTF," meaning the dispatcher is not able to fill the order, and it is canceled from the system. The sum of the filled and unfilled orders represents the total demand for airtankers or helicopters.

The U.S. Forest Service draws from a supply of airtankers to meet the demand of aviation firefighting support. This supply is primarily from a contracted fleet of airtankers, but can extend to sources beyond the primary fleet. This additional supply may come from cooperators including state-operated assets from the California Department of Forestry and Fire Protection (CAL FIRE) and the state of Alaska, military aircraft such as Modular Airborne Fire Fighting System (MAFFS)-equipped C-130s, and aircraft from Canada through international agreement.

Throughout this section, orders filled using the U.S Forest Service contract airtanker fleet are denoted "Filled – FS" and orders filled from other sources are denoted "Filled – Non FS." Further decomposition of the filled order data was not straightforward, but is noted where necessary throughout this section. Details of the filled and unfilled order data filtering are given in Appendix 7.2.

Inconsistencies in how the helicopter data was entered into the ROSS system made it difficult to sort the records by their contract type, i.e., Exclusive Use versus Call When Needed. Throughout this report, filled helicopter requests shown as "Filled – FS" are those with an assigned helicopter name containing "ID-NIC," and "Filled – Non FS" are the remaining filled requests. Future studies should look into matching database records between ROSS and the Exclusive Use contracts based on helicopter tail number.

3.1.1. Aviation Use by Year

Figure 3 shows the number of filled and unfilled airtanker requests from 2007 to 2011. The fire activity for each year is reflected in the number of airtanker requests, with 2007 and 2008 being heavy demand years, and 2010 being a relatively "light" year.

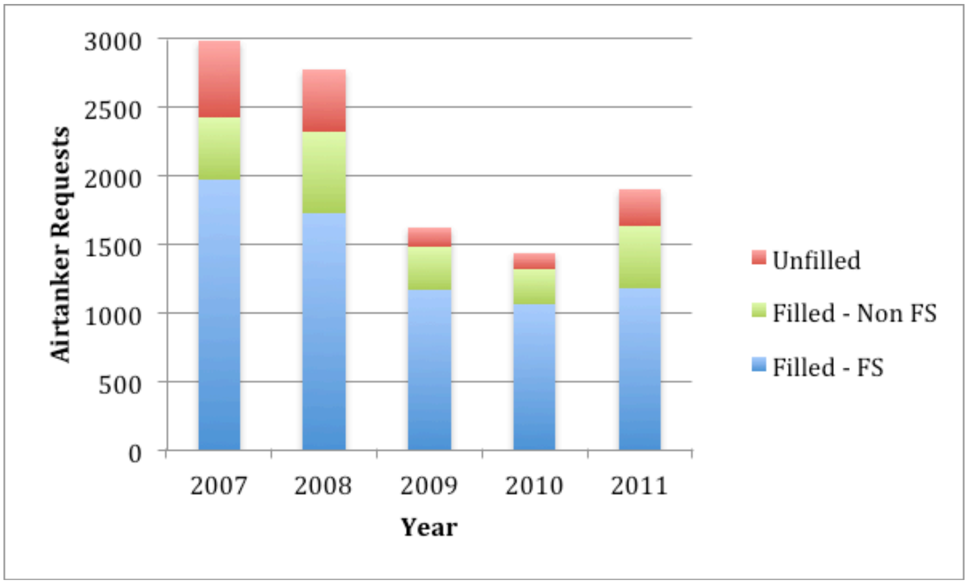

Figure 3 - Airtanker Requests by Year

The same analysis was performed for heavy helicopter requests. Figure 4 shows the number of filled and unfilled helicopter orders from 2007 to 2011. While it is important to note that the mission and use of helicopters differs from that of airtankers, it is interesting to note the similarity in overall usage trends between the two aircraft types.

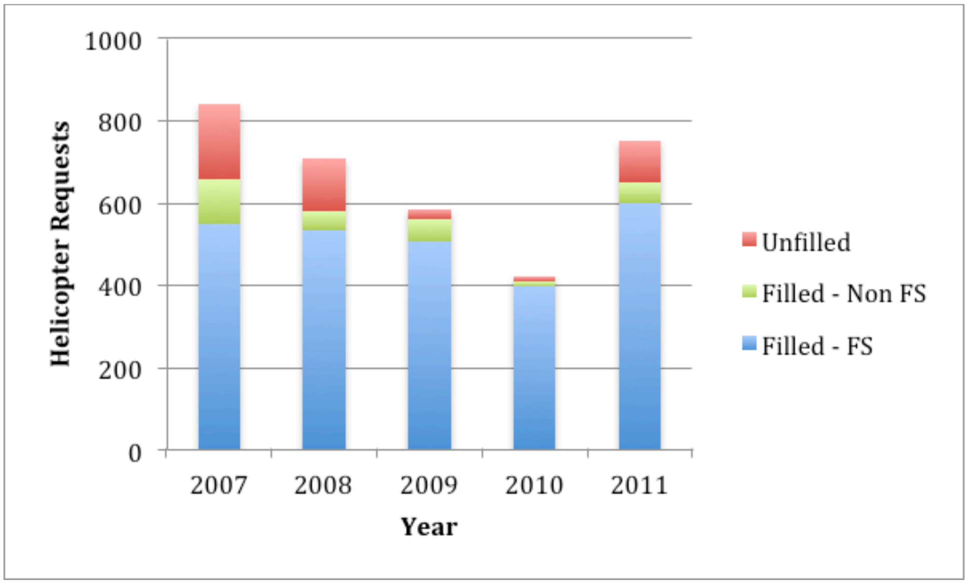

Figure 4 - Helicopter Requests by Year

Scooper request data is also available from ROSS. However, the total number of requests from the 2007-2011 ROSS data that were filled with scoopers (shown in Figure 5) is much less than the number of airtanker or helicopter requests (Figure 3 and Figure 4).

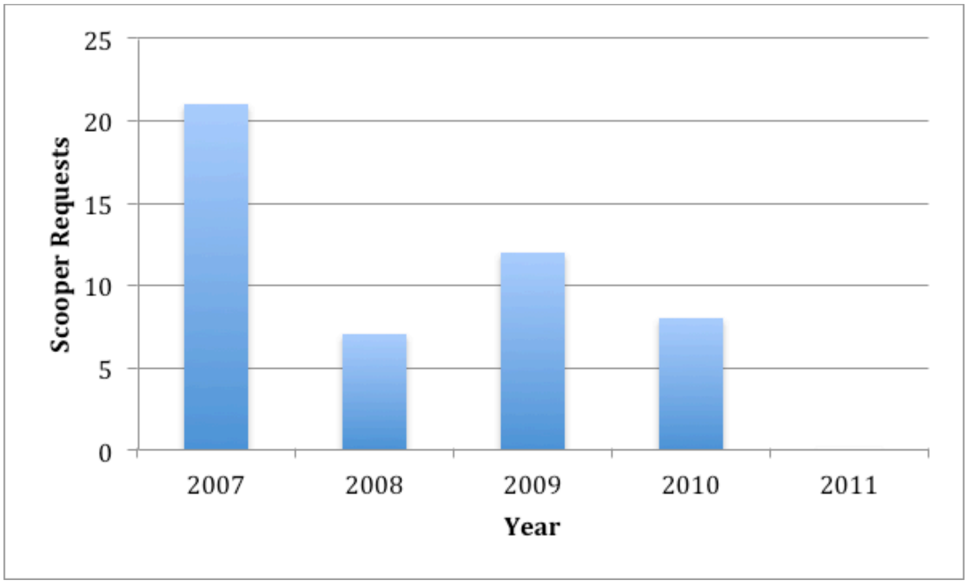

Figure 5 - Scooper Requests by Year

3.1.2. Aviation Use by GACC

A Geographic Area Coordination Center (GACC) is a facility used for the coordination of agency or jurisdictional resources in support of one or more incidents within the geographic coordination areas depicted in Figure 6. Note that the present study did not include Alaska, Hawaii or Puerto Rico.

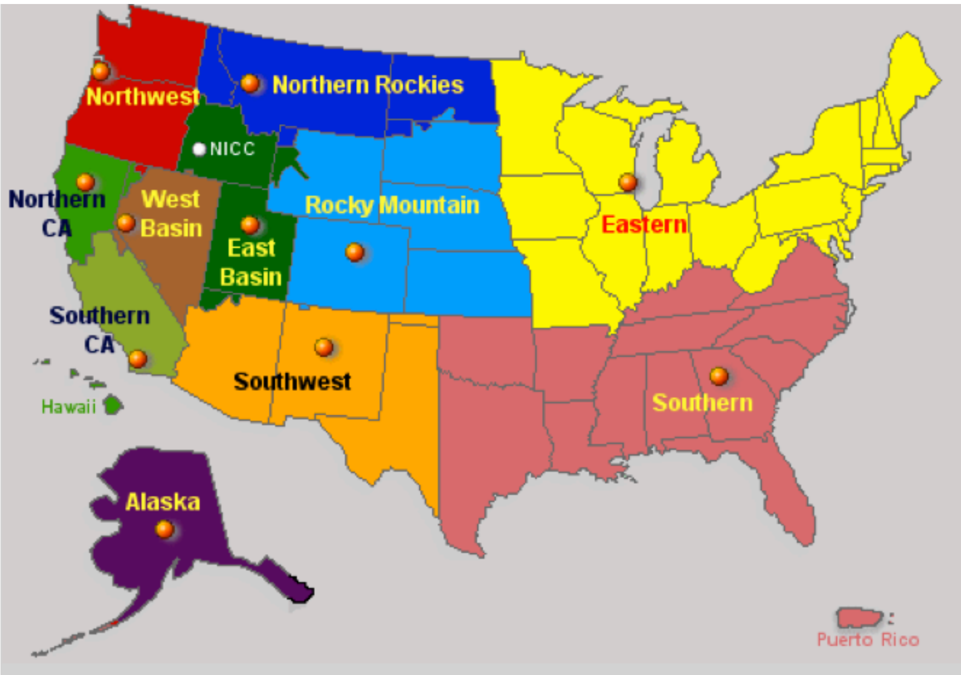

Figure 6 - Geographic Coordination Areas

Figure 7 shows the same request data seen in Figure 3, but averaged over the five years studied (2007-2011) and arranged by requesting GACC. The figure shows that the highest average yearly demand comes from the two California GACCs.

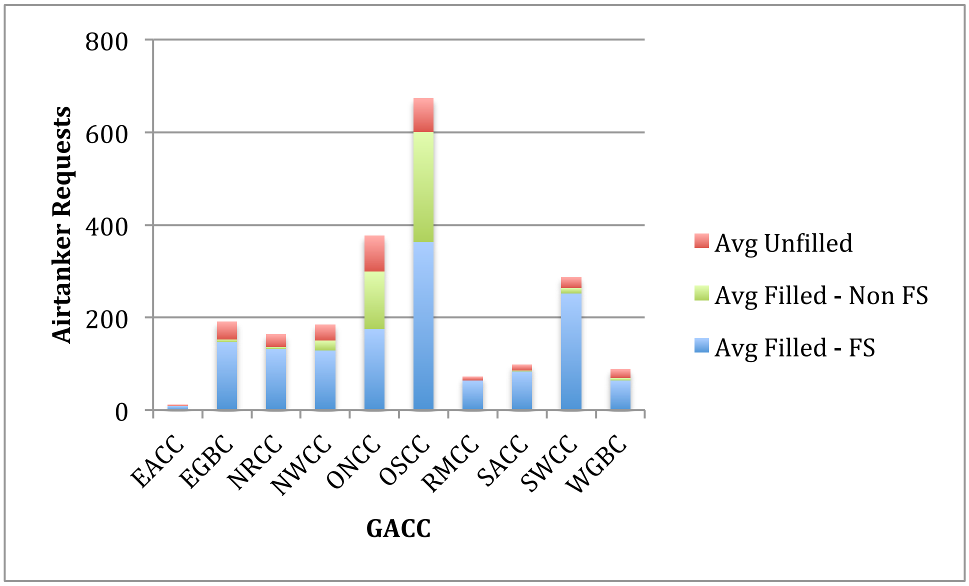

Figure 7 - Airtanker Requests by GACC (2007-2011 Average)

Figure 8 shows the averaged helicopter request data (2007-2011) arranged by requesting GACC. As with the airtanker data, the southern California GACC represents the largest demand.

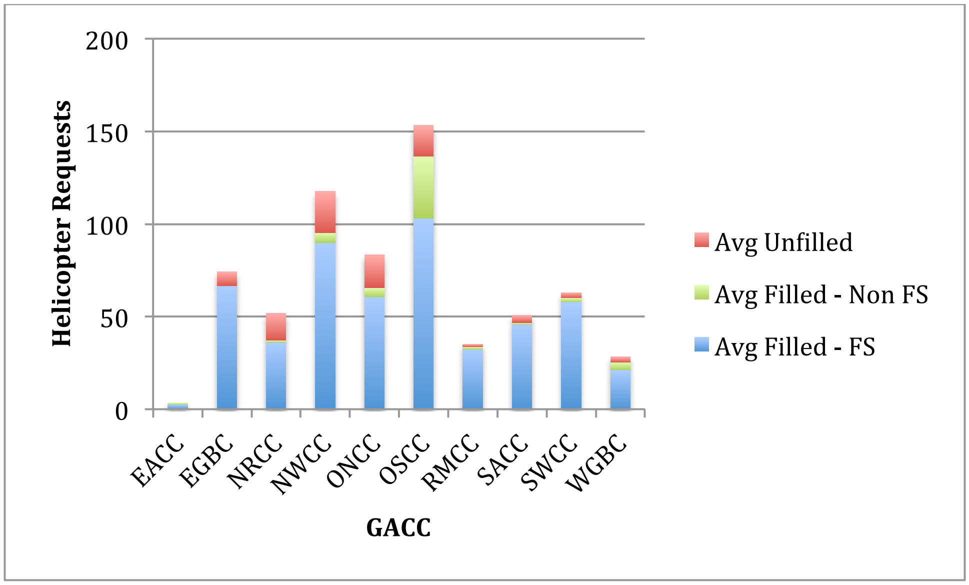

Figure 8 – Helicopter Requests by GACC (2007-2011 Average)

3.1.3. Aviation Use by Fire Size

Figure 9 shows the request data again, this time arranged by Fire Size Class. Class A/B represents fires that, at some point during their burn, only reached 10 acres or less. Class C/D fires reached between 10 and 300 acres in size. Finally, Class E/F/G fires reached a total size of greater than 300 acres. The data shows that there are many more requests for airtanker support for fires that will become large fires, as compared to the other sizes. Note that fire size data from the FPA database only includes the eventual size the fire reaches at some point in its burn lifetime. It does not include intermediate size information such as a day-by-day record of acres burned. Therefore the data shown in Figure 9 for each class of fires include Initial Attack (IA), Extended Attack (EA), and Large Fire Support (LFS). Thus, comparing it to other IA/EA/LFS results is not straightforward. This illustrates in part the difficulty in any IA/EA/LFS analysis, which includes components of both time and area. This is explored further in Section 3.2. It is useful, however, to see that more airtanker resources are used to fight fires that will or have become large, as compared to other fires.

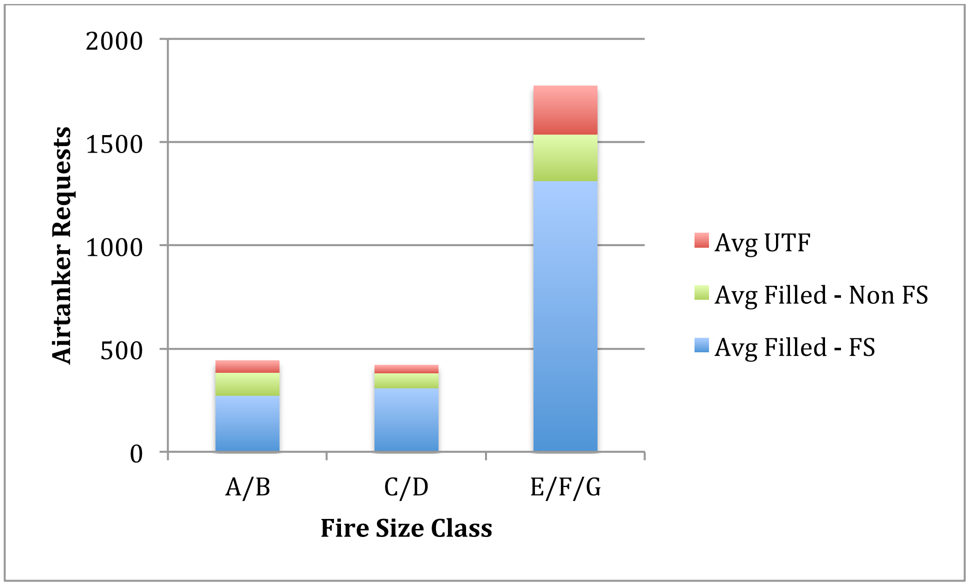

Figure 9 - Airtanker Requests by Fire Class (2007-2011 Average)

To obtain the data represented in Figure 9, ROSS request data was matched with historical fire data from FPA. Because ROSS request data was available from 2007-2011 and historical fire data was available from 1992-2010, record matching was only possible for the four years from 2007 to 2010. The details of how each ROSS record was matched to a corresponding historical fire record are given in Appendix 7.2. The matching process was not straightforward, since there is no unique data key between the two datasets. Despite this difficulty, most request records were matched, as shown in Table 1.

Airtanker Requests	
Year	**Match Success Rate**
2007	97%
2008	90%
2009	85%
2010	91%
All years	91%
Helicopter Requests	
Year	**Match Success Rate**
2007	89%
2008	91%
2009	92%
2010	92%
All years	91%

Table 1 – ROSS Request to Historical Fire Data records match success

Figure 10 shows the same data as in **Figure 9**, but here the data has been normalized by its maximum value, such that percentages can be compared across fire sizes. The data shows that filled vs. unfilled requests are relatively consistent across fire sizes when shown as percentages. This suggests that dispatch priority is driven by more than simple considerations related to fire size.

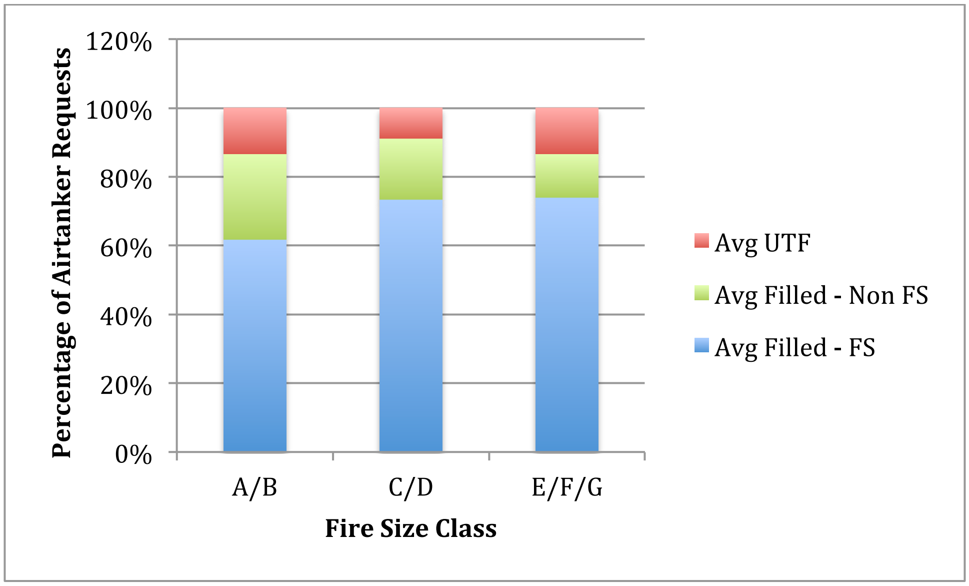

Figure 10 – Percentage of Airtanker Requests by Fire Class (2007-2011 Average)

Once again, this analysis was repeated for heavy helicopters. Figure 11 shows the helicopter requests by Fire Size Class. Compared to the airtanker data shown in Figure 9**,** large fire requests were more than the other two sizes, but the difference between fire sizes is not as dramatic as for airtankers. As with the airtanker analysis, it is important to remember that this data includes IA, EA and LFS and therefore cannot be used to gain insights from those perspectives. It is useful, however, to see the helicopter use trends follow those seen with airtankers, namely that more helicopter resources are used to fight fires that will or have become large, as compared to other fires.

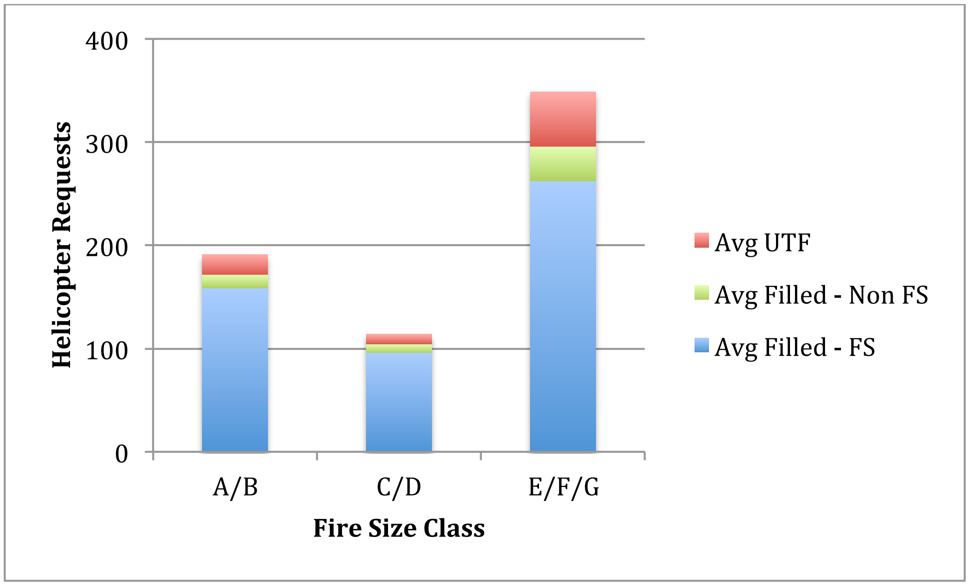

Figure 11 - Helicopter Requests by Fire Class (2007-2011 Average)

Figure 12 shows this same helicopter request data, but here as a percentage of the total requests. When shown as a percentage, the requests filled ranged from about 75% to 85%. As noted above for airtankers, this suggests that dispatch priority is driven by more than simple considerations related to fire size.

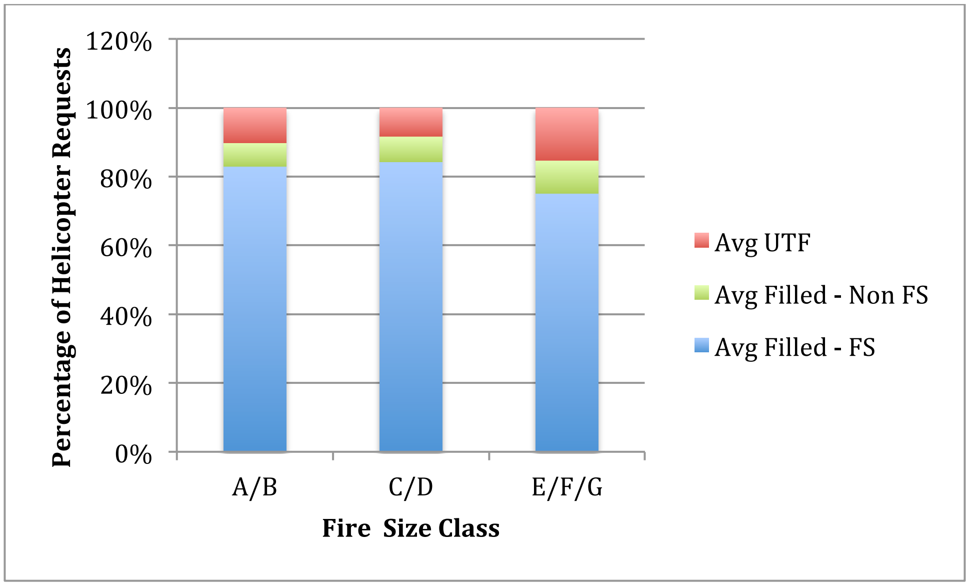

Figure 12 – Percentage of Helicopter Requests by Fire Class (2007-2011 Average)

3.1.4. Aviation Use by Preparedness Level

Figure 13 shows the requests in terms of the national preparedness level at the time of each request. The number of airtanker requests trends upward from Preparedness Levels 1 to 3, but drop off for Preparedness Levels 4 and 5. There are fewer days in a year that have higher Preparedness Levels than the lower levels, possibly leading to the lower number of requests seen in the figure. Once the data is shown as percentages of total requests (Figure 14), the unfilled order rate increases with Preparedness Levels. These higher levels represent times when fire activity is highest, straining the capacity of the firefighting fleet, which may explain the higher proportion of unfilled orders.

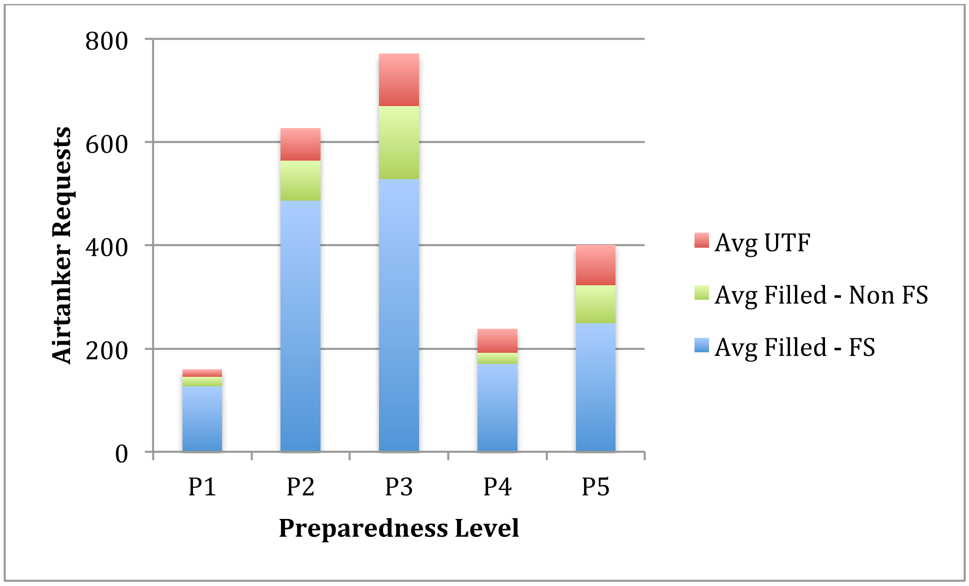

Figure 13 - Airtanker Requests by Preparedness Level (2007-2011 Average)

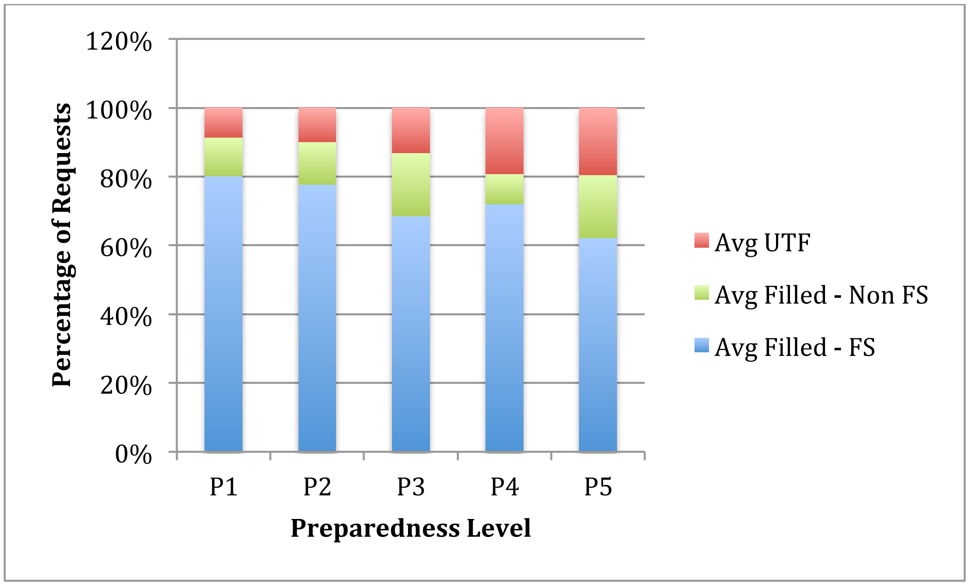

Figure 14 – Percentage of Airtanker Requests by Preparedness Level (2007-2011 Average)

Figure 15 and Figure 16 show the helicopter requests and percentage of requests by national preparedness level. Like airtankers, the number of helicopter requests trends upward from Preparedness Levels 1 to 3, but drop off for Preparedness Levels 4 and 5. Furthermore, the percentages of total requests show a consistent trend, with a greater proportion of orders going unfilled at the higher Preparedness Levels.

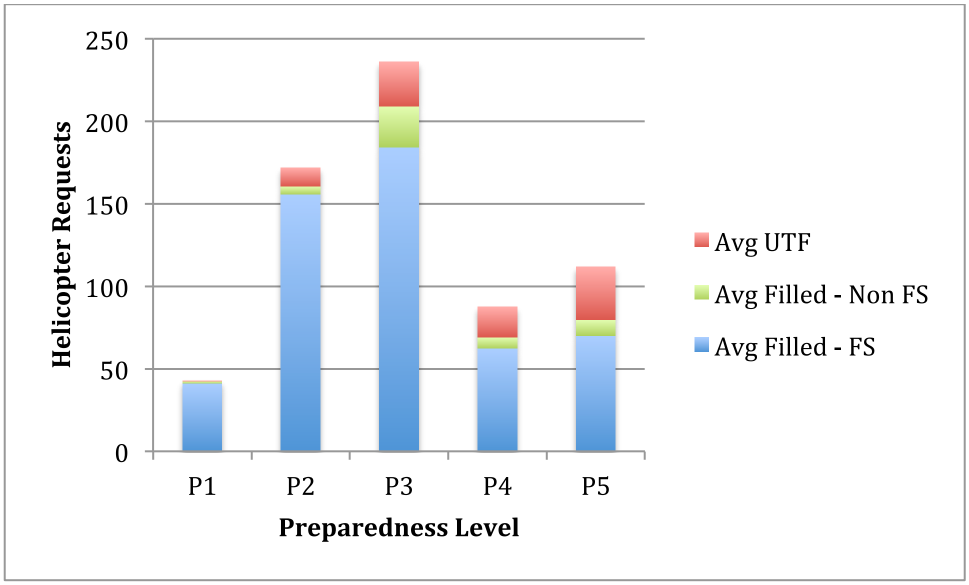

Figure 15 - Helicopter Requests by Preparedness Level (2007-2011 Average)

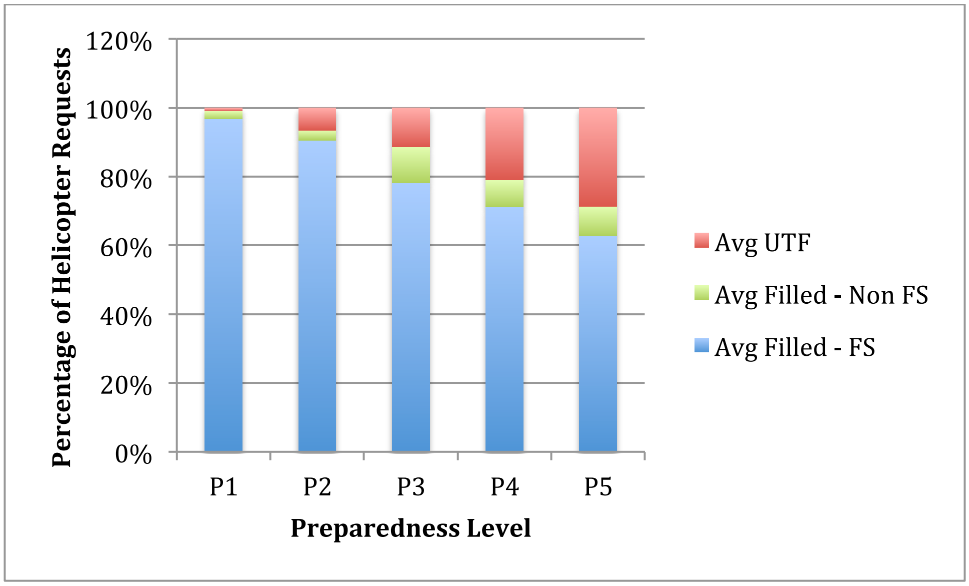

Figure 16 – Percentage of Helicopter Requests by Preparedness Level (2007-2011 Average)

3.2. Fire Mission

Next, the investigation looked into aviation use in the context of Fire Mission. This includes Initial Attack (IA), Extended Attack (EA) and Large Fire Support (LFS). These missions are not simple categorizations of fire size (as discussed above in section 3.1.3), nor are they simple categorizations of fire attack timeframe. Rather, they incorporate elements of both size and time. Standard definitions of the IA, EA and LFS missions were difficult to determine, especially with respect to the timing of IA vs. EA, thus making automated database queries for each mission type problematic. However, there is support for the concept of IA occurring in the first 24 hours of an incident. The "Glossary of Wildland Fire Terminology" (NWCG, 2011) states that operational periods are not usually over 24 hours, while the "National Interagency Mobilization Guide" (NICC, 2012) forms the definition of Initial Attack around the context of containment, with guidelines for resource ordering if the incident "will not be contained during the first operational period." With respect to size, fires greater than 300 acres are generally considered large fires (Thompson, et al., 2012, NSCG 2011).

Given these guidelines, a table of time vs. size was constructed, as shown in Table 2. The top row represents the first 24 hours and becomes the definition of IA, regardless of the final fire size. Next, fires reaching 300 acres in size, as seen in the rightmost column, are defined here as LFS (except for the first 24 hour IA case). One more cell in the table was categorized as LFS (10-300 acres beyond 72 hours in duration) with the remaining cells forming the definition of EA.

With these definitions in place, the next step was to apply them to the available data. The historical fire data from the FPA data source was used to obtain details of the fires for each ROSS request. The details of how each ROSS record was matched to corresponding historical fire data (FPA records) is given in Appendix 7.3. The record matching success rate is detailed in Table 1 above, which shows a match success of 91% over the four years analyzed. Unmatched records were not included in the results described below.

Note that the fire size from the FPA data source is the final fire size, while the aircraft response time is the time from the fire's initial report to the time of the aircraft's arrival at the fire. These two parameters were used to determine the Fire Mission (IA/EA/LFS) as shown.

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	Initial Attack	Initial Attack	Initial Attack
24 to 72 hrs.	Extended Attack	Extended Attack	Large Fire Support
Over 72 hrs.	Extended Attack	Large Fire Support	Large Fire Support

Table 2 – Fire mission definitions

Table 3 shows the historical aviation use as the total number of filled airtanker requests per year for each Fire Mission, averaged over 2007 to 2010. Table 4 shows this same data in terms of the percentage of the total, which helps provide a deeper understanding of the distribution of filled airtanker requests.

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	221 (IA)	227 (IA)	369 (IA)
24 to 72 hrs.	18 (EA)	35 (EA)	273 (LFS)
Over 72 hrs.	38 (EA)	7 (LFS)	545 (LFS)

Table 3 – Average filled airtanker requests by fire mission from 2007 to 2010

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	12.8% (IA)	13.1% (IA)	21.3% (IA)
24 to 72 hrs.	1.0% (EA)	2.0% (EA)	15.8% (LFS)
Over 72 hrs.	2.2% (EA)	0.4% (LFS)	31.4% (LFS)

Table 4 – Average percent filled airtanker requests by fire mission from 2007 to 2010

The first cell of data in the upper-left part of Table 3 shows, for example, that from 2007 to 2010, there were an annual average of 221 requests that were filled by airtankers during the first 24 hours of the fire's initial report and for which the fire's final size did not exceed 10 acres. Note also that for final fire sizes of less than 300 acres and response time greater than 24 hours, there were only a small number of filled airtanker requests in the data, representing less than 6% of the total. Thus, it is difficult to draw conclusions from these cases.

The first column in Table 3, representing small fires, shows an annual average of 221 filled airtanker requests during IA. These small fires are contained before reaching 10 acres, and would not be expected to require airtanker support for an extended period. This is supported by the data, which shows a relatively small number of filled requests (18 and 38) beyond the first 24 hours.

The next column in the table represents fires with a final size from 10 to 300 acres. The results follow the same trends as for the smaller fires. Initial attack appears to have been successful in these cases; final fire size is relatively limited and the need for airtanker resources beyond the first 24 hours is greatly reduced. There are 546 filled airtanker requests in these first two columns, representing approximately a third (31.5%) of the total number in the table.

The final, rightmost, column represents fires with a final size of more than 300 acres. In this situation, there are 369 airtanker requests filled in the first 24 hours of the initial fire report, but more than 800 requests that were filled beyond this initial period, indicating a significant effort spent in containing fires that escaped initial attack.

Summing the appropriate blocks in Table 4 by fire mission shows that the average filled airtanker requests by fire mission is:

IA: 47.2%
EA: 5.2%
LFS: 47.6%

However, if we break down the IA information into those fires with final size less than 300 acres ("contained" IA), and those greater than 300 acres ("escaped" IA), we see the following:

IA (contained):	25.9%
IA (escaped):	21.3%
EA:	5.2%
LFS:	47.6%

Thus, the overall data shows that most of the filled requests fall within the IA and LFS fire missions (as defined here). However, only about half of the IA effort was successful in containing the final fire size to less than 300 acres (25.9% contained vs. 21.3% escaped). Furthermore, nearly half of the total effort (47.6%) was spent in LFS fighting fires that had escaped IA. It should be noted that these results are based only on those fires that received aviation support requests. Further investigation of the aviation deployment decision process is needed to better understand airtanker fleet effectiveness.

Next, the average amount of time in hours each airtanker spent per assignment was computed by comparing the time the airtanker was assigned to the fire and the time it was released, as shown in Table 5. Note that large fluctuations were observed in the time per assignment results for those cases noted above with small datasets, and they were removed from the table below.

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	1.8 (IA)	4.3 (IA)	8.1 (IA)
24 to 72 hrs.	---	---	8.6 (LFS)
Over 72 hrs.	---	---	8.3 (LFS)

Table 5 – Average airtanker time spent per assignment from 2007 to 2010

The data shows that on average for Initial Attack missions, an airtanker spent 1.8 hours per assignment for Class A/B (small) fires and 4.3 hours per assignment For Class C/D (medium) fires. Using an average flight time of about 0.8 hours (Thompson, et al., 2012), this equates to just over 2 flights per assignment for small fires, and just over 5 flights per assignment for medium sized fires. Finally, for Class E/F/G (large) fires of any duration, airtankers spent between 8.1 and 8.6 hours on each assignment, or about 10 flights.

This same analysis was also done for heavy helicopters. Table 6 shows the historical aviation use as the total number of filled helicopter requests per year, for each Fire Mission averaged over 2007 to 2010.

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	57 (IA)	71 (IA)	98 (IA)
24 to 72 hrs.	16 (EA)	22 (EA)	81 (LFS)
Over 72 hrs.	20 (EA)	15 (LFS)	134 (LFS)

Table 6 – Average filled helicopter requests by fire mission from 2007 to 2010

Table 7 shows this same data in terms of the percentage of the total filled helicopter requests

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	11.1% (IA)	13.8% (IA)	19.1% (IA)
24 to 72 hrs.	3.1% (EA)	4.3% (EA)	15.8% (LFS)
Over 72 hrs.	3.9% (EA)	2.9% (LFS)	26.1% (LFS)

Table 7 – Average percent filled helicopter requests by fire mission from 2007 to 2010

Summing the appropriate blocks in the table above shows that the average filled helicopter requests by fire mission was

IA:	44.0%
EA:	11.3%
LFS:	44.7%

Similar to the airtanker results, most of the filled helicopter requests fall within the IA and LFS fire missions as defined above, with approximately equal emphasis on each. However, the EA mission for helicopters represented a higher overall percentage (11.3%) than EA for airtankers (5.3%).

The breakdown of the IA information into those fires with final size less than 300 acres ("contained" IA), and those greater than 300 acres ("escaped" IA), follows similar trends as discussed above for airtankers:

IA (contained):	24.9%
IA (escaped):	19.1%
EA:	11.3%
LFS:	44.7%

Next, the average amount of time each helicopter spent per assignment was computed by comparing the time the helicopter was assigned to the fire and the time it was released, as shown in Table 8. The data indicates that helicopters are assigned for much longer periods of time as compared to airtankers, averaging a week on large fires, and clearly illustrating the differences in how airtankers and helicopters are used.

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	15.7 (IA)	32.9 (IA)	91.7 (IA)
24 to 72 hrs.	156.8 (EA)	73.3 (EA)	119.1 (LFS)
Over 72 hrs.	280.2 (EA)	109.7 (LFS)	124.5 (LFS)

Table 8 – Average helicopter time spent per assignment from 2007 to 2010

Appendix 7.4 contains a detailed breakdown by year of the aviation use by fire mission from 2007 to 2010.

3.3. Demand Pulses

The relative fire activity in a year, as compared to other years and shown in Figure 3 and Figure 4, was analyzed further, based on the historical fire data available from FPA from 1992 to 2010. Three parameters were investigated to measure fire activity: number of fires in a year, number of acres burned in a year, and the average fire size. The data from the three approaches were normalized using their mean and plus/minus two standard deviation (σ) values. Once the measures were normalized in this manner, the data reduced to a series of very similar curves, shown in Figure 17 as a “Relative Fire Activity Index” vs. year. In the figure, the index values represent the standard deviation from the mean. 2007 and 2008 are seen as active years, while 2010 was a less active year, consistent with Figure 3 and Figure 4,

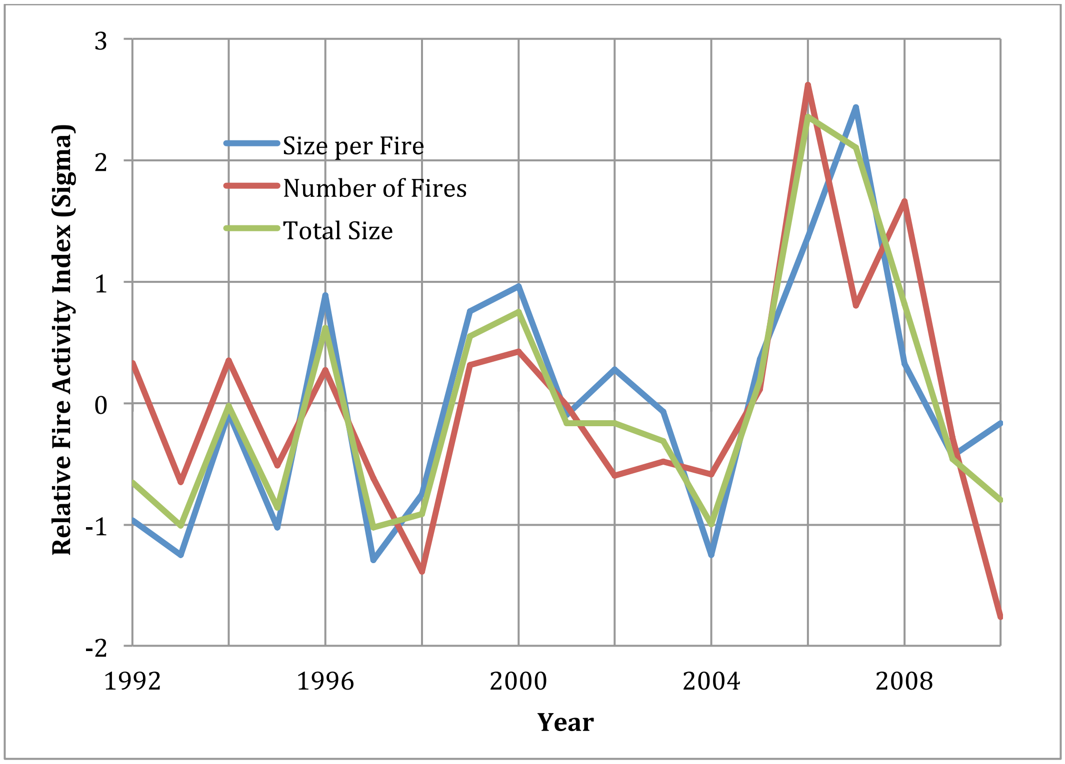

Figure 17 - Relative fire activity from 1992 to 2010

Table 9 shows the means and standard deviations that were determined for each method:

Method	Mean+2σ (worst year)	Mean (average year)	Mean-2σ (best year)	Standard Deviation (σ)
Number Of Fires	40,084	26,334	12,584	6,875
Total Acreage Burned	6,482,265	2,768,879	0	1,856,693
Average Fire Size (acres)	190	98	7	46

Table 9 – Fire activity indices, mean and standard deviations

Although we have FPA data from 1992 to 2010, we only have ROSS data from 2007 to 2011, allowing us to correlate our relative fire activity index to the number of airtanker requests for the four years from 2007 to 2010. Figure 18 shows the correlation between the number of requests and relative fire activity index using the Total Acreage Burned parameter. We used this parameter since it provided a better correlation than the other two.

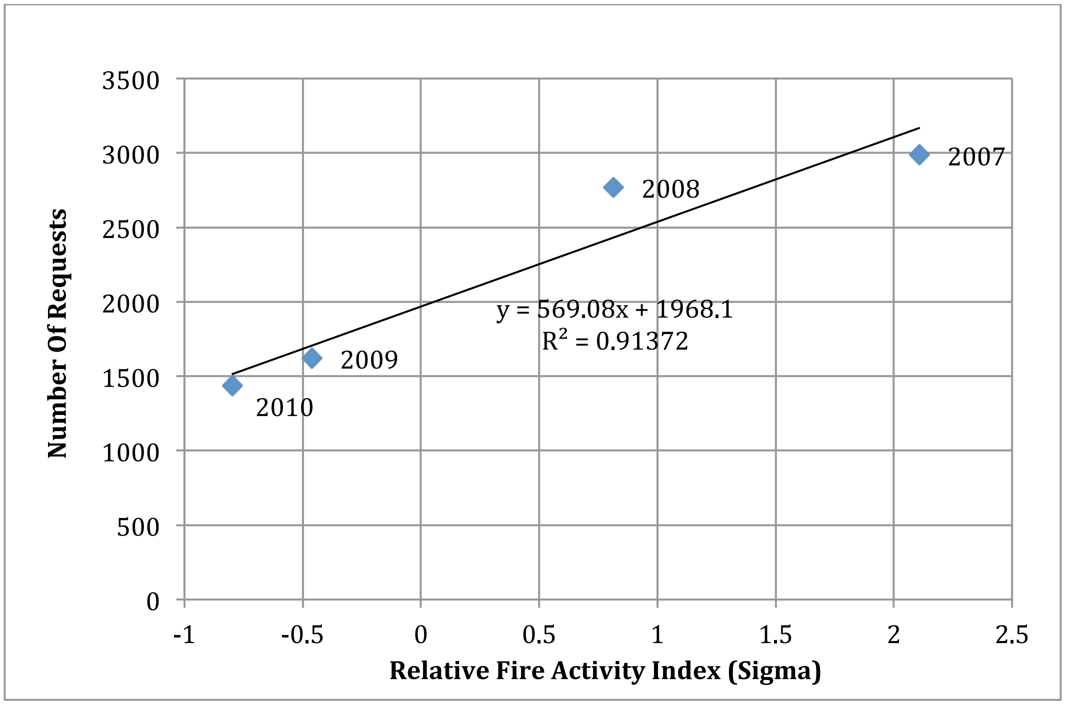

Figure 18 - Correlation between requests and relative fire activity index

3.4. Aviation Supply Sources

As noted in Section 3.1, the U.S. Forest Service draws from a supply of airtankers to meet the demand of aviation firefighting support, including a fleet of USFS-contracted airtankers and an additional supply, from cooperators including state-operated assets, military aircraft, and aircraft through international agreement. Figure 19 shows the airtanker requests by year, and breaks down the additional supply into its components. Use of this additional supply is not as straightforward as a simple call-when-needed relationship (NICC, 2012). For example, the criteria for using military MAFFS-equipped aircraft include specific guidance on availability of other assets, as well as a requirement for a Lead Plane. However, it is useful to see the relationships between contracted and cooperator assets before continuing the analysis further.

The request data shows that the contracted fleet was able to fill more requests in 2011 (1134 orders) than in 2010 (1061 orders), despite the fleet reduction that occurred (from 19 large airtankers in 2010 down to 12 in 2011). The current analysis does not reveal a clear cause of this, and further analysis seems warranted.

Figure 20 shows the airtanker request data in terms of percentage of airtanker requests, and shows that the contracted fleet was able to fill between 60% and 75% of the demand each year, with higher filled percentages seen for less active years. Both figures show that in 2011, when the contracted fleet was reduced in number, a higher reliance on outside sources was seen.

In 2011, about 11% of requests were filled with Canadian airtankers. For this analysis, all orders filled with Convair CV-580 aircraft with Canadian registration numbers were categorized as Canadian. The CV-580 is in operation in Canada, contracted by the State of Alaska and used through cooperator agreements in the U.S. (USDA Forest Service, 2012). The 2011 data showed that of the 11% of the requests that were filled with these aircraft, about 4% recorded a home unit in Alaska, 4% recorded a home unit in Canada, and the remaining orders (about 2%) filled with CV-580 aircraft recorded a home unit of "National Interagency Fire Center." No further analysis was done in this study regarding the distinction between "Alaskan" and "Canadian," and the following figures show them together as "Canadian."

Another 3% of the total 2011 requests were filled with MAFFS-equipped aircraft, and an additional 12% were filled with state resources (11.4% from California and 0.4% from Oregon). The results for the other years (2007-2010) were similar, showing that, of the state resources used, between 95% and 99% were from California.

The data shows that during heavy demand years, or when the contracted fleet size is reduced, the USFS is able to keep unfilled orders below 20%, but must turn to outside sources to accomplish it. This may create additional cost considerations, but was not within the scope of this study to investigate further.

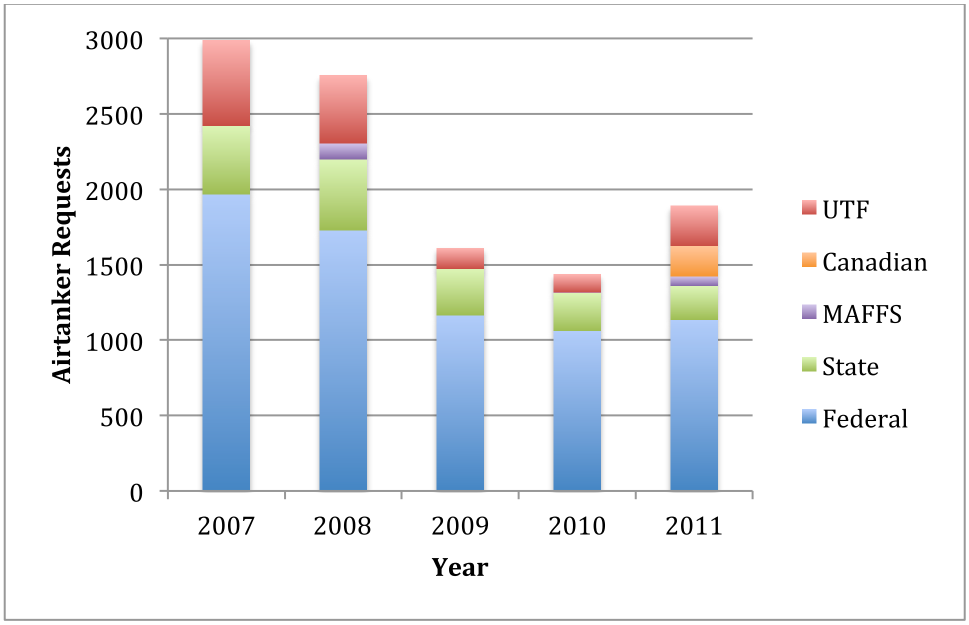

Figure 19 - Airtanker requests by supply source

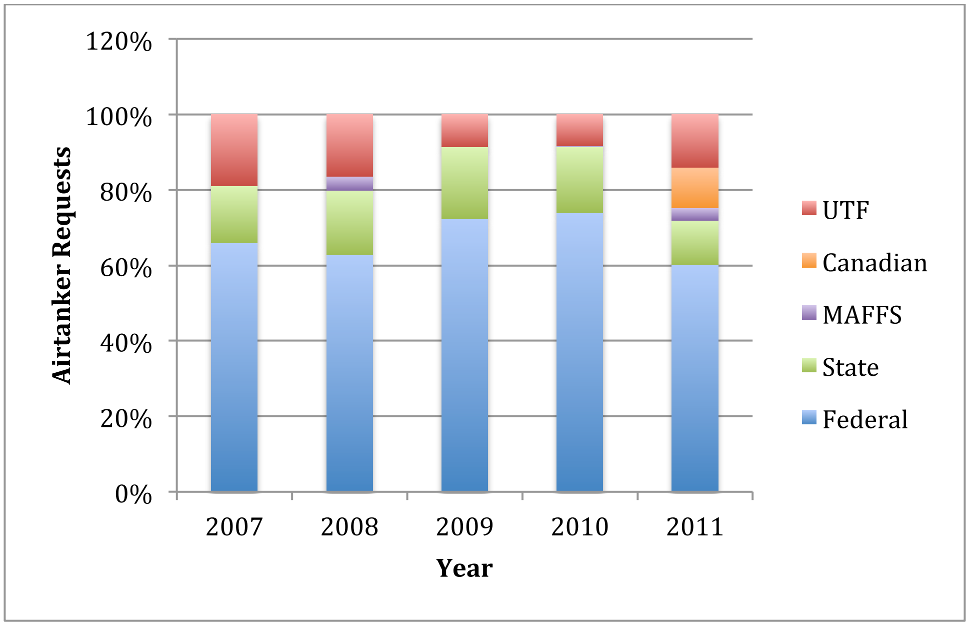

Figure 20 - Percentage of airtanker requests by supply source

3.5. Historical Basing and Movement

Figure 21 shows the average ferry distance in nautical miles from 2010 OLMS data for Type 1 and Type 2 airtankers for each day of the year. The data showed that some flights had no drops, and ended at different locations than where they started. These were considered ferry flights. There were some flights that did have drops, and ended at the same location they started from. These were not considered ferry flights. There was a third type of flight represented in the data, which had drops but did not end at the same location they started from. These were considered hybrid flights, having characteristics of ferry flights and firefighting flights. For these hybrid flights, the longest leg of the flight was considered the ferry portion.

Figure 22 shows the overall demand and supply in 2010 as a function of the day of the year, in terms of the total number of filled airtanker orders and the USFS contracted fleet size, respectively. Note that the fleet size in Figure 22 is from the contract data, and does not reflect unscheduled downtime, or real-world events such as the June 2010 airtanker accident.

The peak of the fire season can be seen in both demand and supply. Qualitatively comparing the ferry distance data with the demand/supply data reveals that there are higher peaks in the ferry distance outside the core fire season, i.e., before approximately day 160 and after day 270. During this time of the year, the contracted fleet has either not yet reached its maximum number, or is being reduced from its maximum. Thus, it is reasonable to conclude that the available airtankers must be ferried farther distances to meet the demand for aviation support.

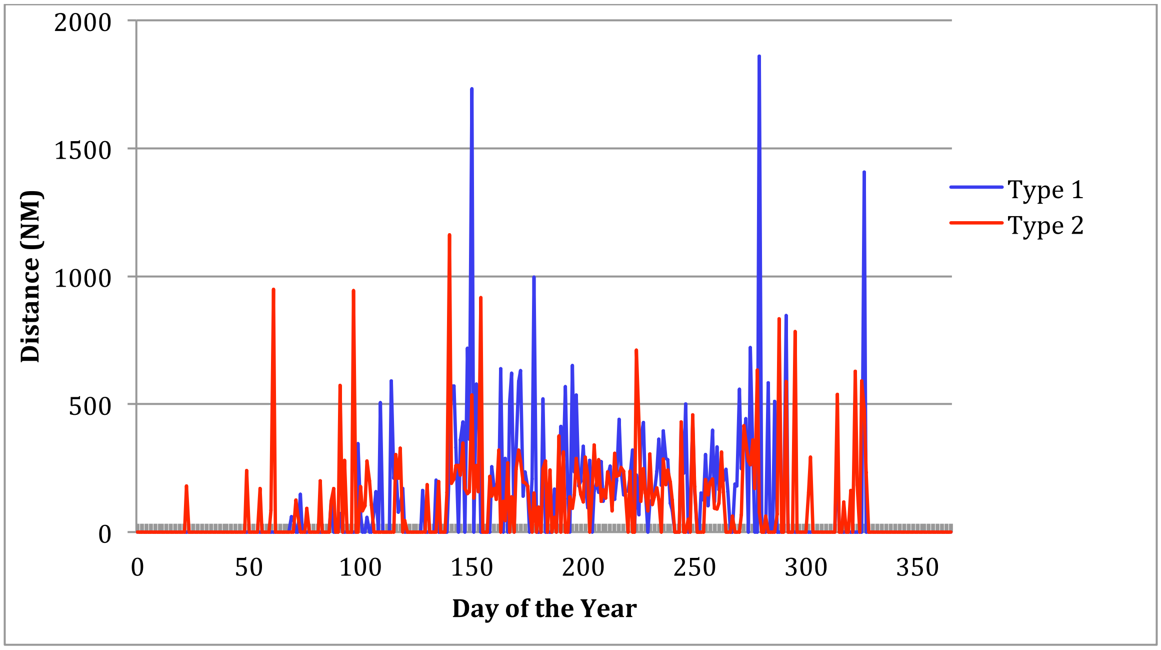

Figure 21 – Average ferry distance for type 1 and type 2 airtankers, 2010

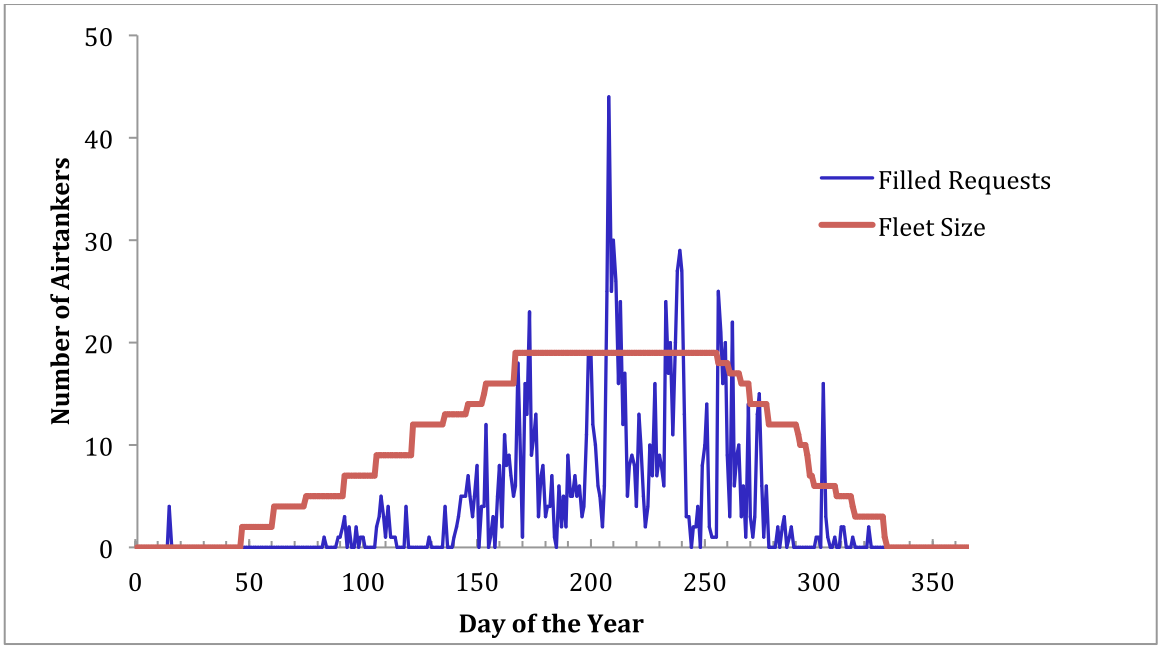

Figure 22 - Number of filled airtanker requests and contracted airtanker fleet size in 2010

4. Modeling

Available data was used to construct large airtanker demand and supply models that can be exercised to predict the ability to meet future needs. The demand model is based on available ROSS requests and historical fire data from FPA, which are used as predictors of the demand for airtankers. The ROSS and FPA data are used without differentiating or filtering based on fire mission (Initial Attack, Extended Attack, Large Fire Support). Thus, the model does not specifically model any particular fire mission. Rather, it predicts the demand for all the fire missions, and the inherent relationships between IA, EA and LFS are captured through use of the historical data as a model basis.

Supply and demand models are used to predict the need for airtanker support and the ability of the USFS contracted fleet to respond to that need, allowing the effects of several parameters to be assessed. The demand model predicts request orders for airtanker assistance that are then filled by "virtual" airtankers based on logic in the supply model. The difference between the predicted demand and the modeled supply represent the predicted level of unfilled orders. This model architecture is shown in Figure 23.

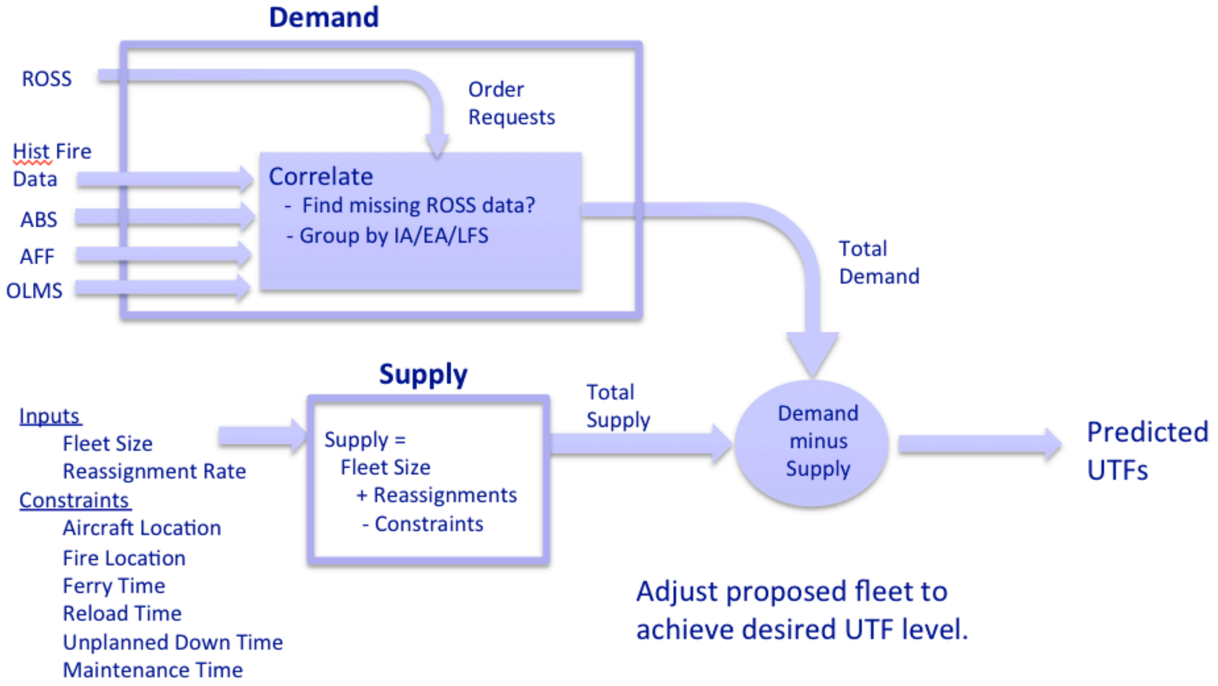

Figure 23 – Demand and Supply Model Architecture

4.1. Demand Model

4.1.1. Demand Model Overview

Direct application of the available airtanker request data into the demand model yields a predicted number of airtankers that might optimally fill requests for the narrow data set from 2007 to 2011, but fails to fill requests for other years that lack known request data. Instead, by defining a probabilistic demand model, fit to actual airtanker requests and historical fire data, hypothetical years of airtanker requests can be generated for any type of year (e.g., very active fire years, relatively "quiet" fire years, etc.). Then, applying the supply model to thousands of these hypothetical years gives a probabilistic fit to the mapping between the number of available airtankers and the percent of filled requests.

First, a discussion of the available information in Section 4.1.1 prescribes the level of detail that can be attained in the current demand model. With the demand framework established, a review of probability theory in Section 7.5 provides background information that will be used to formulate the demand model. The demand model is devised and a methodology is developed to identify its parameters in Section 4.1.2. Results of this identification procedure are then shown in Section 4.1.3, and finally, implementation of the demand model is discussed in Appendix 7.6.

4.1.1. Available Demand Information

Relevant information available to build the demand model includes historical fire data from 1992 to 2010 and airtanker requests from 2007 to 2011. The historical fire data gives start and contain dates as well as maximum fire size. Airtanker request data includes the request date, tail number of responding aircraft, and filled/unfilled status. A function directly linking airtanker requests to fires is currently unattainable without additional information or assumptions. Furthermore, weather data, fuel characterization, and firefighting effectiveness were not within the scope of this study. Though this prevents explicit modeling of fire and request behavior, a probabilistic model has been developed that predicts total airtanker requests in a day based on the actual airtanker request data, which are then assigned to particular locations based on likelihood of a fire from the historical fire data.

4.1.2. Demand Model Formulation

Airtanker demand modeling proceeds in two steps. First, negative binomial distributions, fit for each day of the year based upon a normalization of five years of request information (2007-2011) and combined with a seed random value, give the total airtanker requests for each day of the modeled year across the continental United States. Second, each request is geographically placed within the U.S. based upon a probability distribution generated by summing historical fire data into 0.5-degree latitude/longitude square "buckets" for each day of the year. In order to yield a distribution that guarantees that each request is placed on the map, the probability distribution for the entire United States for each day is normalized by its sum, ensuring that the total of all "buckets" combined has a probability of 1 (i.e., 100% probability). These requests, bound with day and location information, are placed in a list and sent to the airtanker supply model.

Negative binomial distributions for the total airtanker requests in a day require a considerably higher number of data points than the given five points representing five years of data. A two-week windowing function addresses this issue by using all data points between seven days behind and seven days in front of a given day, yielding 70 data points (14-day window containing 5 years of data) with which to create a statistical fit for each day. Even with 70 points of data, the negative binomial distributions would give unrealistically high variance due to light and heavy demand years. By normalizing all years by the sum of total requests through the year, variance is brought to a realistic level while simultaneously giving the user control over what type of year (light vs. heavy fire activity) will be generated.

To fit negative binomial distributions to the airtanker request data, we must first generate cumulative probability distributions for each day of the year. Since each of the 70 observations for a two-week window has a 1 in 70 chance of occurring, we can generate a cumulative probability distribution by stepping through the 70 observances of number of requests. Using number of requests as the independent variable, we step through each number of requests starting with 0 and ending with the maximum number of requests seen in the data. At each step, we check to see how many of the 70 data points match the corresponding number of requests, and increase the dependent axis, which starts at 0, by 1/70 for each match. To reiterate, the steps are explicitly shown below.

1. Take a two-week window of all request data from the past five years
2. Order this data from least to greatest
3. Initialize a "total probability" variable to 0
4. Starting with 0, step an iterator i, one-by-one, until the number matching the highest number of requests is reached
    (a) Check how many data points of the two-week window match i; for every match add 1/70 to the total probability.
5. Repeat Steps 1-4 until all days of the year have a cumulative probability distribution

With cumulative probability distributions calculated, parameters of a negative binomial distribution can be adjusted to yield a match to actual data.

Recall that negative binomial distributions have a cumulative probability shown in Figure 66. This cumulative probability is defined as

$$\boldsymbol{Pr_{cumul}(k) = 1 - I_p(k+1, r)} \tag{1}$$

where

$$I_p(\mathbf{k+1}, r) = \int_0^p \mathbf{t^k}(1-t)^{r-1}\,\mathbf{dt} \tag{2}$$

and k is the independent variable. We seek to adjust the parameters p and r such that the modeled and actual cumulative probabilities match. Minimizing the objective function

$$\mathbf{J} = \sqrt{\sum_{i=0}^{n}\left[\boldsymbol{Pr}_{cumul}^{actual}(\boldsymbol{i}) - \boldsymbol{Pr}_{cumul}(\boldsymbol{i})\right]^2} \tag{3}$$

by running an optimization routine, negative binomial distributions are fit to actual data for each day of the year. Note that n is the maximum number of requests found in the data. This cumulative probability is directly used with a random number between 0 and 1 to give total number of requests for a day for a modeled year.

Since the supply model uses request locations to determine which airtankers are within range, a method of geographically placing each request within the United States is needed. Simply using the actual request data as a geographic predictor forces all requests in a modeled year to fall only in places that received a request in the past five years. This creates an increasingly sparse dataset at each discrete geographic location as the resolution of the discretized U.S. is increased, which inadequately models demand. To alleviate this lack of data, we use historical fire data from 1992-2010 to generate a probability of fires, which is assumed to equal the probability of airtanker requests. This assumption does not hold in areas where historically there are more reported fires but no corresponding rise in airtanker demand, such as remote areas where fires do not pose a threat to population centers. However, this placement approach was sufficient for the current study's modeling requirements, yielding a high degree of model accuracy as compared to actual data. A detailed error analysis of the model is given in section 4.2.4.

For each day of the year, all active fires are placed in 0.5-degree latitude/longitude square "buckets." To give a valid probability distribution, each bucket is divided by the total number of active fires for a day, which ensures that the total probability exactly equals 1, giving a 100% probability that a request will be placed somewhere within the U.S.

Requests are placed in buckets by first assigning each bucket to a segment of values somewhere between 0 and 1, which has a length equal to its probability. Note that the sum of all buckets has a total length of 1, which completely fills all values between 0 and 1. To clarify, the steps to assigning buckets to segments of real values between 0 and 1 are shown below.

1. Initialize a "lower probability" indicator, k, to 0
2. Iterate through every bucket in the United States
   a. When a bucket with non-zero probability is encountered it will take the segment of real values between k and $k+p$, where p is the probability of that particular bucket
   b. Assign k to $k+p$

A random number between 0 and 1 is generated for each request, which is immediately applied to this probability mapping. The bucket with the segment of real values that contains the random value receives the request. Since each bucket has a segment equal to its probability, buckets with higher probabilities have a greater chance of receiving a request.

4.1.3. Demand Model Results

Applying the algorithms described in the previous section to ROSS data from the years 2007-2011 and historical fire data from 1992-2010 yields the total requests predicted per day and the geographic placement of these requests. A few representative plots are utilized here to illustrate the results. The entire set of results can be found in Appendix 0.

Figure 24 and Figure 25 show actual cumulative probability distributions for request data for two-week windows and their commensurate negative binomial fits during heavy and light times in the fire season, respectively. It can be clearly seen that use of the negative binomial function yields a close fit to actual data.

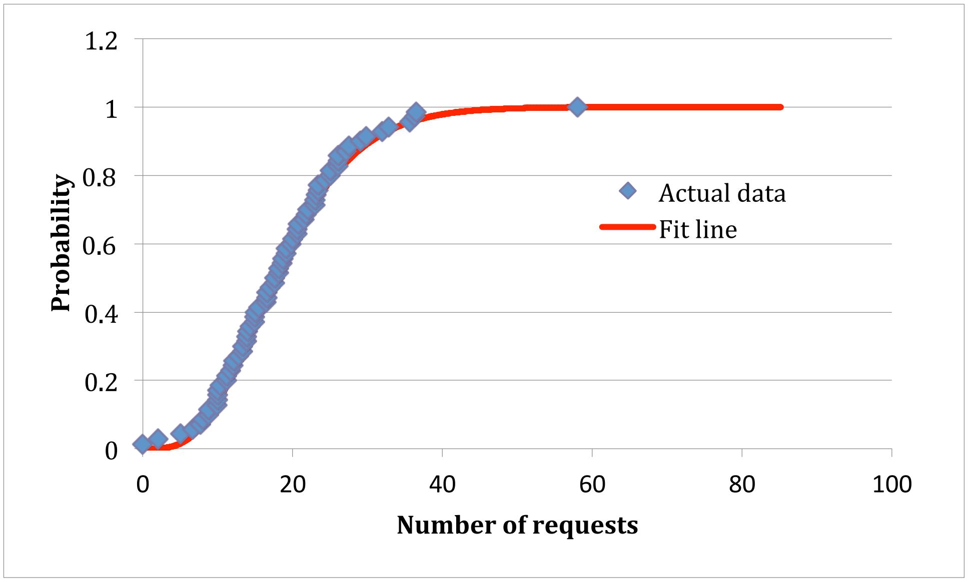

Figure 24 - Cumulative probability fit for day 210

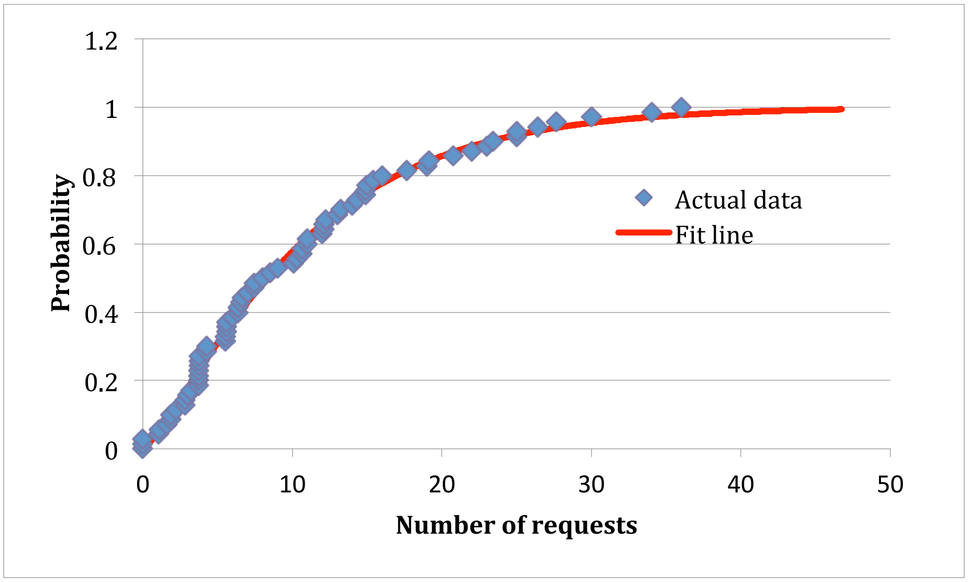

Figure 25 – Cumulative probability fit for day 154

Figure 26 shows a cumulative probability fit towards the beginning of the fire season, which illustrates the case where sparse data is prevalent. Note that though a continuous line is drawn representing the negative binomial fit in these plots, only the points that represent integer values are used in line fitting and request generation.

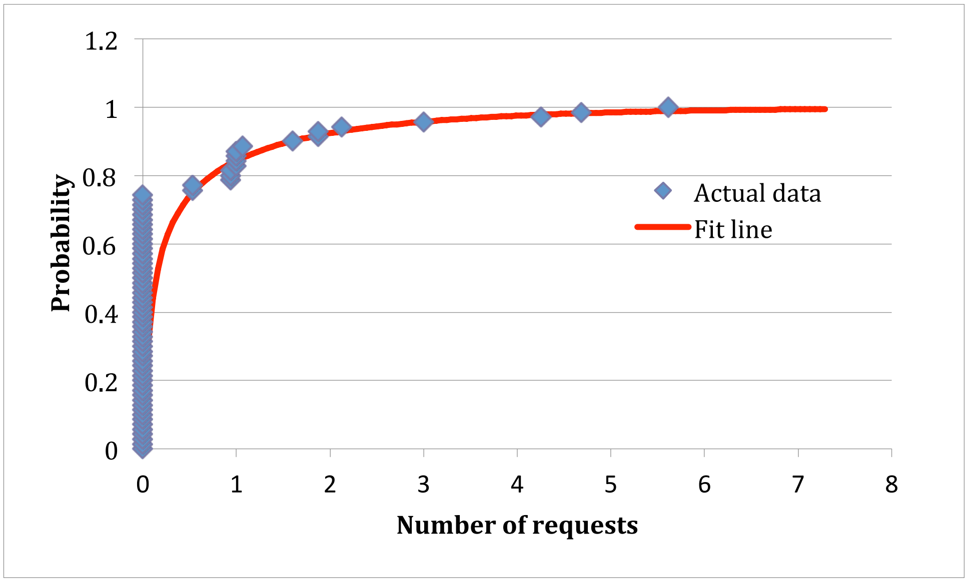

Figure 26 - Cumulative probability fit for day 56

Finally, the question naturally arises, "How well do the modeled years match the five years of actual requests?" Figure 27 shows the total requests for five modeled years while Figure 28 shows the actual five years, normalized to have the same sum of total requests. Qualitatively it can be seen that the modeled total requests match the actual request years well. Recall that the modeled years can be easily scaled to give particular type years (heavy vs. light fire activity) that would subsequently match the non-normalized data.

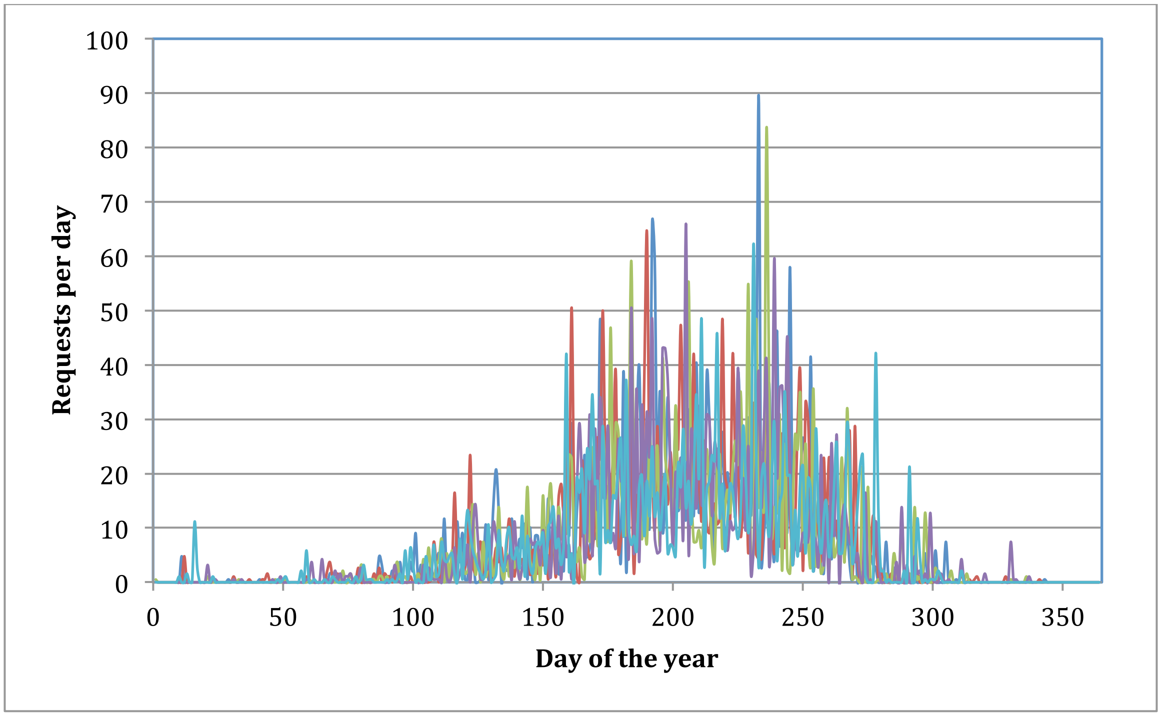

Figure 27 - Total requests for five years of modeled request data

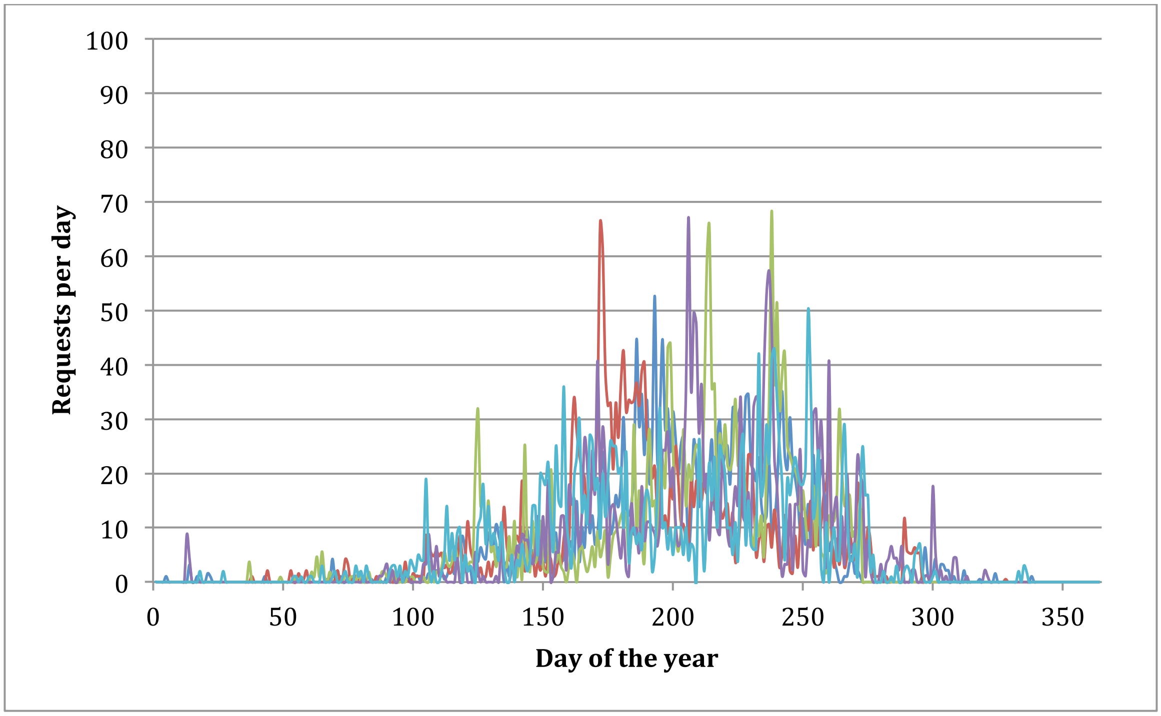

Figure 28 - Total requests for five years of actual request data

With modeled total request years matching actual data, the final step is to place each request on a map of the United States. Figure 29 through Figure 31 show the probability distribution for different representative times throughout the year. Every request generated for a modeled year is placed somewhere in the United States based upon these probability distributions, with red locations having the greatest probability, blue locations having little probability, and transparent locations having no probability. As can be seen, fire activity generally begins in the south (e.g., Texas), which then shifts to California and the southwest, and finally moves northward towards Idaho.

Points east of 90 degrees west latitude (a line extending from approximately the mouth of the Mississippi river northward through the center of Wisconsin) were neglected, to simplify the modeling. The available ROSS data showed that, from 2007 to 2011, there were a total of 10,717 requests. Of these, only 242 were located east of this line.

Details of the demand model implementation are given in Appendix 7.7.

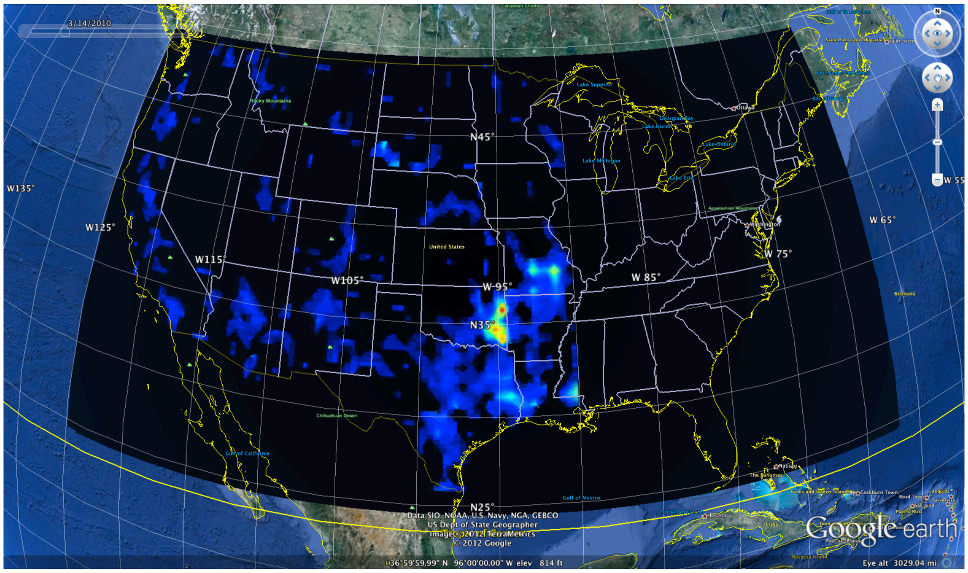

Figure 29 - Fire probability map for day 73 (March 14)

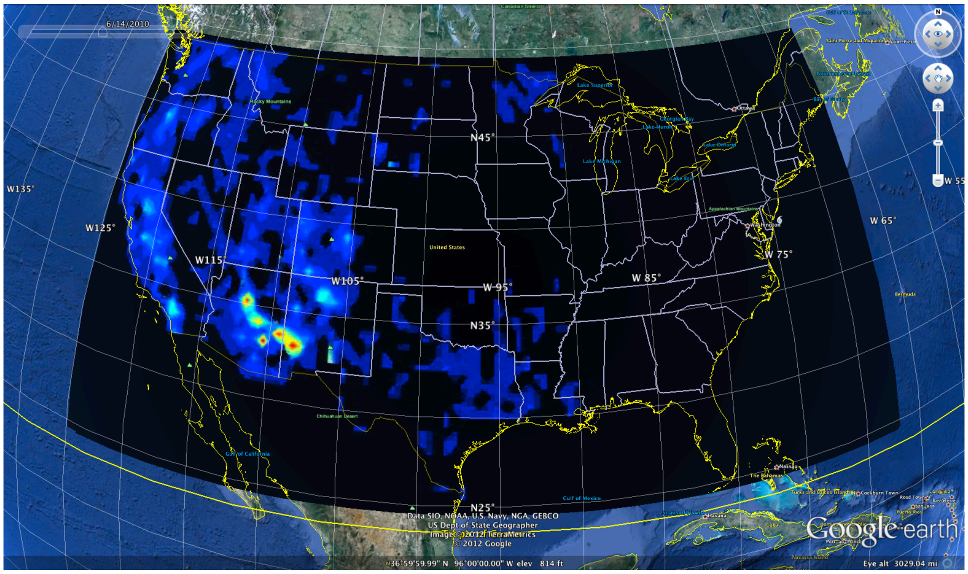

Figure 30 - Fire probability map for day 165 (June 14)

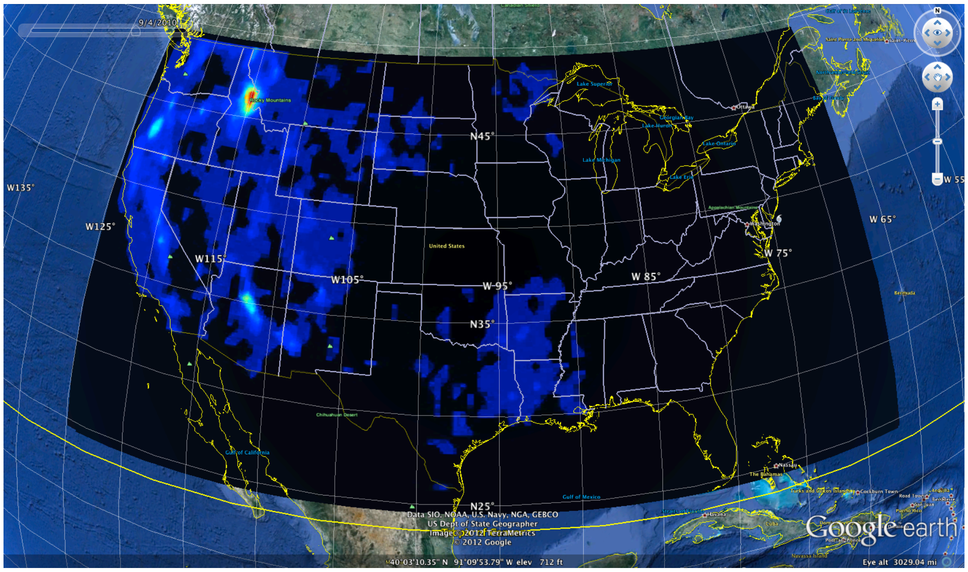

Figure 31 - Fire probability map for day 247 (Sept 4)

4.2. Supply Model

4.2.1. Supply Model Overview

The supply model has been designed to match the supply strategies of the USFS airtanker fleet. Using a correctly tuned supply model and demand model, the number of airtankers needed to reduce the number of unfilled orders can be predicted. At a high level, the supply model is relatively simple, as shown in Figure 32. Requests come into the model and are either filled or not, depending on the logic in the model.

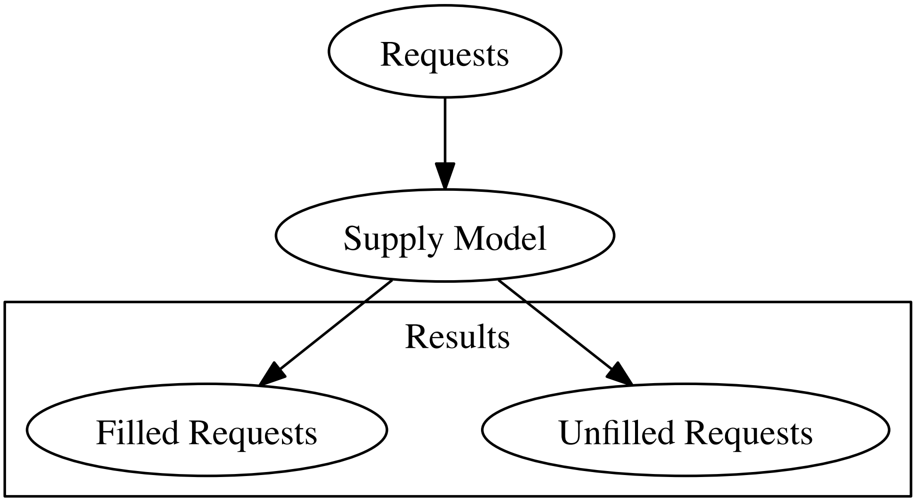

Figure 32 - Supply Model Overview

This section begins with a discussion of how requests are generated or queried from the ROSS database, section 4.2.2. Next, section 4.2.3 provides details of the supply model behavior. The supply model is tuned to replicate known historical behaviors, as described in section 4.2.4.

4.2.2. Supply Model Requests

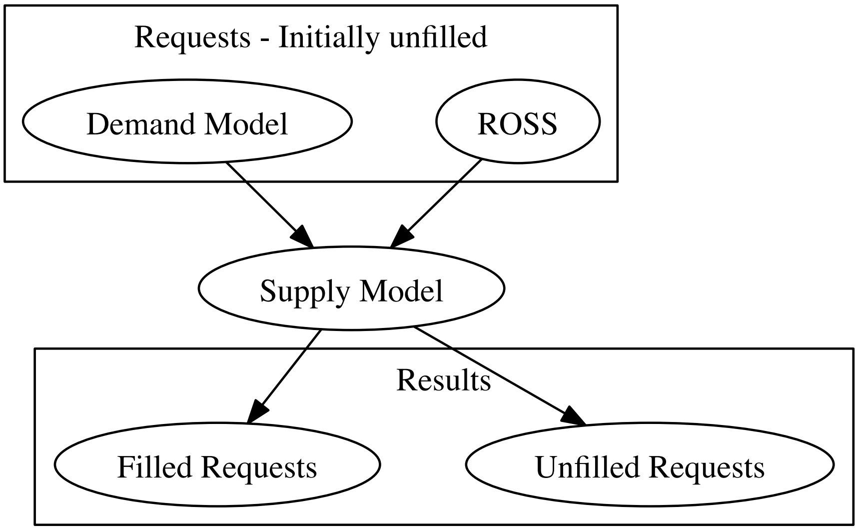

Figure 33 – Creating requests in the supply model

The airtanker supply model can use requests created by two sources: the demand model described in section 4.1, or actual request data found in ROSS (see Figure 33). We used each source independently. Using the demand model, we can generate a fire year with a specific relative fire activity level, and see how the supply behaves on that modeled fire year. Using the actual data, we can tune the supply model to react similarly to the historical supply.

Each request has a date and a location attached to it. Requests come into the supply model from either source as unfilled. The supply model logic then attempts to fill the request. If the request is not filled, it remains unfilled. These two outcomes are shown in Results Box of Figure 33.

4.2.3. Supply Model Logic

This section focuses on the core logic of the supply model, as shown in Figure 34. The supply model marches through each day of the modeled year. On each day, the supply model calculates the airtanker supply and demand.

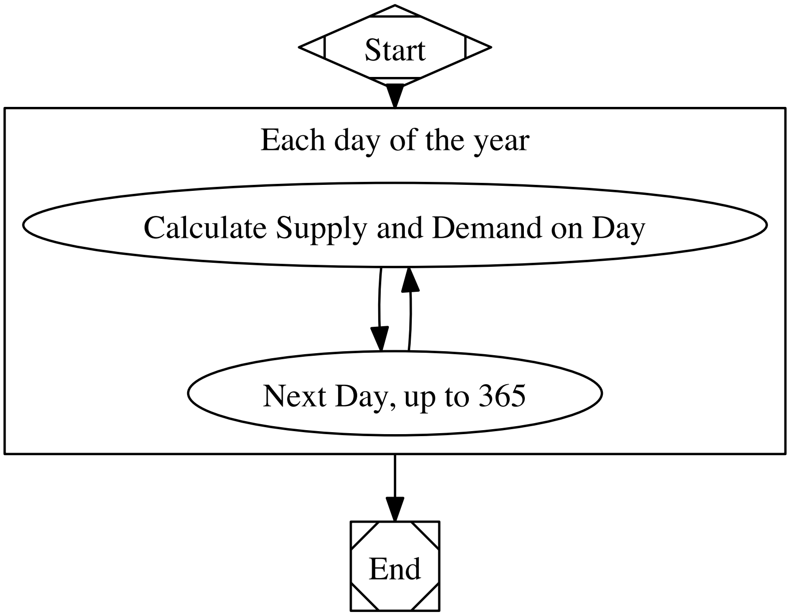

Figure 34 - The core supply logic flowchart

The supply model first finds all the available airtankers and all the requests on the current day, as illustrated in steps D1 and D2, Figure 35. Then it assigns requests to airtankers, step D3. After that each airtanker attempts to fill its requests, step D4. Finally, the supply model prepositions (ferries) aircraft for the next day in step D5. As described in section 4.2.4, factors controlling the range of the modeled aircraft, and the rate of ferrying, are used to tune the supply model and provide a means of studying supply scenarios.

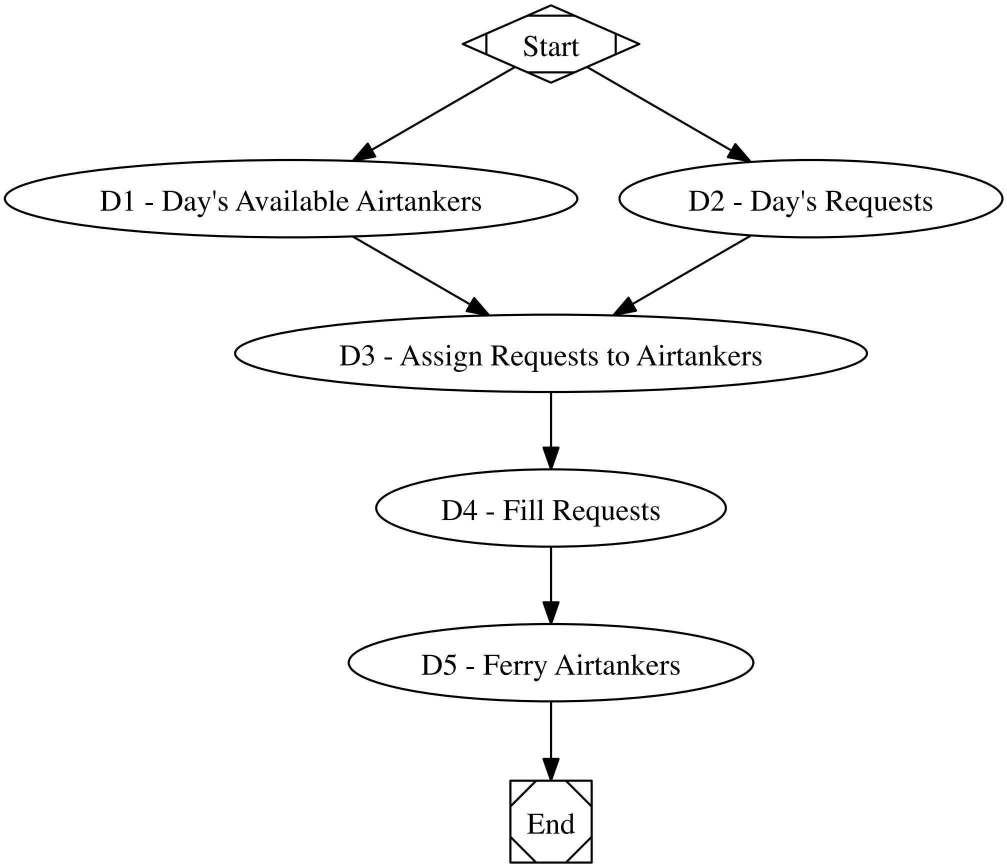

Figure 35 - Supply model logic for a single day.

4.2.3.1. Supply Logic – D1 – Available Aircraft on a day

Table 10 details how the supply model generates hypothetical aircraft, or models aircraft from the contract information, depending on how the supply model logic is being used.

Usage	Available Airtankers
Tuning the Supply Model to Actual Request Data	Models airtankers from the contract information based on the year. For example there were 19 contracted airtankers in 2010 vs. 12 in 2011. This does not include real-world events that cause fleet size fluctuations, and thus isolates those effects from planned fleet size effects.
Running the Supply and Demand Airtanker Study (varying the number of airtankers)	The supply model uses the 19 airtankers and home bases from the 2010 contract information. After the first 19, the supply model generates airtankers and places them at random starting base locations, and thus isolates fleet size effects from prepositioning effects.

Table 10 – Modeling airtanker fleet size and location

According to the available contracts information, all airtankers are off one day per week for scheduled maintenance. The supply model excludes airtankers that are off from the daily available aircraft. For airtankers added from contract data, the supply model uses the off day found the contract information. For generated airtankers, each airtanker is uniformly assigned to a day of the week.

Unscheduled downtime is not currently modeled. When tuning the model, we found that the data suggested that the probability of unscheduled downtime is less than 0.1% for each airtanker on each day.

Generated airtankers (i.e., those that are modeled in excess of the 19 airtankers from 2010) are in service from Jan-1 to Dec-31. The supply model uses the service date found in the contracts for actual airtankers.

The starting position of the airtankers (position of the airtanker at the beginning of the year) has an insignificant effect on the supply model because we model airtanker ferrying (step D5). For generated airtankers, the supply model positions them randomly at known airtanker bases at the beginning of the year. For modeling airtankers on contract, the supply model places them at their known home base as specified in the 2010 contract information.

4.2.3.2. Supply Logic – D2 – Requests for a Day

For each day, the supply model looks up the requests for that day, from either the demand model, or from the actual request data. See section 4.2.2 for more details. The supply model will add requests to the current day that were not filled the previous day. Airtankers must fill the request within 2 days; otherwise, the supply model will leave it unfilled. The previous day's requests have the same priority as the current day's requests.

The ROSS dataset confirms that airtankers are sometimes assigned to requests that were made on previous days. On average from 2007 to 2011, the data shows that 22% of filled requests were ordered on the previous day, as shown in Figure 36. In 4% of the cases, firefighters order airtankers and then wait two or more days before an airtanker is assigned. Note that this is the time between when a request is made and an airtanker is assigned, whereas the data in Table 5 shows that airtankers on average are assigned and released on the same day.

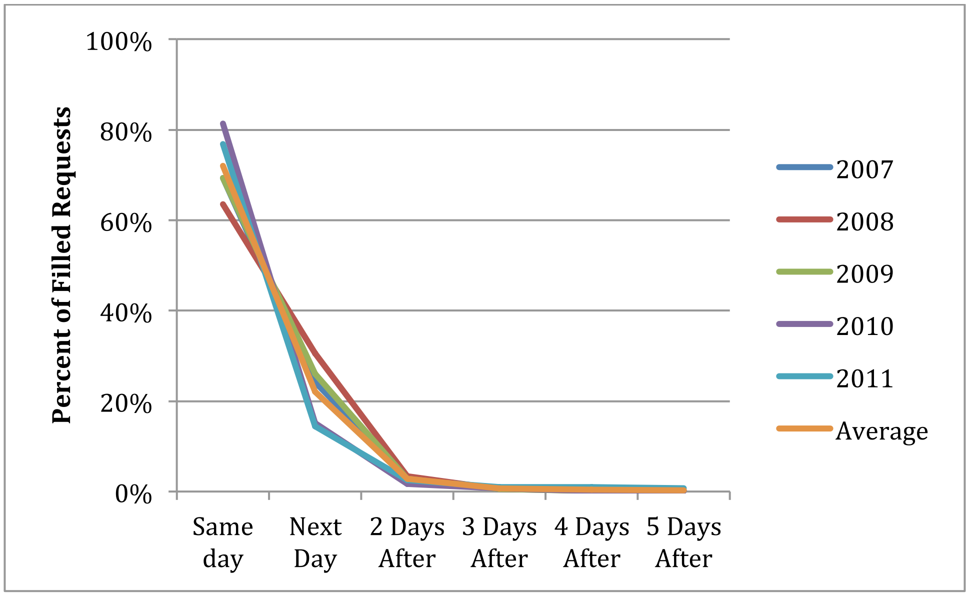

Figure 36 - Number of days from airtanker order date to demobilization date

The ROSS request data also shows that if an order is requested after 17:00 hours, it has a high likelihood of being filled the next day, as seen in Figure 37. The figure shows the number of requests and the time of the day the request was made. 97.2% of requests fall between 7:00 and 20:00 hours and, as the day progresses, airtankers are more likely to fill requests on the next day. The data also shows that aircraft are demobilized rapidly after 17:00 hours (Figure 38). This corresponds to the practice that airtankers only fight fires during the day. Although our model operates on a day-by-day basis, and not hour-by-hour, it fills an average of 24% of requests from the previous day, compared to the 22% found in the actual ROSS data.

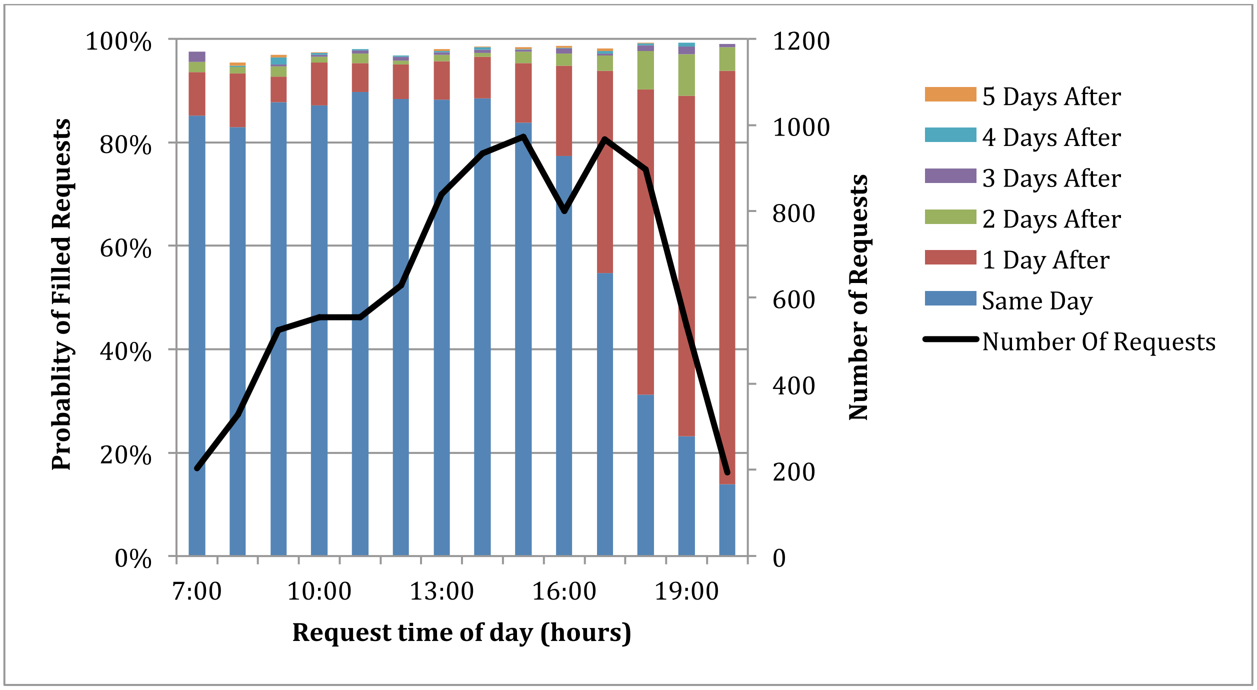

Figure 37 – Probability requests will be filled on the current day or subsequent days (colored bars), and the number of requests (black line), vs. request time (2007-2011)

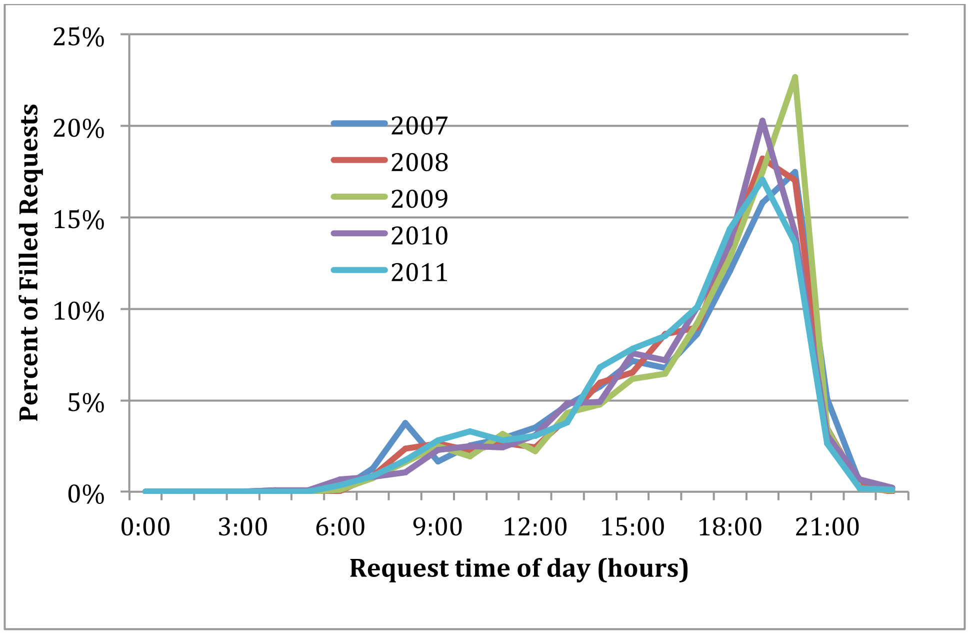

Figure 38 – Demobilization times of airtankers

4.2.3.3. Supply Logic – D3 – Assigning Requests to Aircraft

For each airtanker, the supply model tries to assign all the requests that are within range of the airtanker. The "airtanker max range" is one of the supply model's constraints. We can tune this constraint to fit the model to the actual data. An airtanker's max range is the maximum distance from its starting position to the assigned drop and does not include the return flight. The same request can be within range of multiple airtankers. Therefore, it can be assigned to multiple airtankers. After the supply model finishes assigning the request, it then sorts the requests, as shown in Figure 39.

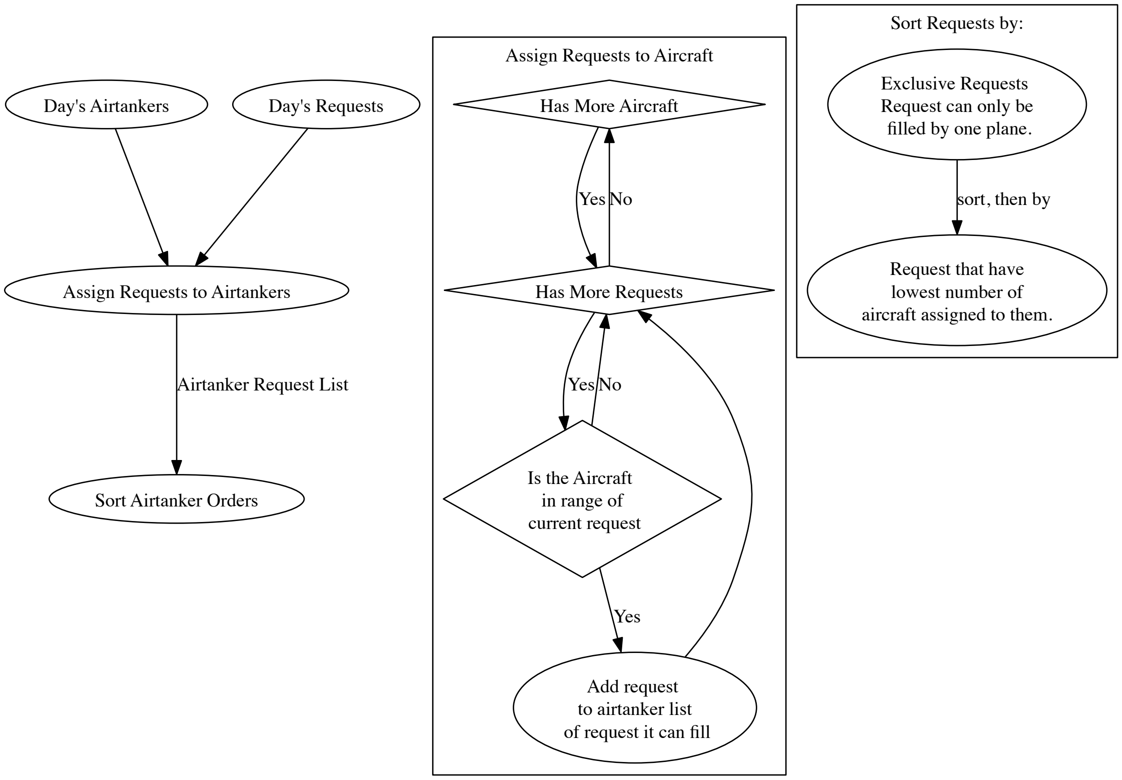

Figure 39 - Assignment of request to airtankers on a day

Each modeled airtanker starts the day at one of the known airtanker bases. The list of bases was determined from several sources, including the "Wildland Fire Management Aerial Application Study" (Fire Program Solutions LLC, 2005), and "Management Efficiency Assessment on Aviation Activities in the USDA Forest Service" (Management Analysis, Inc., 2008). These sources did not include any permanent airtanker bases in Texas, which caused over-predictions of unfilled orders as compared to actual order data. Therefore, any bases in Texas with a runway length over 10,000 feet were included to address this.

This study assumes a level of efficiency in the incident commander's request for and allocation of aerial firefighting resources. Therefore, in an effort to maximize filled requests, the supply model sorts the requests by priority. The sorting logic first finds requests that can only be filled by one airtanker. These are exclusive requests. An exclusive request has the highest priority and airtankers are used to fill them first, which results in more filled orders and fewer underutilized airtankers.

Next, the supply model sorts the requests in ascending order by the number of airtankers assigned to them. Airtankers fill requests with a low number of airtankers assigned to them before filling requests with a higher number of airtankers. This logic assumes that requests that have a high number of airtankers assigned to them will have a better chance of being filled.

4.2.3.4. Supply Logic – D4 – Fill Requests

Once airtankers have requests assigned to them, the supply model fills the requests in the sorted order generated in step D3. It fills requests using an average Airtanker Reassignment Rate, shown in Figure 40. The Airtanker Reassignment Rate represents the probability that an airtanker will fill one or multiple requests on a single day, if there are requests to fill at all. For example, on average from 2007 to 2011, airtankers filled only one request in 72% of all filled orders, as shown by the solid line in the figure. The model returns each airtanker back to its current base before using it to fill additional orders.

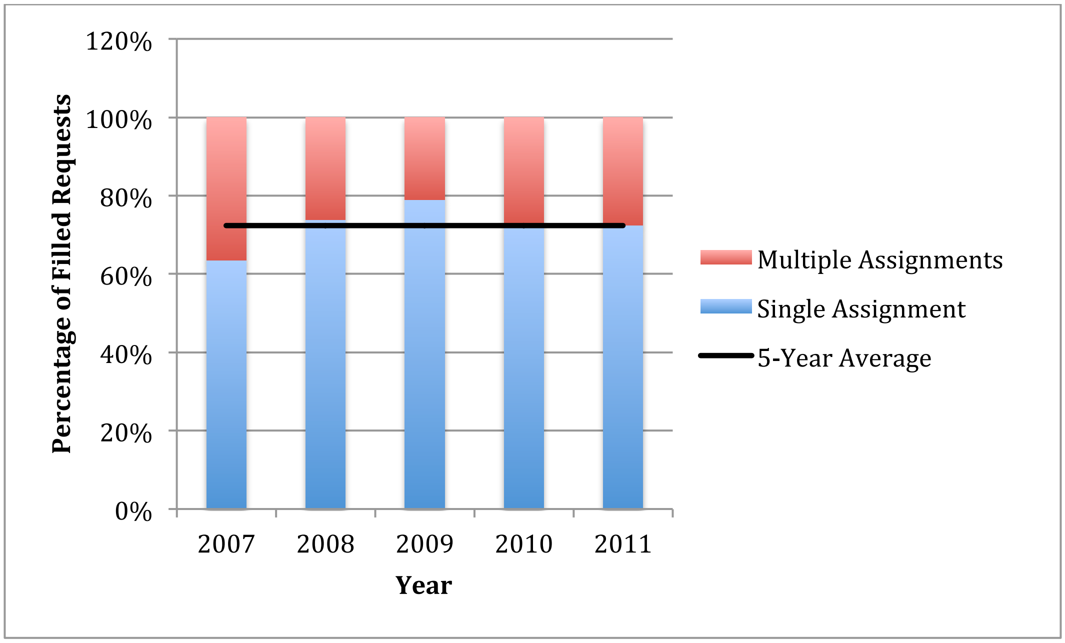

Figure 40 - Airtanker Reassignment Rates

This data does not deviate much from the average for 2008, 2010, and 2011. In 2007, however, which was a year of relatively high fire activity (see section 3.3), the airtankers filled multiple requests in a day more often than the other years. On the other hand, in 2009 (a relatively light year), airtankers filled one request per day more often than the other years. Since the supply model uses the average airtanker reassignment rate, it over-predicts or under-predicts the number of unfilled requests as compared to actual data in 2007 and 2009. More details of the model's tuning and error analysis are in section 4.2.4

In the actual request data from ROSS, the requests are filled in three different ways: single releases, multiple releases, and reassignment. Single releases are where an airtanker fills only one request in a day. Multiple releases are where an airtanker fills a request, is released from one incident, and fills at least one more request. Finally, airtankers can be reassigned from one fire to another higher priority fire. The supply model views all three methods as filled requests and models the behavior of all three using the average reassignment rate.

4.2.3.5. Supply Logic – D5 – Ferry Airtankers

If the supply model does not fill a request on the first day, it can ferry underutilized airtankers to fill the request on the second day. It ferries the airtankers using a "Ferry Factor," defined as the ratio between number of unfilled requests at a base and airtankers. Using this factor, the following equation determines how many airtankers are needed at a base:

$$N = Nr / F - Na$$

where

N = Number airtankers needed to be ferried
Nr = Number of unfilled requests at the airtanker base
F = Ferry Factor
Na = Number airtanker already at the base

For example, if an airtanker base has three unfilled requests on the current day, has no airtankers at it, and the ferry factor is 1.5, then the airtanker base needs two airtankers to fill requests for the next day.

$Nr = 3, F = 1.5, Na = 0$, then
$N = 3 / 1.5 - 0$
$N = 2$

The supply model only ferries an airtanker when it predicts that it will be underutilized for the next day. An underutilized airtanker condition occurs if, and only if, another airtanker base has an airtanker and does not need it for the next day. Airtanker bases with the most unfilled requests have priority over airtanker bases with fewer unfilled requests at the end of each modeled day. If an airtanker is ferried to another base, the model keeps it at that location until it is ferried again. Thus, the locations of the airtankers move throughout the modeled year according to the demand, just as actual airtankers do.

The supply model currently does not have a maximum ferry distance. Airtankers can ferry to any other airtanker base at the end of the day. This models the ability to move airtankers large distances overnight, and carries with it the assumption that suitable ferry crews are available. Furthermore, the supply model does not currently model the role of preparedness level, which can be used to preposition airtankers based on weather conditions, fuels and other factors.

4.2.4. Tuning the Supply Model to the Actual Data

The supply model has two tuning parameters, used to ensure the model can replicate known historical conditions. The tuning parameters are Airtanker Max Range and Ferry Factor, which were used to fit the model to the actual request data found in ROSS from 2007-2011. For modeling purposes, we consider all requests that were filled with non-contract fleet airtankers as unfilled, and we combined requests with status of Released and Reassigned together as filled requests. Some actual data was excluded from tuning, as described in Appendix 7.6.

Requests that were filled with non-USFS contract fleet (see section 3.4) were considered as unfilled because they mask true USFS contract fleet supply. For example, in 2011 the USFS used 12 contracted airtankers to fill as many requests as possible, and then filled subsequent requests with non-contract fleet airtankers. The objective of the supply model was to represent the ability of the contract fleet to respond to requests for aviation support.

The use of non-contract fleet airtankers to meet demand is a complex function of many variables, including the level of demand each day, fire behavior, and existing cooperator agreements. Modeling this type of supply was not performed in the current study.

We combined released and reassigned requests as filled requests, and assigned airtankers to one or more requests per day using an airtanker reassignment rate as described in section 4.2.3.4. It allows us to compare filled requests in the actual ROSS data with filled requests in the model's prediction. Using these assumptions we tuned the model to the following parameter values.

- Airtanker Max Range = 300 NM
- Ferry Factor = 4.0

Our tuned Airtanker Max Range limits airtanker assignments to within 300 NM of their starting position for each day. Onboard aircraft tracking data found in OLMS also supports a max range of 300 NM. The 2010 OLMS data shows a mean drop distance of 57.9 NM with a standard deviation of 116.5 NM. About 95% of all values in a normal distribution fall within two standard deviations of the mean. Thus, from the OLMS data, 95% of airtanker drops happen within 290.9 NM, similar to the Airtanker Max Range determined from our model tuning.

For requests out of range, the supply model can ferry airtankers to get them closer. A Ferry Factor of 4.0 causes the supply model to try to increase a base's airtanker supply by one for the next day, for every four unfilled requests. For example, if an airtanker base has five unfilled requests, the model will attempt to supply it with 1.25 airtankers for the next day. If the base already has an airtanker at it, then the 0.25 airtanker may be filled with an underutilized airtanker.

We tuned the model by simultaneously varying both parameters while minimizing the difference between the model results and the actual data from ROSS. For example, Figure 41 shows the model's results compared to the 2010 actual data for cumulative filled and unfilled requests.

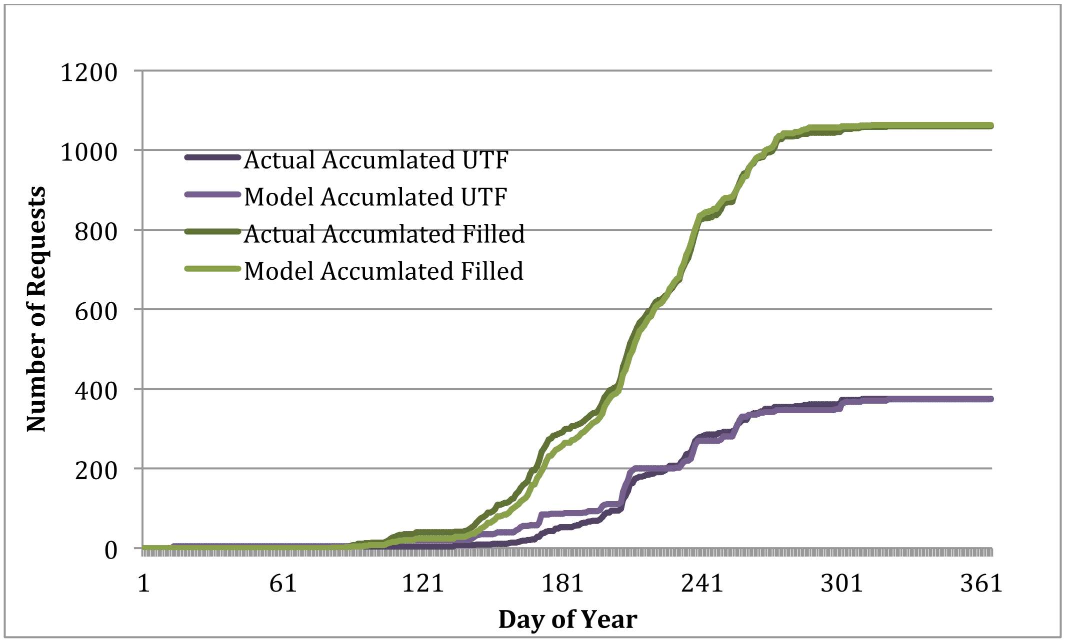

Figure 41 – Cumulative filled and unfilled request comparisons between model and actual 2010 data

Figure 42 shows the day-by-day results comparison for 2010. The number of aircraft available each day was determined from the contracts information, and includes each airtanker's Mandatory Availability Period (MAP) during the year. This is seen in the figure as a general increase in fleet size from about day 46 to day 172, a plateau until about day 255, then a decreasing fleet size through the remainder of the year. The number of aircraft each day also included its scheduled day off each week, which is seen in the figure as a 7-day oscillation. See Appendix 7.8 for the model comparison for each year from 2007 to 2011.

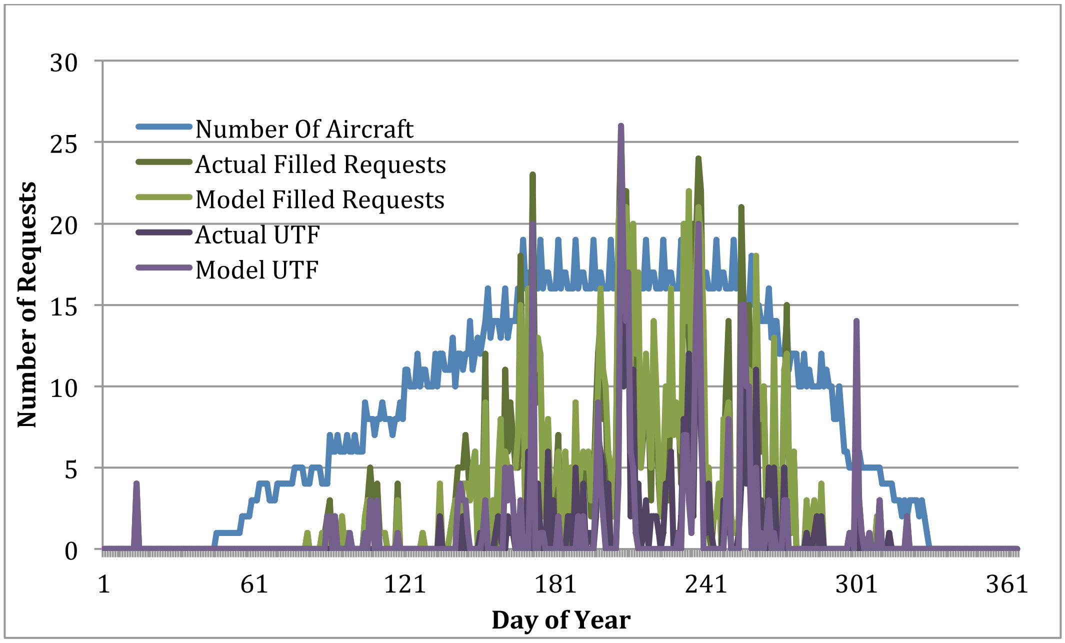

Figure 42 - Day-by-day filled and unfilled request comparisons between model and actual 2010 data

Table 11 shows the computed model error for each year. Two columns describe the accumulated error: Difference and Percent Difference. The difference is the number of unfilled requests the model differed from the actual data. A positive number shows that the model is over predicting the number of unfilled requests. On the other hand, negative numbers show that the model is under predicting the requests. On average the supply model over predicts the number of unfilled orders.

Percent Difference is a normalized absolute difference between actual data and the supply model's prediction. The lower the percent difference, the closer the model is to matching the actual data (0.0% difference means the model performs exactly like the data).

Year	Total Requests	Difference Between Actual and Model Unfilled Requests (Model – Actual)	Percent Difference Between Actual and Model Unfilled Requests
2007	2988	84	7.62%
2008	2771	8	0.76%
2009	1740	35	7.01%
2010	1436	-3	0.80%
2011	1899	2	0.26%
Average		-25.2	4.05%
Standard Deviation		36.0	3.27%

Table 11 – Supply Model Error Analysis

The 2007 and 2009 actual data each show over 7% error compared to the modeled data. After carefully analyzing the data, we believe the ROSS data we received may be missing some records. For example, in the 2009 data sample, no airtanker request data was included from October to December. Also, two airtankers in 2007 were on a "call when needed" basis. Our supply model does not specifically model "call when needed" behavior, and is modeling those two airtankers as normal airtankers. Furthermore, the 2007 and 2009 results had a slightly different airtanker reassignment rate, as shown in Figure 40. These differences contribute to the calculated model error values for 2007 and 2009.

On average, our tuned supply model predicts unfilled requests with a 4.05% error as compared to actual unfilled requests from 2007 to 2011. The tuned supply model drives the supply and demand airtanker study.

5. Airtanker Supply and Demand Study

Using the turned supply model and demand model, we investigated the effects of varying the number of airtankers available in the contracted fleet. As the number of modeled airtankers increased, we observed a decrease in the number of resulting unfilled requests. We also found a point of diminishing return beyond about 40 or 50 airtankers. We modeled demand pulses using the concept of a "Relative Fire Activity Index", as described in section 3.3. The relative fire activity of a year is scaled using the mean fire activity and two standard deviations (2σ) above and below the mean. In this way, we model airtanker demand during active and less active years. These results are shown in Figure 43, along with actual data from ROSS for 2007 to 2011.

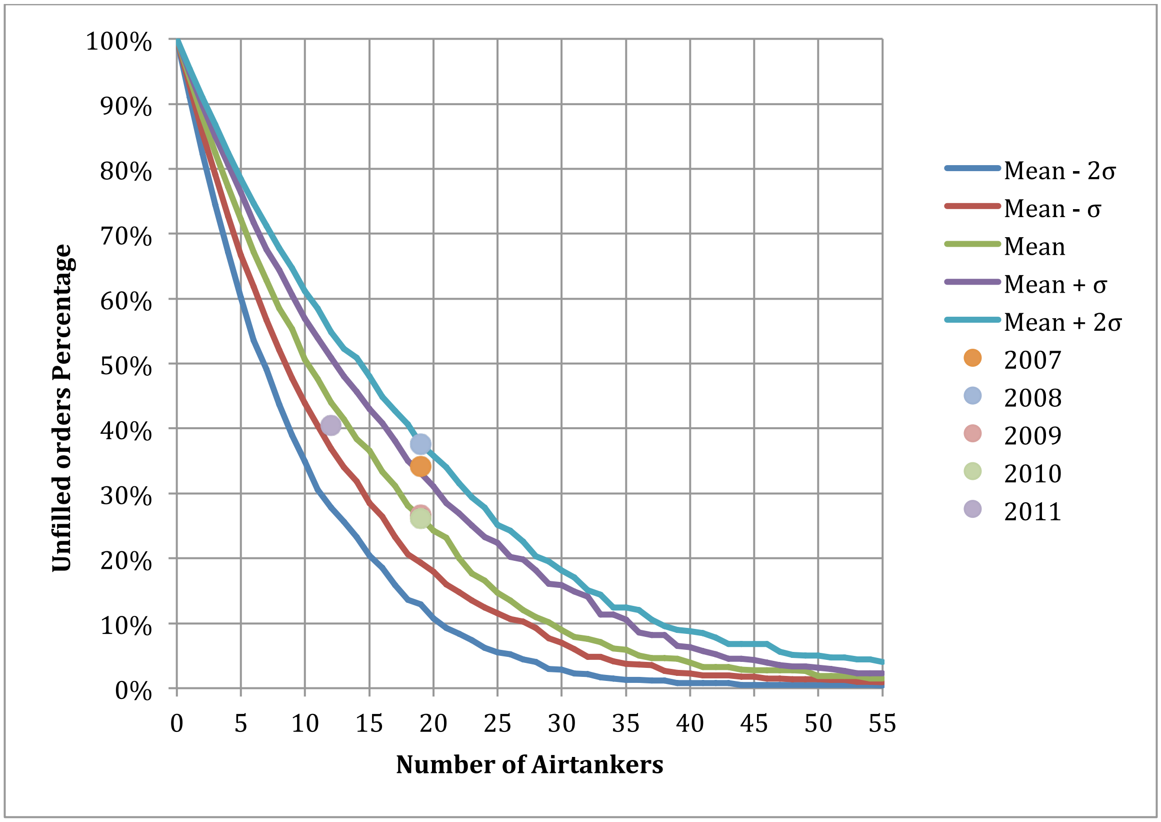

Figure 43 – Modeled and actual percent of unfilled requests vs. number of airtankers for differing relative fire activity

Figure 43 may be used to design an airtanker fleet that meets the USFS needs. For example, if the ability to fill 90% of all requests for a "mean plus one standard deviation year" using only the USFS contract fleet is desired, the modeling and analysis described in this report predict that 35 airtankers would be needed.

Figure 44 shows similar results, but uses actual ROSS data for the demand rather than the modeled demand. This isolates the supply model behavior from the demand model and, based on the similar results, gives us confidence in the demand model's ability to accurately reflect real-world behavior.

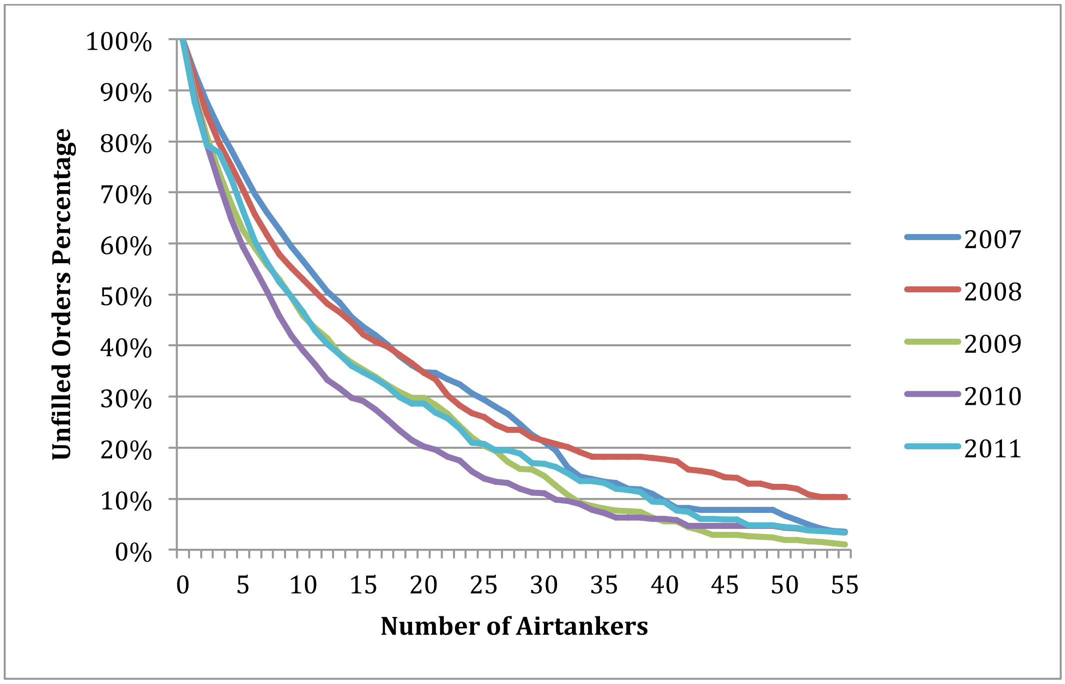

Figure 44 - The results of varying the number of airtankers supply vs. actual request data.

Figure 44 shows that the percentage of unfilled requests, calculated using the supply model and actual demand data, appears to level out at around 53 airtankers. This plateau is mostly likely caused by requests that are out of range of known airtanker bases. Our supply model currently does not support the ability to supply airtankers from temporary airtanker bases.

Improvements in aircraft capabilities are of interest as the USFS makes plans to replace older airtankers in the fleet. Aircraft speed and capacity have been identified as important parameters to consider for NextGen airtankers (USDA Forest Service, 2012). Our model is based on request data from ROSS and historical fire data from FPA, which do not explicitly capture speed or capacity. Thus, our model does not explicitly model airtanker speed or capacity. The model assigns airtankers to predicted requests and does not attempt to predict gallons dropped, or other efficiency-related parameters. However, there are parameters in the current model that characterize the supply fleet, and the concept of improving these parameters was explored by conducting sensitivity analyses.

The first approach to this was to increase the maximum airtanker range in the supply model. The results shown in Figure 43 are for a tuned model using 300 NM as the maximum airtanker range in a day, and airtanker bases currently in use. Figure 45 shows the results of a sensitivity analysis in which the range was increased by 20% to 360 NM for an average year. As seen in the figure, this had very little effect on the percentage of unfilled orders for each fleet size. While not modeled directly, note that increases in airtanker speed and increases in maximum daily range are closely related.

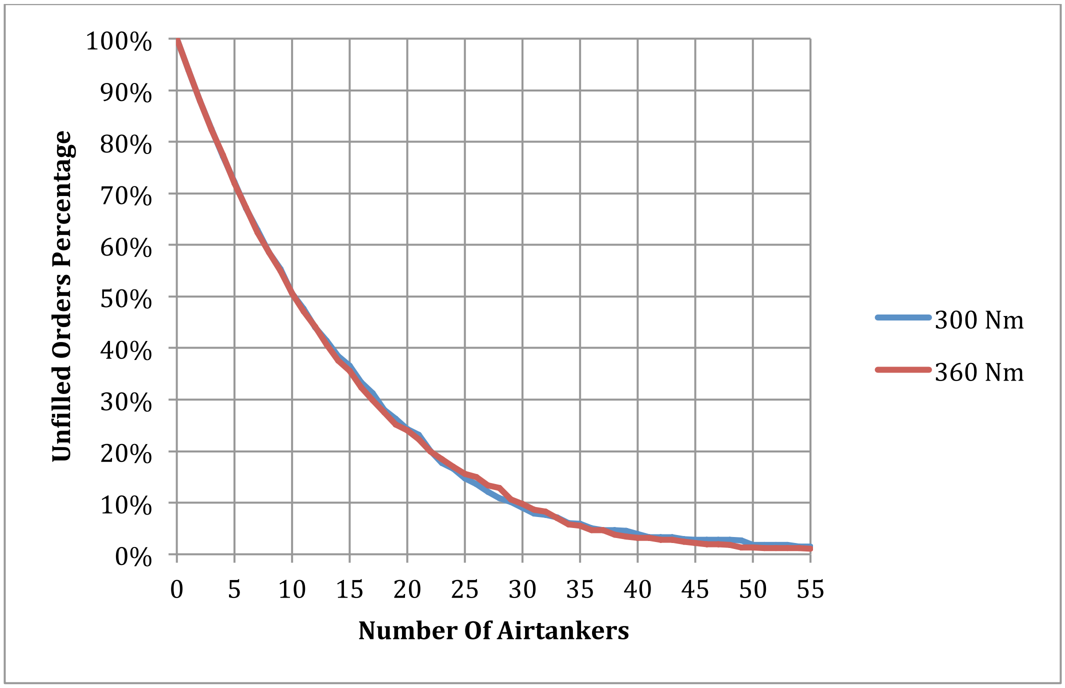

Figure 45 – Increasing the range of the airtankers by 20%

Figure 46 shows range circles of 300 NM around each of the known airtanker bases. The area covers most of the active fire areas, which explains, in part, why increasing an airtanker's range has negligible effect. As airtankers are replaced with more capable aircraft, it may be possible to affect cost savings by reducing the number of bases. Reducing the number of bases, while replacing the fleet with faster aircraft, could have more impact on the number of unfilled orders. However, selecting which bases to close may include several complex factors, and was not explored in the current study.

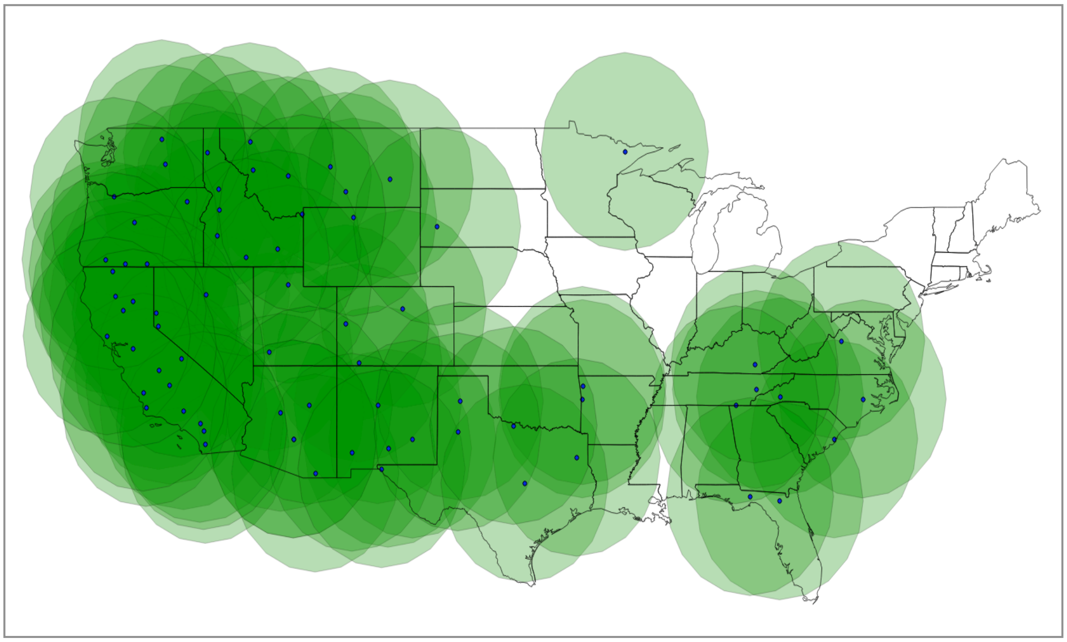

Figure 46 – 300 NM range circles around modeled airtanker bases

The next sensitivity analysis explored increasing the average airtanker reassignment rate for filling one or multiple orders in a day. The model results shown in Figure 43 used an airtanker reassignment rate calculated as an average of actual filled request data from 2007-2011, and shown in Figure 40. As aircraft capabilities improve, the probability that an airtanker can fill more than one request in a day would be expected to increase. Figure 47 shows improvements of 5%, 10%, 15% and 20% in the reassignment rate. For example, as compared to the 2007-2011 actual data average reassignment rate, a 20% increase in capability shows that the probability of an airtanker filling multiple requests in a day increases from 28% to 48%.

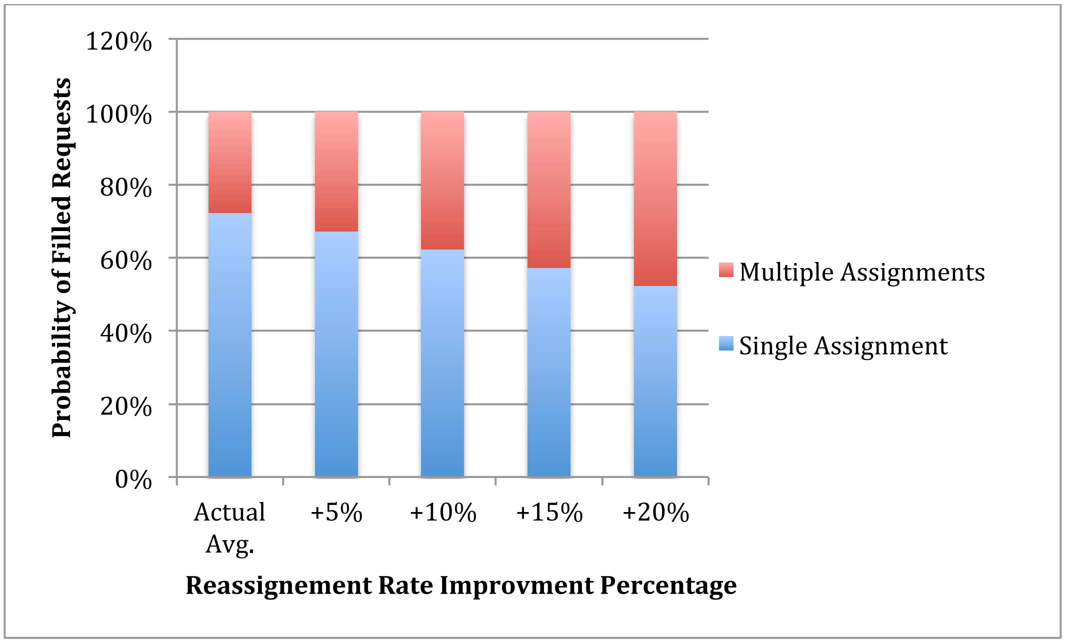

Figure 47 – Sensitivity analysis of Average Airtanker Reassignment Rate

The effects of this change on the model results are shown in Figure 48. In contrast with the sensitivity analysis of maximum airtanker range (Figure 45), an improvement of about 9% is seen in the percentage of unfilled orders as the average airtanker reassignment rate is increased by 20%. In other words, as airtankers are able to fill more orders in a day, a noticeable reduction can be expected in unfilled orders.

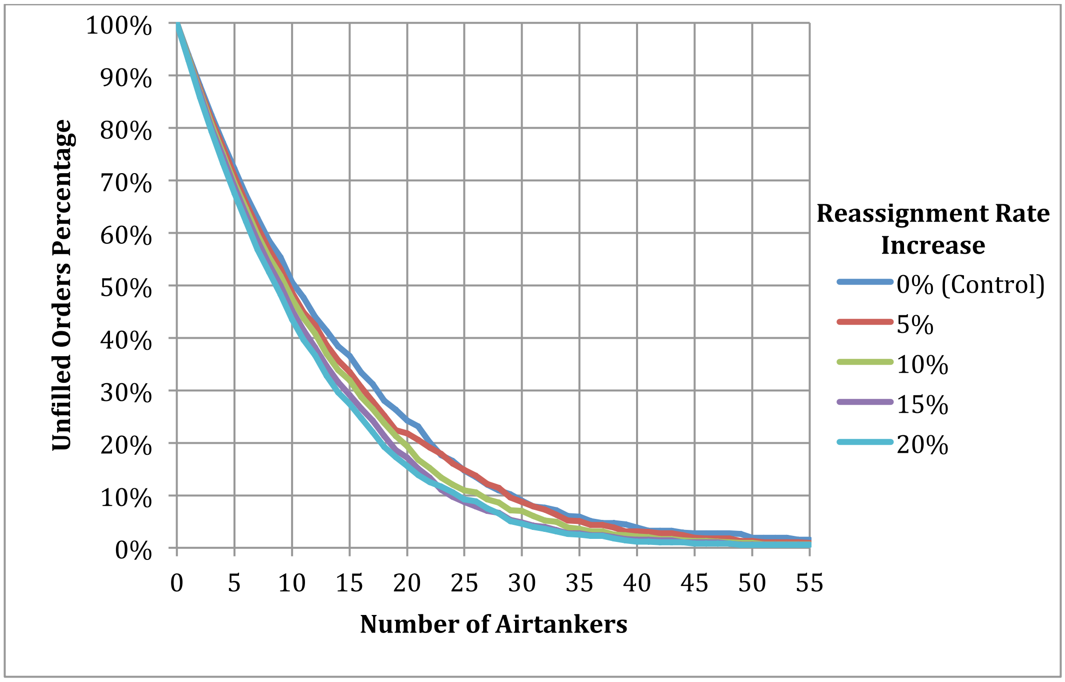

Figure 48 – Increasing the Airtanker Reassignment Rate

6. Summary and Conclusions

Considerable literature was reviewed related to the U.S. Forest Service's use of aviation assets to support wildland fire suppression activities. Much of the literature is related to costs issues and the effectiveness of firefighting. Although these topics are beyond the scope of the current study, clearly they are of interest to the USFS. Further study into cost and effectiveness issues, which leverage the findings of this study, is warranted.

The literature review also provided the AVID-Crown team with insights into the overall methodologies and procedures followed by the USFS in their firefighting aviation mission. This was valuable in our understanding of the use of aircraft for Wildland firefighting. We saw that the use of large airtankers, heavy helicopters, and scoopers differed, and the unique mission each aircraft type performs drives these differences.

This study's data analysis work revealed very different use patterns for large airtankers, heavy helicopters, and scoopers, and supported the findings of our literature review. The use of airtankers and helicopters followed similar trends across the years studied, with heavier use for both types during years with higher fire activity. It was also noted that on average, large airtankers stay about 8 hours or less at an incident, but heavy helicopters tend to stay at an incident for multiple days or, in the case of large fires, even multiple weeks.

The analysis of aviation usage by Geographic Area Coordination Center (GACC) showed that the largest demand for wildland firefighting support is in California for both airtankers and helicopters. This information may not be new to those who are familiar with these topics, but this analysis gives strong, unbiased, data-driven support to this conclusion, which can become valuable in knowing where to base future aviation assets for maximum effectiveness.

In contrast with large airtankers and heavy helicopters, the data analysis showed that the use of scoopers was very small in comparison, leading to the conclusion that their effects on the overall annual firefighting results are minimal. Further analysis of the role of scoopers and their interaction with the rest of the aviation firefighting activities is, however, recommended to develop deeper insights into these unique aircraft.

The use of large airtankers and heavy helicopters in Initial Attack (IA), Extended Attack (EA) and Large Fire Support (LFS) was explored. While no standard for defining these fire missions has been accepted, definitions based on response time and final fire size were used for this study. The recorded data shows that most of the filled requests fall about equally between the IA and LFS fire missions defined here. However, only about half of the IA filled orders were successful in containing the final fire size to less than 300 acres, and nearly half of the total number of filled orders were for fighting large fires that had escaped IA. We note, therefore, that the use of aviation assets in successful IA was lower than expected, given the USFS policy of prioritizing airtanker use for IA (Thompson, 2012). We also note that incident commanders are more likely to request aviation support for the highest risk fires. Thus, aviation assets are likely used on high-risk fires, which may lead to the lower IA success rate shown in this data.

The data analysis also revealed a continuing process of improvement in data collection and storage. While this changing state of the data presented some difficulties during the analysis, it shows a dedication to data improvement that should be continued. Determining a better way of cross-linking requests and incidents will help to streamline future studies. Furthermore, continuing to develop methods for evaluating the effectiveness of all types of firefighting resources is necessary to make investment decisions in the future. Continuing to develop systems onboard the aircraft and devoting resources to the analysis of that data is important. The usability of fire and fire behavior data is in aviation studies is further behind other approaches, and some focus should be placed on more accurately cataloging incidents, times, fire areas, causes, fuel types, weather information, and other relevant data. Since not all of that data can be collected by satellite due to weather, other collection resources should be considered.

Based on the historical data available, statistics-based models were developed for predicting the demand for aviation support, and the ability to supply aircraft to meet that demand. The modeling methodology has the capability to investigate ranges of differing parameters, such as fleet size, relative fire activity, aircraft ferrying and flight range. The model results were validated using actual demand and supply data from 2007-2011. Sensitivity analyses showed that focusing on improving airtanker capabilities to increase the number of orders an airtanker can fill in a day has a much greater effect in reducing unfilled orders than improving airtanker range. However, increases in fleet size showed the largest effect. These results give the USFS a tool to assist in deciding the best level of contracted airtanker supply, supply from other sources, and an expected level of unfilled orders. Rather than addressing policies related to the use of airtanker assets beyond the contracted supply or setting acceptable levels of unfilled orders, this tool is intended to provide the USFS with a predictive capability based on the existing, historical data.

The current models are based on large airtankers. Extension to heavy helicopters and scoopers would increase the USFS's capabilities by modeling a larger range of aircraft types. This could form the groundwork for studying how each aircraft type affects the others' behavior. With these enhanced modeling capabilities, the USFS could project its analysis work into studies of finding the optimal number and mix of aviation assets for a given situation, as well as risk-based analyses of "what-if" scenarios.

While the demand and supply models have given validated results under varying conditions, we see a need to continue refining the models to capture more details of the physics of aviation firefighting. For example, the current models make only implicit assumptions of airtanker capacity, which is accomplished through tuning the model to actual data. The models focus on getting available airtankers to locations where they are needed. With more sophisticated models that explicitly model airtanker capacity, flight conditions and other parameters, the USFS would have the opportunity to delve into matters such as efficiency, which is needed as the fleet moves forward to include NextGen airtankers for wildfire suppression.

7. Appendices

7.1. Appendix: Data Inconsistencies

We received several different sets of data; each falls into one of two categories, human entered, and automatic.

Human Entered:
ROSS requests
ROSS requests (from Rex)
ROSS Incidents - Rex
ABS payment data
ABCD fire codes - Rex
FPA historical fire data

Automatic:
AFF flight data
OLMS flight data
OLMS drop data

Each type is prone to its own type of errors:

Human entered data is prone to a number of possible errors, including
Entering data improperly
Inconsistency
Data entry between people or groups
Data entry between similar tables (e.g. FPA to ROSS Incidents)
Duplicate records
Lack of data entry

Automatic data is often more reliable than data entered by humans, however is also suspect to errors from
Equipment malfunction
Human error when saving the data

Errors could affect data analysis in two ways:
Direct Analysis – Errors such as inconsistency in data make it hard to analyze a single data set against itself.
Correlation Analysis – Errors or lack of data made correlating different sets of tables together when joining database tables.

During the course of our analysis, we initially chose to utilize the ROSS request data to model both demand (requests) and supply (filled requests). When we attempted to verify the filled request data in ROSS with payment data from ABS or flight data from OLMS, we quickly found out that there were drops by aircraft without a corresponding filled request for the aircraft in ROSS, and vice versa where a request would be filled by an aircraft, however there was no verification in ABS or OLMS that the plane actually flew for that request.

Actually joining filled ROSS requests to ABS data turned out to be fairly difficult in some situations due to dissimilarities between the data sets. Both ABS and ROSS have date information and tail number information, however, the ABS set only has the day of the flight, not the specific time, so when an aircraft was reassigned to multiple fires over the course of the day, it would match up to each of these requests. We attempted to use the fire code and incident name to figure out the correct match as well as verify the records that only matched to a single ROSS request, however, because the fire code is not ubiquitous in ROSS, and the incident name is not ubiquitous in ABS, this did not prove to be helpful in many situations. See Appendix 7.3 for more details.

Adding the specific incident and request numbers from ROSS to the ABS database would significantly help to join these two separate databases, as well as make it easy to figure out when planes are dropping on fires for which there is no request in ROSS.

Analysis on the ABS database is also hampered due to inconsistencies in reporting the retardant gallons and Use Code, making it difficult to figure out what the plane is doing for that payment record. We also learned that planes may be dropping on fires and paid without an entry in ABS. This could cause filled ROSS requests to appear unfilled when they are in fact, filled.

Our initial task was to look at ROSS request data for aircraft, only on wildfire incidents. In the ROSS request data set we found several preparedness/preposition requests filed under Fire – Wildfire.

When attempting to extract more information about the fires dropped on, such as fire size and duration, it was difficult to match the historical fire data from FPA to the ROSS incidents. The FPA table uses a non-standardized FPA ID that varies based on many factors in the database. The ROSS Incident table uses the Incident Number, which is unique during a year. Adding the Incident Number to the FPA database would make it much easier to extract this information, or expanding the ROSS Incident table to include the information in the FPA table, so that all of the relevant information is in one place.

Data Inconsistencies:

We found ROSS Incidents where the LAT_DECIMAL is negative and should be positive, or the LONG_DECIMAL is positive and should be negative, or where both of these are true, or where they are swapped.

We found two incidents for 2011, a West Texas IA and Georgia Incident with problems: Both of them are IA incidents with start dates in 2010, resulting in joins with these incidents to be difficult.

We found Preparedness / Preposition requests marked as Fire – Wildfire, throwing off analysis until they were removed from the dataset.

In 2007, we received full contract information on 17 Aircraft, however there were 19 used in ROSS. Upon further investigation, the two aircraft (Tail numbers N1386K and N96278) were call when needed. In addition our contract information for the aircraft with tail number N355MA was lacking a map start/end date.

When importing data, we noticed that in both ABS and ROSS, there were significant changes to the database structure, both adding and removing fields at the start of CY 2011 in ROSS and FY 2011 in ABS.

ABS:

Original Name (in Access)	Type	Size	New Name (in mySQL)
ID	LongInteger	4	ABS_ID
Fiscal Year	Double	8	Fiscal_Year
Aircraft Type	Text	255	Aircraft_Type
Aircraft Registration #	Text	255	Aircraft_Registration_Number
Contract #	Text	255	Contract_Number
Vendor Name	Text	255	Vendor_Name
User Unit Code	Double	8	User_Unit_Code
User Unit Description	Text	255	User_Unit_Description
Job Code	Text	255	Job_Code
Pay Code	Text	255	Pay_Code
Flight Date	Date/Time	8	Flight_Date
Availability Cost ($) (Auto Total)	Double	8	Avialability_Cost_$_Auto_Total
Leg #	Double	8	Leg_Number
Flight Hours (Auto Total)	Double	8	Flight_Hours_Auto_Total
Retardant Gallons (Auto Total)	Double	8	Retardant_Gallons_Auto_Total
Foam Retardant Gallons (Auto Total)	Text	255	Foam_Retardant_Gallons_Auto_Total
Water Retardant Gallons (Auto Total)	Double	8	Water_Retardant_Gallons_Auto_Total
Pay Code Line Amount ($) (Auto Total)	Double	8	Pay_Code_Line_Amount_$_Auto_Total
calandarMonth	Date/Time	8	Calandar_Month
FireCode	Text	255	FireCode
UseCode	Text	20	UseCode
pseudoRetardant	LongInteger		PseudoRetardant
IncName	Text	255	IncName

Schema Info between FY 2010 and FY 2011

New Field (from 2011 data)	Type	Size	Change	Name in mySQL
Aircraft Make	Text	255	New	Aircraft_Make
Aircraft Model	Text	255	New	Aircraft_Model
Aircraft Registration #	Text	255	None	Aircraft_Registration_Number
Aircraft Type	Text	255	None	Aircraft_Type
Vendor Name	Text	255	None	Vendor_Name
Calendar Year	Double	-	New	Calendar_Year
Fiscal Year	Double	-	None	Fiscal_Year
Flight Date	Date/Time	-	None	Flight_Date
Elapsed Time (Hours) (Auto Total)	Double	-	New	Elapsed_Time
Flight Destination	Text	255	New	Flight_Destination
Flight Destination Airport	Text	255	New	Flight_Destination_Airport

Flight Hours (Auto Total)	Double	-	None	Flight_Hours_Auto_Total
Foam Retardant Gallons (Auto Total)	Text	255	None	Foam_Retardant_Gallons_Auto_Total
Invoice #	Int	8	New	Invoice_Number
Job Code	Text	255	None	Job_Code
Leg #	Double	-	None	Leg_Number
Mission Code	Int	8	New	Mission_Code
Mission Code Description	Text	255	New	Mission_Code_Description
Order Number	Text	255	New	Order_Number
Order Type	Text	255	New	Order_Type
Pay Code	Text	255	None	Pay_Code
Pay Code Description	Text	255	New	Pay_Code_Description
Rate	Double	-	New	Rate
Region	Int	8	New	Region
Retardant Gallons (Auto Total)	Double	-	None	Retardant_Gallons_Auto_Total
Retardant Rate ($ per gal)	Double	-	New	Retardant_Rate
Retardant Type	Text	255	New	Retardant_Type
Retardant Type Description	Text	255	New	Retardant_Type_Description
User Code	Int	8	New	User_Code
User Code Description	Text	255	New	User_Code_Description
User Unit Code	Double	-	None	User_Unit_Code
User Unit Description	Text	255	None	User_Unit_Description
Water Retardant Gallons (Auto Total)	Double	-	None	Water_Retardant_Gallons_Auto_Total
GACC Abbreviation	Text	255	New	GACC_Abbreviation
GACC Name	Text	255	New	GACC_Name
Region	--Duplicate--	--	--	--
Region Name	Text	255	New	Region_Name

===========No Change, 2011 to 2012=============

Unused in ABS for FY 2011:

Contract #
Availability Cost
Pay Code Line Amount $
Calendar Month
Fire Code
Use Code
Pseudo Retardant
Incident Name.

In ROSS, the changes to the 2011 database did not contain many useful fields about the resource or reporting agency which made extracting information much more difficult. Among the useful fields lost were: REQ_STATUS_CD, RES_PROV, FILLED_BY, RES_GACC, ASSIGN_DATE, RELEASE_DATE, INITIAL_DATE, and AGENCY_TYPE.

During the initial importing of ROSS data, we ran into a few problems, primarily that there were slash characters (\) in otherwise empty fields in 2006, causing the end double quote character to be escaped and garble the rest of the line.

The Microsoft Access database files were exported to .csv (comma separated value) files. The schema conversions were mapped in .sql scripts for each year.

2007 to 2012 were fairly straightforward.

- Parsed dates with str_to_date(string,format) function
- Checked all numbers for empty fields and set them to null

- Each year had to be mapped individually due to changes in schema.

ROSS Schema Changes:

We compared schema changes between consecutive years from 2004 to June of FY 2012 and noted changes. Between FY 2004 and December of 2010, the schema remained similar with minor changes to field sizes and some additional data fields added. In January of 2011, the schema changed significantly, with many data fields removed or renamed.

Column Name	Change	Size	Type
==============================2004 to 2005==============================			
REQ_CAT_ITEM_NAME:	Size Increase	50 to 100 text	
SPECIAL_NEEDS:	Added	50	text
FILL_CAT_ITEM_NAME:	Size Increase	50 to 100 text	
RES_ID:	Added	16	Decimal
RES_NAME:	Size Increase	100 to 200	text
2005 to 2006			
SPECIAL_NEEDS:	Size Increase	50 to 150 text	
RES_NAME:	Size Decrease	200 to 93 text	
ASSIGN_NAME:	Added	200	text
==============================2006 to 2007==============================			
QUALIFICATION	Renamed	20	text
QUAL_STATUS_DESC (2007 to 2010)			
FILL_OVERRIDE	Added	30	text
PERSON_NAME	Added	100	text
RELEASE_AUTH_CD	Added	2	text
RELEASE_AUTH_REQUIRED_IND	Added	1	text
AVAIL_FOR_REASSIGN	Added	1	text
RELEASE_AUTH_NAME	Added	20	text
==============================2007 to 2008==============================			
AGENCY_TYPE	Size Increase	10 to 12	text
==============================2008 to 2009==============================			
--No Change--			
==============================2009 to 2010==============================			
FINANCIAL_CD	Size Increase	30 to 48	text

2011, major changes:

October to December of Fiscal Year 2011 (October to December of 2010) remained the same as FY 2010. In January of 2011 (Q2 Fiscal Year 2011), the schema changed, There was only one new value, but many other values were renamed or removed.

==============================2010 to 2011==============================

New Name	Change	Size	Type	Old Name (if renamed)
ID	Added	4	Long Integer	
Inc ID	Renamed	8	Double	INC_ID
Inc Number	Renamed	255	Text	INC_NUMBER

Inc Name	Renamed	255	Text	INC_NAME
Inc Type	Renamed	255	Text	INC_TYPE
Req Number	Renamed	255	Text	REQ_NUMBER
Req Status	Renamed	255	Text	REQ_STATUS
Order Date	Renamed	8	Date/Time	ORDER_DATE
Order Date TZ Code	Renamed	255	Text	ORDER_DATE_TZ_CD
Req Catalog Name	Renamed	255	Text	REQ_CAT_NAME
Req Catagory Name	Renamed	255	Text	REQ_CAG
Req Catalog Item Name	Renamed	255	Text	REQ_CAT_ITEM_NAME
Filled Catagory Name	Renamed	255	Text	FILL_CATG_NAME
Filled Catalog Item Name	Renamed	255	Text	FILL_CAT_ITEM_NAME
Res Name	Renamed	255	Text	RES_NAME
Res Owner name	Renamed	255	Text	RES_OWNER
Res Home Unit Org Name	Renamed	255	Text	RES_HOME_UNIT
Mob ETA	Renamed	8	Date/Time	MOB_ETA
Mob ETA TZ Code	Renamed	255	Text	MOB_ETA_TZ_CD
Demob ETD	Renamed	8	Date/Time	DEMOB_ETD
Demob ETD TZ Code	Renamed	255	Text	DEMOB_ETD_TZ_CD
Inc Disp Org Unit Code	Renamed	255	Text	INC_DISP_UNIT_CD
Inc Agency Org Name	Renamed	255	Text	AGENCY
Inc Agency Abbrev	Renamed	255	Text	AGENCY_ABBREV
Inc GACC Org Unit Code	Renamed	255	Text	INC_GACC_UNIT_CD
Req ID	Renamed	8	Double	REQ_ID
Res ID	Renamed	8	Double	RES_ID
Assignment Name	Renamed	255	Text	ASSIGN_NAME

============================2011 to 2012==============================
--No Change—

Data Findings:

ABS:
Planes are not only requested for one day – sometimes they are assigned for more than a single day.

FPA:
46,936 2010 FPA entries
16,383 2010 FPA entries with Fire Code (34.9%)
332 2010 FPA entries with ICS 209 Event ID (0.7%)
228 row overlap (entries with both)

FPA Id is unique in the database, however it does not map to any other database's information directly, making it difficult to extract more detailed information about fires in ROSS from FPA.

ROSS:
Cancelled UTF – one to one (Cancelling Due to UTF)
Reassigned – Moved from one request to another without release
Released – Completed assignment, demobilized. Does not mean that it cannot be assigned again that day.

Not all tactical aviation requests go through ROSS, some initial attack go through WILDCAD.

Similar data (ROSS requests mapped to fire, fire size, etc.) is pulled for dispatch centers for analyzing workload.

OLMS:

OLMS & ABS show us drops per flight that do not make it into ROSS. However, due to difficulties in joining these to ROSS, it was very difficult to correlate this information.

7.2. Appendix: ROSS Data Filtering Logic

Requests filled by the USFS were determined using the following logic (where ROSS field names are capitalized):

1. Either the RES_PROV or RES_HOME_UNIT field is equal to 'National Interagency Fire Center - United States Forest Service’,
   or
2. the RES_HOME_UNIT field is equal to 'National Interagency Coordination Center',
   or
3. either the RES_PROV or RES_HOME_UNIT fields contain ‘National Forest’.

Furthermore, when looking at the requesting agency, we included:

1. all requests by national agencies (i.e., AGENCY_TYPE is equal to ‘National’),
   and
2. any requests by a non-national agency that were filled with federal resources (i.e., AGENCY_TYPE not equal to ‘National’ and RES_PROV is equal to 'National Interagency Fire Center - United States Forest Service’),
   and
3. any requests by a non-national agency that were unfilled (i.e., AGENCY_TYPE not equal to ‘National’ and RES_PROV empty).

Thus, we were able to capture a more complete representation of the demands on the national firefighting aviation assets.

The following national agencies are represented in the ROSS request data:

Bureau of Indian Affairs
Bureau of Land Management
Department of Energy
National Park Service
U.S. Fish and Wildlife Service
U.S. Forest Service
U.S. Army
U.S. Air Force
U.S. Marine Corps

7.3. Appendix: FPA to ROSS Correlation

ROSS request data was matched with FPA historical fire data. Because ROSS request data was available from 2007-2011 and historical fire data was available from 1992-2010, record matching was only possible for the four years from 2007 to 2010. The matching process was not straightforward, since there is no unique data key between the two datasets.

The use of job and fire codes to correlate data sets turned out to be difficult due to several reasons, including the code's lack of uniqueness, allowing for many different fires to use the same code, and its ability to change over the course of a fire's lifetime due to size changes or becoming a complex fire when fires merge or breaking containment. The use of fire and job code was further complicated because it is only ubiquitous in ABS, not in FPA or ROSS. Therefore, a more complex approach was needed, as described below.

Attack Phase Definition Matrix and FPA to ROSS Join for 2010

Motivation

Joining the requests from ROSS and the historical fire data from FPA allows us to find the number of requests for each mission, as defined in section 3.2. ROSS contains all the requests information, as well as *Time after initial action* for each fire. The historical fire data contains the fire class (A through G) for each fire. Joining requests with the historical fire data allows us to determine if a request is for IA, EA, or LFS. Each attack phase is defined using time after initial action and fire class

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	Initial Attack	Initial Attack	Initial Attack
24 to 72 hrs.	Extended Attack	Extended Attack	Large Fire Support
Over 72 hrs.	Extended Attack	Large Fire Support	Large Fire Support

Table 12 – Fire Mission Definitions

Method and Results

We used three tables to join ROSS Requests to historical fire data from FPA: ROSS Incidents, ROSS Requests, and FPA. This is shown in Figure 49.

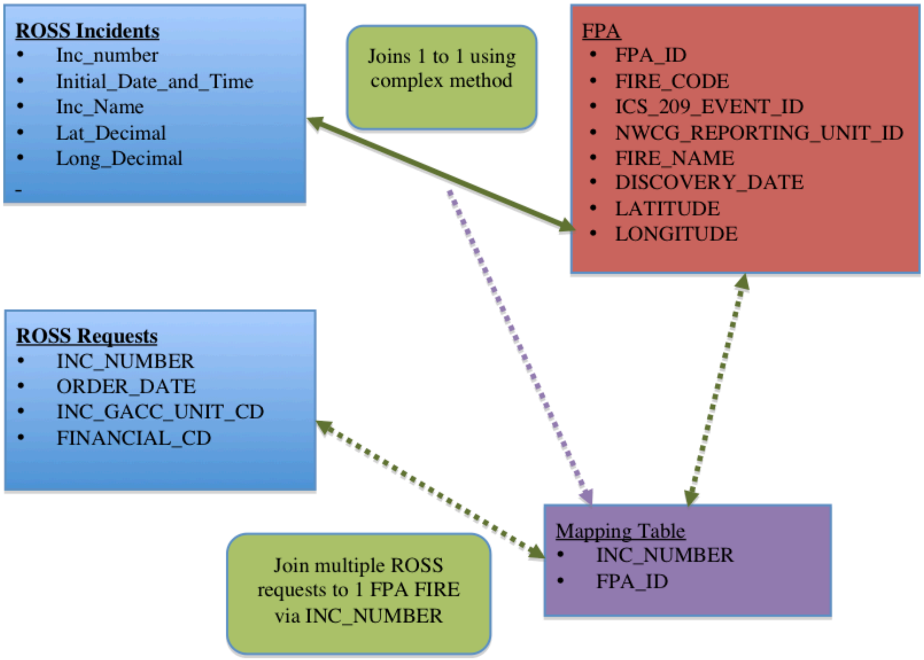

Figure 49 – Tables with fields of interest created from the join between ROSS Incidents and FPA (Ross in blue, FPA in red, Joins in green, and Mapping Table in purple)

Procedure for joining ROSS Requests to FPA and creating the Attack Phase Matrix:

1. Join ROSS Incidents to FPA
   - ROSS Incidents to FPA Join 1 to 1. In most cases; the exceptions are
     i. Complex Fires, there may be different FPA entries when fires join, or escape containment, causing them to become complex incidents. Similarly, the same can happen in ROSS.
     ii. Initial attack incidents may be used for an extended period of time, such as an entire month or year. In this case, many small fires in FPA would join to a single ROSS incident.
   - Produces a mapping between Inc_number and FPA_ID, called Mapping Table – This table will allow us to map requests to fires.
2. Join ROSS Requests to FPA table using the Mapping Table
   - There may be multiple ROSS requests for each fire found in FPA.
3. Produce the Attack Phase Matrix with the ROSS Requests to FPA join.

Step 1 - Join ROSS Incidents to FPA

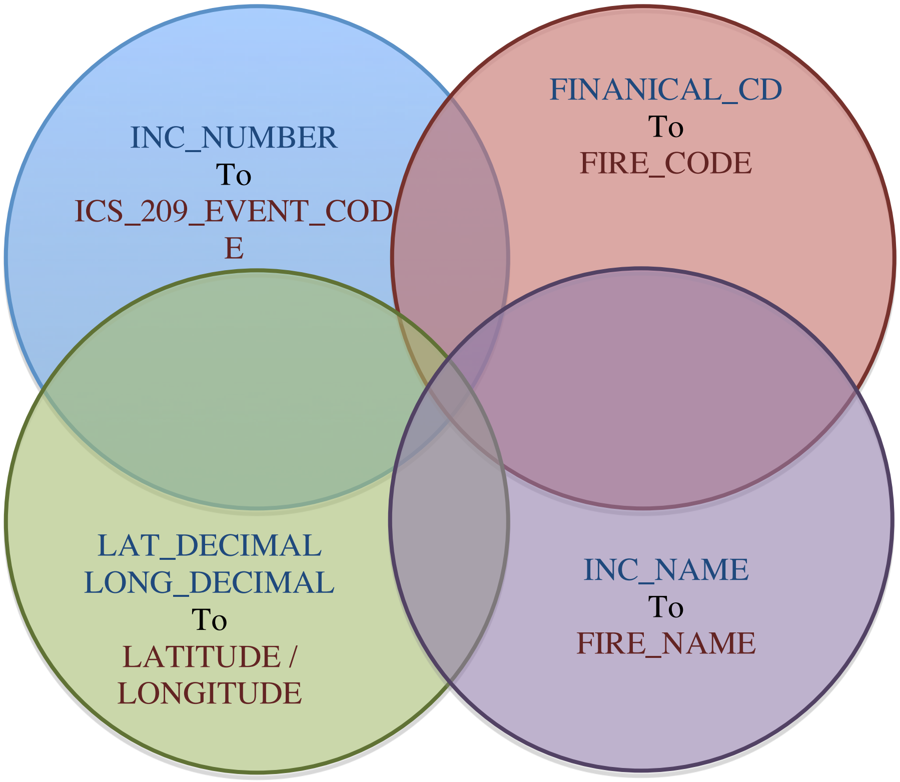

Figure 50 - Four different join strategies to join ROSS Incidents and FPA

We used four different join strategies: Incident Number, Fire Code, Fire Name, and location. The figure above shows all four strategies with their corresponding ROSS and FPA fields. We used all four strategies together and achieved a 90.97% join success on requests. 88.48% of the incidents in ROSS had a corresponding fire in FPA.

Incident Number Join Strategy
INC_NUMBER to ICS_209_EVENT_ID
19.05% Join Success
See 'ICS_209_EVENT_ID_2010_s1.sql' for implementation.

Incident Number, found in ROSS, and ICS_209_EVENT_ID, found in FPA, directly joins when looking at specific fire year. ROSS resets the incident number to 0 at the beginning of each fiscal year.

Unfortunately, the Forest Service collects ICS_209_EVENT_ID for large fires of class D, E, F, and G. This join strategy completely ignores small fires.

Recommendation: *Require an ICS_209_EVENT_ID for every wildland fire. By requiring ICS_209_EVENT_ID joining ROSS Incidents and FPA trivial. Since ICS_209_EVENT_ID is not recorded for small fire 3 other join strategies must be used.*

Fire Code Join Strategy
FINANICAL_CD to FIRE_CODE
15.08% Join Success
See 'FIRE_CODE_2010_s2.sql' for implementation

Using 4 digits after the first two digits in FINANICAL_CD, in ROSS, directly joins with FIRE_CODE in FPA. For example, 'PDFNL8 (1502)' a typical representation of a FINANICAL_CD record. The letters in bold might join to a fire with a FIRE_CODE = 'FNL8' in FPA.

Just like *Incident Number Join Strategy, Fire Code Strategy* only works on large fire (class E, F, G) and human caused fires. All natural caused fires, class A, B, C, and D, use the same financial code in a local region. This causes duplicates, where a single ROSS incident joins with multiple FPA records, which we filter out.

Fire Name Join Strategy
INC_NAME to FIRE_NAME
59.72% Join Success
See 'Join_On_Fire_Name_2010_s3.sql' for implementation

Unlike *Incident Number Join Strategy* and *Fire Code Join Strategy*, *Fire Name Join Strategy* works on all fire sizes. Using FIRE_NAME, DISCOVERY_DATE, and NWCG_REPORTING_UNIT_ID, found in FPA, together produces a unique key FPA. Fire names (FIRE_NAME) aren't duplicated on the same day (DISCOVERY_DATE) on the same forest (NWCG_REPORTING_UNIT_ID).

We found possible FPA fires that could join with each ROSS incident by joining DISCOVERY_DATE, in FPA, with Initial_Date_and_Time, in ROSS (within 1 day), and NWCG_REPORTING_UNIT_ID, in FPA, with ROSS's Inc_Number to filter to a specific forest. See appendix (Join_On_Fire_Name_2010_s3.sql) for the exact join. For each ROSS incident we compared the ROSS incident's INC_NAME with the FPA's FIRE_NAME with the possible FPA fires for that incident. We used the MySQL function "sounds like" to join on the fire name, which handles minor misspellings.

Each record that did not successfully join was analyzed further. In 2010 we mapped the following records to FPA:

INC_ID (ROSS)	FPA_ID (FPA)	INC_NAME (ROSS)	FIRE_NAME (FPA)
MN-SUF-100266	FS-1485696	DEER FOREST ROAD	DEER FOREST RD FIRE
ID-BOF-000499	FS-1487101	LITTLE BEAVER COMPLEX	LITTLE BEAVER

ID-BOF-000746	FS-1488874	FRAZIER (REFER TO THE BOISE COMPLEX)	FRAZIER
UT-SLD-000727	W-613773	8 MILE	EIGHT MILE
CA-MDF-000266	FS-1488278	HAGER	MDF DG BSFMU05 HAGER
CA-MDF-000336	FS-1487401	PEAK	MDF DH PEAK
CA-MDF-000375	FS-1488803	BIRTHDAY	MDFDGBSFMU25BIRTHDAY
CA-PNF-000686	FS-1490849	PNF SPRING	SPRING
CA-NOD-003958	W-612205	S-2 DODGE #2	DODGE 2
OR-PRD-000614	W-615266	0614 LOWER DESCHUTES COMPLEX	614 LOWER DESCHUTES
OR-LAD-100244	W-608650	DOG HOLLOW	DOG
WA-SPA-000029	W-618156	LINE FIRE	LINE
WY-MBF-010239	FS-1489384	ILLINOIS CREEK	ILLINOIS
CO-RTF-000622	FS-1490556	BEAVER FLAT TOPS	BEAVER FLAT TOP
CO-ARF-000579	FS-1490709	PEEWINK MOUNTAIN	PEEWINK
LA-KIF-011010	FS-1492296	CEDAR FIRE	106 CEDAR
CA-LPF-002154	FS-1488171	HUFFS	HUFFS FIRE
CA-CNF-000132	FS-1485407	TENAJA FIRE	TENAJA
CA-CNF-002555	FS-1488092	SCOUT FIRE	SCOUT
CA-BDF-011291	FS-1490894	HOLCOLM	HOLCOMB 2
CA-TUU-000124	CDF_2010_56_2 234_000124	SUCCESS	SUCCESS VALLEY DR PORT 5
CA-TUU-000305	CDF_2010_56_2 234_000305	POWER	POWER F#64
NV-CCD-000709	W-614382	CONSTANTIA COMPLEX	CONSTANTIA
CA-TUU-000381	CDF_2010_56_2 234_000381	ENTRANCE	ENTRANCE F#74
NV-CCD-000785	W-606889	CLAN (NV-CCD-793)	CLAN

Location Join Strategy

LAT_DECIMAL / LONG_DECIMAL to LATITUDE / LONGITUDE

49.03 % Join Success

Just like *Fire Name Join Strategy, Location Join Strategy* works on all fire sizes; however, because it only joins to the closest fire we are not as confident about this join. Invalid joins can happen when many fires start in the same area, or the wrong fire joins due to data accuracy problems in latitude and longitude records. We decided not to use this join alone as an indication of the correct fire, but to add weight to another join in conflicts.

Step 2 - Join ROSS Requests to FPA table using the Mapping Table

The join between ROSS Requests to FPA fires using the Mapping Table is very straightforward after the mapping table is complete; simply looking at the INC_ID, which is unique in the ROSS database.

Step 3 - Produce the Attack Phase Matrix

The following table shows the historical aviation use as the total number of filled airtanker requests per year for each Fire Mission, averaged over 2007 to 2010. ROSS contains the initial_incident_data_and_time (date and time the incident was created) and the order_date (when the request was first received by the dispatch).

Time after fire start	Fire Class A/B Less than 10 acres	Fire Class C/D 10 to 300 acres	Fire Class E/F/G More than 300 acres
Up to 24 hrs.	221 (IA)	227 (IA)	369 (IA)
24 to 72 hrs.	18 (EA)	35 (EA)	273 (LFS)
Over 72 hrs.	38 (EA)	7 (LFS)	545 (LFS)

Table 13 – Average filled airtanker requests by fire mission from 2007 to 2010

Corrected Data

In 2010 we found 18 entries with positive longitude values in ROSS, putting them well outside of the United States. The Incident IDs of these are:
112717, 112767, 112774, 112872, 113012, 113059, 113091, 113085, 113090, 113106, 113105, 113164, 113160, 113174, 113219, 113241, 113358, 120212

Recommendations

The main recommendations from this join are to include ICS 209 information into all FPA entries, which would significantly simplify joining ROSS requests to FPA fire information, and to better document small (ABCD) fires and IA requests.

The ICS 209 event id in FPA joins directly to the ROSS Incident Number when it is recorded in FPA, and is unique in the ROSS Incident table for the fiscal year. Utilizing this field consistently in FPA would make joining these databases trivial.

Because small fires are often recorded with less accuracy and regularity as large fires, they can be much harder to extract good information from for analysis. Adding specific information in ROSS about these fires would make it easier to correlate them to FPA or simply lump them into the ‘IA’ category when possible. Specifically, when using a single Incident for many small fires or IA requests, there should be an additional identifier to tell these apart from requests for larger fires, a specific start date and time for the fire, and an identifier to tell different small fires apart.

7.4. Appendix: Aviation Use by Fire Mission

This appendix contains detailed information about aviation use by Fire Mission (Initial Attack, Extended Attack, Large Fire Support) for the four years from 2007 to 2010.

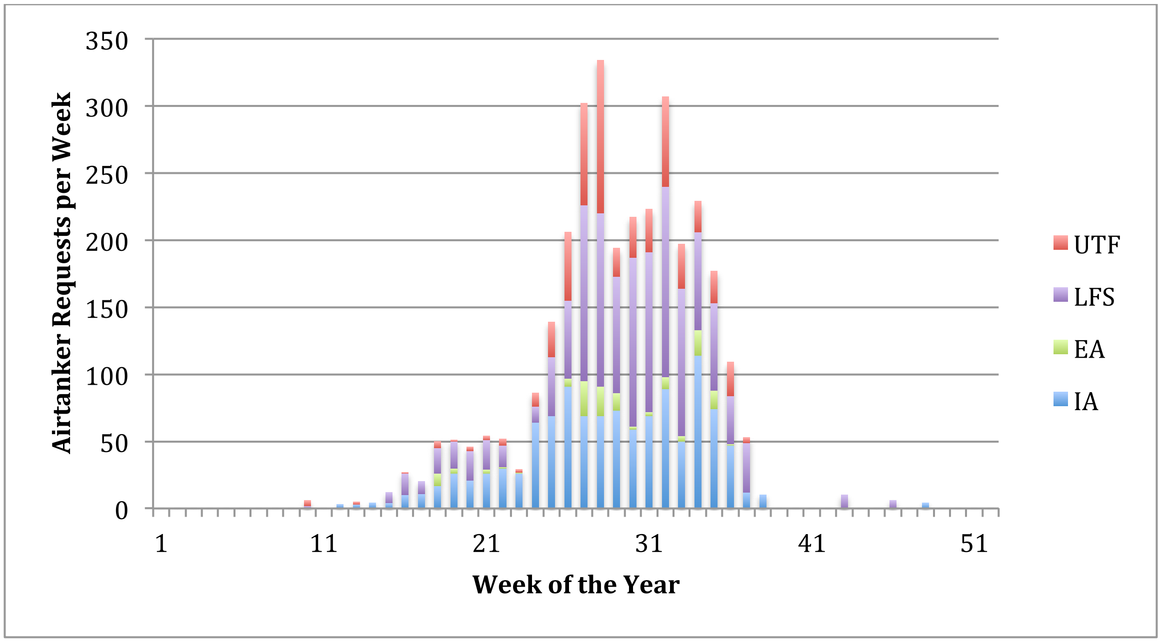

Figure 51 - Airtanker requests per week, 2007

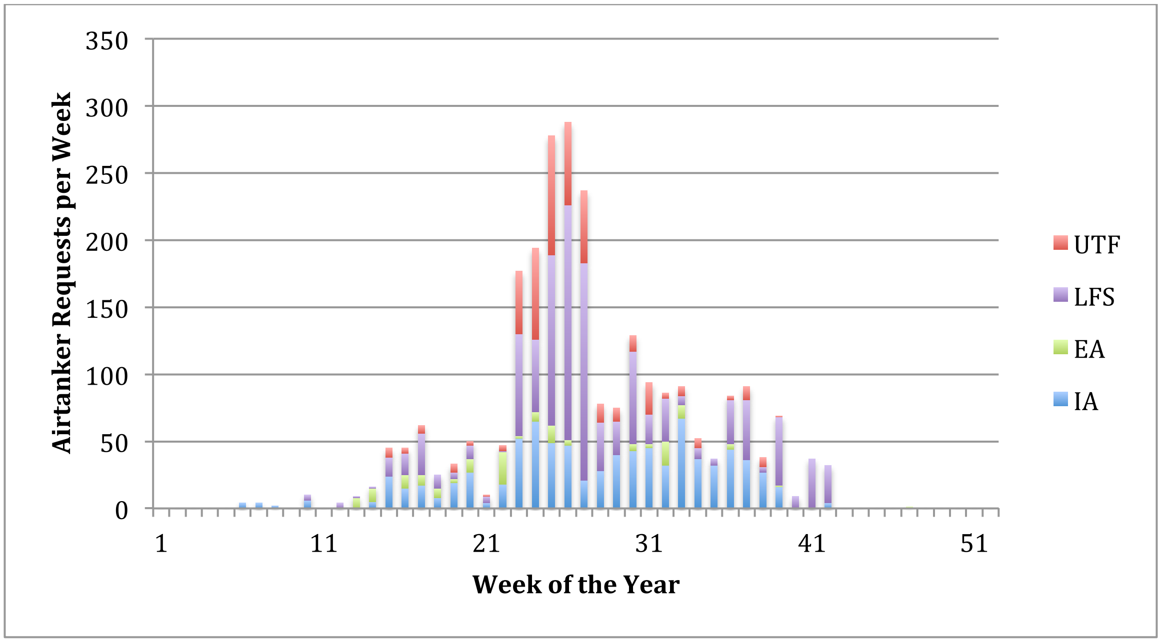

Figure 52 - Airtanker requests per week, 2008

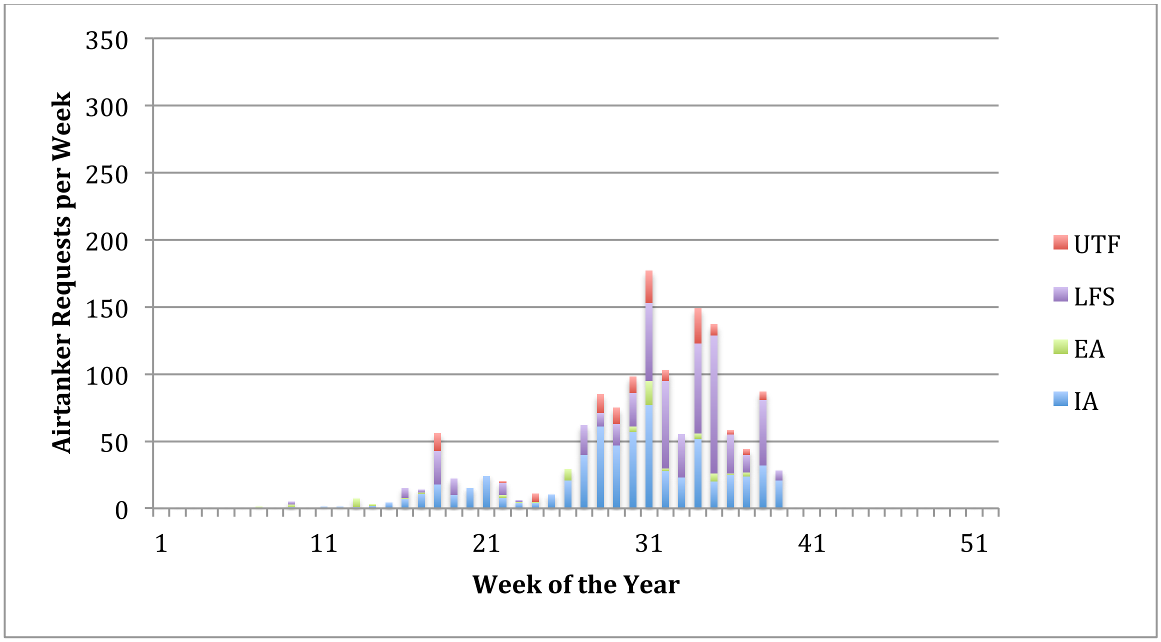

Figure 53 - Airtanker requests per week, 2009

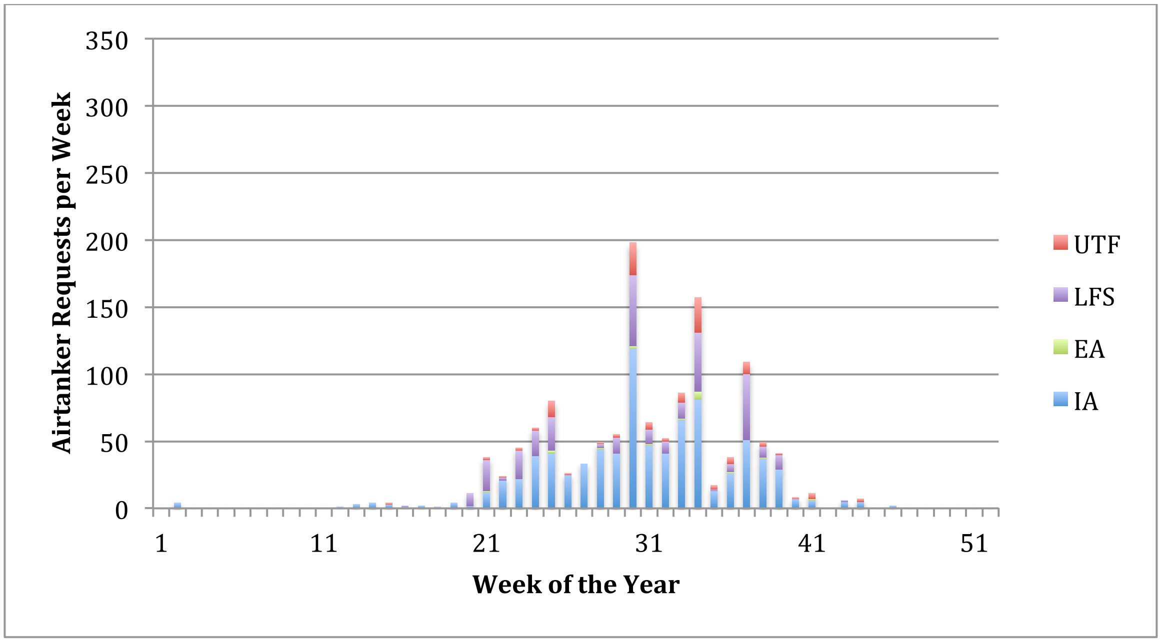

Figure 54 - Airtanker requests per week, 2010

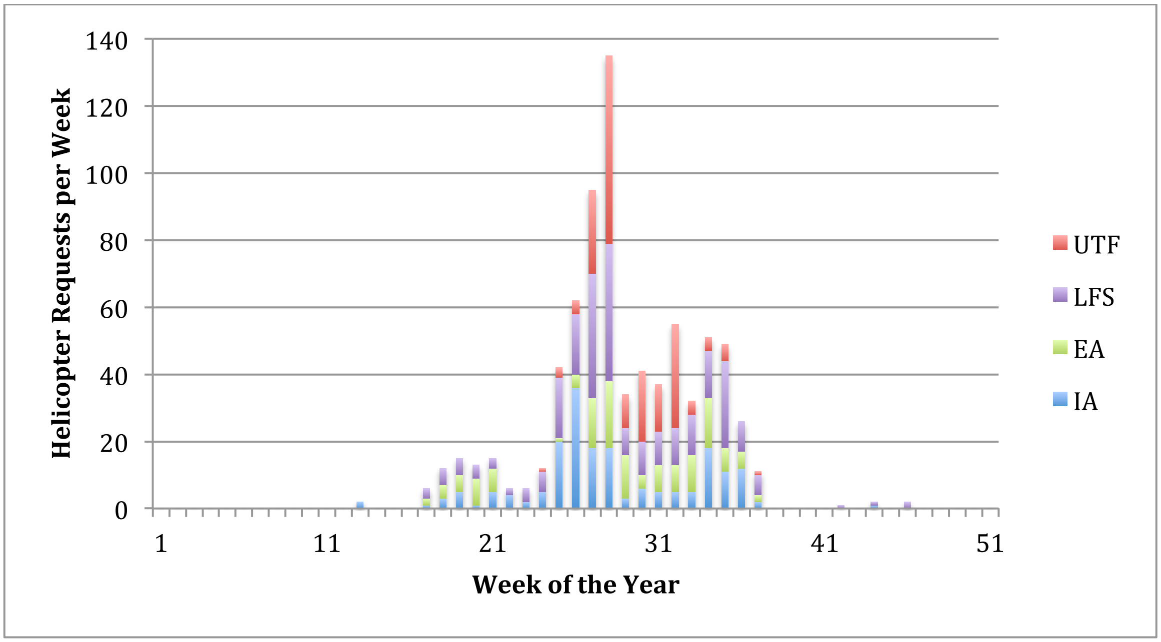

Figure 55 - Helicopter requests per week, 2007

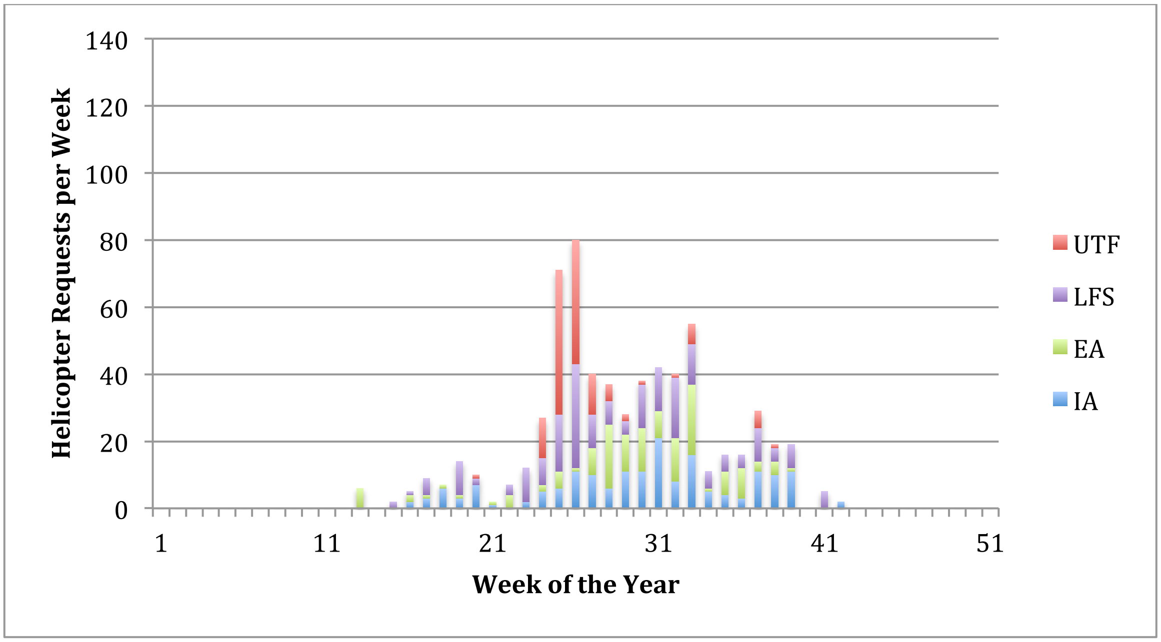

Figure 56 - Helicopter requests per week, 2008

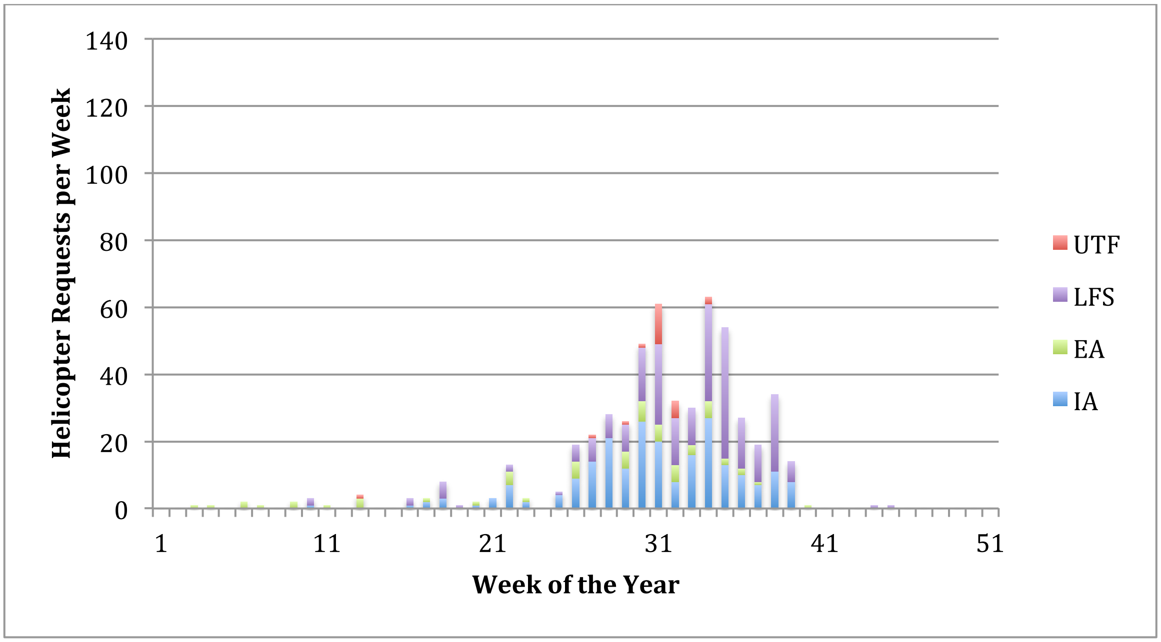

Figure 57 - Helicopter requests per week, 2009

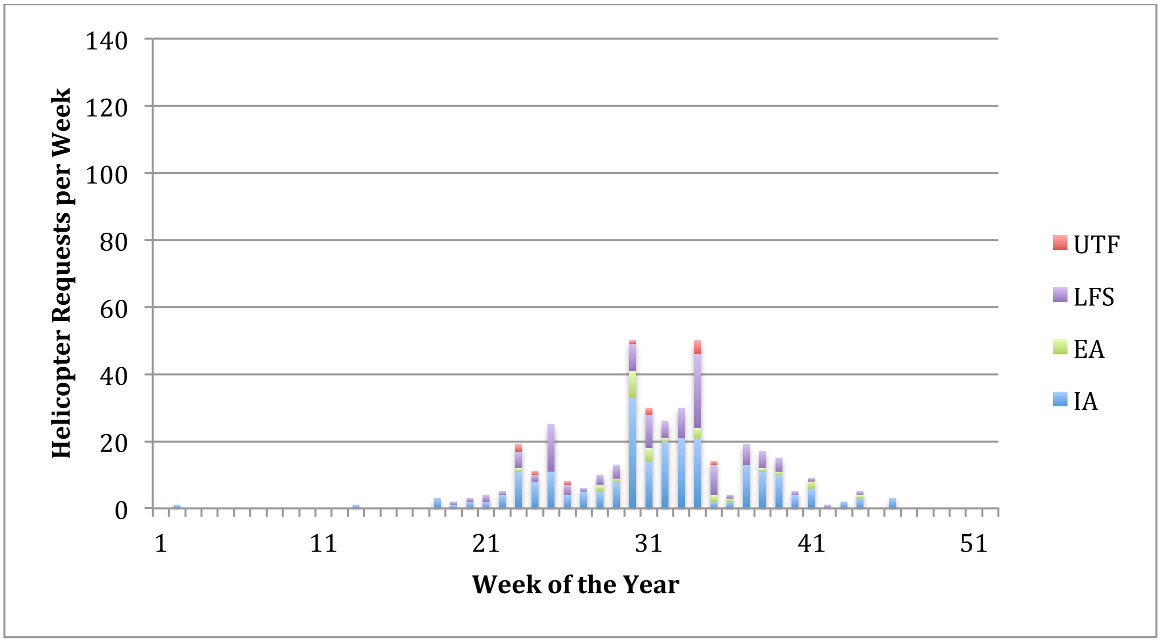

Figure 58 - Helicopter requests per week, 2010

7.5. Appendix: Demand Model Probability Approach

Applying a probabilistic framework to any particular problem generally requires the identification of deterministic and stochastic components. The deterministic component captures ”general” behavior with the mean, or “expected value,” while the stochastic component defines the “peaky” noise behavior with the spread, or “variance.” Adding these two components yields a model that approximates data with noisy behavior. Figure 59 illustrates the concepts behind the expected value and variance. The peaky behavior can be recreated by using a random number in conjunction with a probability distribution with an expected value and variance that matches the actual data.

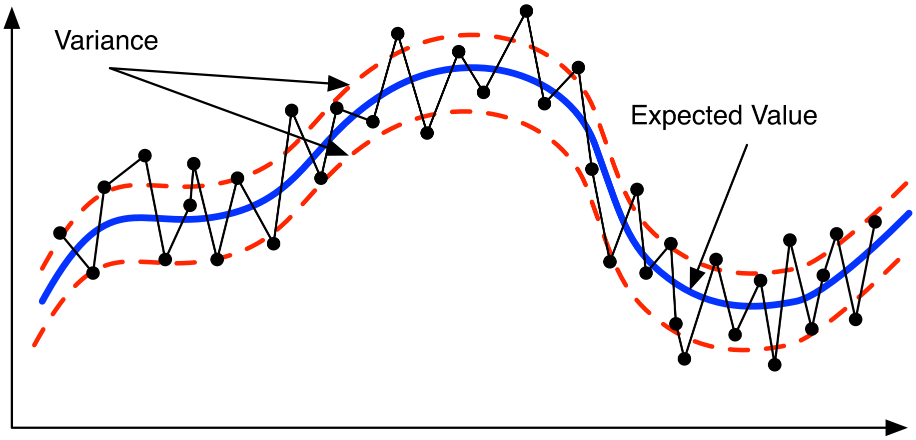

Figure 59 - Illustration of variance and expected value

For most systems the spread of noisy data can be approximated well by a Gaussian “bell” curve shown in Figure 60, which defines the probability of seeing any particular value. Note that the sum of this probability curve always equals to one, meaning there is a 100% chance that a number in the distribution will be selected. This bell curve can be completely defined by the expected value and variance. Adjusting the expected value shifts the peak of the curve while adjusting the variance stretches the bell shape. Greater variance gives a flattened bell shape with a large range of values having similar probabilities, and less variance gives a bell shape that has a sharp peak at the expected value, which has a probability much higher than any other number.

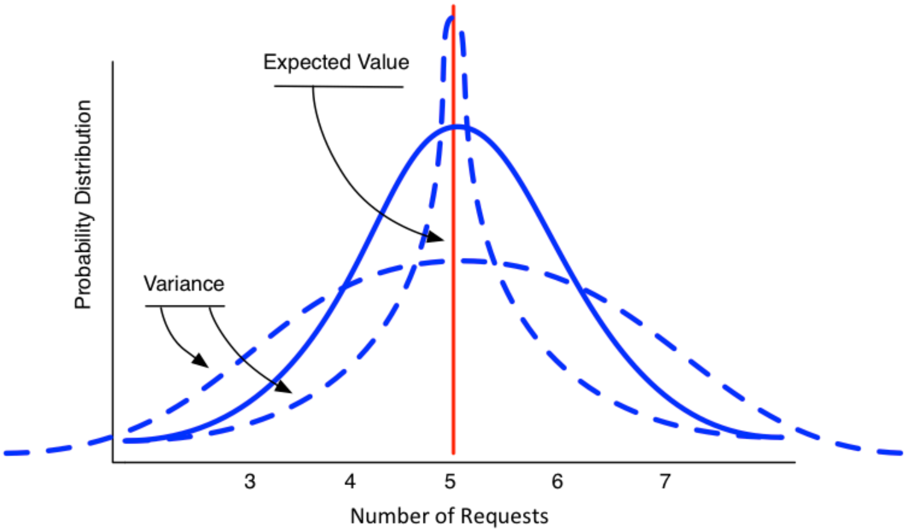

Figure 60 - Probability density function of a Gaussian distribution

Gaussian probability distributions are best applied to systems that produce positive and negative real numbers. However, the airtanker demand model must produce non-negative integers, since negative or fractional airtankers are not realistic. If requests are generated using a Gaussian distribution, a real number will be produced, which must be rounded up or down to the closest integer. The more egregious flaw in this methodology is the ability to produce negative numbers, which are physically unrealistic. This flaw is exacerbated in cases where the expected value is close to zero and the variance is large. Figure 61 and Figure 62 show the effects of rounding and negative number errors respectively. To avoid truncation and round-off errors inherent in the use of Gaussian distribution, a discrete distribution must be chosen.

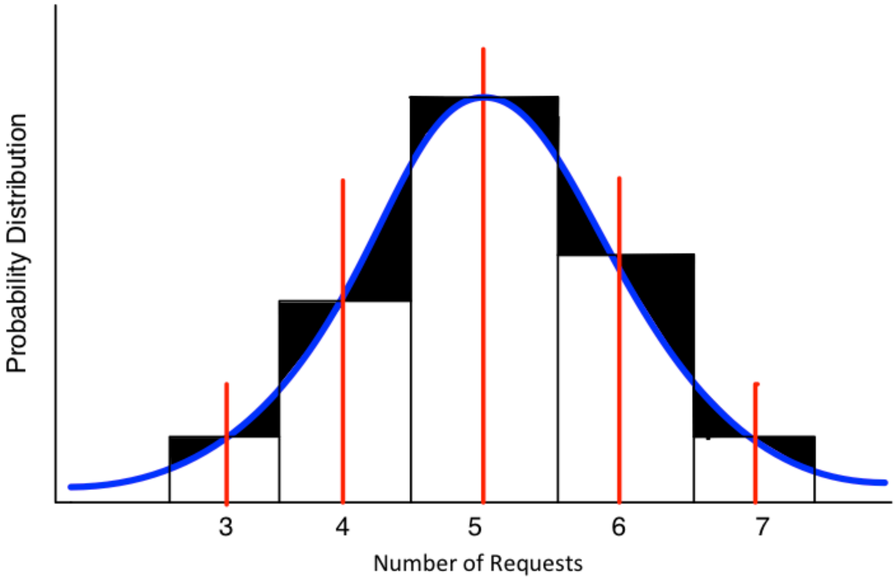

Figure 61 - Rounding errors for Gaussian distributions

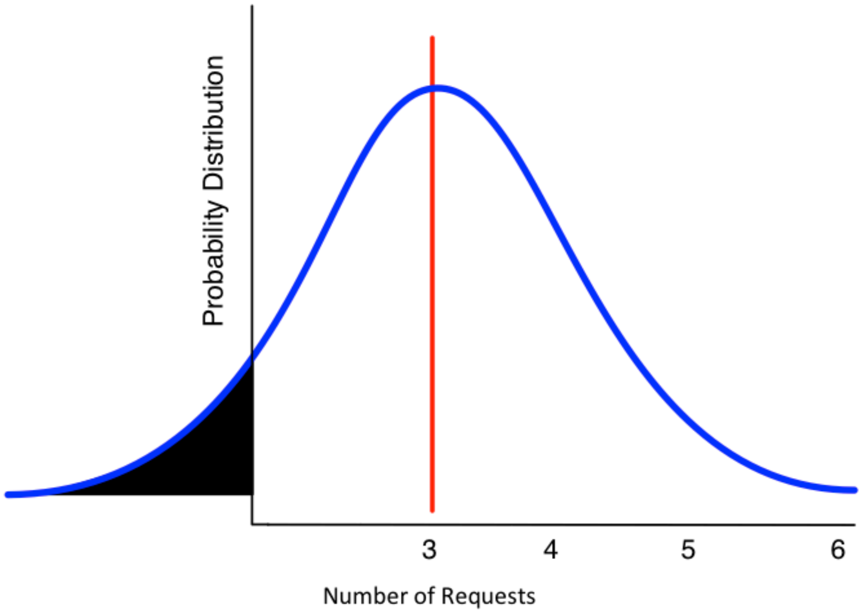

Figure 62 - Truncation errors for Gaussian distributions

The Poisson distribution assigns probabilities to discrete, non-negative events. This distribution constrains the expected value to equal the variance, which is a valid assumption for large data sets that mostly contain zero values. Figure 63 and Figure 64 illustrate the Poisson probability distribution and cumulative probability function respectively. Note that the cumulative probability function gives the accumulated probability between zero and the estimated event (airtanker requests). A notable use of this distribution was by the Prussians in 1898 to model the chance of soldiers being kicked by horses. Unlike ”horse kicking” events, airtanker request data may contain data mostly populated by non-zero values, causing the expected value and variance to differ, which makes the Poisson distribution a poor choice for the airtanker demand model.

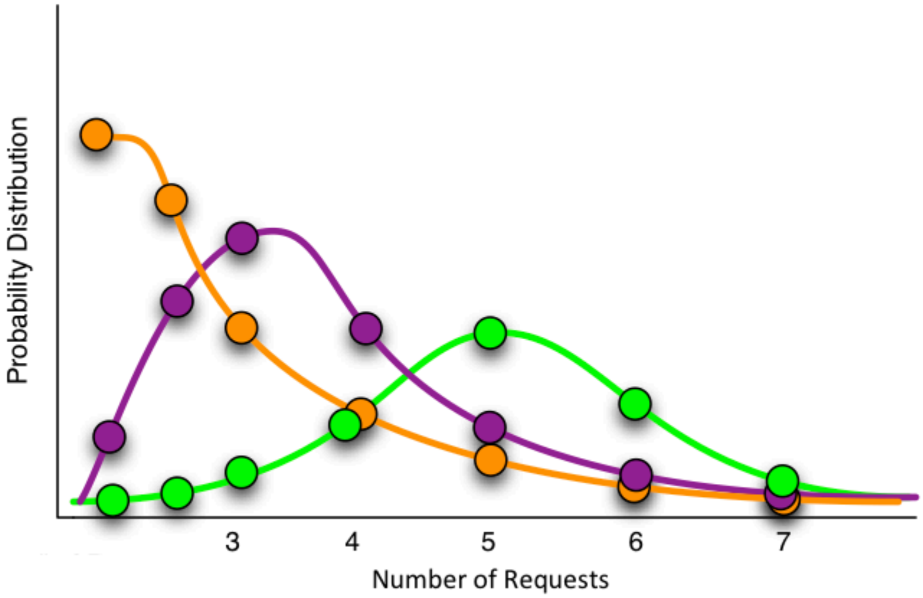

Figure 63 - Poisson probability distribution

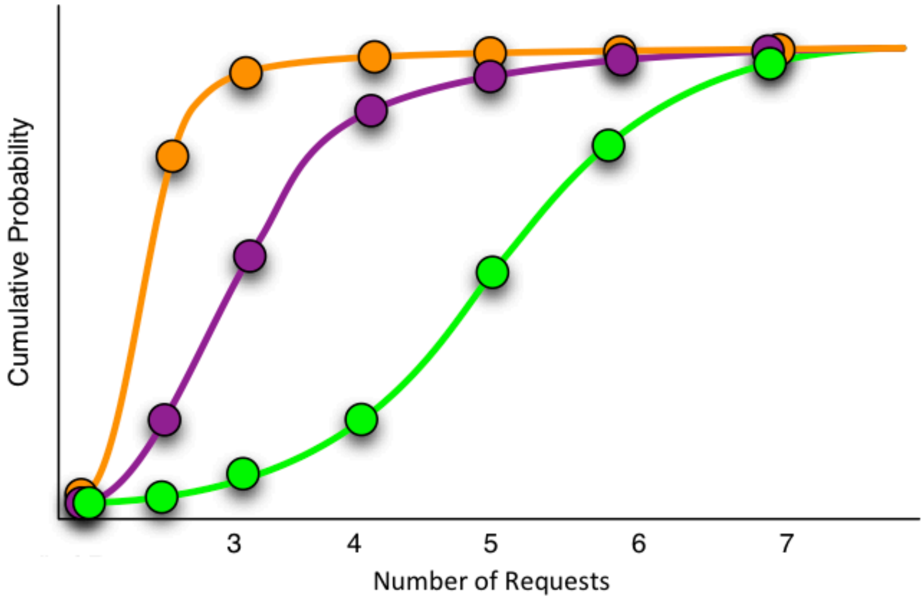

Figure 64 - Cumulative probability function of the Poisson distribution

The negative binomial distribution also assigns probabilities to discrete, non-negative events. However the expected value and variance can be adjusted independently. Figure 65 and Figure 66 illustrate the negative binomial probability distribution and its corresponding cumulative probability function. Note that the solid lines of different color show the same Poisson distribution lines. However, the dotted lines show the additional adjustments to the "spread" that can be made without affecting the expected value. This distribution is ideal for modeling requests for each day of the year, and has been used for similar natural occurrences of contagious events in the past like tornado events in a thunderstorm.

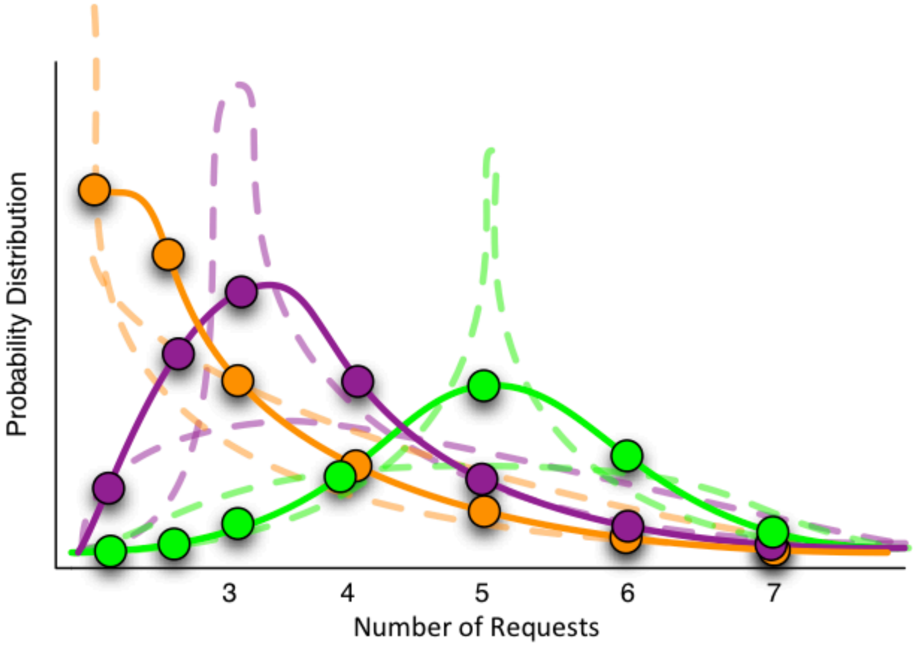

Figure 65 - Negative binomial probability distribution

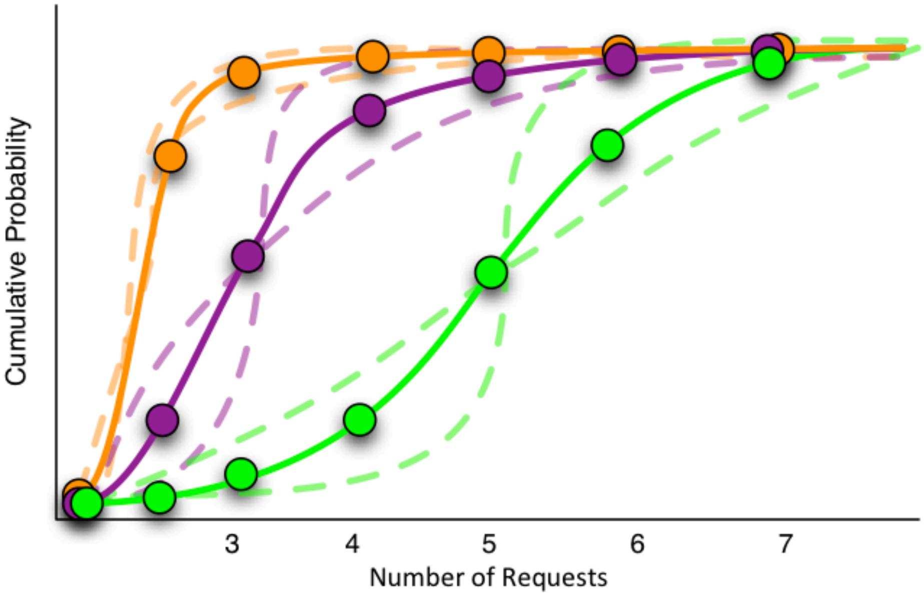

Figure 66 - Cumulative probability function of the negative binomial distribution

7.6. Appendix: Demand Model Implementation

The negative binomial fitting and United States map of fire probabilities were developed in the MATLAB and Python scripting languages. However, implementation of the demand model must be done in a more efficient programming language to reduce CPU overhead per cycle, which speeds up the overall analysis. C++, under the Qt framework, was used to implement both the demand and supply models. With the net improvement in speed of computational analysis, a Monte Carlo approach could be used to find the spread of potential outcomes for a given number of available airtankers.

All binomial coefficients and probability buckets are saved in .mat files in order to interface with the C++ code. The C library “matio” was used to identify a void pointer to the first value in each .mat file, which is then iterated casting new floating-point values, until the specified element length is reached. This .mat file read functionality is incorporated into the “demand” objects constructor, allowing for discreet loading of all the necessary parameters. With the negative binomial coefficients and probabilities for each bucket loaded, computation of total requests by day and their subsequent placement in the United States can proceed.

The “demand” object defines a “generated_demand” function that takes in a single year type parameter, corresponding to the level of fire activity for that year. Using the “boost” library's math functionality to compute equation (2), the cumulative probability for each day can be generated. The cumulative probability distributions for each day, combined with the rand() C++ functionality, provide the number of requests for each day of the year. These values are saved in an object variable to be used to place requests.

The “demand” object also defines a “place_requests” function that takes all requests for each day and executes the placement logic shown in Section 4.1.2 to give the upper and lower ranges of each probability bucket's segment of real lines on the interval from 0 to 1. Specifically, a “QList” for each day contains all buckets with non-zero probabilities. Qt's “qLowerBound” function implements a fast bisection method for QLists that quickly finds the bucket that matches a generated random number. The “qLowerBound” function is used with a new random number for every request. Finally, all requests for a year are combined into a single QList containing “fsRequest” objects, which is then sent to the supply model to be read. Note that these “fsRequest” objects define a request's location and day of year.

7.7. Appendix: Relative Fire Activity Exclusions

The relative fire activity was calculated using all fire historical data (between 1992 – 2010) found in FPA for the following states, and excluding the following years:

State	Excluded Years
CA	1998
FL	1994, 2010
ID	
MO	1996, 1997
NV	1992, 2002, 2009, 2010
NM	1992, 1993, 1998, 2002, 2006, 2008, 2009
OR	
WA	
AR	1998, 2002
TX	1994, 2009, 2010
UT	1993, 2009, 2010
WA	2008, 2009

This data was excluded because it was incomplete based on the FPA_COMPLETENESS table.

7.8. Appendix: Supply Model Tuning

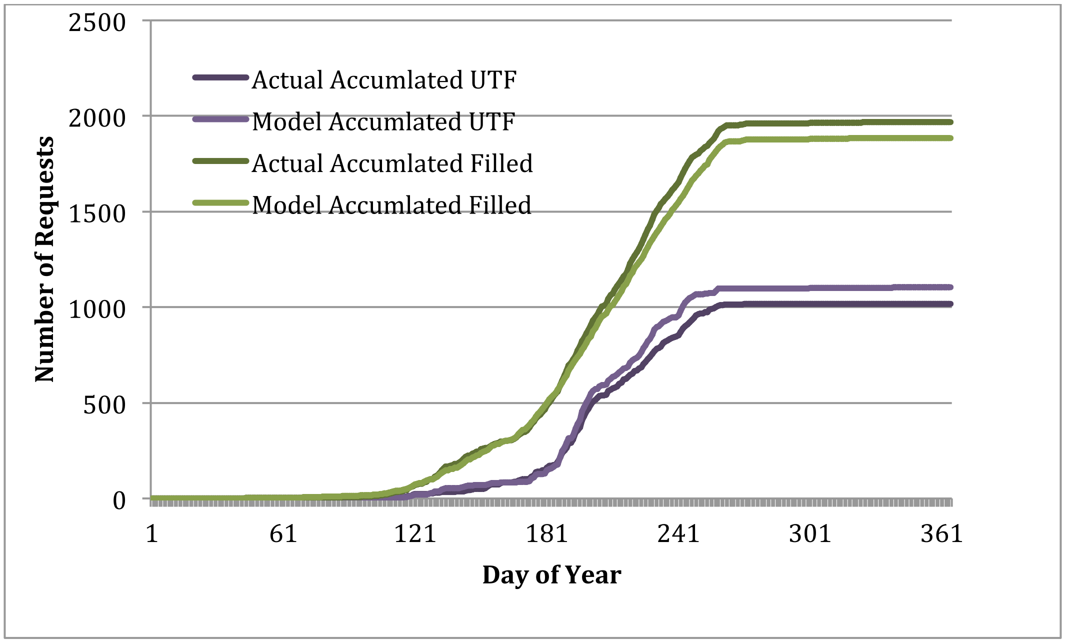

Figure 67 - Cumulative filled and unfilled request comparisons between model and actual 2007 data

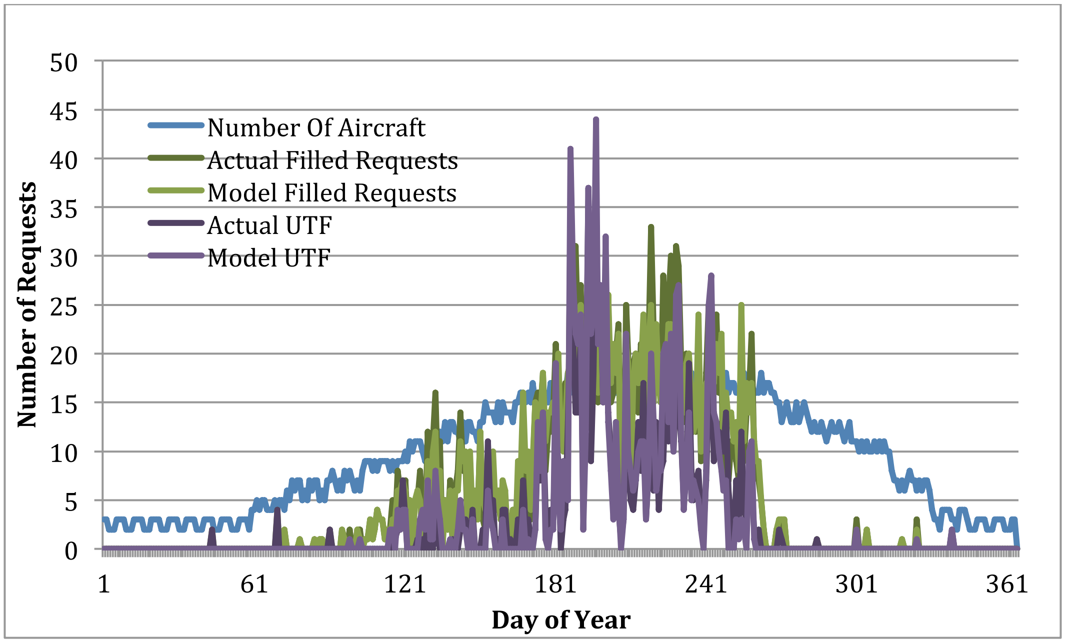

Figure 68 -Day-by-day filled and unfilled request comparisons between model and actual 2007 data

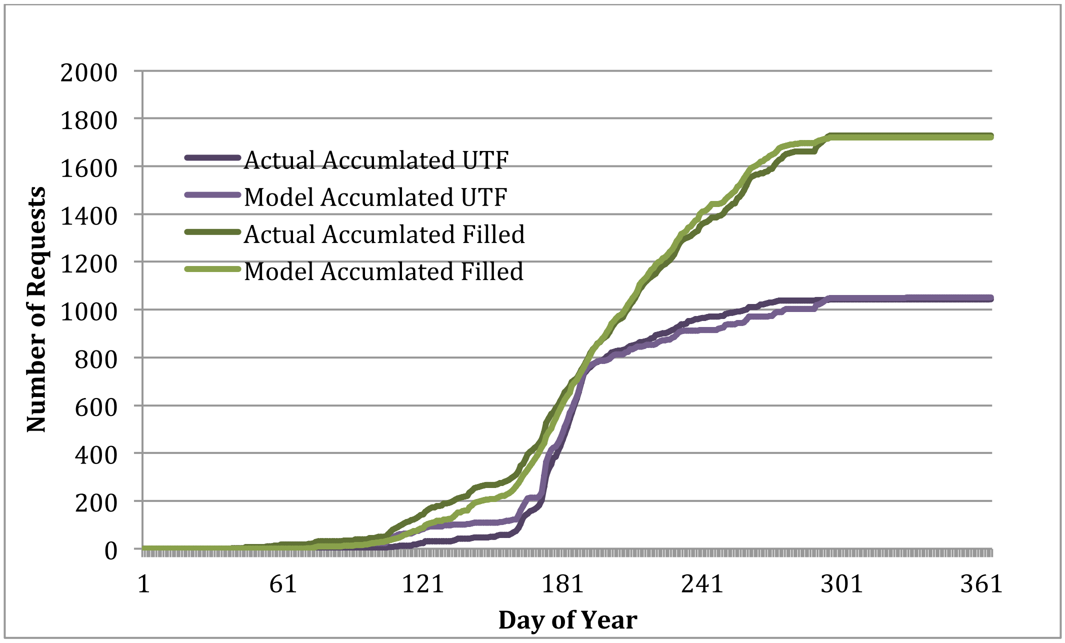

Figure 69 - Cumulative filled and unfilled request comparisons between model and actual 2008 data

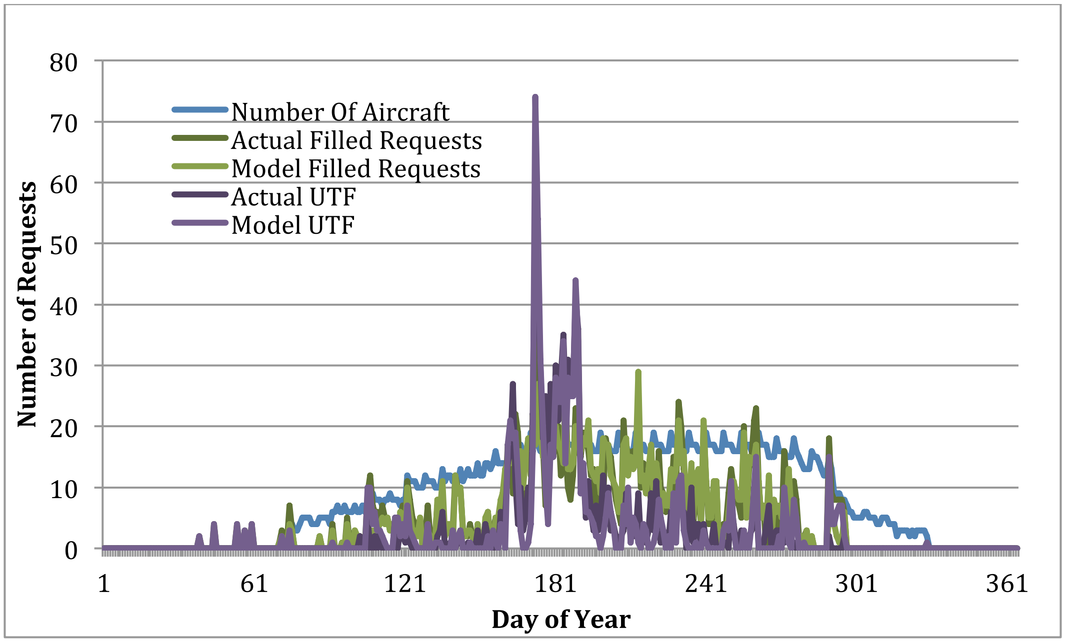

Figure 70 -Day-by-day filled and unfilled request comparisons between model and actual 2008 data

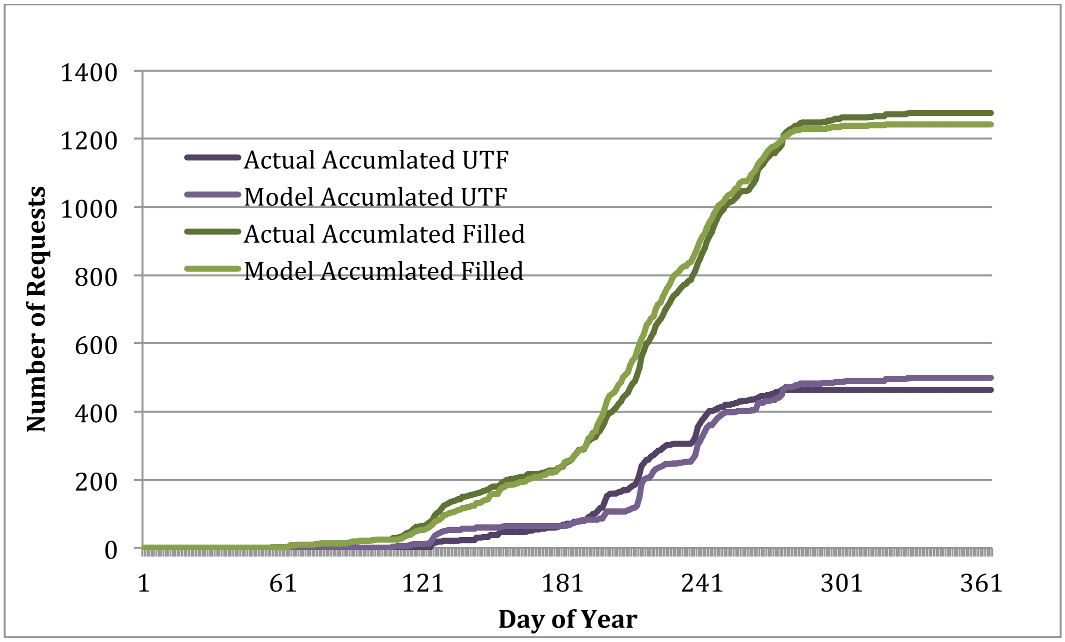

Figure 71 - Cumulative filled and unfilled request comparisons between model and actual 2009 data

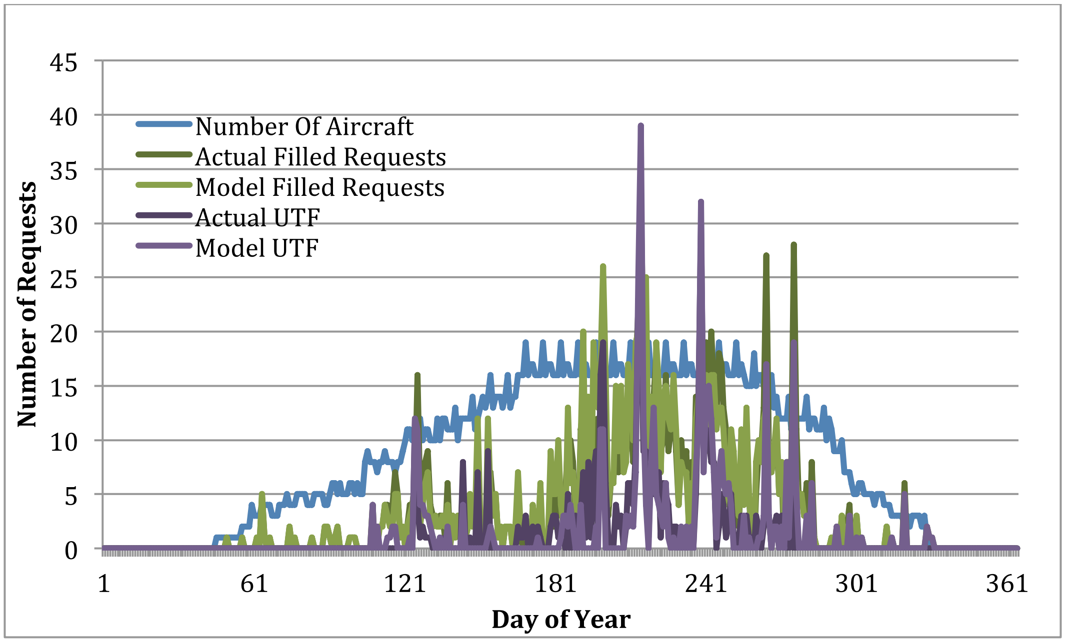

Figure 72 -Day-by-day filled and unfilled request comparisons between model and actual 2009 data

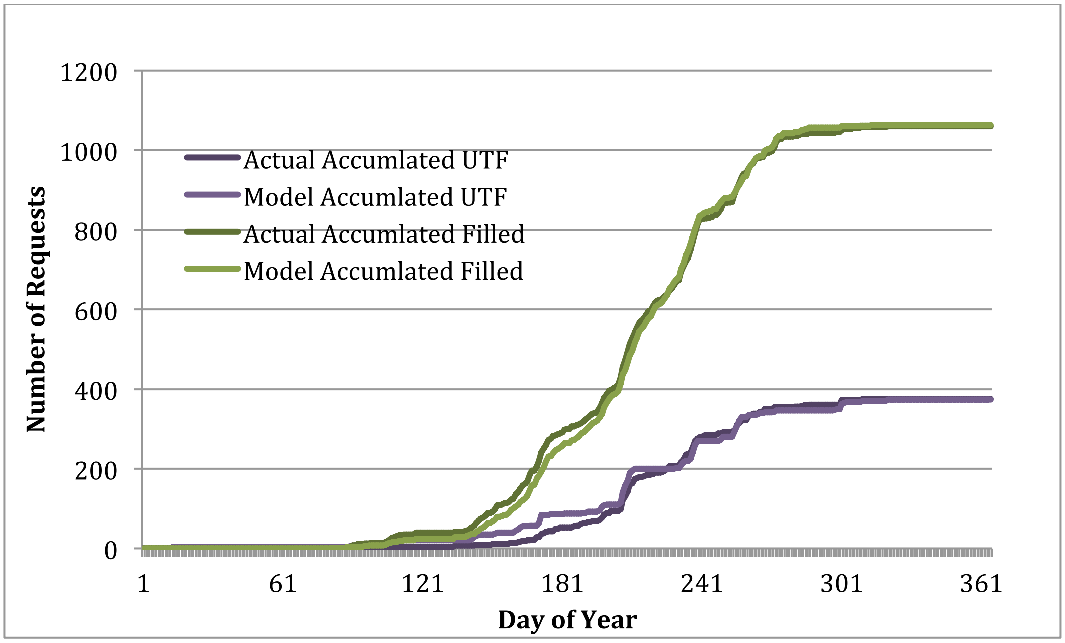

Figure 73 - Cumulative filled and unfilled request comparisons between model and actual 2010 data

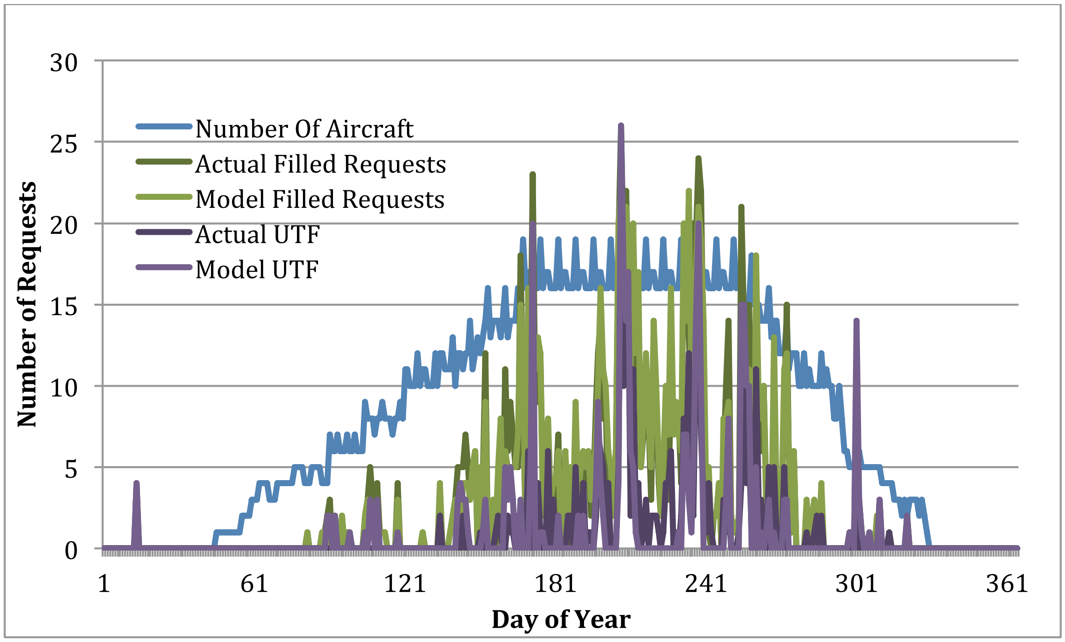

Figure 74 -Day-by-day filled and unfilled request comparisons between model and actual 2010 data

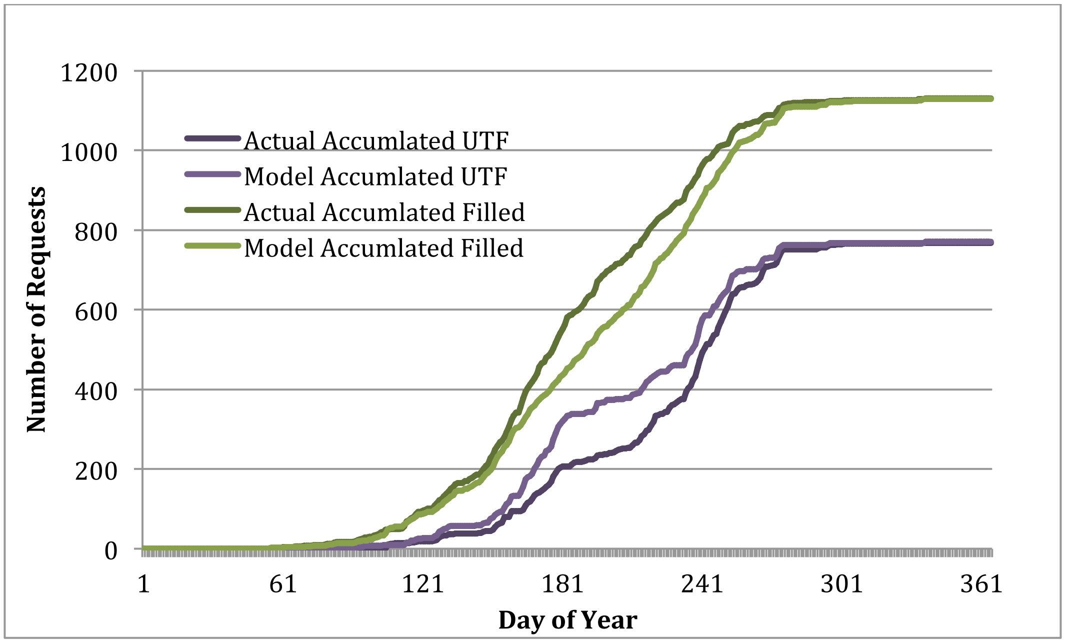

Figure 75 - Cumulative filled and unfilled request comparisons between model and actual 2011 data

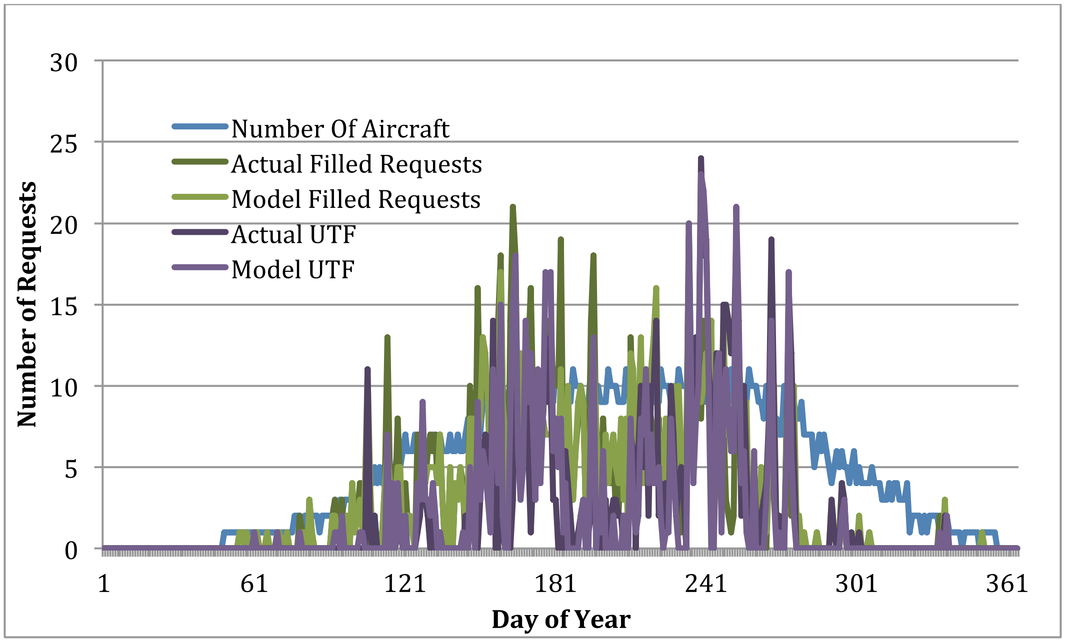

Figure 76 -Day-by-day filled and unfilled request comparisons between model and actual 2011 data

7.9. Appendix: Requirements Traceability Matrix

Source ID	Functional Requirement	Task	Report Section
B.3	**Scope**		
SOW B.3.a.1	The contractor shall be responsible for the following technical services: Review of the scientific literature and internal or contracted reports related to airtanker, helicopter and scooper use, aircraft characteristics, bases, contracts, costs, dispatching, mission objectives, tactics, strategy and communications which identify how the variety of aviation missions have been modeled in the past.	Review literature. Per USFS meeting in Missoula July 11-12, 2012, priority is airtankers, then helicopters, then scoopers.	2
SOW B.3.a.1	The contractor shall be responsible for the following technical services: Review of past studies to identify the primary factors that influence appropriate fleet composition. (www.myfirecommunity.net)	Review information at myfirecommunity.net. Per USFS meeting in Missoula July 11-12, 2012, priority is airtankers, then helicopters, then scoopers.	2
SOW B.3.a.2	Define the utility and operational parameters of large airtankers (LAT), heavy helicopters (defined as Type 1), and water scoopers in accomplishing the variety of aviation missions supporting wildfire management.	Build aircraft models to use in supply models, and evaluate fleet size options. Per USFS meeting in Missoula July 11-12, 2012, priority is airtankers, then helicopters, then scoopers.	4.2, 5
		Build supply model (availability) using aircraft models.	4.2
SOW B.3.a.2	Summarize the circumstances (fire management types; Type 5-Type1, fire size, missions, basing, dispatching, geographic and logistical factors) under which each aircraft type can effectively operate.	Build aircraft models to use in supply models, and evaluate fleet size options. Consider fire management types (Type 5-Type1), fire size, missions (IA, EA, LFS), basing, dispatching, geographic and logistical factors as aircraft parameters/constraints.	3.1
SOW B.3.a.2	The data in the final report shall be identified by aircraft class (LAT, heavy helicopters and water scoopers) and aircraft type.	Analyze ROSS data for demand. How many filled and unfilled orders for each aircraft type, for each year, for each GACC?	3
		Analyze ABS/AFF/OLMS data for demand. Aircraft use by incident, aircraft type, day, GACC.	3

SOW B.3.a.3	Examine recent (CY 2000-CY2011) aviation usage trends (including fire type/size) and explore how various combinations of new and existing aviation resources could meet capacity and demand levels projected from historical use.	Use Demand/Supply models to show effects (UTFs) of alternate fleet sizes.	5
SOW B.3.a.3	This analysis shall identify the appropriate mix of airtankers (Type 1 and Type 2), heavy helicopters (Type 1) and water scoopers.	Use Demand/Supply models to show effects (UTFs) of alternate fleet sizes.	5
B.4.a	**Wildfire Aviation Literature Review**		
SOW B.4.a	The contractor shall conduct a review of the scientific literature and past internal and contracted reports and studies on effective design and composition (number and mixture of assets) of the airtanker, helicopter, and scooper fleet.	Review literature. Per USFS meeting in Missoula July 11-12, 2012, priority is airtankers, then helicopters, then scoopers.	2
SOW B.4.a	Evaluate how these various missions have been modeled [initial attack, extended attack, large fire support] in the past and identify key variables that are most influential in determining modeled aviation effectiveness.	Review literature. Per USFS meeting in Missoula July 11-12, 2012, priority is airtankers, then helicopters, then scoopers.	2
B.4.b	**Aircraft Capability in Meeting Mission Needs**		
SOW B.4.b.1	From the FS data, the contractor shall determine primary and secondary fire missions (IA, EA, LFS) for each class of aircraft (LAT, scooper, heavy helicopter).	Analyze ROSS data for demand. Match each filled and unfilled order with a fire mission (IA/EA/LFS) and aircraft class requested (LAT, helicopter, scooper).	3.1, 3.2
		Correlate ABS/AFF/OLMS data (aircraft use and location) with FPA historical data (fire type, location) to refine link between fire missions (IA/EA/LFS) and aircraft class.	3.2
SOW B.4.b.1	The contractor shall review key variables such as airspeed, cycle time, tank size, relative effectiveness of water/retardant, drop patterns and length, flight characteristics (such as rate of climb) dispersal mechanism, and the relationship of these variables to the different fire missions.	Correlate ABS/AFF/OLMS data (aircraft use and location) with FPA historical data (fire type, location) to refine link between fire missions (IA/EA/LFS) and aircraft data. Include airspeed, cycle time, tank size. Per USFS meeting in Missoula July 11-12, 2012, other variables are lower priority.	3.1, 3.2

SOW B.4.b.1.i	For heavy helicopters & water scoopers, the contractor shall identify and document how logistical factors (e.g., terrain, fuel type, fire behavior, proximity to water bodies) affect the ability of the aircraft to meet fire mission objectives.	Analyze FPA data and correlate with local availability/usability of water source to determine aircraft supply constraints (supply model) for helicopters. Per USFS meeting in Missoula July 11-12, 2012, priority is airtankers, then helicopters, then scoopers.	3.1
SOW B.4.b.1.i	For water scoopers, the contractor shall geospatially identify water sources where scoopers can operate safely (scoop water);	Analyze FPA data and correlate with local availability/usability of water source to determine aircraft supply constraints (supply model) for scoopers. Per USFS meeting in Missoula July 11-12, 2012, priority is airtankers, then helicopters, then scoopers.	3.1
SOW B.4.b.1.i	For water scoopers, the contractor shall identify terrain conditions under which drops are safe and effective.	Analyze FPA data and correlate with local availability/usability of water source to determine aircraft supply constraints (supply model) for scoopers. Per USFS meeting in Missoula July 11-12, 2012, priority is airtankers, then helicopters, then scoopers.	3.1
SOW B.4.b.2	The contractor shall establish ferry times between available aircraft base locations for the different aircraft types using airspeed, flight range, aircraft and base requirements, logistics and terrain information to determine how efficient different aircraft can be mobilized to meet initial attack, extended attack and large fire demand.	Build aircraft models to use in supply models, and evaluate fleet size options. Consider airspeed, flight range, aircraft and base requirements, logistics and terrain information to determine ferry times as aircraft parameters/constraints.	3.5
B.4.c	**Fleet Design & Composition to Effectively Meet Recent Historic Demand**		
SOW B.4.c.1.i	Summarize usage statistics and requests by fire size (IA, extended attack and large fire support) and Geographic Area Coordination Centers (GACC) for all aviation resources (data may not be consistent across aircraft type).	Correlate ROSS, FPA and ABS/AFF data to determine where/when aircraft were assigned. Include the fire type (IA/EA/LFS) they were assigned to. Use to build demand data.	3.1, 3.2
SOW B.4.c.1.ii	The contractor shall document inconsistent data and notify the USFS team.	Document inconsistent data	3, 7.1

SOW B.4.c.1.iii	Summarize historic basing locations and movement characteristics for LATs	Analyze ABS/AFF/OLMS data for aircraft location/movement. Link each aircraft in the fleet to its base. For each order from ROSS, determine the aircraft's movement (ferry time to base nearest the fire, cycle distance to/from fire).	3.5
SOW B.4.c.1.iv	The contractor shall utilize the [ROSS data regarding unable to fill (UTF) orders for LATs and heavy helicopters] to examine any potential substitution effects within resource ordering for [LATs and heavy helicopters] for UTF orders for LATs, and Type I and II Helicopters.	Use Demand/Supply models to show effects (UTFs) of alternate fleet sizes.	3.1
SOW B.4.c.1.v	Explore aviation usage trends as a function of fire activity (ignitions and area burned) and preparedness level by GACC	Analyze ROSS data for demand. How many filled and unfilled orders for each aircraft type, for each year, for each GACC, for each fire ignition, area burned, GACC preparedness level	3.1.1, 3.1.2, 3.1.4
SOW B.4.c.1.vi	Explore airtanker and heavy helicopter annual flight hours, gallons dropped, prepositioning, UTF and/or other airtanker and heavy helicopter use or data variables as a function of demand.	Analyze ABS/AFF/OLMS data for demand. How many UTFs, flight hours, gallons dropped, prepositioning	3.1
SOW B.4.c.1.vii	Examine demand pulses for aviation assets including IA/EA/LFS requests	Analyze ROSS data for demand. How many filled and unfilled orders for each aircraft type, for each year, for each GACC? Determine demand pulses (peak demand) for IA/EA/ILS.	3.3
SOW B.4.c.1.viii	Identify airtanker, helicopter and scooper (FS, DOI, state/local, and other) use from 2000-2011 including Modular Airborne Firefighting System (MAFFS) and leased aviation resources from other sources.	Correlate ROSS, FPA and ABS/AFF data to determine class of aircraft assigned. Include MAFFS. Use to build demand data.	3.4
SOW B.4.c.1.ix	The contractor shall examine and determine if there are relevant data (CAD and WILDCAD) mentioned above [CAD and WILDCAD] but not included within ROSS	Disregard this requirement, per USFS meeting in Missoula July 11-12, 2012.	N/A
SOW B.4.c.2	The contractor shall establish historic annual aviation demand for LATs, scoopers, and heavy helicopters to examine how alternative fleet design and composition and positioning strategies would affect the level of aviation requests not filled for the 2000-2011 fire seasons.	Analyze ROSS data for demand. How many filled and unfilled orders for each aircraft type, for each year, for each GACC?	3.1

		Build demand model. Final report: identify information useful for building demand model.	4.1
B.5.b	**Deliverables**		
SOW B.5.b.1	The contractor shall research, develop, and utilize a conventional methodology to comply with the requirements in this statement of work.	Analyze ROSS data for demand. How many filled and unfilled orders for each aircraft type, for each year, for each GACC?	3
		Analyze ABS/AFF/OLMS data for demand. Aircraft use by incident, aircraft type, day, GACC.	3
		Build demand model.	4.1
		Analyze contracts info to determine aircraft resources (fleet size). Need data by aircraft type. Does contract info determine prepositioning location?	4.2
		Build supply model (availability).	4.2
		Use Demand/Supply models to show effects (UTFs) of alternate fleet sizes.	5
B.5.c	**Final Report**		
SOW B.5.c.1	The contractor shall develop a final report that proposes at least 3 alternatives that demonstrate the effectiveness of airtankers, heavy helicopters and water scoopers.	Use Demand/Supply models to show effects (UTFs) of alternate fleet sizes.	5
SOW B.5.c.1	The final report shall be based on meeting historically observed demand and use for initial attack and extended attack fires.	Use Demand/Supply models to show effects (UTFs) of alternate fleet sizes. One alternative fleet size should be for meeting historical demand with historical supply (baseline) for IA and EA fires.	5
SOW B.5.c.1	The alternatives [in the final report] shall include the effectiveness in large fire support.	Use Demand/Supply models to show effects (UTFs) of alternate fleet sizes.	5
SOW B.5.c.1	The report shall include an assessment of the impact(s) of changes in aircraft design, performance, control and composition has on requirements, effectiveness and the mission	Use Demand/Supply models to show effects (UTFs) of alternate fleet sizes.	5
B.5.d	**Performance Measures**		
SOW B.5.d	The contractor shall formulate and implement a set of performance measures.	Determine performance measure. Per USFS meeting in Missoula July 11-12, 2012, start with UTF.	1, 5

7.10. Appendix: Glossary

Aerial Detection – A system for, or the act of discovering, locating, and reporting fires from aircraft.

Aerial Ignition – Ignition of fuels by dropping incendiary devices or materials from aircraft.

Aerial Observer – A person specifically assigned to discover, locate, and report wildland fires from an aircraft and to observe and describe conditions at the fire scene.

Aerial Reconnaissance – Use of aircraft for detecting and observing fire behavior, values-at-risk, suppression activity, and other critical factors to facilitate command decisions on strategy and tactics needed for fire suppression.

Aerial Supervision – Management of incident airspace and incident air traffic, includes coordination, assignment and evaluation of aerial firefighting resources. Includes

Air Attack – The deployment of fixed-wing or rotary aircraft on a wildland fire, to drop retardant or extinguishing agents, shuttle and deploy crews and supplies, or perform aerial supervision of the overall fire situation.

ASM – Federal designation for an Aerial Supervision Module platform with an Air Tactical Pilot and Air Tactical Supervisor on board. This module can perform aerial supervision and low-level operations including the lead profile.

Airtanker – Fixed-wing aircraft certified by FAA as being capable of transport and delivery of fire retardant solutions.

Airtanker Base – Ground facilities for mixing, storing, and loading fire retardant into airtankers.

Attack a Fire – Limit the spread of fire by any appropriate means.

Cargo Drop – Dropping of equipment or supplies, with or without a parachute, from an aircraft in flight.

Crew Transport – Transport of firefighters by aircraft directly (helicopter) to the fire or to a mobilization area (fixed–wing) near the fire incident base.

Escaped Fire – Fire which has exceeded or is expected to exceed initial attack capabilities or prescription.

Extended Attack – Suppression activity for a wildfire that has not been contained or controlled by initial attack or contingency forces and for which more firefighting resources are arriving, en route, or being ordered by the initial attack incident commander.

Fire Retardant – Any substance except plain water that by chemical or physical action reduces flammability of fuels or slows their rate of combustion.

Fire Suppressant – Any agent used to extinguish the flaming and glowing phases of combustion by direct application to the burning fuel.

Fixed Tank – A device mounted inside or directly underneath an aircraft which can contain water or retardant for dropping onto a fire.

Fixed- Wing – An aircraft with fixed wings as opposed to a rotor wing.

FPA – Fire Program Analysis System

Geographic Area – A boundary designated by governmental agencies (wildland fire protection agencies) within which they work together for the interagency, intergovernmental planning, coordination, and operations leadership for the effective utilization of emergency management resources within their area. There are nine geographic areas. A listing of the areas can be found in the "National Interagency Mobilization Guide," Chapter 20, section 21.1 (NICC, 2012) along with listings of the Geographic Area Coordination Centers.

Geographic Area Coordination Center (GACC) – The physical location of an interagency, regional operation center for the effective coordination, mobilization and demobilization of emergency management resources. See Table below for Specific GACCs.

AICC	**Alaska**
EACC	**Eastern Area**
EGBC	**East Great Basin**
ONCC	**Northern California**
NRCC	**Northern Rockies**
NWCC	**Northwest**
RMCC	**Rocky Mountain**
SACC	**Southern Area**
OSCC	**Southern California**
SWCC	**Southwest**
WGBC	**Western Great Basin**

Helicopter Bucket – Specially designed external bucket carried by a helicopter used for aerial delivery of water or fire retardants.

Helicopter – An aircraft that depends principally on the lift generated by one or more rotors for its support in flight. *synonym:* Rotor Wing, Rotorcraft

Heavy Helicopter – Type 1 Helicopter, see chart below.

Helitack – The utilization of helicopters to transport crews, equipment, and fire retardants or suppressants to the fireline during the initial stages of a fire. The term also refers to the crew that performs helicopter management and attack activities.

Helitack Crew – A crew of firefighters specially trained and certified in the tactical and logistical use of helicopters for fire suppression.

Helitanker – A helicopter equipped with a fixed tank with an in-take snorkel capable of delivering water, foam, or retardant. Usually a large helicopter.

Incident – An occurrence either human-caused or natural phenomenon, that requires action or support by emergency service personnel to prevent or minimize loss of life or damage to property and/or natural resources.

Initial Attack (IA) – A planned response to a wildfire. The objective of initial attack is to stop the fire and put it out in a manner consistent with firefighter and public safety and values to be protected.

Initial Attack Fire (IAF) – Fire that is generally contained by initial attack units without a significant augmentation of reinforcements and is contained or controlled within the first 24 hours.

Large Fire – For statistical purposes, a fire burning more than a specified area of land, e.g., 300 acres. A fire burning with a size and intensity such that its behavior is determined by interaction between its own convection column and weather conditions above the surface.

National Interagency Coordination Center (NICC) – Coordinates allocation of resources to one or more geographic area coordination centers within the nation. Located in Boise, Idaho, at NIFC (see next definition).

National Interagency Fire Center (NIFC) – A facility located at Boise, Idaho, jointly operated by several federal agencies, dedicated to coordination, logistical support, and improved weather services in support of fire management operations throughout the United States.

Night (Aviation) – The time between the end of evening civil twilight and the beginning of morning civil twilight, as published in the American Air Almanac, converted to local time.

OLMS - Operational Loads Monitoring System

Paracargo – Anything intentionally dropped, or intended for dropping, from any aircraft by parachute.

Rappelling – Technique of landing specifically trained and certified (helitack) firefighters from hovering helicopters; involves sliding down ropes with the aid of friction-producing devices.

Restricted Category – Aircraft that is generally used for cargo, retardant dropping, agricultural operations, survey work and other specific projects, and may not transport passengers.

Retardant – A substance or chemical agent which reduces the flammability of combustibles.

Retardant Drop – Fire retardant cascaded from an airtanker or helicopter.

ROSS - National Interagency Resource Ordering and Status System

Smokejumper – A specifically trained and certified firefighter who travels to wildland fires by fixed- wing aircraft and parachutes to the fire.

T1 Airtanker – Type 1 Airtanker, or See Chart below

T2 Airtanker – Type 2 Airtanker, or See Chart below

Type – Refers to resource capability. A Type 1 resource provides a greater overall capability due to power, size, capacity, etc., than would be found in a Type 2 resource. Resource typing provides managers with additional information in selecting the best resource for the task.

HELICOPTERS	**Minimum Standards**		
Components	**Type 1**	**Type 2**	**Type 3**
Allowable Payload @ 59° @ Sea Level	5000	2500	1200
Passenger Seats	15+	9-14	4-8
Water or Retardant Gallons	700	300	100
Max Gross Takeoff/ Landing Weight	12501	6000- 12,500	< 6000

Make Model Example	Sikorsky S-64, Boeing Vertol 107	Bell 205 and 212	Eurocopter AS-350 Bell 407

AIRTANKERS	**Minimum Standards**		
	Type 1	**Type 2**	**Type 3**
Retardant Gallons	3000	1800	800
Make Model Example	P3, C-130	P2V	AT-802, S-2T

Wildfire – An unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out.

Wildland Urban Interface (WUI) – The line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels.

7.11. Appendix: Literature References

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