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Minimizing Security Forces Response Times through the use of Facility Location Methodologies

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THESIS

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Abstract

Since the events of September 11, 2001, security for the nation's Intercontinental Ballistic Missile (ICBM) force has become a prominent concern for personnel in the highest levels of government. This has resulted in many physical security upgrades and new methods for countering hostile activities. Missile maintenance personnel have traditionally been concerned only with preserving high weapon system alert rates. This goal was often achieved at the expense of optimal security for the ICBMs they maintained. This research seeks to find the optimal placement for one layer of the security net protecting these crucial assets, the daily-deployed security forces Fire Teams.

The problem of finding the optimal placement for these forces is modeled as a facility location problem. Three of the many methods of locating facilities available in the literature are selected to solve this problem. This gives decision makers alternate methods to solve the problem based on their objectives. The maximum covering location problem strives to cover the maximum demand possible with a predetermined, finite number of facilities. The p-center problem covers all demand and seeks to minimize the maximum distance between a demand point and a servicing facility. The p-median problem intends to minimize the demand-weighted total distance between demand sites and servicing facilities. In this research, a penetrated Launch Facility represents a demand site and a Fire Team represents a servicing facility. In addition to these three methods, a hybrid model is developed to first employ a p-center solution and then attempt to reduce the total distance using a p-median approach.

Comparison of the four models is based on Fire Team usage, the average response time calculated from the placement of the respective Fire Teams, the average total distance, and the average maximum distance any Fire Team is located from a penetrated Launch Facility. These comparisons take place using actual data from F. E. Warren AFB from January through May of 2004. Decision makers, based on relevant objectives, must determine the preferred solution.

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MINIMIZING SECURITY FORCES RESPONSE TIMES THROUGH THE USE OF FACILITY LOCATION METHODOLOGIES

I. Introduction

Problem and Purpose Statement

Current Intercontinental Ballistic Missile (ICBM) security requirements and missile maintenance objectives are incompatible. Each strives to satisfy a different objective, which often places them in direct conflict with one another. The purpose of this research is to develop models that can be used to minimize security forces response times based on daily scheduled maintenance requirements and to provide managers a decision making tool for evaluating trade-offs between minimizing response times and completing required maintenance actions.

Background

The Minuteman Intercontinental Ballistic Missile weapon system has been a pillar of the United States' strategic deterrence for more than forty years and will continue to be so for the foreseeable future. The ability to maintain and protect the weapon system was a crucial factor in the United States winning the Cold War. The current version of the weapon system, the Minuteman III, is deployed at three wings: Malmstrom AFB, Montana—200 ICBMs; Minot AFB, North Dakota—150 ICBMs; and F. E. Warren AFB, Wyoming—150 ICBMs (F. E. Warren AFB also maintains a contingent of Peacekeeper

missiles, which will be nearly or completely deactivated at the time this thesis is published). All wings are broken down into squadrons of 50 ICBMs each and flights of 10 ICBMs. A site containing an ICBM is known as a Launch facility (LF). A Missile Alert Facility (MAF) is assigned to each flight. The MAF houses the launch control officers, flight security controller, additional support personnel, and maintains the ability to feed and house maintenance and/or additional security personnel required to Remain over Night (RoN). LFs and MAFs at F. E. Warren AFB are alpha-numerically numbered with the letter identifying the flight and the number identifying the LF or MAF number. All MAFs utilize a letter combined with the number 1.

The system has earned credibility as a viable deterrent through its ability to achieve high alert rates on a consistent basis, normally exceeding 99% annually. Dedicated maintainers performing priority, periodic, and weapon system upgrade maintenance are the key to achieving these alert rates. Achieving and sustaining these high alert rates has always been the primary goal of the maintenance efforts. Traditionally, security considerations have been subordinate to this goal, in the minds of most maintainers and maintenance schedulers, and have been an afterthought to achieving high alert rates.

A structured priority system serves as a guide to repair and upgrade the weapon system. Guidance for establishing priorities is contained in Air Force Space Command Instruction (AFSPCI) 21-114, Attachment 2, which is Appendix A to this thesis. The highest priority, Priority 1 discrepancies, are actions required to repair equipment critical to the safe operation of the weapon system and those actions required to prevent damage, or further damage, to the weapon system. Priority 2 discrepancies normally pertain to

off-alert sorties and often consist of major maintenance activities. Major maintenance activities are actions that require the Launcher Closure (LC) door to be opened when the Reentry System (RS) is present. This fully exposes the missile silo and thus the entire weapon system. This is often referred to as an "open-hole" situation. These activities normally require replacement of Aerospace Vehicle Equipment (AVE), which consists of the RS, Missile Guidance System (MGS), and Propulsion System Rocket Engine (PSRE). Certain seldom performed actions may also occur and be considered major maintenance if the LC door requires opening and the RS is present. All other priorities have varying degrees of significance, with Priority 8 as informational and Priority 9 deferred. This hierarchy determines how and when to schedule maintenance actions and places periodic maintenance at the lower end of importance, as Priority 6 discrepancies.

Protecting the weapon system from damage, destruction, and theft is crucial to the nation's security. A specified number of security escorts are allocated to each maintenance team that penetrates an operational Launch Facility (LF) based on the type of maintenance the team is to perform. These security escorts are only required when the LF is to be penetrated, that is, when the maintenance team will enter into the silo itself. Additional requirements ensure that additional forces are able to respond if a hostile event occurs. A much larger security force is required to perform major maintenance activities. The primary goal of security is the protection of the primary nuclear weapon, the RS. Additionally, each LF contains critical classified components, which also require protection.

The events of September 11, 2001 have placed a much higher degree of emphasis on security for ICBMs. The nation cannot afford the dire consequences of damage or

theft of even one of its nuclear assets. Over the course of the past three years, many physical security upgrades were developed and have been, or soon will be, deployed. These physical security upgrades, along with the existing system, are designed to delay a hostile act long enough for a security force to respond to the threat and eliminate it. This was also the purpose of the original Minuteman Entry Control System. The system utilizes a series of user authentications and time delayed entry procedures to ensure proper personnel are accessing the system and delays unauthorized personnel, when the LF is unmanned, long enough for a response to occur. Authorized personnel are also subject to certain delays during entry.

Both a primary and secondary door protects the primary personnel access shaft. The primary door consists of steel and concrete with a magnetic security switch. Split control is inherent throughout the weapon system. To gain entry to the LF, security escorts draw Missile Electronic Encryption Device units (MEEDs) from "A-side" code controllers and maintenance personnel draw MEEDS units from "B-side" code controllers. Access to the primary door is granted by unlocking and removing the Security Pit Vault Door, which also contains a magnetic switch that actuates an alarm when the combination dial is moved a prescribed number of digits away from its null position. This door is often referred to as the "A-circuit" because only the security escorts receive the combination and are permitted to open the door. The secondary door is a 14,000-pound steel cylinder with twelve locking bolts and two combination locks. These locks also contain the same type of magnetic switch/alarm system as the "A-circuit" and the alarm activates after moving a prescribed number of digits from the null position. This door is only opened by maintenance personnel and, as such, is often

referred to as the “B-plug”. After the combination is properly dialed and the locking bolts retracted, a timer actuates and the door will begin to lower after thirty minutes have elapsed. The LC door covers the entire silo and protects it from access and weather exposure. It has a similar magnetic switch to the other doors that activates an alarm when the door is moved a predetermined length. The LC door consists of steel reinforced concrete and weighs 120 tons. Obviously, great measures are taken to protect the system as it lies in its standby state, great measures must also be taken to protect it when it is exposed for maintenance.

Recent demands from the highest levels of government to reduce security forces response times will put an increased strain on the already tenuous availability of security forces. Effectively deploying available security forces and exercising sound decision-making policies when completing all daily maintenance requirements is infeasible is the only way to ensure system protection and effectiveness. These enhanced security requirements will require a balance between achieving maintenance goals and affording the proper level of protection to the weapon system. It is unlikely that both goals can be achieved simultaneously on a consistent basis without some trade-offs occurring. Decision makers will be put in the tenuous position of choosing which goal must be compromised on a daily basis. Consistent cancellation of maintenance actions will undoubtedly cause the system to degrade over time, while even more dire consequences are perceivable without adequate security for the weapon system. This research seeks to remove some of the pressure from decision makers by providing them with a reliable tool(s) that will provide them with options to balance resources among competing objectives.

Research Questions

This research seeks to answer the following question: Can a user-friendly modeling technique be developed to minimize security forces response times while providing decision makers with a tool for balancing trade-offs between maintenance requirements and optimal or near optimal security forces response times? This question addresses the current operating environment and acknowledges the possibility of requiring some trade-offs in alert rates to achieve heightened security. The basis for answering this primary question is answering three investigative questions.

Investigative Questions

1. Does the current method of positioning security forces provide optimal response times?
2. Can a user-friendly tool be developed to assist decision makers?
3. What are the limited numbers of locations that can be selected to minimize response times with available forces?

Methodology

This study utilizes linear optimization techniques to develop theoretical models. This approach incorporates data on LF locations, interconnecting roads that allow security forces to respond to possible hostile events, and available security forces Fire Teams, into four distinct location models. Each of these models can be described as discrete location models composed of different types of servicing facilities and demand nodes. The servicing facilities are the LFs, Missile Alert Facilities (MAFs), and arbitrarily selected staging areas located at selected road intersections. Demand nodes

are penetrated LFs. The models aspire to optimize or near-optimize placement of security forces response teams based on the daily scheduled maintenance requirements. The models can be adjusted to allow decision makers to exercise trade-off options. For instance, a decision maker may wish to ensure that all, or some, periodic maintenance is accomplished on a given day(s). To accomplish this, a weighting factor can be applied to these LFs, or any other LFs requiring penetration to rank order them for maintenance completion. A weighting factor is not used in this research, but can be easily applied within the models.

Scope

This thesis utilizes data collected on the 150 Minuteman III LFs at F. E. Warren AFB, Wyoming for calendar year 2003 and January through May of 2004. The findings and conclusions are applicable only to this wing based on the factors considered. However, it is hoped the results will be generalizeable to other similar units. Changing requirements and variables will impact the effectiveness of employing the developed models at other locations. Although the other two missile wings share similar characteristics, the findings and conclusions must be tailored to those wings' peculiarities before they can be effectively employed.

Assumptions

Several critical assumptions are made in developing this thesis, and they are listed below.

- No consideration is given to higher FPCON (Charlie and Delta) procedures

- The collected data does not differ significantly from other years
- Response times are static—there is no allowance for increased speeds of responders. (NOTE: A speed allowance of 40 mph is selected. This speed is a balance between the required speed on gravel (25 mph) and on paved roads (posted speed not to exceed 65 mph). This allows for response forces that would likely increase speed on gravel in a real world hostile situation and accounts for slower winter driving conditions.)
- Data collected from F. E. Warren AFB is representative of the other wings
- No Peacekeeper LF maintenance requirements were considered
- The required number of Fire Teams stipulated by instruction are always available
- A Fire Team covering an open-hole site is unavailable to cover any other penetrated LFs

Significance

It is hoped that the utilization of the methods described in this thesis will lead to faster response times without significantly sacrificing alert rates. It is believed that the methods described here may be employed at all three existing Minuteman III ICBM units at Malmstrom AFB, Minot AFB, and F. E. Warren AFB with adjustments for individual wing variables. By utilizing the models presented in this research, security forces and maintenance planners can have a structured method of assigning security forces and a tool for decision making. This represents a marked improvement over the current methods employed at F. E. Warren AFB, Wyoming.

Thesis Overview

This chapter provides the rationale for constructing models to minimize security forces response times. Relevant background information is provided as a frame of reference. This research will provide decision makers with a tool for minimizing response times and balancing trade-offs.

Chapter II describes the requirements specified in applicable DoD and Air Force directives. The chapter covers some of the previous efforts to improve security forces response times. The chapter addresses some of the previous research conducted in the area of location analysis and focuses on the three methods selected for this research.

Chapter III presents the methodology of this thesis. It covers the collection of the data, the selection and formulation of the location modeling techniques and the specific model set formulations which for the basis for analysis in Chapter IV.

Chapter IV discusses the results of each different model set. Comparisons within each model type and between model types are displayed. These comparisons form the basis for conclusions in Chapter V.

Chapter V discusses the conclusions and inferences that can be drawn from the model results. Recommendations are provided to implement the use of these models and suggestions for future research possibilities are discussed.

II. Background

Introduction

This chapter reviews the pertinent DoD and Air Force directives that establish current doctrine. Relevant directives for both maintenance and security personnel are described. The general security requirements and definition of a penetrated site are presented. Additionally, previous attempts by individuals to improve weapon system security are described, and the current method of deploying Fire Teams at F. E. Warren AFB is outlined. Characteristics of facility location models are also presented, and they will form the basis for the developed models. This includes a brief history on the development of location analysis and some of the different methods employed by various researchers. A general description of heuristics and the particulars of the GRASP (Greedy Randomized Adaptive Search Procedures) heuristic are provided. Finally, a focus on the three facility location methods used in this research and their relevant objectives is presented.

DoD and Air Force Objectives

DoD S-5210.41-M (Draft) establishes the general security requirements for the nation's nuclear assets. Air Force specific policy is derived from these general DoD requirements. These requirements revolve around six security concept elements: denial, detection, delay, assessment, communications, and response. These concept elements present a hierarchy of actions to employ to protect the ICBM force, with the primary goal of denial. Commands are responsible for formulating security procedures, augmented by security plans developed by local commanders. Maximum response times to unmanned,

secured LFs are presented in this DoD policy, but no specific response times are mandated for responding to a possible hostile event at a penetrated LF. (DoD S-5210.41-M (Draft), undated) Due to the classification of this regulation, Unclassified Nuclear Control Information (UNCI), a minimal amount of the actual requirements are presented in this research.

Air Force Space Command Instruction (AFSPCI) 31-1101 establishes security requirements for the Minuteman III and Peacekeeper weapon systems (Peacekeeper is nearing completion of deactivation). This instruction identifies LFs containing a Reentry System as a Protection Level (PL) 1 asset. (AFSPCI 31-1101, 2004) PL 1 assets are afforded the highest degree of protection possible and must retain maximum means to achieve detection, interception, and defeat of a hostile force before it is able to seize, damage, or destroy assets. (AFPAM 36-2241, 2003) Within this instruction are specific procedures for granting access to LFs and MAFs. Specific steps are outlined for authentication of personnel and for securing the system during component failure situations. Protection of the weapon system is attained through a layered approach. This includes the physical security attributes of the LF and several different teams and compositions of security forces personnel. (AFSPCI 31-1101, 2004)

The specific number of required security escorts at a penetrated LF is stipulated and the minimum number of deployed Fire Teams is outlined for each wing. The only current requirement is to have these Fire Teams deployed within the missile complex, which, at F. E. Warren AFB, is an approximately 12,600 square mile area. A Fire Team normally consists of four security forces personnel equipped with appropriate armaments specified in the Air Force Supplement to DoD S-5210.41-M. The instruction also

contains procedures for responding to possible hostile events. Fire Teams are just one component of a Response Force designated by security forces personnel, but normally have more personnel and better equipment than designated initial responders, Security Response Teams (SRTs). (AFSPCI 31-1101, 2004)

Each wing is charged to develop a Flight Time-Distance Response Matrix for all of its flights. These matrices display response times for security forces in individual flight areas. They identify response times from each flight's MAF to a range of sites. Each matrix requires review annually. (AFSPCI 31-1101, 2004) At F. E. Warren AFB, these matrices identify all the LFs within sixty minutes of respective MAFs. These matrices are primarily used to ascertain response times to unmanned LFs by SRTs when a security zone violation occurs. Security zone violations can be caused by actual hostile activities or something as unthreatening as a rabbit entering the zone. The matrices at F. E. Warren AFB do not identify response times between each LF or from potential staging areas to LFs. Therefore, they are of little use unless responding security forces are only positioned at a MAF. AFSPCI 31-1101 is concerned with the security of the weapon system and establishes the security forces operating environment.

Air Force Instruction (AFI) 21-114, *Managing Intercontinental Ballistic Missiles Maintenance*, establishes the basic doctrine for managing the ICBM fleet. It states

> Ensure activities aim toward and support the Single Integrated Operational Plan or assigned mission, i.e., deactivation or conversion and the force development evaluation program. Follow maintenance management policy and procedures to achieve the most efficient use of manpower and fiscal resources, safety, surety, readiness, and maintenance productivity. The Maintenance/Logistics Group Commander will: Ensure a safe, timely response to discrepancies at missile sites, missile alert facilities, and support facilities, placing extra emphasis towards clearing non-mission capable and partial-mission-capable discrepancies; Direct

> maintenance production efforts; Coordinate with appropriate agencies to ensure accomplishment of the maintenance mission; Determine maintenance priorities and schedule expenditures of resources in support of the maintenance priority system. (AFI 21-114, 2000)

The Single Integrated Operational Plan is the outline for the actual use of nuclear weapons in a wartime environment. It describes a range of scenarios and tactics to employ should the need to use nuclear weapons ever arise.

AFSPCI 21-114, *Intercontinental Ballistic Missile (ICBM) Maintenance Management*, states that

> All maintenance actions and management efforts must be directed towards maximum availability of ICBMs in support of the United States Strategic Command (USSTRATCOM) requirements directives. All maintenance supervisors are mandated to use all resources in the most effective and efficient way with emphasis on the safety and welfare of the technician. Maintenance activities will ensure complete quality maintenance and absolute compliance with technical data, safety and security standards. (AFSPCI 21-114, 2003)

Requirements for all levels of ICBM maintenance managers are detailed in this instruction. It also advocates close coordination between maintenance schedulers and security forces to ensure proper security coverage. This instruction is concerned with the upkeep of the weapon system and establishes the missile maintainers' operating environment.

Previous Initiatives

Innovative deployment of security forces is not a practice that only began after September 11, 2001. A similar concept to the one discussed in this research was proposed in 1999 by (then) Captain Jack Seaberg of the 790th Security Forces Squadron at F. E. Warren AFB. (Seaberg, 1999) The concept was to create a security "umbrella"

under which maintenance would be conducted. The following was the general proposal: "The umbrella security concept is to cluster all penetrated site maintenance within a specified area of the missile field to ensure greater protection and deterrence." (Seaberg, 1999) This proposal attempted to limit maintenance operations that required an open hole or penetrated LF to remain within the umbrella. The proposal also had a goal of limiting below-grade maintenance operations to the hours of 0700-1700, with a targeted LF closing time, fully secured, of 1900. This was deemed necessary to allow Fire Teams to travel to their RoN locations to receive sufficient rest before the next day's operations. The umbrella was to be centered at one of F. E. Warren's twenty MAFs to provide a base of operations that would allow Fire Teams to branch out and respond to any hostile threats. The goal was to ensure the umbrella Fire Teams could respond to any penetrated LF within 60 minutes. The proposal went on to state "Umbrella positioning will be maintenance driven and determined by maintenance requirements." (Seaberg, 1999)

A penetrated site is one in which the inner security zone is entered into to perform maintenance. It is what the mainstream public may visualize when they think of nuclear weapons; technicians are actually within the missile silo working on the missile or its support components. This is when the LF requires special security considerations. The presence and potentially unobstructed access to both the nuclear warhead and classified critical components creates the need for these security considerations. Other types of maintenance are often performed at an LF that does not require penetration, and this could include above grade maintenance and maintenance within the Launch Support Building (LSB). The LSB contains standby power systems and environmental control components that are not critical for launch. No special security considerations are

warranted during these actions because the inner security zone remains intact and no unobstructed access is provided.

The security umbrella concept was not well received by maintenance planners and was tested but never implemented. Although the stated goal was to ensure umbrella positioning was driven by maintenance requirements, the actual testing resulted in pre-ordained positioning of the umbrella by security forces. This had the effect of limiting maintenance to only the area covered by the umbrella, thus, it was not truly maintenance driven. This created an open rift between maintenance planners and security forces leadership. This reflects the previously mentioned mentality of maintainers in achieving their goals. Still, this concept is very similar to this research. The main difference is that positioning of security forces *is* driven by maintenance requirements in this study and the goal will be to achieve an optimum or near optimum minimum response time, instead of a goal of 60-minutes.

Another approach to deal with enhancing security was proposed by Captain Jerome James and the 341st Maintenance Group in a presentation to General Lord of Air Force Space Command in early 2004. (James, 2004) In their proposal, the option of removing the Reentry System and performing all annually required maintenance during a set period of time was advocated. This method would require extensive coordination between the various types of maintenance teams and likely result in much overtime pay for civilian workers. This method purports to reduce the number of security escorts required per day, but comes at a high cost. The negative impact on the maintenance effort is extreme and will likely require a re-structuring of periodic maintenance requirements. Further, by the proposers' own estimation, the loss of only one or two days

of maintenance could take months to recover from. (James, 2004) This is highly likely since all three wings normally lose several days of maintenance per year due to extreme weather conditions, often found at these northern tier bases. More maintenance days are normally lost to safety down days and other extraneous events.

Current Method

The current approach to deploying Fire Teams at F. E. Warren AFB is determined on a daily basis. The criterion is based upon the Fire Teams' location at the time and the location of penetrated LF maintenance activities. Security forces schedulers attempt to deploy teams to limit the amount they will have to travel to get to their RoN locations while also positioning them near penetrated LFs. There is currently no structured or automated system for ascertaining optimum positioning of Fire Teams. In October 2004, a security conference was convened at F. E. Warren AFB, which included attendees from all three missile wings, 20th Air Force, AF Space Command, and DoD security personnel. A tentative decision was made to modify DoD S-5210.41-M to employ the umbrella concept for performing maintenance and deploying security forces personnel. (Seaberg, 2004)

To date, no AFIT theses or other known studies have been conducted concerning the optimal placement of security forces personnel. Several classified exercises and studies have occurred intended to analyze the inherent vulnerabilities of the system and potential physical security preventative measures. Some of these physical measures have already been, or soon will be, deployed. Improved security forces tactics have also arisen

based on these exercises. These exercises and studies are highly classified and no attempt was made to obtain the data within them.

Location Analysis

Location selection has been a concern of man since the dawn of time. Man first sought those areas that afforded him the most protection and available food sources. The first areas of civilization sprung up near areas abundant in natural resources. As civilizations began trading, cities were located along transportation routes, most notably in areas with natural harbors. Location in recent times has been a primary concern for both business and family dwelling locations. Businesses seek to maximize their competitive advantage at the lowest possible cost while homeowners attempt to ensure a safe living environment and a good return on their investment. These desires inevitably led to the development of location selection theories.

Drezner and Hamacher, in their book *Facility Location: Applications and Theory*, attempt to outline the history of location methodology. (Drezner & Hamacher, 2002) According to these authors, location selection as a science likely began sometime in the seventeenth century. The initial premise was to find the spatial median. Essentially every location problem developed was spawned by this initial mathematical problem. The history is very convoluted and many authors attribute the origination of the spatial median problem to different scholars during this time. Still, the timeframe is fairly consistent, no matter who the actual credit is attributed to. For years, it appears that the problem was difficult to solve and its solution bore little fruit as a useful tool. Therefore,

the problem remained in the realm of theory for scholarly debate until early in the twentieth century.

The Industrial Revolution provided an outlet for application of the theories as businesses sought to locate their factories where they could minimize transportation costs. One early solution is based on what is commonly known as the Weber Problem. (Freidrich, 1929) The formulation of this problem attempts to find the point that minimizes the sum of weighted Euclidean distances from the chosen location. The weights are typically associated with fixed points and represent costs per unit distance. The location that minimizes these costs is then chosen for building a factory, warehouse, or distribution center. (Drezner & Hamacher, 2002)

Since these early location optimization formulations, a myriad of different methods have been proposed, based on the needs of the user. Most problems can be described as continuous, if there is an infinite or unknown number of possible locations, or discrete, if only a predetermined number of possibilities exist. Continuous location problems are normally designed as "site generating" (Drezner & Hamacher, 2002) because they are initially designed to find a limited number of possibilities. Many heuristics have been developed to limit the number of candidate sites based on some predetermined criteria. These were necessary in the era of limited computer power and may still be so for very large problems with a multitude of decision variables. This research employs optimization and heuristic techniques and is a discrete location problem, since the range of locations has already been limited to specific geographical points.

Even with a limited number of location possibilities, discrete location problems can be very difficult to solve, especially optimally. Their computational complexity has limited wide spread use of solution methods until high-speed computer use became commonplace. Each location model is also very application specific based on the objectives, constraints, and variables presented by the entity seeking a solution. Consequently, a generalized model appropriate for all situations or applications does not exist. However, most location models are derivations of eight basic models: set-covering, maximal covering, p-center, p-dispersion, p-median, fixed charge, hub, and maxisum. (Drezner & Hamacher, 2002) Each of these models presents different objectives which can be tailored to individual requirements through inclusion of user-specified variables and constraints.

The objective of the set covering problem (Toregas & Revelle, 1972) is to locate the minimum number of facilities required to service, or cover, all of the demand nodes. The objective is constrained to a maximum allowable distance in order to be considered covered. The solution to this problem is not bounded to a certain number of facilities; it can result, therefore, in a theoretically infinite number of selected facilities. This model represents a budget-less solution. (Drezner & Hamacher, 2002) The other seven models are step-wise derivations of this model, modified to incorporate different objectives. To modify the problem and constrain it to an upper limit for facilities, the maximal covering location problem (MCLP) is used. (Church & Revelle, 1974) In this formulation, the objective is to locate a predetermined number of facilities, p, in a manner that maximizes the demand that is covered. Both of these formulations assume that the covering distance is a predetermined, fixed distance. (Drezner & Hamacher, 2002)

The p-center problem (Hakimi, 1964) expands on the MCLP by minimizing the maximum distance between a demand node and its closest servicing facility, given the already predetermined number of facilities to locate. It can be either a vertex p-center problem, where the set of candidate facility sites are restricted to the nodes of the network, or an absolute p-center problem, which permits facilities to be located anywhere along the arcs of the network. The primary objective of the p-dispersion problem is to maximize the minimum distance between two facilities. This problem remains limited to the predetermined number of facilities and is useful in reducing cannibalization between stores, reducing vulnerabilities, and other objectives that require facilities to be widely separated. (Drezner & Hamacher, 2002)

The p-median problem seeks to minimize the demand-weighted total distance between facilities and demand nodes. The weighting factor is normally cost, but can be any other chosen variable. This model assumes that fixed costs are the same for locating a facility at a potential site, there are no capacity constraints, and the number of facilities to locate is predetermined and fixed. The fixed charge location problem was developed to address objectives that are contrary to these assumptions. Its objective is to minimize both facility and transportation costs. Utilizing this method, the optimal number, location, and demand assignments are determined. (Drezner & Hamacher, 2002)

Hub location problems are formulated to locate the hubs and delivery routes of hub and spoke systems. These models attempt to minimize total cost, normally as a function of distance. The objective function minimizes the sum of transporting items between non-hub nodes and their respective hubs, the cost from the final hub to the destination, and the inter-hub movement costs. The maxisum location problem is

generally concerned with the location of undesirable facilities. Its objective seeks to maximize the demand-weighted distance between demand nodes and the facilities to which they are assigned. (Drezner & Hamacher, 2002) This model may be appropriate for prisons, landfills, etc.

In his book *Network and Discrete Location: Models, Algorithms, and Applications* author Mark S. Daskin provides a comprehensive introduction to the art and science of locating facilities. (Daskin, 1995) The book espouses to be a hands-on guide to using and developing facility location models. It introduces model-building methods and solution algorithms. Daskin identifies four classical location problems: covering, center, median, and fixed charge. Derivations of these four problems can produce the same eight location models identified by Drezner and Hamacher. The stated objectives for these models provided by Daskin are very similar to those identified by Drezner and Hamacher. Daskin provides some methodological tools for solving location models and provides insights into when each approach is useful and what information it provides. (Daskin, 1995) This information was useful in ascertaining which types of location models to use in this research.

There are literally thousands of articles and books written on various location analysis models. Many of the mathematical models are developed to solve narrowly focused objectives. Since user requirements are often unique, a potentially infinite number of models can be developed and utilized. Each is dependent on the objectives and constraints identified by the end user. Facility location methodologies have been employed in a wide range of decisions; locating distribution centers and factories, machinery dispersion in a factory, computer network designs, and various military

applications. The literature review for the models selected in this research will focus on some of the military studies that were accomplished utilizing those particular models.

There are essentially three ways in which the problem in this study can be framed. It can be seen as a maximum covering location problem, whereby the maximum achievable number of scheduled penetrated LFs would be covered within a specified response time given the number of Fire Teams available. This requires the use of a maximum covering location problem model. The second alternative is to minimize the aggregate, or total, response time. This requires all scheduled penetrated LFs to be covered and minimizes the overall response time. This requires the use of a p-median location model, where p is the number of Fire Teams available. The third alternative is to minimize the maximum response time to any one penetrated LF. This method again entails covering all scheduled penetrated LFs but seeks to achieve the lowest possible maximum response time to any particular penetrated LF using a p-center solution. All three are viable alternatives and can be used depending upon the nature of instructional requirements and maintenance and security goals. This research intends to develop a model for all three methods that can be used by managers for comparative analysis and in deploying their security forces. Additionally, a hybrid model is developed that first employs a p-center solution and then strives to improve the total distance objective by employing a p-median solution.

Maximum Covering Location Problem (MCLP)

The maximum covering location problem is appropriate if policy or instruction requires a specified response time. The objective applicable to this research is to locate a

specified number of Fire Teams in a manner that maximizes the number of covered, penetrated LFs. This method would quickly display the tradeoff between response times and maintenance requirements. Since the number of Fire Teams is deterministic, the response time is entered into the model as the primary constraint by converting it to a distance. Any LFs that cannot be covered within the specified response time (distance) are canceled from that day's schedule. This would show managers what maintenance requirements are foregone, allow them to re-designate priorities, and plan to compensate for missed maintenance. Since it is likely that not all sites will be covered with this method everyday, this can quickly cause an unmanageable backlog of maintenance requirements. This researcher considers this the last resort, to be used only if Air Force or higher instructions require a specified response time. This methodology has been utilized in several military applications, including AFIT theses.

In 1997, Major Douglas E. Fuller studied the optimal placement of airborne surveillance assets. His AFIT thesis sought to provide an automated planning tool for optimum positioning of Air Force surveillance assets for theater-level campaigns. In his study, Fuller used a heuristic to solve the MCLP because of the large number of potential positioning locations. Fuller utilized Euclidean distance measurements in his research because the stated covering radius was of short length. Fuller employed two scenarios to test his model, one for Iraq and one for the Far East. Both scenarios employed a 175 nautical mile cover radius. (Fuller, 1997)

The Iraq scenario identified 205 potential targets inside a 900 by 900 nautical mile cover grid. Total coverage was obtained in his model with only four aircraft. Fuller was further able to demonstrate that 99% of the required coverage could be accomplished

with only three aircraft. The Far Eastern scenario contained 133 potential targets inside an approximately 1,260 by 1,260 nautical mile cover grid. In this scenario, 90% of the required coverage was accomplished with only three aircraft. However, 100% coverage could not be completed using six aircraft. This demonstrates the economy of assigning additional resources to obtain minimal benefit. His models and results can assist planners and commanders with at least good approximations of the number of aircraft required to fulfill the surveillance mission. (Fuller, 1997)

The MCLP methodology was also used by 1st Lieutenant M. Melih Basdemir in an AFIT thesis that attempted to find the optimal locations for stationing search and rescue units in the Aegean and Western Mediterranean regions of Turkey. In his formulation, Basdemir assigned bonus values to high priority demand points. This effectively weighted the model to strive to cover these high priority demand points. Candidate location points were limited to existing military facilities and other potential sites. As in this research, Basdemir's model had more candidate points than demand points. Contrary to this research, however, demand points were not fixed. Basdemir used demand points that represented a specific area requiring coverage and were adjustable. This significantly adds to the complexity of the MCLP model. (Basdemir, 2000)

Basdemir examined the problem in three stages. The first solved the problem with normal coverage distances. The second incorporated abnormal coverage distances. Finally, the third applied worst-case scenarios. This obviously produced three different solutions and Basdemir chose to develop a combined decision based on the results. The combined solution incorporated the maximum coverage solution from each scenario and

the alternative optimal solutions. The union of these solutions was then ascertained and the solution that maximized coverage with the minimum number of Search and Rescue stations was selected. (Basdemir, 2000)

p-median Problem

The p-median methodology should be employed if minimizing the weighted response time is the primary goal. This methodology can also be employed, as is the case in this research, to minimize the aggregate response time when no weighting factor is employed. In this research, response time is dependent on distance, so the appropriate objective then is to minimize the total distance between Fire Teams and penetrated LFs. This research assumes that all demand is equal, so no weighting factor is employed. This is appropriate because any penetrated LF containing a Reentry System has the same vulnerabilities and is exposed to an equal amount of threat. All penetrated LFs are covered utilizing this method. This methodology, along with the p-center methodology, has been utilized in several military applications, including AFIT theses, two of which are portrayed here.

Major David L. Merrill's limited distribution AFIT thesis addressed minimizing the enroute distance of flight inspection missions. His major objective was to evaluate the merits of an initial proposal to base, at that time, new C-29 aircraft at Scott AFB. It was already decided that the six new aircraft would be based at a single location. To solve the p-median problem, Merrill weighted the distances by the frequency of inspection missions that occurred. He limited his calling population to the top fifty requesting bases, out of a possible 103 locations. At the time his thesis was completed,

1989, computing power was far from what it is today. Therefore, his analysis was performed by developing a simple distance matrix. (Merrill, 1989)

Merrill calculated the median by taking the minimum of all column averages. The resulting optimal location utilizing the p-median methodology was Tinker AFB, Oklahoma. Merrill developed a "radius of distinction" of 500 to 600 miles and found that Scott AFB fell well within this radius. He therefore surmised that a move from the original basing location appeared to be unwarranted. Merrill suggested that his research be furthered by including all 103 data locations to determine if the results would be similar. (Merrill, 1989) This seems a logical course of action and would have been easier to accomplish with the passage of time, as computing power and speed progressed.

Another AFIT thesis written by Captain Jon A. Eberlan is strikingly similar to this research, yet his methods are relevant for a different objective. Eberlan's goal was to optimize the location of the continental United States strip alert sites to support homeland defense. His research was also inspired by the events of September 11, 2001, which necessitated better protection of the homeland and more dedicated aircraft to achieve this goal. As in this research, demand was assumed to be equal, so no weighting factor is applied, and the primary objective is minimized response time. (Eberlan, 2004)

In Eberlan's formulation, aircraft numbers and sorties fluctuated, but the cover area was assumed to be constant. He identified 202 potential candidate sites based on support and runway length requirements, among other minor considerations. He employed four different models based on coverage for different types of areas and inclusion/exclusion of certain demand and candidate points. A critical distance was used as the driver of the computation of the objective function. Each model was placed

through several iterations with varying launch times and aircraft speeds. Each model produced different results due to different numbers of demand and candidate location sites included. (Eberlan, 2004)

p-center Problem

The p-center methodology should be used when the goal is to minimize the maximum response time to any particular penetrated LF. The p-center objective in this research is to minimize the maximum distance, thus minimizing the response time, between a penetrated LF and its closest Fire Team. This method allows managers to view individual response times to each LF and to add or drop maintenance requirements to observe the impact on response times. All penetrated LFs are covered with this method and each receives equal weight. The same AFIT theses mentioned for the p-median problem also used the p-center problem formulation.

Merrill, as in his p-median formulation, also used a weighting factor in his p-center formulation. He used the same distance matrix developed for the p-median problem and identified the center as the minimum distance of all column maximums. (Merrill, 1989) No weighting factor is applied to the p-center problem in this research. Merrill found that his p-center solution was very sensitive to changes in the number of visits to particular locations, especially distant overseas locations. More frequent visits to Europe drove his p-center solution towards the eastern United States, while more frequent visits to Japan drove the solution towards the western United States. (Merrill, 1989) This is logical because of the weighting factor he used and the objective of the p-

center problem, which is to minimize the maximum distance between a facility and a demand node.

Eberlan utilized a classic vertex p-center model identical to the one utilized in this research. The objective of minimizing response times is the same as that of this research. Again, due to different parameters in the four models utilized, he arrived at different conclusions for each model. The different iterations within each model, using varied launch times and air speeds, produced the same results. This is because the same objective of minimizing the maximum distance was prevalent. (Eberlan, 2004)

Heuristics

Heuristics are generic "rules of thumb" employed in decision making. They allow for quick decisions when a "good" solution is adequate to satisfy the needs of the decision maker. The use of heuristics *can* result in an optimal solution, but this is normally not the case. One reason to utilize a heuristic is to avoid the extensive amount of time, or expense, as in this research, associated with finding an optimal solution. A good, working definition of a heuristic is provided by Hinkle and Kuehn (1967):

> A heuristic…is a short cut process of reasoning…that searches for a satisfactory, rather than optimal, solution. The heuristic which reduces the time spent in the search for the solution of a problem, comprises a rule or a computational procedure which restricts the number of alternative solutions to a problem, based upon the analogous human trial-and-error process of reaching acceptable solutions to problems for which optimizing algorithms are not available. (Hinkle & Kuehn, 1967)

Many different heuristics are available with varying degrees of accuracy. Accuracy is normally measured by the percentage deviation from the optimal solution,

when it is known. The performance of heuristics is a function of the method employed, the problem requiring a solution, and the number of variables and constraints.

GRASP

The Greedy Randomized Search Procedure (GRASP) is an iterative search process initially created by Feo and Resende (1989). A solution to an optimization problem is generated during each iteration and the best of all the solutions is kept as the overall best result. Basically, the procedure is designed to find a localized optimum solution based on pre-established parameters and then check other areas for a better solution. If a better solution is found, it becomes the best solution unless another better solution is found during subsequent iterations. This process continues until the procedure reaches some predefined stopping point.

Resende and Ribeiro (2002) provide an excellent explanation of how GRASP works and describe its basic formulation. These authors describe GRASP as a "multi-start or iterative process" consisting of two phases; a construction phase and a local search phase. The construction phase develops a feasible solution and then the local search phase searches the neighborhood around that solution until a local minimum is found. This result is kept and a greedy function is used to select the next element to incorporate. The greedy function is tied to a cost function. This leads to the development of a restricted candidate list (RCL) consisting of the elements having the best outcome on the cost function. The elements to be drawn into the partial solution are then randomly selected from the RCL. The RCL is then updated and the effect of the incorporated

elements are evaluated. The criterion for stopping is established by specifying a maximum number of iterations to perform. (Resende & Ribeiro, 2002)

Feo and Resende (1989) tested their procedure on six set covering problems. Their results showed that the procedure found the optimal solution in four of the problems and the best known solution to the other two (the ability to generate an optimal solution did not exist at that time because of the size of the problems). (Feo & Resende, 1989) As with all heuristics, the performance of this procedure can vary depending on the problem at hand and the number of variables and constraints involved.

Resende and Werneck (2002) tested a variation of GRASP, know as GRASP with path-relinking, on the p-median problem. In their study, they were able to show that their method obtained solutions within 0.2 percent of the best know solutions in all testing cases. Their study compared their results to other heuristics, including the normal GRASP procedure. This comparison showed that normal GRASP performs very well with the p-median problem. One class of p-median problems they tested, known as ORLIB (acronym for OR-Library), shows that normal GRASP does not deviate at all from the optimal solution in 39 of 40 cases with n ranging from 100 to 900 and p ranging from 5 to 200. The one deviation occurred with n equal to 900 and p equal to 90. This produced only a 0.02 percent deviation from the optimal solution. (Resende & Werneck, 2002)

Other Considerations

Daskin acknowledges that location selection does not occur in a vacuum without considering other influences. The following excerpt addresses the problem faced in this

research and the ever-present issue of funding: “The number of facilities to be located as well as the size of the individual facilities is often a function of the service/cost tradeoffs. In many cases, the quality of service improves as the number of facilities located increases, but the cost of providing the service also increases.” (Daskin, 1995) Although security forces Fire Teams are not facilities, they will be located statically each day for response purposes. This allows facility location methodologies to be employed. Although the number of Fire Teams is established by instruction, any attempt to increase their number would obviously result in higher costs for the Air Force.

The selection by decision makers of which methodology to employ will be a crucial factor in balancing conflicting goals. The maximum covering location problem model will allow decision makers to view any lost maintenance while establishing a maximum allowable response time. The selection of the p-median, p-center, or hybrid methodologies provides simultaneous accomplishment of both goals. These methodologies will allow all maintenance to be conducted and provide the optimal, or near optimal, placement of Fire Teams to minimize response times, based on the particular sites that are scheduled daily. However, this optimal, or near optimal, response time may be greater than the decision makers are willing to accept. Therefore, these models will allow decision makers to remove any sites they wish from the schedule and recalculate the deployment of Fire Teams and their response times.

Summary

This chapter described some of the aspects of DoD and Air Force directives relevant to this research. A penetrated site was defined and the current method of

deploying Fire Teams at F. E. Warren AFB was outlined. Previous attempts to improve security for the weapon system were detailed. A brief history of location analysis was presented with specific focus on the three methods utilized in this research. Chapter III will describe the methodology employed to solve this problem utilizing the three different methods and show how the models are developed.

III. Methodology

Introduction

This chapter introduces the methods employed to form the basis for analysis in this research. The three location analysis methods utilized and solution techniques employed are described in detail. The mathematical formulation of the three location type models and distance and response time calculations are outlined. The hybrid p-center/p-median model developed utilizes the formulations and methods of these two model types in a sequential manner. The solutions to the constructed models form the basis of the results and analysis presented in Chapter IV.

Problem/Purpose Statement

Current security requirements and maintenance objectives are incompatible. Each strives to satisfy a different objective, which often places them in direct conflict with one another. The purpose of this research is to develop models for decision makers to minimize security forces response times while simultaneously achieving an adequate maintenance schedule.

Theoretical Model

The hypothesis is that the available number of Fire Teams can be positioned using a facility location methodology to ensure minimum response times are achieved. Candidate locations are selected from all existing Minuteman LFs, MAFs, and a set of arbitrary points selected by the researcher within the missile road complex utilizing F. E.

Warren AFB's route folder. This results in 233 candidate locations as staging areas. The arbitrarily selected points are all located at road intersections and are chosen based on their proximity to LFs. The current method of deploying Fire Teams is described in Chapter II of this research. Since there is no established method associated with the current deployment scheme, the four models must be compared to each other for analysis.

Data

The following data was collected from F. E. Warren AFB for calendar year 2003, except Daily LF maintenance performed, which was collected for January through May of 2004:

- Security forces response times matrices from Missile Alert Facilities (MAFs) to LFs
- Daily Status Sheets from January through May of 2004
- Periodic maintenance due dates
- Daily security escort availability and number requested by maintenance
- Daily off-alert sorties and location
- Daily Priority 1 maintenance occurrences
- Daily LF maintenance performed
- Off-alert hours per sortie by date

Not all of this data is required for this research, but may be useful in furthering the findings of this research. All data reflects historical records maintained at F. E. Warren AFB and was obtained from Twentieth Air Force. (Overholts, 2004) Some data was missing on security escort availability and number requested by maintenance, mostly

weekend and holiday data. Priority one maintenance occurrences were received only as a total number for the year and the number that required LF penetration. Daily LF maintenance was determined from the Daily Status Sheets maintained at the wing for January through May of 2004. Off-alert hours were taken from data stored in the Improved Maintenance Management Program (IMMP).

Data on LF and MAF latitude/longitude coordinates is collected from a public website (http://w3.uwyo.edu/~jimkirk/warren-mm.html). Coordinates for the arbitrarily selected staging areas are obtained by using the free trial version of *AccuGlobe®*, found at website http://www.ddti.net/accuglobe_info.asp. Road overlays for Colorado, Nebraska, and Wyoming are obtained at http://arcdata.esri.com/data/tiger2000/tiger_download.cfm. Latitude/longitude coordinates of the arbitrarily selected staging areas are obtained by plotting the staging areas on these maps and viewing the displayed coordinates.

Data Analysis

Major Jack Seaberg from the 790 MSFS at F. E. Warren AFB confirmed the coordinates for each LF and MAF to be accurate. These coordinates are presented in degrees, minutes, and seconds format. To be incorporated into the models, the coordinates are converted to decimal degrees. This is accomplished by dividing the stated minutes by 60 and the stated seconds by 3600. This number is then added to the respective number of degrees. The coordinates for the arbitrarily selected staging areas are determined using AccuGlobe®, which reports coordinates to the third decimal point.

This data is then used to build a distance matrix detailing the mileage between each LF, MAF, and staging area.

The incorporation of actual penetrated sites into the models is achieved by reviewing the Daily Status Sheets provided. This data is subject to interpretation because, in many cases, several Daily Status Sheets were developed during the course of a single day. When in question, the tendency in this research is to incorporate the highest number of LFs that may have been penetrated. This method is employed to account for unplanned diversion of teams to penetrate sites that are not documented on the Daily Status Sheets. These diversions occur regularly in real world scenarios. This is inconsequential to the performance of the models since even randomly generated LFs would serve as a basis for comparing the performance of the models. All Fridays, Saturdays, and Sundays are excluded due to the normally low workload attempted during these days. Although Peacekeeper maintenance was still ongoing during the data collection period, those penetrated LFs are not incorporated as penetrated sites nor are any allowances made to allocate Fire Teams to Peacekeeper LFs incurring major maintenance activities. This produces 53 useable data points (days) for analysis.

Data on the number of Fire Teams available during the data collection period is unavailable. The number of Fire Teams input into the models for comparison purposes is based on the requirements stipulated in AFSPCI 31-1101, unless there were open-holes. LFs with open holes are not input into the models and the number of Fire Teams available is adjusted down one for each open-hole LF. This is based on the practice of assigning responsibility for an open-hole LF to a Fire Team and no other penetrated LFs are assigned to that Fire Team. These LFs are not included as penetrated LFs requiring

coverage in the models, as they are considered covered by a single Fire Team and that Fire Team is able to cover only that LF.

Since there currently is no structured method of deploying Fire Teams at F. E. Warren AFB and no historical account of how the Fire Teams were deployed within the data collection period, each model is compared to the others based on Fire Team utilization, average response time, average total distance, average maximum distance any Fire Team is located from a penetrated LF, and number of scheduled LFs not covered by a Fire Team. The number of Fire Teams required is developed as a user input to the models. This allows for adjustment when Fire Teams are dedicated to cover an open-hole LF.

Distance Metric Selection

There are three distance metrics commonly used in location analysis. These distance metrics are: 1. Geographic distance (using latitude and longitude); 2. Euclidean or straight-line distance; and 3. Rectilinear or Manhattan distance. (Eberlan, 2004) Also, a routing factor can be used to adjust any of these three measures to more closely approximate real world routing distances. The missile complex road network consists mainly of gravel roads and some interstate and state highway systems; therefore, the network is not a normal urban network and the rectilinear distance option is eliminated for this study. Routing factor weighting is also not used in this research. Instead, the geographic distance metric is selected over the Euclidean distance metric because of the availability of the latitude and longitude coordinates of F. E. Warren AFB's Minuteman missile sites and the desire for accuracy and ease of use of the computed latitude-

longitude distances. Specifically, the geographic metric takes into account the curvature of the earth using great circles while the Euclidean distance metric is exclusively a straight-line measure. (Eberlan, 2004) Therefore, this selection provides a compromise between Euclidean and rectilinear distance selection. Once the coordinates are obtained, distance matrices between all LFs, MAFs, and staging areas are developed. Using actual route distances would improve the accuracy of this research but these are not used due to unavailability and to minimize the complexity of the problem.

Calculation of Geographic Distances

The following excerpt is from Eberlan (2004) and explains how geographic distances are calculated in the research:

> The calculation of geographic distances between candidate staging areas and LFs of interest are done by using the Haversine method. The Haversine method allows the calculation of distances between two locations on the earth's surface. This method compensates for the curvature of the earth through the use of great circles. The equations for calculating distance using the Haversine Method as described by Bell and McMullen (2003) are:
>
> $$Dist_{ij} = r * (2\tan^{-1}(\sqrt{b}, \sqrt{1-b})) \quad (20)$$
>
> $$b = \left[\sin\left(\frac{(\varphi_j - \varphi_i)}{2}\right)\right]^2 + \cos(\varphi_i) * \cos(\varphi_j) * \left[\sin\left(\frac{(\gamma_j - \gamma_i}{2}\right)\right]^2 \quad (21)$$
>
> where
>
> $Dist_{ij}$ = Distance between LF of interest *i* and candidate staging area *j*
>
> r = Radius of the earth, equal to approximately 3437.67 nautical miles
>
> φ = Latitude of a candidate alert site or area of interest
>
> γ = Longitude of a candidate alert site or area of interest
>
> "The radius of the earth is entered in nautical miles. Distance calculations were accomplished for each possible candidate staging area and LF of interest combination through the use of a C++ code developed

by Bell and McMullen (2003)." In order to use the code, the degree-minute-second latitude and longitude coordinates for each candidate staging area and each LF of interest had to be converted to decimal form and entered. This conversion was accomplished by using the following widely known formula:

$$DD = d + \frac{m}{60} + \frac{s}{3600} \quad (22)$$

where

DD = Decimal degrees
d = Degrees
m = Minutes
s = Seconds. (Eberlan, 2004)

This code returns distances in meters, therefore, the values are divided by 1609.334 to return mileage calculations.

Modeling Approach

These factors (distance and number of Fire Teams available) form the basis for the decision variables within the models. The models were developed with the intent of obtaining optimal, or near optimal, response times based on the type of location model utilized. There is no guarantee that the solution obtained is the only optimal solution or even an optimal solution, in the case of the p-median solution. Due to the structure of the problems, multiple optimal solutions may exist but improvement upon the objective function will not occur, except possibly for the p-median solution which uses a heuristic. Many alternatives are possible for the MCLP problem since the model stops when it has found a solution that covers all penetrated LFs within the given distance limitation. This means that the minimum response time is not an objective of this type of model.

The first step in the modeling process is to develop a distance matrix for candidate staging areas and possible penetrated LFs. This is performed by computing great circle

distances between each LF and potential staging area. Great circle distance calculations are incorporated in the model by utilizing an Excel® macro developed by Eberlan and Weir. (Eberlan, 2004) This distance was originally calculated in meters, so it is adjusted by dividing the returned value by 1609.334 to arrive at a mileage calculation. Although it is a great circle/straight line distance, it can be assumed a reasonable estimate of actual distances. The use of rectilinear distance could be more representative, but may also produce an error rate as high as forty-one percent. (Haithcoat, undated) As discussed previously, routing factors or actual network road distances could also improve the accuracy, but they were not used in this research in order to limit the complexity of the models. The final distance calculations are converted to a response time in minutes by multiplying the distance by a factor of 60/40, to represent forty miles per hour average driving speeds.

In order to allow decision makers to balance possible trade-offs between completing maintenance objectives and minimizing response times, four different types of models were developed and used in this study. These models make use of three different location methodologies: the Maximal Covering Location Problem (MCLP) methodology, the p-median problem methodology, and the p-center problem methodology. In addition, each model allows the user to specify a solution that evaluates all staging areas or one that utilizes only MAFs as staging areas. This produces eight distinct models. A MAF location may be preferable to management at certain times because of the support facilities available. Finally, the user is given the option of comparing all of the aforementioned solutions based on average response time, average total distance, maximum distance any Fire Team is located from a penetrated LF, number

of Fire Teams used, and number of scheduled LFs not covered. The general characteristics and attributes of each methodology are described in Chapter II.

In developing the models, scaled-down versions of the models were first developed utilizing the data from sites A-1 through E-11 and all arbitrarily selected staging areas. This was done to ensure the models operate properly without obtaining an enhanced version of Solver™, which allows for more variables. The MCLP model was developed first and the other models were derived from it. All models incorporate Visual Basic® programming for ease of use. This allows the user to simply press a button to find the solution for Fire Team placement. Random sites were then input into these models as scheduled sites to verify that all Excel® calculations performed properly. The Solver™ add-in to Excel® is used to arrive at optimal or near optimal solutions for the placement of Fire Teams.

Next, full versions of the models were developed utilizing the data from all Minuteman LFs, MAFs, and the arbitrarily selected staging areas. Again, random sites were input into these models as scheduled sites to verify that all Excel® calculations perform properly. The Solver™ add-in to Excel® is again used to obtain the best solutions for placement of Fire Teams. It is at this point that it becomes obvious the p-median problem is too large to solve to optimality with only Solver™. Theorizing that the models may actually be employed in the field, and wanting to avoid burdening units with additional costs to procure enhanced Solver™ versions, the decision was made to employ a heuristic to help solve the p-median problem. The heuristic GRASP is used in this research to arrive at an acceptable solution. The limitations of heuristics are explained in Chapter II. It was also apparent that, since each location methodology seeks

to optimize only one objective, combining two methodologies may prove useful. The p-center and p-median were chosen for a hybrid model to gain the optimal maximum distance between a Fire Team and a penetrated site first, and then attempt to improve the total distance while still maintaining that maximum distance.

In each model, the average response times are obtained by inputting the actual (subjectively determined by reviewing the Daily Status Sheets) penetrated LFs from the selected days during the period January through May of 2004 at F. E. Warren AFB into each model. A daily response time average is computed for each of these days. After aggregating the averages for each model, an overall average is obtained for each model. The same procedure is performed for the two distance calculations, number of Fire Teams used, and LFs that cannot be covered. A daily total is obtained and then aggregated over the inclusion period. Uncovered LFs can only occur in the Maximal Covering Location Problem model since the other models require all penetrated LFs to be covered. The number of Fire Teams available is input into the models as previously stipulated. The results display the number of Fire Teams available for the given day and the number actually used in the solution. This is useful information because all available Fire Teams may not be required to meet the objectives of the models, in certain instances. This is especially true when using a MCLP solution since the distance constraint is its main driver and this methodology seeks to use the minimum number of Fire Teams within that distance constraint. In order to show the relevant decision making factors, the option to compare all solutions is selected within the models. This outputs the average response time, the average total distance, the maximum distance any Fire Team is located from a penetrated LF, the number of Fire Teams used, and number of scheduled LFs not

covered for each type of model, including all staging areas and MAF only staging areas solutions.

Because the normal propensity is to try to position Fire Teams at MAFs for convenience, comfort, and simplicity reasons, models for MAF only solutions are also developed for the four location problems used in this research. The same procedures for obtaining average response times, distances, Fire Team utilization, and tabulating LFs that cannot be covered are incorporated. These models are then compared to their corresponding type of location problem models incorporating all potential staging areas to ascertain the degradation, if any, realized considering factors other than response times. Additionally, this can form the basis to compare the methods utilized in this research with the "umbrella concept" which is to, presumably, be employed by all the missile wings. The performance of these models forms the basis for the recommendations and conclusions in Chapter V.

Mathematical Formulation of the Maximum Covering Location Problem

The purpose of the maximum covering problem is to maximize the number of covered demands (scheduled penetrated LFs) with a given number of facilities (Fire Teams) to be located. An additional constraint is added to prevent the maximum response time from exceeding 30 minutes, for purposes of this research. This is done by placing a distance constraint of twenty miles, which translates to a thirty-minute response time, assuming forty miles per hour driving speeds. The developed models allow the user to adjust this time by inputting a maximum acceptable distance. The problem is then to cover the maximum amount of scheduled penetrated LFs while not exceeding the number

of Fire Teams available or the specified response time. Church and ReVelle (1974) originally formulated this model, but the method used in this research is from Daskin (1995). The formulation presented by Daskin includes a multiplicative weighting factor for the amount of demand at each demand node. All demand is assumed to be equal in this model, therefore, no weighting factor is used. The distance metric used and computation of the critical distance was previously discussed in this chapter. The problem is structured as an integer programming problem. All facility costs are assumed to be identical in this formulation and are not included in the objective function. The notation used is stated as:

Z_i = number of covered penetrated LFs

P = Number of Fire Teams available

i = the index of scheduled penetrated LFs or nodes;

j = the index of candidate staging areas or nodes;

a_{ij} = 0, 1. This is a binary coefficient which takes a value of 1 if a Fire Team at candidate staging area j can cover the demand at penetrated LF i, 0 if it cannot;

d_{ij} = the distance between points or nodes i and j;

X_j = 0, 1. It is 1 if a Fire Team is located at candidate staging area j, and 0 otherwise.

The maximum covering formulation used in this research is as follows:

MAXIMIZE $\sum_j Zi$ (1)

SUBJECT TO: $Z_i - \sum_j a_{ij} X_j \leq 0 \quad \forall i$ (2)

$$\sum_j X_j \le P \qquad (3)$$

$$X_j \in \{0,1\} \quad \forall j \qquad (4)$$

$$Z_i \in \{0,1\} \quad \forall i \qquad (5)$$

$$a_{ij} = \begin{cases} 1 \text{ if } d_{ij} \le 20 \\ 0 \text{ otherwise} \end{cases}, \text{ where } d_{ij} \text{ is distance in miles from } i \text{ to } j \qquad (6)$$

The objective function (1) maximizes the number of covered demands (scheduled penetrated LFs). Constraint (2) states that penetrated LF, *i*, cannot be covered unless at least one of the candidate staging areas, *j*, that cover LF *i* is selected and a Fire Team placed there. Constraint (3) states that no more than P Fire Teams can be located. Constraints (4) and (5) are the integrality constraints on the decision variables. Constraint (6) limits the maximum distance a Fire Team can be located from a LF to be covered to 20 miles

Now that the mathematical formulation for the maximum covering location problem is determined, the p-median problem utilized in this research is formulated with the goal of minimizing response times to an acceptable level while covering all penetrated LFs.

Mathematical Formulation of the p-Median Problem

The formulation of Daskin (1995) with four minor adjustments is utilized in this research. The first adjustment removes the demand weight multiplier from the objective function, because the demand in this model is assumed equal. The second adjustment allows for more than one Fire Team to be capable of covering a particular LF of interest. The third adjustment allows fewer than the available number of Fire Teams to be utilized. This is necessary when the number of available Fire Teams exceeds the number of

scheduled sites or when deploying additional Fire Teams will not improve upon the objective function. The final adjustment allows each penetrated LF to be assigned to more than one Fire Team. This is feasible because, theoretically, Fire Teams may be placed in close enough proximity to one another to allow for an overlap of coverage. That is, one Fire Team could respond to a LF within another Fire Team's assigned coverage area should that team be responding at another LF. The formulation is as follows:

$$\text{MINIMIZE} \qquad \sum_i \sum_j d_{ij} Y_{ij} \qquad (7)$$

SUBJECT TO:

$$\sum_j Y_{ij} = 1 \qquad \forall i \qquad (8)$$

$$\sum_j X_j \le P \qquad (9)$$

$$Y_{ij} - X_j \le 0 \qquad \forall i, j \qquad (10)$$

$$X_j \in \{0,1\} \qquad \forall j \qquad (11)$$

$$Y_{ij} \in \{0,1\} \qquad \forall i, j \qquad (12)$$

where

X_j = 1 if we locate a Fire Team at candidate staging area j, 0 otherwise

Y_{ij} = 1 if penetrated LF i is served by candidate staging area j, 0 otherwise

d_{ij} = the distance between points or nodes i and j

P = number of Fire Teams to be located.

The objective function (7) minimizes aggregate travel distance, thus minimizing response times, between all penetrated LFs and selected staging areas where Fire Teams are placed. Constraint (8) requires that at least one Fire Team cover each penetrated LF. Constraint (9) states that no more than P Fire Teams are to be located. Constraint (10)

links the location variables (X_j) and the allocation variables (Y_{ij}). Constraints (11) and (12) are integrality constraints.

The GRASP heuristic is used to generate solutions for the p-median problem. The heuristic begins by checking all possible combinations of scheduled LFs as potential staging areas and also searches the areas around those points. The best solution found, which has the minimum total distance, is kept. The randomized portion of the heuristic is then performed, evaluating the neighborhoods around 100 randomly chosen points and comparing the solutions to the best original solution. If a better solution is found, it is kept as the very best solution. The solution identifies the locations of the staging areas, the allocations of penetrated LFs to the staging areas, and the overall response distance/time. This model assumes that all Fire Teams are available. Next, the mathematical formulation of the p-center problem is developed so that the worst-case scenario can be determined.

Mathematical Formulation of the p-Center Problem

The objective of the p-center model is to minimize the maximum response time or distance between a Fire Team placed at a staging area and a penetrated LF. As discussed in Chapter II, there are two different formulations of the p-center problem: the vertex p-center problem and the absolute p-center problem. The vertex p-center formulation will be used in this model because staging areas can only be located on the candidate staging area nodes and not on the arcs (anywhere along the routes), as in the absolute p-center problem. The formulation used in this research is from Daskin (1995) with minor adjustments. As in the previous modeling techniques used in this chapter, this modeling

formulation again removes the demand-weighted multiplier. The same adjustments pertaining to Fire Teams made in the p-median formulation are included in this model. The formulation is as follows:

$$\text{MINIMIZE} \quad W \tag{13}$$

$$\text{SUBJECT TO:} \quad \sum_j Y_{ij} = 1 \qquad \forall i \tag{14}$$

$$\sum_j X_j \le P \tag{15}$$

$$Y_{ij} - X_j \le 0 \qquad \forall i, j \tag{16}$$

$$\sum_j d_{ij} Y_{ij} \le W \qquad \forall i \tag{17}$$

$$X_j \in \{0,1\} \qquad \forall j \tag{18}$$

$$Y_{ij} \in \{0,1\} \qquad \forall i, j \tag{19}$$

where

W = maximum distance between a penetrated LF and its assigned Fire Team

Y_{ij} = 1 if penetrated LF i is assigned to candidate staging area j, 0 otherwise

X_j = 1 if we locate a Fire Team at candidate staging area j, 0 otherwise

P = number of Fire Teams to locate

d_{ij} = the distance between points or nodes i and j

The objective function (13) minimizes the maximum distance that any penetrated LF is from a deployed Fire Team. Constraint (14) requires that each penetrated LF be assigned to at least one Fire Team. Constraint (15) stipulates that no more than P Fire Teams are to be located. Constraint (16) states that a penetrated LF, i, cannot be assigned to a candidate staging area, j, unless a Fire Team is located at staging area j. Constraint (17) states that the maximum distance between a penetrated LF and a Fire Team must be greater than or equal to the distance between any penetrated LF, i, and the Fire Team at

staging area, *j*, to which it is assigned. Constraints (18) and (19) are the integrality and non-negativity constraints, respectively.

This model is solved to optimality by using the Bisection method to achieve the lowest maximum distance any Fire Team is located from a penetrated LF. Because the maximum distance between any two points in the distance matrix is 93.29 miles, the method begins with a maximum value of forty-seven and a minimum value of zero. The maximum and minimum values are bisected until the lowest distance that covers all scheduled penetrated LFs, within one-tenth of a mile, is found. The Bisection method can be slow to converge to the optimal solution, but is guaranteed to obtain the optimal solution within the specified accuracy. (Faires & Burden, 1993) Once all assumptions are made and incorporated into the models, distance metric selection and distance calculations are accomplished so that the spreadsheet models can be constructed and solved.

Hybrid Formulation

The hybrid model utilizes the p-center and p-median formulations previously described. No adjustments are required. This is the only model formulation that seeks to improve multiple objectives, but only the objective of minimizing the maximum distance between a penetrated LF and its assigned Fire Team can be solved to optimality. Again, the Bisection method is used to solve the p-center portion and then, sequentially after the p-center solution, the GRASP heuristic is employed to minimize the total distance within the p-center solution maximum distance constraint.

Summary

This chapter discussed the methods employed to calculate distance measurements in the utilized models. The mathematical formulation of each model was presented and the nature of the basis for model comparison was discussed. Chapter IV will present the results of the model comparisons, total Fire Team usage percentage, total average response times, average total distance, and average maximum distance any Fire Team is located from a penetrated LF. The number of cancelled scheduled LFs that exceeded the distance constraint for the maximal covering location problem model will also be presented.

IV. Analysis

Introduction

This chapter addresses the results obtained when inputting the available data on actual penetrated LFs at F. E. Warren AFB from January through May of 2004. Overall averages for the entire data set are aggregated and analyzed. This analysis is performed on the number of Fire Teams available versus the number used and the percentage used, average response times, average total distance, and the average maximum distance any Fire Team is positioned from a penetrated LF. The maximal covering location problem (MCLP) model results also include the number of LFs, if any, that cannot be covered within the response time constraint. The analysis is performed within and across all four model types, MCLP, p-median, p-center, and hybrid, and comparison is also performed between solutions for all staging areas and MAF only staging areas. Sensitivity analysis is performed by changing input parameters for the number of available Fire Teams and the response time constraint. Daily calculations for these parameters are attached as Appendix B through Appendix S.

Analysis Preparation

Initial analysis was conducted utilizing the scaled down version of the models with randomly selected LFs as inputs for scheduled sites. This often produced short response times since the sites incorporated are fairly close, geographically, and all arbitrarily selected staging areas were included. Analysis was then conducted with the full-scale version of the models. The randomly selected sites were augmented by arbitrarily selecting widely dispersed sites to ascertain how each model performs when

maintenance may be occurring throughout the missile complex. Finally, the actual penetrated sites data obtained from F.E. Warren AFB was input to allow comparison of average response times, percentage of total Fire Teams used, average total distance, average maximum distance of any Fire Team to a penetrated LF, and view any LFs that cannot be covered utilizing the maximum covering location problem model.

Initial Observations

Initial review of the results shows that twelve of the days input produce a response time of zero in the p-median, p-center, and hybrid models for the all staging areas solution of the original data set. This is due to the fact that these particular days incorporate a number of scheduled penetrated LFs that is less than or equal to the number of Fire Teams available. The obvious optimal solution, therefore, is to position the Fire Teams at the scheduled penetrated LFs, producing zero response times. The MCLP model, because of its formulation, does not achieve the same results. This model uses a different positioning scheme that produces positive response times. In order to avoid any potential bias of the results, analysis is performed on the full data set and then on a reduced data set created by removing the zero response time days from all models. The reduced data set comparisons have twelve fewer data points for the all staging areas solution versus the MAF only staging areas solution because no zero response times occur, or are possible, in the MAF only staging area solutions. Therefore, all parameters in the MAF only staging areas solution remain the same in the reduced data set as they were in the original data set. The full data set, containing the zero response time days, is

still useful for comparison within each model. This data set has the potential to better display the trade-offs required to achieve a MAF only staging areas solution.

Analysis Method

This analysis first compares the results obtained within each model type to delineate any differences between all staging areas solutions and MAF only staging areas solutions. Minimum and maximum values are shown for the within model comparisons, but the basis for comparing all staging areas solutions and MAF only staging areas solutions, as well as comparing each model to the other, is parameter averages over the entire data set. These maximum and minimum values are highly dependent upon the ratio of available Fire Teams to the number of scheduled penetrated LFs and the dispersion of those LFs. These dependencies render any statistical analysis useless for practical purposes. Percentage differences identified are based on the difference from the all staging areas solution to the MAF only staging areas solution. Differences in the number of scheduled penetrated sites not covered by the MCLP model solution types are reported as numerical differences.

Comparison of each model type to the other is then performed, first with the all staging areas solutions, then the MAF only staging areas solutions. Percentage differences identified are the deviation from the result that better fulfills the objective in the comparison. Results from the full data set are first presented, followed by the results obtained for the reduced data set with the zero response time days removed. The aggregate number of available Fire Teams for all models in the original full data set is

232 and 179 Fire Teams are available for the all staging areas solution in all models of the original reduced data set.

MCLP Model, Original Full Data Set

The all staging areas solution shows that 66.38% of the available Fire Teams, 154 of 232, are used. The MAF only staging areas solution requires 77.59% of the available Fire Teams, 11.21% more than is required for the all staging areas solution. All scheduled penetrated LFs are covered in the all staging areas solution, but the MAF only staging areas solution leaves three scheduled penetrated LFs uncovered, a difference of three. The all staging areas solution produces an average response time of 20.73 minutes, a maximum average of 26.14 minutes, and a minimum average of 14.57 minutes. The MAF only staging areas solution has a maximum average response time of 21.18 minutes, a minimum average of 10.78 minutes, and an overall average response time of 16.37 minutes. The MAF only staging areas solution, therefore, represents a 21.03% improvement over the all staging areas solution in average response time.

The average total distance for covering all scheduled penetrated LFs in the all staging areas solution is 96.88 miles, with a maximum total distance of 202.91 miles and a minimum total distance of 29.92 miles. The MAF only staging areas solution of 78.30 miles shows a 19.18% improvement over the all staging areas solution. The maximum value is 178.15 miles and the minimum is 15.79 miles. The average maximum distance that any Fire Team is located from a penetrated LF is 18.54 miles in the all staging areas solution and 16.81 miles in the MAF only staging areas solution, a 9.33% improvement over the all staging areas solution. The all staging areas solution has a maximum value of

19.96 miles and a minimum of 15.92 miles, while the MAF only staging areas solution produces a maximum value of 19.91 miles and a minimum of 8.07 miles.

p-median Model, Original Full Data Set

This model uses 97.84% of the available Fire Teams in both the all staging areas and MAF only staging areas solutions. The average response times are 4.92 minutes for the all staging areas solution and more than double that for the MAF only staging areas solution, which produces an average response time of 12.38 minutes. The MAF only staging areas solution represents a 151.63% increase from the objective function versus the all staging areas solution. Maximum values are 13.80 minutes in the all staging areas solution and 16.28 minutes in the MAF only staging areas solution. The all staging areas solution has a minimum value of zero minutes, while the MAF only staging areas minimum time is 9.43 minutes.

A similar percentage difference, 107.87%, arises when comparing the average total distance between the two solution types. The all staging areas solution produces an average total distance of 28.83 miles, with a maximum total distance of 126.96 miles and a minimum total distance of zero. The MAF only staging areas solution results in an average distance of 59.93 miles, a maximum distance of 151.93 miles, and a minimum distance of 15.79 miles. The difference in the average maximum distance any Fire Team is located from a penetrated LF is less dramatic with 10.95 miles for the all staging areas solution and 12.98 miles in the MAF only solution, which is an 18.54% increase compared to the all staging areas solution. The all staging areas solution has values of

28.66 miles for the maximum distance and zero for the minimum distance. The MAF only staging areas maximum is 25.34 miles and the minimum is 8.07 miles.

p-center Model, Original Full Data Set

The p-center model solution uses 97.84% of the available Fire Teams in the all staging areas solution and 90.52% in the MAF only staging areas solution, an improvement of 7.32%. The average response time for the all staging areas solution is 7.73 minutes and 13.44 minutes for the MAF only staging areas solution. Therefore, the MAF only staging areas solution average response time is 73.87% longer than the all staging areas solution. The maximum values are 19.65 minutes in the all staging areas solution and 24.73 minutes in the MAF only staging areas solution. The all staging areas solution has a minimum time of zero and the MAF only staging areas minimum average response time is 9.43 minutes.

The all staging areas solution provides an average total distance of 43.94 miles and the MAF only staging areas solution reports a distance of 66.55 miles, a 51.46% increase. The all staging areas solution has a maximum of 157.87 miles and a minimum of zero. The MAF only staging areas distances are 214.31 as a maximum and 15.79 as the minimum. The average maximum distance that any Fire Team is located from a penetrated LF is 71.64% higher in the MAF only staging areas solution than in the all staging areas solution, with 12.53 miles versus 7.30 miles. The maximum distance is 18.15 miles in the all staging areas solution, with a minimum of zero. The MAF only staging areas solution shows a maximum distance of 22.88 miles and a minimum of 8.07 miles.

Hybrid Model, Original Full Data Set

The hybrid model, as it should, reports the same average maximum distance any Fire Team is located from a penetrated LF and same percentage difference as the p-center model. The maximum and minimum values for this parameter in both solution types also remain the same as the p-center solution. Fire Team usage is at 97.84% in both the all staging areas solution and the MAF only staging areas solution. The average response time in the all staging areas solution is 5.76 minutes, with a maximum average of 15.84 minutes and a minimum average of zero. The MAF only staging areas solution has an average response time of 12.71 minutes, with maximum and minimum values of 20.66 and 9.43 minutes. The MAF only solution has an average response time 120.66% greater than the all staging areas solution.

The all staging areas solution provides an average total distance of 33.75 miles, with a maximum value of 147.88 miles and a minimum of zero. The MAF only staging areas distance is 84.62% greater at 62.31 miles. The maximum value in this solution is 179.04 miles and the minimum is 15.79 miles. A comparison of the two types of solutions, all staging areas and MAF only staging areas, for each of the four model types in shown in Table 1 below.

Table 1. Original Full Data Set

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	66.38%	20.73 mins.	96.88 miles	18.54 miles	None
p-median	97.84%	4.92 mins.	28.83 miles	10.95 miles	None
p-center	97.84%	7.73 mins.	43.94 miles	7.30 miles	None
Hybrid	97.84%	5.76 mins.	33.75 miles	7.30 miles	None
	MAF Only Staging Areas				
MCLP	77.59%	16.37 mins.	78.30 miles	16.81 miles	3
p-median	97.84%	12.38 mins.	59.93 miles	12.98 miles	None
p-center	90.52%	13.44 mins.	66.55 miles	12.53 miles	None
Hybrid	97.84%	12.71 mins.	62.31 miles	12.53 miles	None
	Percentage Change of MAF Only Solution				
MCLP	11.21%	-21.03%	-19.18%	-9.33%	3
p-median	--	151.63%	107.87%	18.54%	N/A
p-center	-7.32%	73.87%	51.46%	71.64%	N/A
Hybrid	--	120.66%	84.62%	71.64%	N/A

Four Model Comparison, Original Full Data Set

The comparison of the four types of models is based on percentage of available Fire Teams used, average response time, average total distance, average maximum distance any Fire Team is located from a penetrated LF, and number of scheduled penetrated LFs uncovered. The MCLP model produces the lowest percentage usage of available Fire Teams in the all staging areas solution with 66.38% usage, compared to 97.84% for the p-median, p-center, and hybrid models, an improvement of 31.46% over all three models. The MCLP model also performs better in this comparison in the MAF only staging areas solution, utilizing 77.59% of the available Fire Teams versus 97.84% in the p-median and hybrid model solutions and 90.52% in the p-center model solution. The MCLP utilizes 20.25% fewer Fire Teams than the p-median and hybrid models and 12.93% fewer than the p-center model. The p-center solution then utilizes 7.32% fewer Fire Teams than the p-median and hybrid solutions. The all staging areas solution for the MCLP model has no uncovered LFs but three are uncovered in the MAF only staging

areas solution. Because the p-median, p-center, and hybrid models are formulated to cover all scheduled penetrated LFs, the MAF only staging areas solution of the MCLP model represents an increase of three uncovered LFs over the other models.

The p-median model produces the lowest average response time in both the all staging areas and the MAF only staging areas solutions with 4.92 minutes and 12.38 minutes respectively. The hybrid model closely follows with an average response time of 5.76 minutes in the all staging areas solution and 12.71 minutes in the MAF only staging areas solution. These hybrid model times are 17.07% greater than the p-median times in the all staging areas solution and only 2.67% greater in the MAF only staging areas solution. The p-center model has an average response time of 7.73 minutes for the all staging areas solution and 13.44 minutes for the MAF only staging areas solution. The p-center model times are 57.11% higher than the p-median in the all staging areas solution and 8.56% higher in the MAF only staging areas solution. The average response time in the all staging areas solution of the p-center model is 34.20% greater than the hybrid model solution and 5.74% greater in the MAF only staging areas solution. The MCLP model produces the highest average response times with 20.73 minutes in the all staging areas solution and 16.37 minutes in the MAF only staging areas solution. The all staging areas solution for the MCLP model is 321.34% higher than the p-median solution, 259.90% above the hybrid solution, and 168.18% higher than the p-center solution. The difference in the MAF only staging areas solution for the MCLP model is not nearly as daunting, being 32.23% higher than the p-median solution, 28.80% longer than the hybrid solution, and 21.80% higher than the p-center solution.

The p-median model also produces the lowest average total distance for both staging area solution types. This appropriately fulfills the objective of this type of model. The average total distance in the all staging areas solution is 28.83 miles and 59.93 miles in the MAF only staging areas solution. The hybrid distance in the all staging areas solution is 17.07% greater with 33.75 miles and only 3.97% greater in the MAF only staging areas solution at 62.31 miles. The p-center model distance of 43.94 miles for the all staging areas solution is 52.41% greater than the p-median model and 11.05% greater for the MAF only staging areas solution at 66.55 miles. These p-center solution distances are 30.19% longer than the hybrid distance in the all staging areas solution and 6.80% longer in the MAF only staging areas solution. The MCLP model again performs poorly in this category with 96.88 miles for the all staging areas solution and 78.30 miles for the MAF only staging areas solution. The all staging areas solution is 236.04% greater than the p-median model solution, 187.05% more than the hybrid model solution, and 120.48% greater than the p-center model solution. The MAF only staging areas solution for the MCLP compares much better while being 30.65% greater than the p-median model solution, 25.66% over the hybrid model solution, and 17.66% greater than the p-center model solution.

The p-center model, as should be the case with its stated objective, conveys the lowest average maximum distance any Fire Team is located from a penetrated LF. The hybrid model, employing the same initial objective, has the same results for this parameter. The all staging areas solution produces an average maximum distance of 7.30 miles. The p-median model solution of 10.95 miles is 43.84% greater and the MCLP model solution of 18.54 miles is 153.97% higher. The MCLP model solution is also

69.32% greater than the p-median model solution. The MAF only staging areas solutions in the p-center and hybrid models provide an average maximum distance of 12.53 miles. The p-median model solution distance is only slightly higher at 12.98 miles, a difference of 3.59%. The MCLP model is 34.16% greater than the p-center and hybrid model solutions and 29.97% greater than the p-median model solution with 16.81 miles. A summary of these results appears in Table 2 below.

Table 2. Four Model Comparison, Original Data Set

	All Staging Areas					MAF Only Staging Areas				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	Max Distance	Uncovered
MCLP	66.38%	20.73 mins.	96.88 miles	18.54 miles	None	77.59%	16.37 mins.	78.30 miles	16.81 miles	3
p-median	97.84%	4.92 mins.	28.83 miles	10.95 miles	None	97.84%	12.38 mins.	59.93 miles	12.98 miles	None
p-center	97.84%	7.73 mins.	43.94 miles	7.30 miles	None	90.52%	13.44 mins.	66.55 miles	12.53 miles	None
Hybrid	97.84%	5.76 mins.	33.75 miles	7.30 miles	None	97.84%	12.71 mins.	62.31 miles	12.53 miles	None
	Percentage of Improvement					Percentage of Improvement				
MCLP vs. p-median	31.46%	-321.34%	-236.04%	-69.32%	N/A	20.25%	-32.23%	-30.65%	-29.97%	-3
MCLP vs. p-center	31.46%	-168.18%	-120.48%	-153.97%	N/A	12.93%	-21.80%	-17.66%	-34.16%	-3
MCLP vs. Hybrid	31.46%	-259.90%	-187.05%	-69.32%	N/A	20.25%	-28.80%	-25.66%	-34.16%	-3
p-median vs. p-center	--	57.11%	52.41%	-43.84%	N/A	-7.32%	8.56%	11.05%	-3.59%	N/A
p-median vs. Hybrid	--	17.07%	17.07%	-43.84%	N/A	--	2.67%	3.97%	-3.59%	N/A
p-center vs. Hybrid	--	-34.20%	-30.19%	N/A	N/A	-7.32%	-5.74%	-6.80%	N/A	N/A

MCLP Model, Original Reduced Data Set

The same parameters compared in the full data set appear in all model comparisons of the reduced data set analysis. The comparisons between staging area types are still performed, but the all staging areas solution employs twelve fewer data points in all four models due to the removal of the zero response time days. The figures for the MAF only staging areas solutions remain the same as the full data set so only the percentage difference from these values is shown. In this reduced data set, the MCLP utilizes 127 of 179 available Fire Teams, 70.95%, in the all staging areas solution, an

increase of 6.64% over the MAF only staging areas solution. As in the full data set, the all staging area solution has no uncovered LFs, three less than the MAF only staging areas solution. The average response time is 19.64% lower in the MAF only staging areas solution than in the all staging areas solution which produces 20.37 minutes. The maximum average response time in the all staging areas solution is 24.41 minutes and the minimum average response time is 14.57 minutes.

The average total distance in the all staging areas solution is 107.97 miles, with a MAF only staging areas solution 37.89%. The all staging areas solution has a maximum distance of 202.91 miles and a minimum of 59.39 miles. . The average maximum distance any Fire Team is located from a penetrated LF is 18.68 miles for the all staging areas solution. The MAF only staging areas solution represents a decreased distance of 10.01%. A maximum value of 19.96 miles and a minimum value of 16.26 miles exist in the all staging areas solution. Three fewer scheduled penetrated LFs are uncovered in the all staging areas solution of this data set.

p-median Original Model, Reduced Data Set

The p-median model employs all of the available Fire Teams in the all staging areas solution and the MAF only staging areas solution requires 2.16% fewer Fire Teams. This reduced data set again produces a dramatic difference in average response times between the all staging areas solution and the MAF only solution. The MAF only staging areas solution is 94.65% greater than the all staging areas solution of 6.36 minutes. The all staging areas solution reports a maximum average response time of 13.80 minutes and a minimum of 1.16 minutes.

The average total distance is nearly as skewed with the MAF only staging areas distance being 60.80% greater than the all staging areas distance of 37.27 miles. This parameter has a maximum distance of 126.96 miles and a minimum distance of 4.61 miles in the all staging areas solution. The average maximum distance any Fire Team is from a penetrated LF is actually slightly higher in the all staging areas solution than in the MAF only staging areas solution. The MAF only staging areas solution distance is 10.01% lower than the all staging areas distance of 14.16 miles. The maximum in the all staging areas solution is 28.66 miles and the minimum is 4.61 miles.

p-center Model, Original Reduced Data Set

The p-center model utilizes 100% of the available Fire Teams in the all staging areas solution and 9.48% fewer of those available in the MAF only staging areas solution. The average response time is 34.40% greater in the MAF only staging areas solution than in the all staging areas solution. The average response time for the all staging areas solution is 10 minutes. The all staging areas solution conveys a maximum average response time of 19.65 minutes and a minimum of 1.50 minutes.

A difference of 17.17% is seen when comparing the average total distances. The all staging areas solution produces a distance of 56.80 miles. The all staging areas solution has a maximum distance of 157.87 miles and a minimum of 5 miles. The average maximum distance of any Fire Team to a penetrated LF in the MAF only solution is 32.73% greater than the all staging areas solution of 9.44 miles. The maximum distance in the all staging areas solution is 18.15 miles and the minimum is 2.78 miles.

Hybrid Model, Original Reduced Data Set

The all staging areas solution in the hybrid model utilizes all available Fire Teams and the MAF only staging areas solution requires 2.16% fewer. The average response time in the all staging areas solution is 7.45 minutes and the MAF only staging areas solution produces a time 70.60% greater. The all staging areas solution has a maximum average response time of 15.84 minutes and a minimum of 1.50 minutes. The average total distance in the MAF only staging areas solution is 42.81% greater than the all staging areas solution distance of 43.63 miles. The maximum distance in the all staging areas solution is 147.88 miles and the minimum is 5 miles. All values for the average maximum distance any Fire Team is located from a penetrated LF are the same as the p-center model values. A summary of the comparisons between the solutions for all staging areas and MAF only staging areas for each model type is shown below in Table 3.

Table 3. Original Reduced Data Set

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	70.95%	20.37 mins.	107.97 miles	18.68 miles	None
p-median	100.00%	6.36 mins.	37.27 miles	14.16 miles	None
p-center	100.00%	10 mins.	56.80 miles	9.44 miles	None
Hybrid	100.00%	7.45 mins.	43.63 miles	9.44 miles	None
	MAF Only Staging Areas				
MCLP	77.59%	16.37 mins.	78.30 miles	16.81 miles	3
p-median	97.84%	12.38 mins.	59.93 miles	12.98 miles	None
p-center	90.52%	13.44 mins.	66.55 miles	12.53 miles	None
Hybrid	97.84%	12.71 mins.	62.31 miles	12.53 miles	None
	Percentage Change of MAF Only Solution				
MCLP	6.64%	-19.64%	-37.89%	-10.01%	3
p-median	-2.16%	94.65%	60.80%	-8.33%	N/A
p-center	-9.48%	34.40%	17.17%	32.73%	N/A
Hybrid	-2.16%	70.60%	42.81%	32.73%	N/A

Four Model Comparison, Original Reduced Data Set

The MAF only staging areas model type comparison values remain the same as the full data set. Therefore, only the all staging areas model comparisons are portrayed here. As in the full data set, the MCLP model utilizes the lowest percentage of available Fire Teams with 70.95%. This is 29.05% lower than that of the p-median, p-center, and hybrid model solutions, which utilized all available Fire Teams. No scheduled penetrated LFs are left uncovered in the all staging areas solution of the MCLP model. Once again, the p-median model produces the lowest average response time. In the all staging areas solution, the p-median model average response time is 6.36 minutes. The MCLP model arrives at an average response time 220.28% higher with 20.37 minutes. The p-center model solution is 57.23% higher than the p-median at 10 minutes, but this is also an improvement of 103.70% over the MCLP model solution. The hybrid model average response time of 12.71 minutes is 17.17% greater than the p-median time but 173.42% lower than the MCLP model time and 34.23% lower than the p-center model time.

The p-median model again meets its objective in the reduced data set with the lowest average total distance of 37.27 miles. The p-center model solution requires an average total distance 52.40% greater than the p-median solution and 30.19% greater than the hybrid model with 56.80 miles. This p-center solution is 90.09% better than the MCLP model solution of 107.97 miles. The MCLP model solution is 189.70% worse than the p-median model solution and adds 147.47% to the hybrid model distance of 43.63 miles. The hybrid model solution distance is 17.06% greater than the p-median model distance.

As should be expected, the p-center and hybrid models again produce the lowest average maximum distance any Fire Team is located from a penetrated LF. The distances and differences shown apply to both models. The average distance in the all staging areas solution is 9.44 miles. The p-median model produces an average distance 50% greater than this at 14.16 miles for the all staging areas solution. The MCLP model's average maximum distance of 18.68 miles in the all staging areas solution is 97.88% greater than the p-center and hybrid solutions and 31.92% greater than the p-median solution in this category. These comparisons appear in Table 4 below.

Table 4. Four Model Comparison, Original Reduced Data Set

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	70.95%	20.37 mins.	107.97 miles	18.68 miles	None
p-median	100.00%	6.36 mins.	37.27 miles	14.16 miles	None
p-center	100.00%	10 mins.	56.80 miles	9.44 miles	None
Hybrid	100.00%	7.45 mins.	43.63 miles	9.44 miles	None
	Percentage of Improvement				
MCLP vs. p-median	29.05%	-220.28%	-189.70%	-31.92%	N/A
MCLP vs. p-center	29.05%	-103.70%	-90.09%	-97.88%	N/A
MCLP vs. Hybrid	29.05%	-173.42%	-147.47%	-97.88%	N/A
p-median vs. p-center	--	57.23%	52.40%	-50.00%	N/A
p-median vs. Hybrid	--	17.14%	17.06%	-50.00%	N/A
p-center vs. Hybrid	--	-34.23%	-30.19%	N/A	N/A

Comparison of Original Data Sets

Removing the zero response time dates from the full data set has a slight effect on the percentage of difference, but does not change which model performs best in each category. All MAF only staging area comparisons remain the same in both data set types since no data points are removed for this solution type. In the Fire Team usage category for the all staging areas solution, the MCLP model utilizes 31.46% fewer Fire Teams than the p-median, p-center, and hybrid models in the full data set, compared to 29.05% fewer

in the reduced data set. The number of scheduled penetrated LFs that are not covered is the same in both data sets with zero in the all staging areas solution.

The p-median model solution provides the lowest average response times in both data sets. In the all staging areas solution of the full data set, this time is 321.34% lower than the MCLP model time, 57.11% lower than the p-center model time, and 17.07% lower than the hybrid model time. The MCLP model time exceeds the hybrid model time by 259.90%. The p-center time is 168.18% under that of the MCLP model and 34.20% greater than the hybrid model. The reduced data set produces similar results in the all staging areas solution, with the p-median average response time 220.28% lower than the MCLP model, 57.23% lower than the p-center model, and 17.14% lower than the hybrid model. The MCLP model time is 173.42% greater than the hybrid model time. The p-center model time is 103.70% lower than the MCLP model yet 34.23% greater than the hybrid model time.

The p-median model performs best in both data sets with respect to minimizing the average total distance. The all staging areas solution in the full data set show the MCLP model at a distance 236.04% greater than the p-median, 187.05% greater than the hybrid model, and 120.48% greater than the p-center model. The p-center model distance is 52.41% greater than that of the p-median model and 30.19% beyond the hybrid model distance. The hybrid model distance is 17.07% greater than the p-median model distance. The reduced data set differences are slightly less profound. The MCLP model distance in the all staging areas solution is 189.70% beyond that of the p-median model, 147.47% greater than the hybrid model, and 90.09% above the p-center model distance. The p-center model distance is 52.40% greater than the p-median model and 30.19% greater

than the hybrid model distance. The hybrid model distance exceeds that of the p-median model by 17.07% again.

The p-center and hybrid models, in conjunction with their primary objective, perform best in both data sets for minimizing the maximum distance any Fire Team is located from a penetrated LF. For the all staging areas solution in the full data set, the MCLP model distance is 153.97% greater than the p-center and hybrid model distances and 69.32% greater than the p-median model distance. The p-median model distance is 43.84% beyond the p-center and hybrid model distances. The reduced data set in the all staging areas solution shows the MCLP model distance is 97.88% above the p-center and hybrid model distances and 31.92% above the p-median model distance. The p-median model exceeds the p-center and hybrid model distances by 50%. The side-by-side comparison between the two data sets for all staging areas is shown below in Table 5.

Table 5. All Staging Areas Solution Comparison, Original Data Sets

All Staging Areas										
	Full Data Set					Reduced Data Set				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	Distance	Uncovered
MCLP	66.38%	20.73 mins.	96.88 miles	18.54 miles	None	70.95%	20.37 mins.	107.97 miles	18.68 miles	None
p-median	97.84%	4.92 mins.	28.83 miles	10.95 miles	None	100.00%	6.36 mins.	37.27 miles	14.16 miles	None
p-center	97.84%	7.73 mins.	43.94 miles	7.30 miles	None	100.00%	10 mins.	56.80 miles	9.44 miles	None
Hybrid	97.84%	5.76 mins.	33.75 miles	7.30 miles	None	100.00%	7.45 mins.	43.63 miles	9.44 miles	None
	Percentage of Improvement					Percentage of Improvement				
MCLP vs. p-median	31.46%	-321.34%	-236.04%	-69.32%	N/A	29.05%	-220.28%	-189.70%	-31.92%	N/A
MCLP vs. p-center	31.46%	-168.18%	-120.48%	-153.97%	N/A	29.05%	-103.70%	-90.09%	-97.88%	N/A
MCLP vs. Hybrid	31.46%	-259.90%	-187.05%	-69.32%	N/A	29.05%	-173.42%	-147.47%	-97.88%	N/A
p-median vs. p-center	--	57.11%	52.41%	-43.84%	N/A	--	57.23%	52.40%	-50.00%	N/A
p-median vs. Hybrid	--	17.07%	17.07%	-43.84%	N/A	--	17.14%	17.06%	-50.00%	N/A
p-center vs. Hybrid	--	-34.20%	-30.19%	N/A	N/A	--	-34.23%	-30.19%	N/A	N/A

Sensitivity Analysis

Two more sets of model runs are presented for the purposes of sensitivity analysis and to test assumptions. The first model set changes the assumption about the number of Fire Teams available. In this model set, the number of Fire Teams available is standardized at two below the number required by AFSPCI 31-1101. This shows the effect that two open holes per day, the normally accepted maximum, can have on the analysis parameters. The total number of available Fire Teams is then 159 in the full data set and 153 in the reduced data set. The full data set with reduced Fire Teams produces only two days with zero response times for the p-median, p-center, and hybrid solutions, so the reduced data set contains all except these two days of data. Again, the MAF only staging areas solution is unaffected by this and all parameters remain the same in both data sets.

The second model set adjusts the maximum distance from twenty miles to ten miles. This results in the same number of zero response time days as the original data set, so the reduced data set with the reduced maximum distance removes the same number of days as the original reduced data set. Only the MCLP model results are affected in this model set; the p-median, p-center, and hybrid solutions remain the same as in the original data set. The number of available Fire Teams remains the same as the original data set for both the full and reduced data set with reduced maximum distance.

MCLP Model, Full Data Set w/ Reduced Fire Teams

The all staging areas solution employs 88.05% of the available Fire Teams. The MAF only staging areas solution extends the employment of available Fire Teams to

94.97%, an increase of 6.92% over the all staging areas solution. Two scheduled penetrated LFs are not covered in the all staging areas solution and twenty-eight are left uncovered in the MAF only staging areas solution, an increase of 26. The MAF only staging areas solution average response time of 16.39 minutes represents an improvement of 20.78% over the all staging areas average response time of 20.69 minutes. The maximum average response time seen in the all staging areas solution is 26.14 minutes and the minimum is 14.57 minutes. The MAF only staging areas solution provides a maximum average response time of 21.10 minutes and a minimum time of 10.78 minutes.

The average total distance of 72.43 miles in the MAF only staging areas solution is 24.34% lower than the 95.73 miles that the all staging areas solution produces. A maximum distance of 202.64 exists in the all staging areas solution, with a minimum value of 29.92 miles. The MAF only staging areas solution produces a maximum distance of 143.60 miles and a minimum of 15.79 miles. The average maximum distance that any Fire Team is located from a penetrated LF is also lower in the MAF only staging areas solution at 16.63 miles versus the all staging areas solution of 18.49 miles, a difference of 10.06%. The maximum value for this parameter in the all staging areas solution is 19.96 miles, with a minimum of 15.92 miles. These values are 19.69 miles for the maximum and 8.07 for the minimum in the MAF only staging areas solution.

p-median Model, Full Data Set w/ Reduced Fire Teams

The p-median model requires the use of 99.37% of the available Fire Teams in both the all staging areas and MAF only staging areas solutions. The average response time of 15.22 minutes in the MAF only staging areas solution is 44.68% above the all

staging areas solution time of 10.52 minutes. The all staging areas solution produces a maximum average response time of 19.07 minutes and zero minutes for the minimum. The MAF only staging areas times are 21.86 minutes for the maximum average and 9.78 minutes for the minimum average.

The MAF only staging areas solution produces an average total distance 35.49% beyond the all staging areas solution with 75.21 miles and 55.51 miles, respectively. The maximum value in the all staging areas solution is 164.35 miles and zero miles for the minimum. The MAF only staging areas solution has a maximum distance of 182.15 miles and a minimum of 15.79 miles. The average maximum distance any Fire Team is located from a penetrated LF is actually slightly lower in the MAF only staging areas solution. This solution produces a distance of 19.05 miles, which is a 0.16% improvement upon the all staging areas solution of 19.08 miles. The maximum distance in the all staging areas solution is 33.47 miles with another zero value for the minimum. The MAF only staging areas solution's maximum distance is 36.38 miles and the minimum is 8.07 miles.

p-center Model, Full Data Set w/ Reduced Fire Teams

The p-center model utilizes 99.37% of the available Fire Teams in the all staging areas solution and 98.11% in the MAF only staging areas solution, a 1.26% improvement. The average response time of 17.38 minutes in the MAF only staging areas solution is 19.04% longer than the all staging areas solution time of 14.60 minutes. The maximum average response time in the all staging areas solution is 25.32 minutes

and the minimum is zero. The MAF only staging areas solution produces maximum and minimum average response times of 27.57 minutes and 9.78 minutes, respectively.

The all staging areas solution produces an average total distance of 74.77 miles and the MAF only staging areas solution is 16.68% higher at 87.24 miles. The all staging areas solution has a maximum distance of 199.06 miles, with a minimum distance of zero. The MAF only staging areas values are 222.03 miles for the maximum and 15.79 miles for the minimum. The average maximum distance that any Fire Team is located from a penetrated LF is 32.61% higher for the MAF only staging areas solution with 17.12 miles, compared to 12.91 miles in the all staging areas solution. The all staging areas minimum is again zero and the maximum is 21.57 miles. The MAF only staging areas solution maximum is 27.31 miles and the minimum is 8.07 miles, the same minimum value in all four model types.

Hybrid Model, Full Data Set w/ Reduced Fire Teams

The hybrid model requires 99.37% of the available Fire Teams in both staging areas solution types. The MAF only staging areas average response time of 16.33 minutes is 35.41% greater than the all staging areas solution time of 12.06 minutes. The maximum average response time in the all staging areas solution is 23.31minutes with a minimum of zero. The MAF only staging areas maximum and minimum average response times are 25.35 minutes and 9.78 minutes, respectively.

The average total distance in the all staging areas solution is 63.82 miles, with a maximum distance of 198.88 miles and a minimum of zero. The MAF only staging areas average total distance is 28.17% greater at 81.80 miles, with a maximum of 204.21 miles

and a minimum of 15.79 miles. The comparisons for average maximum distance any Fire Team is located from a penetrated LF, including maximum and minimum values, are the same as those in the p-center model. Comparisons of the two types of solutions, all staging areas and MAF only staging areas, for each of the four model types is shown in Table 6 below.

Table 6. Full Data Set with Reduced Fire Teams

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	88.05%	20.69 mins.	95.73 miles	18.49 miles	2
p-median	99.37%	10.52 mins.	55.51 miles	19.08 miles	None
p-center	99.37%	14.60 mins.	74.77 miles	12.91 miles	None
Hybrid	99.37%	12.06 mins.	63.82 miles	12.91 miles	None
	MAF Only Staging Areas				
MCLP	94.97%	16.39 mins.	72.43 miles	16.63 miles	28
p-median	99.37%	15.22 mins.	75.21 miles	19.05 miles	None
p-center	98.11%	17.38 mins.	87.24 miles	17.12 miles	None
Hybrid	99.37%	16.33 mins.	81.80 miles	17.12 miles	None
	Percentage Change of MAF Only Solution				
MCLP	6.92%	-20.78%	-24.34%	-10.06%	26
p-median	--	44.68%	35.49%	-0.16%	N/A
p-center	-1.26%	19.04%	16.68%	32.61%	N/A
Hybrid	--	35.41%	28.17%	32.61%	N/A

Four Model Comparison, Full Data Set w/ reduced Fire Teams

As in the original data set, the comparison of the four types of models is based on percentage of available Fire Teams used, average response time, average total distance, and average maximum distance any Fire Team is located from a penetrated LF. The MCLP model requires 88.05% of available Fire Teams in the all staging areas solution, in contrast to 99.37% for the p-median, p-center, and hybrid models, an improvement of 11.32% over the other models. The MCLP model also requires fewer Fire Teams in the MAF only staging areas solution with 94.97% versus 99.37% in the p-median and hybrid model solutions and 98.11% in the p-center model solution. The MCLP model requires

4.40% fewer Fire Teams than the p-median and hybrid models and 3.14% fewer than the p-center model. The p-center model employs 1.26% fewer Fire Teams than the p-median and hybrid models. It should be noted that this improvement in Fire Team utilization comes at the expense of not covering two of three hundred seventy five scheduled penetrated LFs in the all staging areas solution and twenty-eight in the MAF only staging areas solution. This represents 0.53% of the scheduled LFs in the all staging areas solution and 7.47% in the MAF only staging areas solution. The MCLP model has two more uncovered LFs than the p-median, p-center, and hybrid models in the all staging areas solution and twenty eight more in the MAF only staging areas solution.

The p-median model again produces the lowest average response time in the all staging areas and the MAF only staging areas solutions with 10.52 minutes and 15.22 minutes, respectively. The hybrid model time of 12.06 minutes in the all staging areas solution is 14.64% greater than the p-median model time and the hybrid time of 16.33 minutes in the MAF only staging areas solution is 7.29% greater than the p-median model time. The p-center model produces a time of 14.60 minutes in the all staging areas solution, which is 38.78% higher than the p-median model solution and 21.06% greater than the hybrid model solution, but 41.71% lower than the MCLP model solution of 20.69 minutes. The p-center model MAF only staging areas solution time of 17.38 minutes is 14.19% higher than the p-median, 6.43% higher than the hybrid, and 6.04% higher than the MCLP model solution of 16.39 minutes. The MCLP model times exceed those of the p-median model by 96.67% in the all staging areas solution and by 7.69% in the MAF only staging areas solution. These percentages are 71.56% in the all staging areas solution and 0.37% in the MAF only staging areas solution when compared to the

hybrid model. Again, assessment of the MCLP model times must be tempered with its inability to cover all scheduled penetrated LFs in both solution types.

The p-median model produces the lowest average total distance in the all staging areas solution with 55.51 miles. The MCLP model exceeds this distance by 72.46% with 95.73 miles. This distance is also 50% greater than the hybrid model distance of 63.82 miles and exceeds the p-center distance of 74.77 miles by 28.03%. The p-center model distance is 34.70% greater than the p-median model distance and 17.16% greater than the hybrid model distance. The hybrid model distance is 14.97% greater than the p-median model distance. The results differ in the MAF only staging areas solution because of the loss of covered sites. In this solution type, the MCLP model produces the lowest distance with 72.43 miles. The p-median distance of 75.21 miles exceeds that of the MCLP model by 3.84%. The hybrid model distance of 81.80 miles exceeds the MCLP model by 12.94% and the p-median model distance by 7.29%. The p-center model distance of 87.24 miles is 20.45% greater than the MCLP model distance, 16% beyond the p-median model distance, and 6.65% above the hybrid model distance.

The p-center and hybrid models have the lowest average maximum distance any Fire Team is located from a penetrated LF in the all staging areas solution with 12.91 miles. The MCLP model distance is 43.22% greater than this at 18.49 miles, yet is 3.19% better than the p-median model distance of 19.08 miles. This p-median distance exceeds the p-center and hybrid solutions by 47.80%. Again, the MAF only staging areas solution requires consideration of the uncovered scheduled penetrated LFs. The MCLP model solution is best in this category at 16.63 miles. The p-median model solution of 19.05 miles is 14.55% greater than this and exceeds the p-center and hybrid model

solution of 17.12 miles by 11.27%. The p-center and hybrid solutions are then 2.95% greater than the MCLP model solution. A summary of these results appears in Table 7 below.

Table 7. Four Model Comparison, Full Data Set with Reduced Fire Teams

	All Staging Areas					MAF Only Staging Areas				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	Max Distance	Uncovered
MCLP	88.05%	20.69 mins.	95.73 miles	18.49 miles	2	94.97%	16.39 mins.	72.43 miles	16.63 miles	28
p-median	99.37%	10.52 mins.	55.51 miles	19.08 miles	None	99.37%	15.22 mins.	75.21 miles	19.05 miles	None
p-center	99.37%	14.60 mins.	74.77 miles	12.91 miles	None	98.11%	17.38 mins.	87.24 miles	17.12 miles	None
Hybrid	99.37%	12.06 mins.	63.82 miles	12.91 miles	None	99.37%	16.33 mins.	81.80 miles	17.12 miles	None
	Percentage of Improvement					Percentage of Improvement				
MCLP vs. p-median	-11.32%	96.67%	72.46%	3.19%	-2	-4.40%	-7.69%	3.84%	14.55%	-28
MCLP vs. p-center	-11.32%	-41.71%	-28.03%	-43.22%	-2	-3.14%	6.04%	20.45%	2.95%	-28
MCLP vs. Hybrid	-11.32%	-71.56%	-50.00%	3.19%	-2	-4.40%	-0.37%	12.94%	2.95%	-28
p-median vs. p-center	--	38.78%	34.70%	-47.80%	N/A	1.26%	14.19%	16.00%	-11.27%	N/A
p-median vs. Hybrid	--	14.64%	14.97%	-47.80%	N/A	--	7.29%	8.76%	-11.27%	N/A
p-center vs. Hybrid	--	-21.06%	-17.16%	N/A	N/A	-1.26%	-6.43%	-6.65%	N/A	N/A

MCLP Model, Reduced Data Set w/ Reduced Fire Teams

The reduced data set analysis compares the same parameters as the full data set. The MAF only staging areas values are the same as the original data set so only the percentage difference is shown, along with the new all staging areas solution values. In this data set, the all staging areas solution of the MCLP model utilizes 88.89% of the available Fire Teams and the MAF only staging areas solution employs 6.08% fewer of the available Fire Teams. The number of scheduled penetrated LFs that cannot be covered remains the same as the full data set. The average response time in the MAF only staging areas solution improves upon the all staging areas solution of 20.67 minutes by 20.71%. A maximum average response time of 26.14 minutes and a minimum

average of 14.57 minutes are apparent in the all staging areas solution. The MAF only staging areas average total distance betters the all staging areas solution of 98.12 miles by 26.18%. The maximum distance in the all staging areas solution is 202.64 miles, with a minimum distance of 45.57 miles. The average maximum distance any Fire Team is located from a penetrated LF is 10.30% better in the MAF only staging areas solution versus the 18.54 miles obtained in the all staging areas solution. The MAF only staging areas solution leaves twenty six more scheduled penetrated LFs uncovered than the two uncovered in the all staging areas solution. The maximum value for the all staging areas solution is 19.96 miles and the minimum is 15.92 miles. .

p-median Model, Reduced Data Set w/ Reduced Fire Teams

The p-median model in this data set utilizes all available Fire Teams in the all staging areas solution and 0.63% fewer in the MAF only staging areas solution. The difference in average response times between the all staging areas solution and the MAF only solution is not nearly as wide as in the original data set. The MAF only staging areas solution time is 39.38% greater than the all staging areas solution time of 10.92 minutes. The maximum average response time in the all staging areas solution is 19.07 minutes and the minimum average is 2.85 minutes.

The MAF only staging areas average total distance exceeds by 30.46% that of the all staging areas distance of 57.65 miles. A maximum distance of 164.35 miles appears in the all staging areas solution and a minimum of 7.60 miles. The average maximum distance any Fire Team is from a penetrated LF is only 3.93% higher in the MAF only staging areas solution than the 19.47 miles produced in the all staging areas solution. The

all staging areas solution has a maximum distance of 33.47 miles and a minimum of 5.59 miles.

p-center Model, Reduced Data Set w/ Reduced Fire Teams

The p-center model requires all of the available Fire Teams in the all staging areas solution and 1.89% fewer of them in the MAF only staging areas solution. The MAF only staging areas average response time exceeds the all staging areas time of 15.17 minutes by 14.57%. The maximum average response time in the all staging areas solution is 25.32 minutes and the minimum average is 4.68 minutes. A similar percentage difference is apparent in the comparison of average total distances. The MAF only staging areas distance is 12.26% beyond the all staging areas distance of 77.71 miles. The maximum value for the all staging areas solution is 199.06 miles and the minimum is 12.48 miles. The average maximum distance any Fire Team is located from a penetrated LF in the MAF only staging areas solution is 30.10% greater than the all staging areas solution distance of 13.42 miles. The all staging areas solution produces a maximum distance of 21.57 miles and a minimum distance of 4.59 miles.

Hybrid Model, Reduced Data Set w/ Reduced Fire Teams

The all staging areas solution requires all available Fire Teams and the MAF only staging areas solution employs 0.63% fewer. The average response time is 30.32% greater in the MAF only staging areas solution than the 12.53 minutes in the all staging areas solution. The maximum average response time is 23.31 minutes and the minimum average is 3.37 minutes. The average total distance in the MAF only staging areas

solution exceeds the all staging areas solution of 66.32 miles by 23.34%. The maximum total distance value is 198.88 miles and the minimum is 4.59 miles. The values in average maximum distance any Fire Team is from a penetrated LF are the same as the p-center model values. The solution type comparisons for each model are shown below in Table 8.

Table 8. Reduced Data Set with Reduced Fire Teams

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	88.89%	20.67 mins.	98.12 miles	18.54 miles	2
p-median	100.00%	10.92 mins.	57.65 miles	19.83 miles	None
p-center	100.00%	15.17 mins.	77.71 miles	13.42 miles	None
Hybrid	100.00%	12.53 mins.	66.32 miles	13.42 miles	None
	MAF Only Staging Areas				
MCLP	94.97%	16.39 mins.	72.43 miles	16.63 miles	28
p-median	99.37%	15.22 mins.	75.21 miles	19.05 miles	None
p-center	98.11%	17.38 mins.	87.24 miles	17.12 miles	None
Hybrid	99.37%	16.33 mins.	81.80 miles	17.12 miles	None
	Percentage Change of MAF Only Solution				
MCLP	6.08%	-20.71%	-26.18%	-10.30%	26
p-median	-0.63%	39.38%	30.46%	-3.93%	N/A
p-center	-1.89%	14.57%	12.26%	27.57%	N/A
Hybrid	-0.63%	30.32%	23.34%	27.57%	N/A

Four Model Comparison, Reduced Data Set w/ Reduced Fire Teams

As in the original data sets, this comparison is only relevant for the all staging areas solution because the MAF only staging areas comparisons values remain the same as the full data set. Because only two days of data are removed for producing response times of zero, the four model comparison in this reduced data set is very similar to the full data set comparison. The MCLP model again utilizes fewer Fire Teams than the other models. The MCLP model utilization rate of 88.89% in the all staging areas solution is 11.11% lower than the p-median model, p-center, and hybrid model rates of 100%. The

all staging areas MCLP model leaves two scheduled penetrated LFs uncovered, which is two more than the other models since they, of course, cover all scheduled penetrated LFs.

The p-median model produces the lowest average response time in the all staging areas solution with 10.92 minutes. The MCLP model time of 20.67 minutes is 89.29% above the p-median model time, 64.96% greater than the hybrid model time of 12.53 minutes, and 36.26% higher than the p-center model time of 15.17 minutes. The p-center model time is 38.92% greater than the p-median time and 21.07% greater than the hybrid model average response time. The hybrid model average response time exceeds that of the p-median model by 14.74%.

The p-median produces the lowest average total distance in the all staging areas solution with 57.65 miles. The MCLP model distance of 98.12 miles is 70.20% greater than the p-median model, 47.95% beyond the hybrid model distance of 66.32 miles, and 26.26% greater than the p-center model distance of 77.71 miles. This p-center model distance exceeds the p-median model distance by 34.80% and the hybrid model distance by 17.17%. The hybrid model distance is 15.04% greater than the p-median model distance. The p-center and hybrid models achieve the lowest average maximum distance any Fire Team is located from a penetrated LF in the all staging areas solution with 13.42 miles. The p-median model solution of 19.83 miles exceeds this by 47.76% and is 6.96% greater than the MCLP model solution of 18.54 miles. The MCLP model distance is 38.15% greater than the p-center and hybrid model distance. These comparisons are summarized below in Table 9.

Table 9. Four Model Comparison, Reduced Data Set with Reduced Fire Teams

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	88.89%	20.67 mins.	98.12 miles	18.54 miles	2
p-median	100.00%	10.92 mins.	57.65 miles	19.83 miles	None
p-center	100.00%	15.17 mins.	77.71 miles	13.42 miles	None
Hybrid	100.00%	12.53 mins.	66.32 miles	13.42 miles	None
	Percentage of Improvement				
MCLP vs. p-median	11.11%	-89.29%	-70.20%	6.96%	-2
MCLP vs. p-center	11.11%	-36.26%	-26.26%	-38.15%	-2
MCLP vs. Hybrid	11.11%	-64.96%	-47.95%	-38.15%	-2
p-median vs. p-center	--	38.92%	34.80%	-47.76%	N/A
p-median vs. Hybrid	--	14.74%	15.04%	-47.76%	N/A
p-center vs. Hybrid	--	-21.07%	-17.17%	N/A	N/A

Comparison of Data Sets w/ Reduced Fire Teams

Because only two zero response time dates are removed to produce the reduced data set, very little difference occurs between the full and reduced data sets all staging areas solutions. The MAF only staging areas solutions do not appear in this comparison since no changes occur between the data sets. Fire Team usage in the all staging areas solution of the full data set shows the MCLP model uses 11.32% fewer teams than the p-median, p-center, and hybrid models. This difference minutely adjusts in the reduced data set, by 0.23%, to 11.11%. The difference between the p-median, p-center, and hybrid models remains at zero in both the full and reduced data sets. Both the full and reduced data sets MCLP models cannot cover the same two scheduled penetrated LFs in the all staging areas solution.

The p-median model produces the lowest average response times in both data sets. The MCLP model all staging areas average response time in the full data set exceeds the p-median model time by 96.67%, the hybrid model time by 71.56%, and the p-center model time by 41.71%. The p-center time is 38.78% longer than the p-median

model time and 21.06% longer than the hybrid model time. The hybrid model time is 14.64% greater than the p-median model time. The reduced data set shows the MCLP model time exceeds the p-median model time by 89.29%, the hybrid model average response time by 64.96%, and the p-center model time by 36.26%. The p-center model time exceeds the p-median model time by 38.92% and the hybrid model time by 21.07%, with the hybrid model time 14.74% greater than the p-median model time.

With the all staging areas solution in the full data set, the average total distance of the MCLP model exceeds the p-median model distance by 72.46%, the hybrid model distance by 50%, and the p-center model distance by 28.03%. The p-center model exceeds the distance of the p-median model by 34.70% and the hybrid model distance by 17.16%. The hybrid model distance is 14.97% beyond the p-median model distance. In the reduced data set, the MCLP model produces a total distance 70.20% longer than the p-median model, 47.95% longer than the hybrid model, and 26.26% beyond the p-center model distance. The p-center model distance exceeds that of the p-median model by 34.80% and is 17.17% greater than the hybrid model distance. The hybrid model has a distance 15.04% greater than the p-median model.

The all staging areas solution in the full data set shows the maximum distance any Fire Team is located from a penetrated LF is 43.22% longer in the MCLP model than in the p-center and hybrid models and the p-median model exceeds the p-center and hybrid model distance by 47.80%. The p-median model also exceeds the MCLP model distance by 3.19%. The p-median model distance in the reduced data set is 47.76% beyond the p-center and hybrid model distances and 6.96% higher than the MCLP model distance. The

MCLP model has a distance 38.15% above the p-center and hybrid model distances. The all staging areas solutions are shown below in Table 10.

Table 10. All Staging Areas Solution Comparison, Data Sets with Reduced Fire Teams

All Staging Areas										
	Full Data Set					Reduced Data Set				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	MaxDistance	Uncovered
MCLP	88.05%	20.69 mins.	95.73 miles	18.49 miles	2	88.89%	20.67 mins.	98.12 miles	18.54 miles	2
p-median	99.37%	10.52 mins.	55.51 miles	19.08 miles	None	100.00%	10.92 mins.	57.65 miles	19.83 miles	None
p-center	99.37%	14.60 mins.	74.77 miles	12.91 miles	None	100.00%	15.17 mins.	77.71 miles	13.42 miles	None
Hybrid	99.37%	12.06 mins.	63.82 miles	12.91 miles	None	100.00%	12.53 mins.	66.32 miles	13.42 miles	None
	Percentage of Improvement					Percentage of Improvement				
MCLP vs. p-median	-11.32%	96.67%	72.46%	3.19%	-2	11.11%	-89.29%	-70.20%	6.96%	-2
MCLP vs. p-center	-11.32%	-41.71%	-28.03%	-43.22%	-2	11.11%	-36.26%	-26.26%	-38.15%	-2
MCLP vs. Hybrid	-11.32%	-71.56%	-50.00%	3.19%	-2	11.11%	-64.96%	-47.95%	-38.15%	-2
p-median vs. p-center	--	38.78%	34.70%	-47.80%	N/A	--	38.92%	34.80%	-47.76%	N/A
p-median vs. Hybrid	--	14.64%	14.97%	-47.80%	N/A	--	14.74%	15.04%	-47.76%	N/A
p-center vs. Hybrid	--	-21.06%	-17.16%	N/A	N/A	--	-21.07%	-17.17%	N/A	N/A

MCLP Model, Full Data Set w/ Reduced Maximum Distance

The reduced maximum distance in this data set and its companion reduced data set only affect the solutions for the MCLP model. The p-median, p-center, and hybrid models retain the same solutions as in the original data set comparison. Therefore, only the MCLP model and the four model comparisons are of renewed interest. In this data set, the MAF only staging areas Fire Team utilization of 85.78% % is 6.89% lower than the all staging areas utilization of 92.67%. The MAF only staging areas average response time of 10.27 minutes is only 3.32% greater than the all staging areas time of 9.94 minutes. The maximum average response time in the all staging areas solution is 13.43 minutes, with a minimum average response time of 7.17 minutes. The MAF only staging

areas solution has a maximum average response time of 12.82 minutes and a minimum average of 8.21 minutes.

The MAF only staging areas average total distance of 34.98 miles is actually 19.60% lower than the all staging areas distance of 43.51 miles. A maximum value of 80.25 miles appears in the all staging areas solution, as well as a minimum value of 13.65 miles. The maximum value in the MAF only staging areas solution is 56.74 miles and the minimum value is 15.79 miles. The average maximum distance any Fire Team is located from a penetrated LF is also 5.31% lower in the MAF only staging areas solution with 8.92 miles versus 9.42 miles in the all staging areas solution. The all staging areas solution presents a maximum distance of 9.99 miles and a minimum of 6.91 miles. The maximum value in the MAF only staging areas solution is 9.98 miles and the minimum is 6.33 miles. In this data set, twenty-seven scheduled penetrated LFs are not covered in the all staging areas solution and an astounding 103 of 375 are left uncovered in the MAF only staging areas solution, an increase of seventy six over the all staging areas solution. Comparison of these MCLP model results are shown below in Table 11.

Table 11. Full Data Set with Reduced Maximum Distance

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	92.67%	9.94 mins.	43.51 miles	9.42 miles	27
	MAF Only Staging Areas				
MCLP	85.78%	10.27 mins.	34.98 miles	8.92 miles	103
	Percentage Change of MAF Only Solution				
MCLP	-6.89%	3.32%	-19.60%	-5.31%	76

Four Model Comparison, Full Data Set w/ Reduced Maximum Distance

The basis for comparison, once again, is percentage of available Fire Teams used, average response time, average total distance, and average maximum distance any Fire Team is located from a penetrated LF. Because the values when comparing the p-median, p-center, and hybrid models to each other remain the same as the original data set, only the comparisons between the MCLP model and these other three models are pertinent in this analysis. The p-median, p-center, and hybrid models utilize 97.84% of the available Fire Teams in the all staging areas solution. The MCLP model utilizes 5.17% fewer available Fire Teams in this solution with 92.67%. The MCLP model utilization rate of 85.78% in the MAF only staging areas solution is 12.06% less than the p-median and hybrid model rates of 97.84% and 5.17% less than the p-center model rate of 90.52%. In the all staging areas solution, the MCLP model leaves twenty-seven penetrated LFs uncovered, which is 27 more than the other models which cover all scheduled penetrated LFs. The MCLP model in the MAF only staging areas solution is unable to cover one hundred three scheduled penetrated LFs, which is one hundred three more than the other models.

The MCLP model average response time of 9.94 minutes in the all staging areas solution exceeds the p-median model time by 102.03%, the hybrid model time by 72.27%, and the p-center model time by 28.59%. The MAF only staging areas solution times are counterintuitive due to the number of scheduled penetrated LFs left uncovered. The MCLP model average response time of 10.27 minutes is 20.55% less than the p-median model time, 23.76% less than the hybrid model time, and 30.87% less than the p-center model time. The average total distance in the MCLP model of 43.51 miles

exceeds the p-median distance by 50.92% and the hybrid model distance by 28.92%, but is actually 0.99% less than the p-center model distance in the all staging areas solution. The MCLP model produces a MAF only staging areas average total distance of 34.98 miles. The p-median model exceeds this distance by 71.33%, the hybrid model exceeds it by 78.13%, and the p-center model exceeds it by 90.25%. In the all staging areas solution, the MCLP model distance of 9.42 miles exceeds the p-center and hybrid model distances by 29.04% but is 16.24% below the p-median model distance. In the MAF only staging areas solution, the MCLP model produces the lowest average maximum distance any Fire Team is located from a penetrated LF with 8.92 miles. The p-median model extends this distance by 45.52% and the p-center and hybrid model distances are 40.47% greater than the MCLP model distance. These results appear in Table 12 below.

Table 12. Four Model Comparison, Full Data Set with Reduced Maximum Distance

	All Staging Areas					MAF Only Staging Areas				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	Max Distance	Uncovered
MCLP	92.67%	9.94 mins.	43.51 miles	9.42 miles	27	85.78%	10.27 mins.	34.98 miles	8.92 miles	103
p-median	97.84%	4.92 mins.	28.83 miles	10.95 miles	None	97.84%	12.38 mins.	59.93 miles	12.98 miles	None
p-center	97.84%	7.73 mins.	43.94 miles	7.30 miles	None	90.52%	13.44 mins.	66.55 miles	12.53 miles	None
Hybrid	97.84%	5.76 mins.	33.75 miles	7.30 miles	None	97.84%	12.71 mins.	62.31 miles	12.53 miles	None
	Percentage of Improvement					Percentage of Improvement				
MCLP vs. p-median	5.17%	-102.03%	-50.92%	16.24%	-27	12.06%	20.55%	71.33%	45.52%	-103
MCLP vs. p-center	5.17%	-28.59%	0.99%	-29.04%	-27	4.74%	30.87%	90.25%	40.47%	-103
MCLP vs. Hybrid	5.17%	-72.57%	-28.92%	-29.04%	-27	12.06%	23.76%	78.13%	40.47%	-103

MCLP Model, Reduced Data Set w/ Reduced Maximum Distance

In this reduced data set, the MAF only staging areas solution values remain the same as the full data set and only the percentage difference is shown here. The MAF

only staging areas solution requires 11.99% fewer Fire Teams than the all staging areas solution of 97.77%. The MAF only staging areas average response time is 1.932% longer than the all staging areas solution time of 9.87 minutes. For the all staging areas solution, the maximum average response time is 13.43 minutes and the minimum is 7.17 minutes. The MAF only staging areas average total distance is 21.59% less than the all staging areas distance of 48.36 miles, which has a maximum distance of 80.25 miles and a minimum of 27.76 miles. The MAF only staging areas solution also produces a 4.77% lower average maximum Fire Team distance than the 9.42 miles in the all staging areas solution. The maximum distance any Fire Team is located from a penetrated LF is 9.99 miles with a minimum of 6.91 miles. In this data set, the number of scheduled penetrated LFs left uncovered remains the same in the all staging areas solution, so the difference from the MAF only staging areas solution is also the same. These results are shown below in Table 13.

Table 13. Reduced Data Set with Reduced Maximum Distance

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	97.77%	9.87 mins.	48.36 miles	9.42 miles	27
	MAF Only Staging Areas				
MCLP	85.78%	10.27 mins.	34.98 miles	8.92 miles	103
	Percentage Change of MAF Only Solution				
MCLP	-11.99%	4.05%	-38.25%	-5.31%	76

Four Model Comparison, Reduced Data Set w/ Reduced Maximum Distance

Once again, the reduced data set only affects the parameters in the all staging areas solution and only those values are shown. As in the full data set, only the comparisons between the MCLP model and the other three model types are pertinent in

this analysis. In this reduced data set, the p-median, hybrid, and p-center models deploy all of the available Fire Teams in the all staging areas solution. The MCLP model utilizes 2.23% fewer available Fire Teams with 97.77%. The MCLP model is unable to cover twenty seven of the scheduled penetrated LFs, which is twenty seven more than the other models.

The MCLP model average response time is 55.19% greater than the p-median model time, 32.46% greater than the hybrid model time, but 1.32% lower than the p-center model time. The MCLP model average total distance of 48.36 miles is 29.76% longer than the p-median model distance, 10.84% greater than the hybrid model distance, and 17.45% less than the p-center model distance.

With the addition of the ten-mile maximum distance constraint, the MCLP model has the lowest average maximum distance any Fire Team is located from a penetrated LF. The p-median model distance in the all staging areas solution category is 50.32% greater than the MCLP model distance, while both the p-center and hybrid model distances are only 0.21% greater. These results are shown below in Table 14.

Table 14. Four Model Comparison, Reduced Data Set with Reduced Maximum Distance

	All Staging Areas				
	Usage	**Response time**	**Total Distance**	**MaxDistance**	**Uncovered**
MCLP	97.77%	9.87 mins.	48.36 miles	9.42 miles	27
p-median	100.00%	6.36 mins.	37.27 miles	14.16 miles	None
p-center	100.00%	10 mins.	56.80 miles	9.44 miles	None
Hybrid	100.00%	7.45 mins.	43.63 miles	9.44 miles	None
	Percentage of Improvement				
MCLP vs. p-median	2.23%	-55.19%	-29.76%	50.32%	-27
MCLP vs. p-center	2.23%	1.32%	17.45%	0.21%	-27
MCLP vs. Hybrid	2.23%	-32.48%	-10.84%	0.21%	-27

Comparison of Data Sets w/ Reduced Maximum Distance

No comparison between the data sets is required in the MAF only staging areas solution since all values remain the same. These data sets for the all staging areas solution have the same number of zero response time days removed as the original data set. The p-median, p-center, and hybrid models retain the same solutions as the original data set, but the more restrictive nature of a ten-mile maximum distance has a great impact on the MCLP model, especially regarding the number of uncovered, penetrated LFs. The percentage of Fire Teams used in the all staging areas solution of the full data set is 5.17% lower in the MCLP model than the p-median, p-center, and hybrid models. The difference becomes 2.23% in the reduced data set. Both the full and reduced data set MCLP model solution leaves twenty-seven scheduled penetrated LFs uncovered.

The MCLP model average response time exceeds the p-median model time by 102.03%, the hybrid model time by 72.57%, and the p-center model time by 28.59% in the full data set. In the reduced data set, the MCLP model average response time is 55.19% above the p-median model time and 32.48% longer than the hybrid model time. The p-center model time is actually 1.32% greater than the MCLP model time in this reduced data set.

The MCLP model average total distance is 50.92% greater than the p-median model distance and 28.92% greater than the hybrid model distance in the full data set. The p-center model distance exceeds the MCLP model distance by 0.99% in the full data set. The reduced data set shows the MCLP model average total distance exceeds the p-median model distance by 29.76% and the hybrid model distance by 10.84%. The p-center model distance is 17.45% beyond that of the MCLP model.

The MCLP model average maximum distance any Fire Team is located from a penetrated LF in the full data set is 29.04% longer than the p-center and hybrid model distances, but the p-median model distance is 16.24% greater than the MCLP model distance. The reduced data set shows the p-median model distance exceeds the MCLP model by 50.32% and the p-center and hybrid models exceed the MCLP distance by an inconsequential 0.21%. The all staging areas solutions are shown below in Table 15.

Table 15. All Staging Areas Solution Comparison, Data Sets with Reduced Maximum Distance

All Staging Areas										
	Full Data Set					Reduced Data Set				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	MaxDistance	Uncovered
MCLP	92.67%	9.94 mins.	43.51 miles	9.42 miles	27	97.77%	9.87 mins.	48.36 miles	9.42 miles	27
p-median	97.84%	4.92 mins.	28.83 miles	10.95 miles	None	100.00%	6.36 mins.	37.27 miles	14.16 miles	None
p-center	97.84%	7.73 mins.	43.94 miles	7.30 miles	None	100.00%	10 mins.	56.80 miles	9.44 miles	None
Hybrid	97.84%	5.76 mins.	33.75 miles	7.30 miles	None	100.00%	7.45 mins.	43.63 miles	9.44 miles	None
	Percentage of Improvement					Percentage of Improvement				
MCLP vs. p-median	5.17%	-102.03%	-50.92%	16.24%	-27	2.23%	-55.19%	-29.76%	50.32%	-27
MCLP vs. p-center	5.17%	-28.59%	0.99%	-29.04%	-27	2.23%	1.32%	17.45%	0.21%	-27
MCLP vs. Hybrid	5.17%	-72.57%	-28.92%	-29.04%	-27	2.23%	-32.48%	-10.84%	0.21%	-27

Comparison of All Data Sets

MAF only staging areas comparisons are only applicable to the full data sets of each type. Reducing the number of Fire Teams has an impact on the effect of the parameters in the all staging areas solution of the p-median, p-center, and hybrid models. This effect is seen to a lesser degree in the MAF only staging areas solution. This reduction in the number of Fire Teams has a minor impact on the parameters of the MCLP model, except in Fire Team usage and the number of scheduled penetrated LFs left uncovered.

The MCLP model still utilizes the lowest percentage of Fire Teams in the data set with reduced Fire Teams, but these percentages increase over the original full data set by 21.67% in the all staging areas solution and 17.38% in the MAF only staging areas solution. In the reduced data set, the percentage increase in the all staging areas solution over the original data set is 17.94%. The number of scheduled penetrated LFs left uncovered in the all staging areas solution of both the full and reduced data sets increase by two over the original data set and the MAF only staging areas solution shows an increase of twenty five uncovered scheduled penetrated LFs in the full data set over the original value of three.

The p-median model maintains the lowest average response time in the full and reduced data sets with reduced Fire Teams of both solution types. This time increases by 113.82% over the original value in the all staging areas solution of the full data set and by 71.70% in the reduced data set. The percentage increase in the MAF only staging areas solution is much lower with 22.94% in the full data set.

The p-median model in this data set with reduced Fire Teams produces the lowest average total distance in the all staging areas solution of the full and reduced data sets, but arrives at slightly higher values than the MCLP model in the MAF only staging areas solution. The all staging areas solution increases by 92.54% over the original value in the full data set and by 54.68% in the reduced data set. Smaller increases are again seen in the MAF only staging areas solution with 25.50% in the full data set.

The p-center and hybrid models retain the lowest average distance any Fire Team is located from a penetrated LF in the all staging areas solution with reduced Fire Teams, but are bested by the MCLP model in the MAF only staging areas solution. The full data

set shows a 76.85% increase over the original distance in the all staging areas solution and the reduced data set with this solution shows a 42.16% increase. The MAF only staging areas parameters increase over the original distance is 36.63% in the full data set.

The data set with reduced maximum distance only changes the values in the MCLP model; the p-median, p-center, and hybrid models retain their original parameter values. In the all staging areas full data set solution, Fire Team usage increases by 26.29% over the original data set and by 26.82% in the reduced data set for this solution type. The number of scheduled penetrated LFs uncovered increases by 27 over the original value of zero in both the full and reduced data sets. The MAF only staging areas solution shows an 8.19% increase in Fire Team usage over the original value in the full data set. An enormous increase is seen in the full data set for this solution type in the number of scheduled penetrated LFs uncovered, with an increase of one hundred three in the full data set.

The MCLP model in the data set with reduced maximum distance does show improvement in average response time, average total distance, and average maximum distance any Fire Team is located form a penetrated LF. These improvements, as seen above, come at a high cost of canceling maintenance activities. Average response times in the all staging areas solution improve over the original times by 52.05% in the full data set and 51.55% in the reduced data set. These times also improve in the MAF only staging areas solution by 37.26% in the full data set. The average total distance improvement over the original distance is 55.09% in the all staging areas solution of the full data set and 55.21% in the reduced data set. The MAF only staging areas solution shows a similar improvement percentage with 55.33% in the full data set. The average

maximum distance any Fire Team is located from a penetrated LF is reduced by 49.19% over the original value in the all staging areas solution of the full data set and by 49.57% in the reduced data set. The improvement in the MAF only staging areas solution is 46.94% in the full data set.

The data set with reduced maximum distance has similar differences when comparing it to the data set with reduced Fire Teams. In the all staging areas solution, Fire Team usage increases by 4.62% over the reduced Fire Teams usage in the full data set and by 8.88% in the reduced data set. The MAF only staging areas solution shows a decrease in usage of 9.19% in the full data set. The number of scheduled penetrated LFs uncovered increases by 25 in the all staging areas solutions of the full and reduced data sets. The MAF only staging areas increase in uncovered penetrated LFs is seventy five in the full data set.

Both distance parameters and average response time again show improvement in this comparison. The average response time decrease from the reduced Fire Teams data set is 51.96% in the full data set with the all staging areas solution and 52.25% in the reduced data set. The MAF only staging areas solution conveys a 37.34% improvement in the full data set. The average total distance improves by 54.55% in the all staging areas solution for the full data set and by 50.71% in the reduced data set. Similarly, the MAF only staging areas solution shows a 51.71% improvement in the full data set. The average distance any Fire Team is located from a penetrated LF improves in the full data set with the all staging areas solution by 49.05% over the reduced Fire Teams figure and by 49.26% in the reduced data set. The MAF only staging areas solution shows a 46.36% improvement in the full data set.

Table 16, below, compares both the data set with reduced Fire Teams and the data set with reduced maximum distance to the original data set in the all staging areas solution of the full and reduced data sets. Table 17 follows and displays the same comparison, for the full data set only, in the MAF only staging areas solution. These tables also display the differences between the data set with reduced Fire Teams and the data set with reduced maximum distance.

Table 16. All Staging Areas Solution Comparison between Data Set Types

Original Data Sets										
All Staging Areas										
	Full Data Set					Reduced Data Set				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	Distance	Uncovered
MCLP	66.38%	20.73 mins.	96.88 miles	18.54 miles	None	70.95%	20.37 mins.	107.97 miles	18.68 miles	None
p-median	97.84%	4.92 mins.	28.83 miles	10.95 miles	None	100.00%	6.36 mins.	37.27 miles	14.16 miles	None
p-center	97.84%	7.73 mins.	43.94 miles	7.30 miles	None	100.00%	10 mins.	56.80 miles	9.44 miles	None
Hybrid	97.84%	5.76 mins.	33.75 miles	7.30 miles	None	100.00%	7.45 mins.	43.63 miles	9.44 miles	None
Data Sets with Reduced Fire Teams										
All Staging Areas										
	Full Data Set					Reduced Data Set				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	MaxDistance	Uncovered
MCLP	88.05%	20.69 mins.	95.73 miles	18.49 miles	2	88.89%	20.67 mins.	98.12 miles	18.54 miles	2
p-median	99.37%	10.52 mins.	55.51 miles	19.08 miles	None	100.00%	10.92 mins.	57.65 miles	19.83 miles	None
p-center	99.37%	14.60 mins.	74.77 miles	12.91 miles	None	100.00%	15.17 mins.	77.71 miles	13.42 miles	None
Hybrid	99.37%	12.06 mins.	63.82 miles	12.91 miles	None	100.00%	12.53 mins.	66.32 miles	13.42 miles	None
	Percentage Change from Original Data Set					Percentage Change from Original Data Set				
MCLP	21.67%	-0.19%	-1.19%	-0.27%	2	17.94%	-1.47%	-9.12%	-0.75%	2
p-median	1.53%	113.82%	92.54%	74.25%	N/A	---	71.70%	54.68%	40.04%	N/A
p-center	1.53%	88.87%	70.16%	76.85%	N/A	---	51.70%	36.81%	42.16%	N/A
Hybrid	1.53%	109.38%	89.10%	76.85%	N/A		68.19%	52.01%	42.16%	N/A
Data Sets with Reduced Maximum Distance										
All Staging Areas										
	Full Data Set					Reduced Data Set				
	Usage	Response time	Total Distance	MaxDistance	Uncovered	Usage	Response time	Total Distance	MaxDistance	Uncovered
MCLP	92.67%	9.94 mins.	43.51 miles	9.42 miles	27	97.77%	9.87 mins.	48.36 miles	9.42 miles	27
p-median	97.84%	4.92 mins.	28.83 miles	10.95 miles	None	100.00%	6.36 mins.	37.27 miles	14.16 miles	None
p-center	97.84%	7.73 mins.	43.94 miles	7.30 miles	None	100.00%	10 mins.	56.80 miles	9.44 miles	None
Hybrid	97.84%	5.76 mins.	33.75 miles	7.30 miles	None	100.00%	7.45 mins.	43.63 miles	9.44 miles	None
	Percentage Change from Original Data Set					Percentage Change from Original Data Set				
MCLP	26.29%	-52.05%	-55.09%	-49.19%	27	26.82%	-51.55%	-55.21%	-49.57%	27
	Percentage Change from Data Set w/ Reduced Fire Teams					Percentage Change from Data Set w/ Reduced Fire Teams				
MCLP	4.62%	-51.96%	-54.55%	-49.05%	25	8.88%	-52.25%	-50.71%	-49.26%	25

Table 17. MAF Only Staging Areas Solution
Comparison between Data Set Types

Original Data Set					
MAF Only Staging Areas					
	Usage	Response time	Total Distance	Max Distance	Uncovered
MCLP	77.59%	16.37 mins.	78.30 miles	16.81 miles	3
p-median	97.84%	12.38 mins.	59.93 miles	12.98 miles	None
p-center	90.52%	13.44 mins.	66.55 miles	12.53 miles	None
Hybrid	97.84%	12.71 mins.	62.31 miles	12.53 miles	None
Data Set w/ Reduced Fire Teams					
MAF Only Staging Areas					
	Usage	Response time	Total Distance	Max Distance	Uncovered
MCLP	94.97%	16.39 mins.	72.43 miles	16.63 miles	28
p-median	99.37%	15.22 mins.	75.21 miles	19.05 miles	None
p-center	98.11%	17.38 mins.	87.24 miles	17.12 miles	None
Hybrid	99.37%	16.33 mins.	81.80 miles	17.12 miles	None
Percentage Change from Original Data Set					
MCLP	17.38%	0.12%	-7.50%	-1.07%	25
p-median	1.53%	22.94%	25.50%	46.76%	N/A
p-center	7.59%	29.32%	31.09%	36.63%	N/A
Hybrid	1.53%	28.48%	31.28%	36.63%	N/A
Data Set w/ Reduced Maximum Distance					
MCLP	85.78%	10.27 mins.	34.98 miles	8.92 miles	103
Percentage Change from Original Data Set					
MCLP	8.19%	-37.26%	-55.33%	-46.94%	100
Percentage Change from Data Set w/ Reduced Fire Teams					
MCLP	-9.19%	-37.34%	-51.71%	-46.36%	75

Summary

This chapter presents the analysis of the data and the comparisons within and between model types. This comparison occurs with two different data sets, the original data set and a reduced data set that removes the days from the models that had fewer or the same number of scheduled penetrated LFs as Fire Teams available. Chapter V

includes discussion of this analysis and applicable conclusions derived from the analysis. Final recommendations and suggestions for future research also appear in Chapter V.

V. Discussion, Conclusions, and Recommendations

Introduction

This chapter discusses relevant extrapolations from the analysis of the results of the four different model types. The conclusions and recommendations resulting from this research are pertinent only to F.E. Warren AFB but can be applied to other units by incorporating the pertinent data from those units. These conclusions are based on the data analyzed and could conceivably change with a different data set and/or with a change to the previously stated assumptions. Suggestions for future research identify possibilities to improve response times even further. Screenshots of Excel® model outputs are shown for each model type and data set in Appendix B through Appendix S.

Model Choice

The choice of which model to employ is dependent upon management objectives. If the true objective is the minimum response time, the model that fulfills that objective is the clear choice for use. This same objective will minimize the average total distance. Overall, the p-median model reports the lowest response times and lowest average total distance in all data sets except the MAF only staging areas solution of the data set with reduced maximum distance. In this data set, the MCLP provides the lowest response time, but at the high cost of not covering one hundred three of three hundred seventy five scheduled penetrated LFs. This would lead to cancelled, or at least postponed, maintenance activities. Strict maximum response times may dictate another model choice, but this may come at the expense of completing all scheduled maintenance

actions, and will not guarantee optimal response times. If this becomes the management objective, the MCLP model is the likely choice. This model will provide a solution, but does not guarantee optimal response times. Another choice this research provides is to minimize the maximum distance any Fire Team is from a scheduled penetrated LF. The p-center model can accomplish this but, as the analysis shows, does not provide the lowest average response time in any of the data sets. Finally, the hybrid model can be chosen if the objective is to minimize the maximum distance any Fire Team is located from a scheduled penetrated LF and then attempt to reduce the total distance and average response times.

Minimum Response Time

The p-median model provides an average response time in the original full data set with the all staging areas solution of 4.92 minutes, with an average total distance of 28.83 miles. The MAF only staging areas solution in this data set produces an average response time of 12.38 minutes with an average total distance of 59.93 miles. The reduced data set produces an average response time of 6.36 minutes, with an average total distance of 37.27 miles. These times and distances are the same in the data set with reduced maximum distance because this reduced distance has no effect on the p-median, p-center, or hybrid models. The data set with reduced Fire Teams produces response times in the all staging areas solution of 10.51 minutes for the full data set, with an average total distance of 55.49 miles, and 10.92 minutes in the reduced data set, having an average total distance of 57.66 miles. The MAF only staging areas solution has an

average response time of 15.22 minutes and an average total distance of 75.21 miles in the full data set.

Predetermined Maximum Response Time

The MCLP model, based on a 30-minute maximum response time, produces average response times of 20.73 minutes and 16.37 minutes for the all staging areas solution and MAF only staging areas solution, respectively, in the original full data set. The all staging areas solution time changes to 20.37 minutes in the original reduced data set. This model produces much higher average response times than the other three models in the all staging areas solution and nominally higher in the MAF only staging areas solutions. Available Fire Teams are less taxed in this model, with usage in the original full data set at 66.38% for the all staging areas solution and 77.59% for the MAF only staging areas solution. The original reduced data set employs 70.95% of available Fire Teams for the all staging areas solution. This lower percentage of Fire Team usage also means each Fire Team is responsible for a larger area of coverage than in the other models or scheduled penetrated LFs are left uncovered. No scheduled penetrated LFs are left uncovered in either original data set for the all staging areas solution but three are left uncovered in the MAF only staging areas solution of the full data set.

The all staging areas solution of the full data set with reduced Fire Teams shows a slight improvement in response time and distance to 20.69 minutes and 95.73 miles, with Fire Team usage increasing to 88.05%. The reduced data set shows a slight degrade in response times with an improvement in total distance with 20.67 minutes and 98.12 miles, using 88.89% of available Fire Teams. Both data sets are unable to cover two

scheduled penetrated LFs. The MAF only staging areas solution average response time increases slightly in the full data set to 16.39 minutes and the average total distance decreases to 72.43 miles. Fire Team usage rises to 94.97% in this data set. The MAF only staging areas improvements come at the expense of twenty eight uncovered penetrated LFs.

Both data sets with reduced maximum distance show marked improvement in response times and average total distance, but at a very high cost in maintenance performance. These improvements should be apparent since the maximum distance is reduced to ten miles, equating to a maximum response time of fifteen minutes. The all staging areas solution of the full data set shows an average response time of 9.94 minutes with an average total distance of 43.51 miles and 92.67% Fire Team usage. The reduced data set provides a similar solution with 9.87 minutes, 48.36 miles, and usage at 97.77%. Both data sets sacrifice twenty seven scheduled penetrated LFs. The MAF only staging areas solution of the full data set produces an average response time of 10.27 minutes and an average total distance of 34.98 miles. Fire Team usage is at 85.78% and a staggering one hundred three scheduled penetrated LFs remain uncovered.

Minimized Maximum Distance

In this research, the p-center and hybrid models produce an average maximum distance of any Fire Team from a penetrated LF in the original full data set of 7.30 miles for the all staging areas solution, with an average response time of 7.73 minutes, and 12.53 miles in the MAF only staging areas solution, with an average time of 13.44 minutes. The original reduced data set produces a distance of 9.44 miles for the all

staging areas solution with an average response time of 10 minutes. Again, these times and distances are the same in the data sets with reduced maximum distance. The full data set with reduced Fire Teams provides distances of 12.91 miles in the all staging areas solution and 17.12 miles in the MAF only staging areas solution. Average response times are 14.60 minutes and 17.38 minutes, respectively. The reduced data set has a distance of 13.42 miles in the all staging areas solution with an average response time of 15.17 minutes.

Multiple Objectives

The hybrid model is able to minimize the average maximum distance of any Fire Team from a scheduled penetrated LF and then improve the total distance over that of the p-center model. It provides the same distance in every data set type as the p-center model, but reduces the average total distance and average response time over the entire data set. The original full data set shows the hybrid model reduces the p-center average total distance from 43.94 miles to 33.75 miles in the all staging areas solution and average response time from 7.73 minutes to 5.76 minutes. The MAF only staging areas solution shows reductions in average total distance from 66.55 miles to 62.31 miles and average response time from 13.44 minutes to 12.71 minutes. The original reduced data set shows improvement in the all staging areas solution in average total distance from 56.80 miles in the p-center model to 43.63 miles in the hybrid model. The average response time reduces from 10 minutes to 7.45 minutes. These figures remain the same in the data set with reduced maximum distance.

The data sets with reduced Fire Teams also shows marked improvement in average total distance and average response time when employing the hybrid model over the p-center model. In the all staging areas solution of the full data set, distance is reduced from 74.77 miles to 63.82 miles and average response time from 14.60 minutes to 12.06 minutes. The MAF only staging areas solution has reductions in average total distance from 87.24 miles to 81.80 miles and average response time from 17.38 minutes to 16.33 minutes. The reduced data set has improvements in the all staging areas solution from 77.71 miles to 66.32 miles for average total distance and from 15.17 minutes to 12.53 minutes for average response time.

Conclusions and Recommendations

This researcher advocates the use of the hybrid model utilizing the all staging areas solution. This solution minimizes the "radius of responsibility" for Fire Teams by positioning them in a manner that minimizes the furthest distance from a penetrated LF, and then seeks the lowest overall response time. This model delivers only slightly higher response times than the p-median model but prevents extreme distances between Fire Teams and penetrated LFs, as shown when comparing the maximum distances obtained over entire data sets for this parameter. The maximum distance any Fire Team is located from a penetrated LF in the all staging areas solution of the original full data set is 18.15 miles in the hybrid model and 28.66 miles in the p-median model. The MAF only staging areas solution in this data set shows the maximum distance for the hybrid model at 22.88 miles and 25.34 miles for the p-median model. The reduced Fire Teams full data set has a maximum distance in the all staging areas solution of the hybrid

model at 21.57 miles compared to 33.36 miles in the p-median model. The MAF only staging areas hybrid model maximum distance in this data set is 27.31 miles and 36.38 miles for the p-median model. Use of this model requires a trade-off of positioning Fire Teams at the selected staging areas, which may forego the creature comforts of MAF positioning.

The p-median model can be considered as the secondary choice if the only objective is to minimize average response times. The p-median model produces the lowest average response times and lowest average total distance, without sacrificing any scheduled maintenance. Comparing it with the results from the MCLP and p-center models shows the GRASP heuristic obtains, at minimum, a very good solution.

The p-center model may be used to prevent any single, or possibly multiple, penetrated LFs from exceeding some established threshold for distance from a Fire Team. This model produces good average response times, yet still exceeds the p-median model times by just over 57% in both original data sets and, thus, both data sets with reduced maximum distance. The data sets with reduced Fire Teams show the p-center solution has at least 51% greater response times in the all staging areas solution and more than 27% in the MAF only staging areas solutions. The hybrid model is able to produce better average response times while still maintaining the maximum distance any Fire Team is located from a penetrated LF obtained from the p-center model solution, so it should be considered superior to a p-center model solution.

The MCLP model should only be utilized in an iterative manner. This model provides the highest average response times unless the maximum allowable distance is reduced in an iterative manner, and then some scheduled penetrated LFs are likely to be

left uncovered. This may allow users to view what, if any, scheduled penetrated LFs may have to be sacrificed to achieve a specified response time. The only possible positive aspect of this model is it may allow for instances of "roving" Fire Teams when usage is under 100%. This, however, likely provides little enhancement to security and, as shown, produces a higher average response time.

This research has shown that, in most cases, the MAF only staging areas solution produces much higher average response times. The instances where average response times decrease occur because scheduled penetrated LFs are left uncovered. At times, a very large percentage of scheduled penetrated LFs are left uncovered with this solution type. Improved response times utilizing current methods are unlikely to occur if these limited number of staging areas are consistently used.

No matter the choice of model, subjective decision making should still be employed. The MCLP model clearly shows the effect on maintenance of establishing rigid response time thresholds. Several of the scheduled penetrated LFs left uncovered using this model are only a fraction over the specified distance constraint. This would result in cancelled maintenance if decision makers are not given the latitude to exercise prudent judgment. Similarly, decision makers may be willing to sacrifice a small amount of response time to position forces at a MAF. This would not be possible if the objective to minimize response times is blindly employed.

Suggestions for Further Study

One aspect that may provide significant furthering of this research is a study on better maintenance scheduling methods. It may be possible to more closely align priority

maintenance and periodic maintenance schedules. This may be very difficult since priority maintenance problems generally have an unpredictable pattern. Scheduling priority maintenance to be more closely aligned with periodic maintenance requirements would likely require a relaxation of alert rate standards. It may be feasible to achieve this alignment by limiting scheduled maintenance to certain days of the week and performing priority maintenance that falls outside the general geographical area of the ongoing scheduled maintenance during the remaining days.

To ensure complete accuracy, actual distances can be recorded and incorporated into the model. Some of this data may already be available, but it would require extensive effort to obtain actual distances to complete the entire distance matrix. Additional, or different, staging areas may also be identified and incorporated into the model. Latitude and longitude coordinates will be required to achieve this, but incorporation into the models is easily accomplished with this data. All models and documentation for use will be delivered to Twentieth Air Force at the conclusion of this research.

Summary

This chapter summarized the findings of this research. Options and specific recommendations for model use were presented. Comparisons of the model options were shown based on the original analysis parameters. Suggestions for further study were provided in the hope of further reducing response times and enhancing ICBM security.

Appendix A: Missile Maintenance Priority Designators

ATTACHMENT 2

MISSILE MAINTENANCE PRIORITY DESIGNATORS

Table A2.1. Priority Designators.

MAINTENANCE PRIORITY	APPLICATION	SUGGESTED UND (Supply System Priority
1	Repair of critical equipment needed for safe operation of the weapon system Maintenance actions needed to prevent damage or further damage to the weapon system, avoid injury to personnel or render the weapon system safe	A

Appendix A: Missile Maintenance Priority Designators

2	Priority 2 maintenance is listed by order of relative priority	A
	Return of an LCC to operational status when three or more are non-operational in the same squadron	
	Maintenance required to retain/return "A Category (CAT)" sorties to EWO alert status	
	Actual EWO generation of "F CAT" and "L CAT" sorties	
	Time change requirements for re-entry systems when the due date is within 30 days	A
	Maintenance required to reposture LFs and LCCs being returned from modification/test programs	
	When a known environmental compliance discrepancy exists which could result in a violation of federal, state or local regulations or Air Force/base instructions	
	Repair of severed, damaged or seriously degraded Hardened Intersite Cable System (HICS)	
	Multiple outages of command and control systems (Strategic Automated Command and Control System (SACCS), Milstar, Air Force Satellite Communications (AFSATCOM), Survivable Low Frequency Communications System (SLFCS), ICBM SHF Satellite Terminal (ISST) and UHF Radio System) which will seriously jeopardize alert notification to two or more LCCs in a squadron	
	Restoration of squadron IPD collection capability to the Missile Support Base	
	Maintenance required to deposture LFs and LCCs committed to modification/command approved or directed test programs	

Appendix A: Missile Maintenance Priority Designators

33 (Cont)	Discrepancies expected to affect alert posture or degrade impact accuracy	A
	Discrepancies which are time sensitive as directed by technical data or which, because of the nature of the discrepancy, require periodic monitoring	
	Maintenance required to return an LCC to operational status when two are non-operational in the same squadron	
	Return of a single command and control communications system at an LCC involving SACCS, Milstar, AFSATCOM, SLFCS, EWO-2, Hardened Voice Channel (HVC), ISST or UHF Radio System	
	All PMC conditions not specifically identified as Priority 4	
	A hardness/survivability PMC discrepancy within the launch tube or which affects the missile	
	Maintenance to clear discrepancies which require camper alert teams	
	Support of Dash 6 periodic maintenance schedules even though the package may be composed of discrepancies of lower priority	A
	Support equipment requiring emergency repair or calibration, the lack of which will delay or prevent mission accomplishment	
	Critical end items and repairable spares designated "Priority Repair"	
	Actions to accomplish immediate MCLs	
	Maintenance required to bring serviceable quantities to established critical levels	

Appendix A: Missile Maintenance Priority Designators

4	Hardness/survivability discrepancies in the LERs, but not in the launch tube Outages on non-command and control communications systems Impairments to any command and control communications systems Scheduled training dispatches/tasks Training devices requiring repair which prevent or delay training Return of an LCC to operational status when four are operational in the same squadron	A
5	Hardness/survivability discrepancies in the LCC TCTOs and MCLs, which if not promptly completed, could exceed recession date; also MCLs designated as "Urgent" Overdue periodic inspections and overdue time change items Site or support equipment discrepancies not expected to result in a PMC condition, but if corrected will enhance safety, weapon system operation or reliability Impairments to non-command and control communication systems	B

Appendix A: Missile Maintenance Priority Designators

6	Periodic Inspections, TCTOs, MCLs and time change items Communications preventative maintenance inspections (PMI) Routine maintenance of training devices Scheduled calibration of support equipment not listed under a higher priority	B
7	Minor repair of missiles and support equipment not listed under a higher priority Fabrication and repair of weapon system items not carrying a higher priority of non-weapon system items Communication discrepancies which don't affect equipment status	C
8	Informational entries	N/A
9	Deferred discrepancies	N/A

Appendix B: MCLP Results, Original Full Data Set

			Max Cover									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	23.80	3	111.07	19.58		19.23	2	89.75	19.29	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	20.32	3	94.82	19.54		19.12	3	89.25	19.29	
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	21.98	2	131.87	19.10		14.90	4	89.39	19.29	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	22.80	4	121.61	19.54		15.86	4	84.60	19.29	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	17.57	3	82.02	19.54		16.49	3	76.95	19.29	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	19.51	4	143.05	19.22		20.00	4	146.67	19.91	
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	16.67	4	122.21	19.79		15.20	5	111.45	18.55	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	17.82	3	59.39	18.65		20.09	3	66.97	17.82	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	23.68	3	157.85	19.71		18.85	4	125.66	17.32	
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	17.09	3	79.74	19.47		12.24	3	57.14	12.71	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	21.02	2	84.10	19.96		11.66	3	46.64	12.71	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	20.23	3	134.87	16.74		18.89	3	125.96	18.68	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	19.24	2	128.27	17.19		19.33	3	128.83	18.68	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	20.11	4	147.51	19.80		17.03	3	124.87	19.69	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	18.91	2	75.64	18.41		13.29	4	53.14	14.71	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	16.19	3	107.94	19.22		16.28	4	108.52	17.72	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	19.65	4	144.07	18.66		17.45	5	127.97	17.72	
2/12/2004	5	, E-11, D-7, B-4, D-10	17.09	1	45.57	18.40		19.41	2	51.76	18.30	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	21.53	4	186.62	19.58		16.81	4	134.44	18.56	, G-11
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	21.74	4	202.91	19.70		19.09	4	178.15	19.80	
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	14.57	3	97.15	17.23		17.12	4	102.72	17.89	, F-4
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	20.85	3	83.41	16.26		17.30	4	69.19	18.06	
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	20.95	2	125.73	18.03		16.19	4	97.11	13.27	
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	19.77	3	105.44	19.96		18.05	4	96.28	19.69	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	19.49	2	64.98	19.45		15.50	2	51.67	16.51	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	21.18	4	98.84	17.81		16.11	4	64.45	18.55	, N-7
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	21.78	2	101.66	17.13		12.32	3	57.50	15.02	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	21.77	2	101.58	17.13		14.88	4	69.42	18.55	
3/8/2004	4	, E-6, G-4, A-8, B-7	19.46	3	51.89	19.68		13.53	3	36.09	11.84	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	24.41	3	130.18	18.57		15.27	4	81.45	16.29	
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	23.40	3	109.21	18.57		15.70	4	73.27	15.02	
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	24.40	3	81.34	19.65		12.47	3	41.56	12.26	
3/15/2004	4	, D-5, G-4, A-5, E-8	21.83	3	58.22	18.56		14.55	3	38.79	14.71	
3/16/2004	3	, G-4, E-8	22.44	2	29.92	17.00		11.84	2	15.79	8.07	
3/17/2004	4	, G-4, E-8, A-8, G-6	20.69	2	55.16	18.75		13.36	3	35.63	10.15	
3/18/2004	5	, G-4, E-6, A-5, A-8	21.80	2	58.14	15.92		14.61	3	38.96	14.71	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	22.41	2	74.70	19.54		15.88	3	52.94	18.94	
3/23/2004	5	, E-6, A-5, G-9, G-11, E-8	22.94	2	76.45	19.70		20.04	2	66.79	18.94	
3/24/2004	5	, E-6, E-8, A-6, I-8, C-4	26.14	3	87.14	19.54		16.44	3	54.80	17.12	
3/25/2004	5	, E-8, I-8, A-6	19.94	2	39.87	17.45		21.10	2	42.19	17.12	
3/29/2004	4	, E-6, E-10, M-5, M-6	23.58	2	62.87	17.13		10.78	2	28.76	10.50	
3/30/2004	4	, E-6, E-10, M-5, M-6	23.58	2	62.87	17.13		10.78	2	28.76	10.50	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	18.83	3	75.31	18.15		15.22	4	60.90	17.30	
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	16.52	3	66.08	16.37		18.53	3	74.12	17.30	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	22.15	5	118.12	19.24		15.70	5	83.72	17.30	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	19.68	2	91.86	16.66		15.34	3	71.57	16.51	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	19.99	3	79.94	18.33		15.31	3	61.26	17.54	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	16.77	4	67.07	19.07		15.64	5	62.58	19.69	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	22.40	4	134.38	19.26		20.01	5	120.05	19.61	
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	19.37	5	142.07	19.26		21.18	4	155.36	19.12	
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	20.53	3	82.13	19.26		17.79	4	71.17	18.21	
5/9/2004	5	, O-4, G-7, A-11, C-8, G-2	23.99	3	79.96	17.51		19.04	3	63.46	17.51	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	23.99	3	79.96	17.51		19.04	3	63.46	17.51	
Total:	232	**Averages and Total number of FTs Used:**	20.73	154	96.88	18.54		16.37	180	78.30	16.81	
			% FTs used	66.38%				**% FTs used**	77.59%			
			Max.		**Max.**	**Max.**		**Max.**		**Max.**	**Max.**	
			26.14		202.91	19.96		21.18		178.15	19.91	
			Min.		**Min.**	**Min.**		**Min.**		**Min.**	**Min.**	
			14.57		29.92	15.92		10.78		15.79	8.07	

Appendix C: p-median Results, Original Full Data Set

			P-Median									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	3.92	5	18.28	9.86		12.29	5	57.37	10.50	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	9.22	3	43.05	13.96		14.36	3	67.04	17.64	
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	4.86	5	29.19	9.34		10.78	5	64.69	12.33	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	4.62	5	24.63	13.81		11.78	5	62.83	12.33	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	2.32	5	10.83	5.87		11.25	5	52.51	9.66	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	9.53	5	69.92	15.82		15.08	5	110.58	19.34	
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	7.50	5	55.02	15.20		11.62	5	85.19	11.77	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	3.27	4	10.89	10.89		13.30	4	44.33	10.15	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	11.66	4	77.73	20.62		14.14	4	94.27	22.79	
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	6.30	4	29.41	13.90		11.38	4	53.12	10.50	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	1.16	5	4.64	4.64		10.65	5	42.62	10.15	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	7.12	5	47.46	13.42		13.08	5	87.23	12.15	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	6.69	5	44.63	13.42		12.56	5	83.74	11.12	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	5.79	5	42.48	10.20		11.16	5	81.81	11.12	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	3.61	4	14.44	9.79		11.19	4	44.75	14.71	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	5.29	5	35.29	12.23		11.04	5	73.61	10.77	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	6.54	5	47.95	12.97		12.52	5	91.78	12.71	
2/12/2004	5	, E-11, D-7, B-4, D-10	0.00	4	0.00	0.00		10.67	4	28.45	10.05	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	13.80	4	119.56	28.66		16.05	4	139.06	25.34	
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	13.60	4	126.96	26.21		16.28	4	151.93	18.68	
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	9.23	4	61.54	15.28		14.30	4	95.33	23.43	
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	7.64	4	30.56	21.01		14.13	4	56.51	21.58	
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	9.64	4	57.85	17.49		14.80	4	88.81	12.97	
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	7.48	4	39.89	14.99		14.98	4	79.92	13.27	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	1.38	4	4.61	4.61		11.17	4	37.24	10.45	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	11.94	4	55.74	23.11		16.07	4	74.99	20.54	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	6.86	3	32.02	10.50		10.58	3	49.39	10.50	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	2.74	5	12.78	7.29		10.68	5	49.85	10.50	
3/8/2004	4	, E-6, G-4, A-8, B-7	0.00	4	0.00	0.00		11.74	4	31.30	10.15	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	6.17	4	32.92	17.24		12.06	4	64.32	11.84	
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	5.86	4	27.32	17.24		11.25	4	52.49	10.15	
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	1.41	4	4.71	4.71		10.16	4	33.86	10.15	
3/15/2004	4	, D-5, G-4, A-5, E-8	0.00	4	0.00	0.00		12.71	4	33.90	9.82	
3/16/2004	3	, G-4, E-8	0.00	2	0.00	0.00		11.84	2	15.79	8.07	
3/17/2004	4	, G-4, E-8, A-8, G-6	0.00	4	0.00	0.00		13.32	4	35.52	10.15	
3/18/2004	5	, G-4, E-6, A-5, A-8	0.00	4	0.00	0.00		12.78	4	34.08	10.15	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	2.76	4	9.18	9.18		10.78	4	35.93	9.82	
3/23/2004	5	, E-6, A-5, G-9, G-11, E-8	0.00	5	0.00	0.00		12.36	5	41.21	10.12	
3/24/2004	5	, E-6, E-8, A-6, I-8, C-4	0.00	5	0.00	0.00		10.63	5	35.43	8.74	
3/25/2004	5	, E-8, I-8, A-6	0.00	3	0.00	0.00		11.41	3	22.82	8.74	
3/29/2004	4	, E-6, E-10, M-5, M-6	0.00	4	0.00	0.00		10.78	4	28.76	10.50	
3/30/2004	4	, E-6, E-10, M-5, M-6	0.00	4	0.00	0.00		10.78	4	28.76	10.50	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	8.95	4	35.82	18.37		13.52	4	54.10	14.23	
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	1.50	5	6.01	6.01		14.24	5	56.96	16.37	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	5.59	5	29.82	19.71		14.42	5	76.92	16.37	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	10.54	3	49.19	18.15		14.10	3	65.79	17.30	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	6.36	3	25.42	15.13		9.78	3	39.12	10.15	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	2.57	5	10.26	10.26		9.83	5	39.33	9.16	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	8.67	5	52.02	21.11		14.43	5	86.59	20.07	
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	10.07	5	73.84	24.00		14.04	5	102.93	19.00	
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	2.65	5	10.62	10.62		12.18	5	48.72	12.05	
5/9/2004	5	, O-4, G-7, A-11, C-8, G-2	0.00	5	0.00	0.00		9.43	5	31.43	8.65	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	4.12	4	13.72	13.72		9.43	4	31.43	8.65	
Total:	232	**Averages and Total number of FTs Used:**	4.92	227	28.83	10.95		12.38	227	59.93	12.98	
			% FTs used	97.84%				**% FTs used**	97.84%			
			Max.		**Max.**	**Max.**		**Max.**		**Max.**	**Max.**	
			13.80		126.96	28.66		16.28		151.93	25.34	
			Min.		**Min.**	**Min.**		**Min.**		**Min.**	**Min.**	
			0.00		0.00	0.00		9.43		15.79	8.07	

Appendix D: p-center Results, Original Full Data Set

			P-Center									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	6.82	5	31.85	6.12		12.29	4	57.37	10.50	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	12.35	3	57.62	10.50		14.36	3	67.04	17.64	
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	8.01	5	48.07	8.77		10.78	5	64.69	12.33	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	10.21	5	54.44	9.38		11.78	5	62.83	12.33	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	4.56	5	21.29	5.87		11.25	5	52.51	9.66	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	11.73	5	85.99	10.52		16.84	5	123.49	17.64	
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	11.67	5	85.58	9.62		11.62	5	85.19	11.77	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	4.88	4	16.27	6.57		13.30	4	44.33	10.15	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	15.51	4	103.39	14.86		18.85	4	125.66	17.32	
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	7.76	4	36.19	9.80		11.38	4	53.12	10.50	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	2.11	5	8.44	3.03		10.65	4	42.62	10.15	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	8.30	5	55.31	9.16		13.59	5	90.60	12.15	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	7.45	5	49.64	7.88		12.86	5	85.76	11.12	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	8.35	5	61.21	9.58		11.16	5	81.81	11.12	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	5.59	4	22.37	7.27		12.02	4	48.08	12.79	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	9.13	5	60.85	8.70		11.04	5	73.61	10.77	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	10.94	5	80.25	9.94		12.52	5	91.78	12.71	
2/12/2004	5	, E-11, D-7, B-4, D-10	0.00	4	0.00	0.00		10.67	3	28.45	10.05	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	18.22	4	157.87	18.15		24.73	4	214.31	22.88	
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	16.25	4	151.70	15.21		19.12	4	178.47	18.27	
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	14.25	4	94.97	11.62		21.90	4	146.03	20.62	
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	17.63	4	70.52	13.96		16.69	4	66.75	18.06	
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	12.41	4	74.46	10.16		14.80	4	88.81	12.97	
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	10.00	4	53.33	9.89		15.58	4	83.09	13.27	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	1.50	4	5.00	2.78		11.17	4	37.24	10.45	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	19.65	4	91.68	14.67		20.71	4	96.65	20.54	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	8.70	3	40.58	9.26		11.01	3	51.40	10.50	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	5.74	5	26.80	6.12		12.06	3	56.28	10.50	
3/8/2004	4	, E-6, G-4, A-8, B-7	0.00	4	0.00	0.00		12.22	4	32.59	10.15	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	12.33	4	65.75	11.84		12.44	4	66.34	11.84	
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	10.76	4	50.22	10.15		11.68	4	54.50	10.15	
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	2.71	4	9.03	4.14		10.54	3	35.15	10.15	
3/15/2004	4	, D-5, G-4, A-5, E-8	0.00	4	0.00	0.00		13.49	4	35.98	9.82	
3/16/2004	3	, G-4, E-8	0.00	2	0.00	0.00		11.84	2	15.79	8.07	
3/17/2004	4	, G-4, E-8, A-8, G-6	0.00	4	0.00	0.00		14.10	4	37.59	10.15	
3/18/2004	5	, G-4, E-6, A-5, A-8	0.00	4	0.00	0.00		13.26	3	35.37	10.15	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	2.81	4	9.38	4.80		10.78	4	35.93	9.82	
3/23/2004	5	, E-6, A-5, G-9, G-11, E-8	0.00	5	0.00	0.00		12.36	3	41.21	10.12	
3/24/2004	5	, E-6, E-8, A-6, I-8, C-4	0.00	5	0.00	0.00		10.63	4	35.43	8.74	
3/25/2004	5	, E-8, I-8, A-6	0.00	3	0.00	0.00		11.41	3	22.82	8.74	
3/29/2004	4	, E-6, E-10, M-5, M-6	0.00	4	0.00	0.00		10.78	2	28.76	10.50	
3/30/2004	4	, E-6, E-10, M-5, M-6	0.00	4	0.00	0.00		10.78	2	28.76	10.50	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	13.25	4	53.00	10.36		15.42	4	61.69	14.23	
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	4.89	5	19.56	4.94		16.76	4	67.04	16.37	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	10.95	5	58.41	10.92		14.42	5	76.92	16.37	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	16.15	3	75.39	13.32		15.34	3	71.57	16.51	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	9.74	3	38.97	7.86		9.78	3	39.12	10.15	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	8.62	5	34.49	6.41		9.83	5	39.33	9.16	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	16.58	5	99.47	14.84		18.39	5	110.35	17.26	
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	15.18	5	111.31	13.59		19.46	4	142.69	17.26	
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	6.53	5	26.11	5.82		12.82	5	51.27	12.05	
5/9/2004	5	, O-4, G-7, A-11, C-8, G-2	0.00	5	0.00	0.00		9.43	4	31.43	8.65	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	9.67	4	32.24	8.65		9.43	4	31.43	8.65	
Total:	232	**Averages and Total number of FTs Used:**	7.73	227	43.94	7.30		13.44	210	66.55	12.53	
			% FTs used	97.84%				**% FTs used**	90.52%			
			Max.		**Max.**	**Max.**		**Max.**		**Max.**	**Max.**	
			19.65		157.87	18.15		24.73		214.31	22.88	
			Min.		**Min.**	**Min.**		**Min.**		**Min.**	**Min.**	
			0.00		0.00	0.00		9.43		15.79	8.07	

Appendix E: Hybrid Results, Original Full Data Set

			Hybrid									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	4.46	5	20.82	6.12		12.29	5	57.37	10.50	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	11.45	3	53.41	10.50		14.36	3	67.04	17.64	
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	6.32	5	37.91	8.77		10.78	5	64.69	12.33	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	8.77	5	46.80	9.38		11.78	5	62.83	12.33	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	2.32	5	10.83	5.87		11.25	5	52.51	9.66	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	11.73	5	85.99	10.52		16.74	5	122.74	17.64	
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	8.10	5	59.41	9.57		11.62	5	85.19	11.77	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	3.33	4	11.09	6.57		13.30	4	44.33	10.15	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	12.84	4	85.59	14.86		15.77	4	105.11	17.32	
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	7.34	4	34.23	9.80		11.38	4	53.12	10.50	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	2.11	5	8.44	3.03		10.65	5	42.62	10.15	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	7.41	5	49.37	9.16		13.08	5	87.23	12.15	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	7.45	5	49.64	7.88		12.56	5	83.74	11.12	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	6.58	5	48.27	9.58		11.16	5	81.81	11.12	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	4.33	4	17.31	7.27		12.02	4	48.08	12.79	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	6.84	5	45.59	8.70		11.04	5	73.61	10.77	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	7.13	5	52.26	9.94		12.52	5	91.78	12.71	
2/12/2004	5	, E-11, D-7, B-4, D-10	0.00	4	0.00	0.00		10.67	4	28.45	10.05	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	15.02	4	130.21	18.15		20.66	4	179.04	22.88	
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	15.84	4	147.88	15.21		18.37	4	171.44	18.27	
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	14.25	4	94.97	11.62		15.70	4	104.65	20.62	
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	9.19	4	36.78	13.96		14.85	4	59.41	18.06	
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	10.60	4	63.60	10.16		14.80	4	88.81	12.97	
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	9.04	4	48.22	9.89		14.98	4	79.92	13.27	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	1.50	4	5.00	2.78		11.17	4	37.24	10.45	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	14.06	4	65.61	14.67		16.07	4	74.99	20.54	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	7.21	3	33.67	9.26		10.58	3	49.39	10.50	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	3.49	5	16.27	6.12		10.68	5	49.85	10.50	
3/8/2004	4	, E-6, G-4, A-8, B-7	0.00	4	0.00	0.00		11.74	4	31.30	10.15	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	7.35	4	39.20	11.84		12.06	4	64.32	11.84	
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	5.86	4	27.37	10.15		11.25	4	52.49	10.15	
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	2.71	4	9.03	4.14		10.16	4	33.86	10.15	
3/15/2004	4	, D-5, G-4, A-5, E-8	0.00	4	0.00	0.00		12.71	4	33.90	9.82	
3/16/2004	3	, G-4, E-8	0.00	2	0.00	0.00		11.84	2	15.79	8.07	
3/17/2004	4	, G-4, E-8, A-8, G-6	0.00	4	0.00	0.00		13.32	4	35.52	10.15	
3/18/2004	5	, G-4, E-6, A-5, A-8	0.00	4	0.00	0.00		12.78	4	34.08	10.15	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	2.81	4	9.38	4.80		10.78	4	35.93	9.82	
3/23/2004	5	, E-6, A-5, G-9, G-11, E-8	0.00	5	0.00	0.00		12.36	5	41.21	10.12	
3/24/2004	5	, E-6, E-8, A-6, I-8, C-4	0.00	5	0.00	0.00		10.63	5	35.43	8.74	
3/25/2004	5	, E-8, I-8, A-6	0.00	3	0.00	0.00		11.41	3	22.82	8.74	
3/29/2004	4	, E-6, E-10, M-5, M-6	0.00	4	0.00	0.00		10.78	4	28.76	10.50	
3/30/2004	4	, E-6, E-10, M-5, M-6	0.00	4	0.00	0.00		10.78	4	28.76	10.50	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	9.29	4	37.17	10.36		13.52	4	54.10	14.23	
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	2.35	5	9.41	4.87		14.24	5	56.96	16.37	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	5.76	5	30.71	10.92		14.42	5	76.92	16.37	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	12.87	3	60.05	13.32		15.34	3	71.57	16.51	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	6.37	3	25.50	7.86		9.78	3	39.12	10.15	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	2.87	5	11.49	6.41		9.83	5	39.33	9.16	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	9.73	5	58.38	14.84		16.52	5	99.13	17.26	
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	11.84	5	86.85	13.59		15.34	5	112.47	17.21	
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	2.73	5	10.91	5.82		12.18	5	48.72	12.05	
5/9/2004	5	, O-4, G-7, A-11, C-8, G-2	0.00	5	0.00	0.00		9.43	5	31.43	8.65	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	4.26	4	14.20	8.65		9.43	4	31.43	8.65	
Total:	232	Averages and Total number of FTs Used:	5.76	227	33.75	7.30		12.71	227	62.31	12.53	
			% FTs used	97.84%				% FTs used	97.84%			
			Max.		Max.	Max.		Max.		Max.	Max.	
			15.84		147.88	18.15		20.66		179.04	22.88	
			Min.		Min.	Min.		Min.		Min.	Min.	
			0.00		0.00	0.00		9.43		15.79	8.07	

Appendix F: MCLP Results, Original Reduced Data Set

			Max Cover				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	23.80	3	111.07	19.58	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	20.32	3	94.82	19.54	
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	21.98	2	131.87	19.10	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	22.80	4	121.61	19.54	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	17.57	3	82.02	19.54	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	19.51	4	143.05	19.22	
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	16.67	4	122.21	19.79	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	17.82	3	59.39	18.65	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	23.68	3	157.85	19.71	
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	17.09	3	79.74	19.47	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	21.02	2	84.10	19.96	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	20.23	3	134.87	16.74	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	19.24	2	128.27	17.19	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	20.11	4	147.51	19.80	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	18.91	2	75.64	18.41	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	16.19	3	107.94	19.22	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	19.65	4	144.07	18.66	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	21.53	4	186.62	19.58	
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	21.74	4	202.91	19.70	
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	14.57	3	97.15	17.23	
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	20.85	3	83.41	16.26	
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	20.95	2	125.73	18.03	
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	19.77	3	105.44	19.96	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	19.49	2	64.98	19.45	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	21.18	4	98.84	17.81	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	21.78	2	101.66	17.13	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	21.77	2	101.58	17.13	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	24.41	3	130.18	18.57	
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	23.40	3	109.21	18.57	
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	24.40	3	81.34	19.65	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	22.41	2	74.70	19.54	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	18.83	3	75.31	18.15	
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	16.52	3	66.08	16.37	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	22.15	5	118.12	19.24	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	19.68	2	91.86	16.66	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	19.99	3	79.94	18.33	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	16.77	4	67.07	19.07	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	22.40	4	134.38	19.26	
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	19.37	5	142.07	19.26	
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	20.53	3	82.13	19.26	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	23.99	3	79.96	17.51	
Total:	179	**Averages and Total number of FTs Used:**	20.37	127	107.97	18.68	
			% FTs used	70.95%			
			Max.		**Max.**	**Max.**	
			24.41		202.91	19.96	
			Min.		**Min.**	**Min.**	
			14.57		59.39	16.26	

Appendix G: p-median Results, Original Reduced Data Set

			P-Median				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	3.92	5	18.28	9.86	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	9.22	3	43.05	13.96	
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	4.86	5	29.19	9.34	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	4.62	5	24.63	13.81	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	2.32	5	10.83	5.87	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	9.53	5	69.92	15.82	
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	7.50	5	55.02	15.20	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	3.27	4	10.89	10.89	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	11.66	4	77.73	20.62	
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	6.30	4	29.41	13.90	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	1.16	5	4.64	4.64	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	7.12	5	47.46	13.42	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	6.69	5	44.63	13.42	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	5.79	5	42.48	10.20	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	3.61	4	14.44	9.79	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	5.29	5	35.29	12.23	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	6.54	5	47.95	12.97	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	13.80	4	119.56	28.66	
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	13.60	4	126.96	26.21	
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	9.23	4	61.54	15.28	
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	7.64	4	30.56	21.01	
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	9.64	4	57.85	17.49	
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	7.48	4	39.89	14.99	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	1.38	4	4.61	4.61	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	11.94	4	55.74	23.11	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	6.86	3	32.02	10.50	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	2.74	5	12.78	7.29	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	6.17	4	32.92	17.24	
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	5.86	4	27.32	17.24	
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	1.41	4	4.71	4.71	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	2.76	4	9.18	9.18	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	8.95	4	35.82	18.37	
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	1.50	5	6.01	6.01	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	5.59	5	29.82	19.71	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	10.54	3	49.19	18.15	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	6.36	3	25.42	15.13	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	2.57	5	10.26	10.26	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	8.67	5	52.02	21.11	
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	10.07	5	73.84	24.00	
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	2.65	5	10.62	10.62	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	4.12	4	13.72	13.72	
Total:	179	**Averages and Total number of FTs Used:**	6.36	179	37.27	14.16	
			% FTs used	100.00%			
			Max.		**Max.**	**Max.**	
			13.80		126.96	28.66	
			Min.		**Min.**	**Min.**	
			1.16		4.61	4.61	

Appendix H: p-center Results, Original Reduced Data Set

			P-Center				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	6.82	5	31.85	6.12	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	12.35	3	57.62	10.50	
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	8.01	5	48.07	8.77	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	10.21	5	54.44	9.38	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	4.56	5	21.29	5.87	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	11.73	5	85.99	10.52	
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	11.67	5	85.58	9.62	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	4.88	4	16.27	6.57	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	15.51	4	103.39	14.86	
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	7.76	4	36.19	9.80	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	2.11	5	8.44	3.03	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	8.30	5	55.31	9.16	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	7.45	5	49.64	7.88	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	8.35	5	61.21	9.58	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	5.59	4	22.37	7.27	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	9.13	5	60.85	8.70	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	10.94	5	80.25	9.94	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	18.22	4	157.87	18.15	
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	16.25	4	151.70	15.21	
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	14.25	4	94.97	11.62	
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	17.63	4	70.52	13.96	
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	12.41	4	74.46	10.16	
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	10.00	4	53.33	9.89	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	1.50	4	5.00	2.78	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	19.65	4	91.68	14.67	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	8.70	3	40.58	9.26	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	5.74	5	26.80	6.12	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	12.33	4	65.75	11.84	
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	10.76	4	50.22	10.15	
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	2.71	4	9.03	4.14	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	2.81	4	9.38	4.80	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	13.25	4	53.00	10.36	
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	4.89	5	19.56	4.94	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	10.95	5	58.41	10.92	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	16.15	3	75.39	13.32	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	9.74	3	38.97	7.86	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	8.62	5	34.49	6.41	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	16.58	5	99.47	14.84	
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	15.18	5	111.31	13.59	
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	6.53	5	26.11	5.82	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	9.67	4	32.24	8.65	
Total:	179	**Averages and Total number of FTs Used:**	10.00	179	56.80	9.44	
			% FTs used	100.00%			
			Max.		**Max.**	**Max.**	
			19.65		157.87	18.15	
			Min.		**Min.**	**Min.**	
			1.50		5.00	2.78	

Appendix I: Hybrid Results, Original Reduced Data Set

			Hybrid				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	4.46	5	20.82	6.12	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	11.45	3	53.41	10.50	
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	6.32	5	37.91	8.77	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	8.77	5	46.80	9.38	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	2.32	5	10.83	5.87	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	11.73	5	85.99	10.52	
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	8.10	5	59.41	9.57	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	3.33	4	11.09	6.57	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	12.84	4	85.59	14.86	
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	7.34	4	34.23	9.80	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	2.11	5	8.44	3.03	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	7.41	5	49.37	9.16	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	7.45	5	49.64	7.88	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	6.58	5	48.27	9.58	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	4.33	4	17.31	7.27	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	6.84	5	45.59	8.70	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	7.13	5	52.26	9.94	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	15.02	4	130.21	18.15	
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	15.84	4	147.88	15.21	
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	14.25	4	94.97	11.62	
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	9.19	4	36.78	13.96	
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	10.60	4	63.60	10.16	
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	9.04	4	48.22	9.89	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	1.50	4	5.00	2.78	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	14.06	4	65.61	14.67	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	7.21	3	33.67	9.26	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	3.49	5	16.27	6.12	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	7.35	4	39.20	11.84	
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	5.86	4	27.37	10.15	
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	2.71	4	9.03	4.14	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	2.81	4	9.38	4.80	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	9.29	4	37.17	10.36	
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	2.35	5	9.41	4.87	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	5.76	5	30.71	10.92	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	12.87	3	60.05	13.32	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	6.37	3	25.50	7.86	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	2.87	5	11.49	6.41	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	9.73	5	58.38	14.84	
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	11.84	5	86.85	13.59	
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	2.73	5	10.91	5.82	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	4.26	4	14.20	8.65	
Total:	179	**Averages and Total number of FTs Used:**	7.45	179	43.63	9.44	
			% FTs used	100.00%			
			Max.		**Max.**	**Max.**	
			15.84		147.88	18.15	
			Min.		**Min.**	**Min.**	
			1.50		5.00	2.78	

Appendix J. MCLP Results, Full Data Set w/Reduced Fire Teams

			Max Cover									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	3	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	23.80	3	111.07	19.58		19.23	2	89.75	19.29	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	20.32	3	94.82	19.54		19.12	3	89.25	19.29	
1/12/2004	3	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	21.98	2	131.87	19.10		14.90	3	89.39	19.29	
1/13/2004	3	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	18.90	3	100.81	19.10		16.16	3	75.42	19.29	, B-2
1/14/2004	3	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	17.57	3	82.02	19.54		16.49	3	76.95	19.29	
1/20/2004	3	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	20.23	3	148.39	19.29		20.46	3	136.37	19.34	, E-9
1/21/2004	3	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	19.14	3	140.39	19.17		15.19	3	101.30	18.55	, A-8
1/22/2004	3	, A-3, A-8, B-3, C-9, G-10	17.82	3	59.39	18.65		20.09	3	66.97	17.82	
1/27/2004	3	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	17.25	3	115.01	19.96		15.96	3	85.13	17.43	, D-2, E-7
1/28/2004	3	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	17.09	3	79.74	19.47		12.24	3	57.14	12.71	
1/29/2004	3	, E-7, G-2, A-2, I-9, A-8, A-11	21.02	2	84.10	19.96		11.66	3	46.64	12.71	
2/3/2004	3	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	15.26	3	101.75	17.19		18.89	3	125.96	18.68	
2/4/2004	3	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	19.24	2	128.27	17.19		19.33	3	128.83	18.68	
2/5/2004	3	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	18.35	3	134.56	17.57		17.03	3	124.87	19.69	
2/9/2004	3	, E-11, G-2, C-5, A-5, O-11, E-9	18.91	2	75.64	18.41		13.29	3	53.14	14.71	
2/10/2004	3	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	16.19	3	107.94	19.22		15.97	3	95.83	17.72	, M-4
2/11/2004	3	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	16.77	3	123.00	19.32		16.20	3	108.02	18.68	, E-9
2/12/2004	3	, E-11, D-7, B-4, D-10	17.09	1	45.57	18.40		19.41	2	51.76	18.30	
2/17/2004	3	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	21.36	3	185.09	19.22		15.06	3	100.41	17.00	, J-6, N-11, N-7
2/18/2004	3	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	21.71	3	202.64	19.60		17.95	3	143.60	17.45	, J-6, N-11
2/19/2004	3	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	14.57	3	97.15	17.23		16.10	3	85.89	16.97	, E-9, F-4
2/23/2004	3	, E-9, G-3, A-9, A-11, K-10, N-8	20.85	3	83.41	16.26		17.62	3	58.74	18.06	, G-3
2/24/2004	3	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	20.95	2	125.73	18.03		15.72	3	83.84	12.97	, E-9
2/25/2004	3	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	17.48	3	93.23	18.32		17.57	3	81.99	19.69	, L-4
2/26/2004	3	, E-9, G-3, D-7, L-10, E-8	19.49	2	64.98	19.45		15.50	2	51.67	16.51	
3/2/2004	3	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	22.59	3	105.40	17.81		17.82	3	59.40	18.55	, A-9, N-7
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	21.78	2	101.66	17.13		12.32	3	57.50	15.02	
3/4/2004	3	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	21.77	2	101.58	17.13		14.88	3	69.42	18.55	
3/8/2004	3	, E-6, G-4, A-8, B-7	17.44	3	46.50	17.13		13.53	3	36.09	11.84	
3/9/2004	3	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	24.41	3	130.18	18.57		16.09	3	75.07	16.29	, E-6
3/10/2004	3	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	23.40	3	109.21	18.57		16.72	3	66.89	15.02	, E-6
3/11/2004	3	, A-9, E-6, G-4, H-9, A-8	24.40	3	81.34	19.65		12.47	3	41.56	12.26	
3/15/2004	3	, D-5, G-4, A-5, E-8	21.83	3	58.22	18.56		14.55	3	38.79	14.71	
3/16/2004	3	, G-4, E-8	22.44	2	29.92	17.00		11.84	2	15.79	8.07	
3/17/2004	3	, G-4, E-8, A-8, G-6	20.69	2	55.16	18.75		13.36	3	35.63	10.15	
3/18/2004	3	, G-4, E-6, A-5, A-8	21.80	2	58.14	15.92		14.61	3	38.96	14.71	
3/22/2004	3	, E-6, E-8, G-9, A-5, B-4	22.41	2	74.70	19.54		15.88	3	52.94	18.94	
3/23/2004	3	, E-6, A-5, G-9, G-11, E-8	22.94	2	76.45	19.70		20.04	2	66.79	18.94	
3/24/2004	3	, E-6, E-8, A-6, I-8, C-4	26.14	3	87.14	19.54		16.44	3	54.80	17.12	
3/25/2004	3	, E-8, I-8, A-6	19.94	2	39.87	17.45		21.10	2	42.19	17.12	
3/29/2004	3	, E-6, E-10, M-5, M-6	23.58	2	62.87	17.13		10.78	2	28.76	10.50	
3/30/2004	3	, E-6, E-10, M-5, M-6	23.58	2	62.87	17.13		10.78	2	28.76	10.50	
4/5/2004	3	, E-10, B-4, M-9, J-11, N-6, G-6	23.18	3	92.72	19.71		16.82	3	56.06	17.30	, B-4
4/6/2004	3	, D-9, E-10, B-6, B-7, B-9, F-4	16.52	3	66.08	16.37		18.53	3	74.12	17.30	
4/7/2004	3	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	22.09	3	103.09	19.71	, E-10	18.59	3	74.36	17.30	, N-6, M-5
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	19.68	2	91.86	16.66		15.34	3	71.57	16.51	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	19.99	3	79.94	18.33		15.31	3	61.26	17.54	
4/29/2004	3	, O-4, M-9, C-3, A-9, J-5, O-9	22.36	3	89.44	19.54		19.16	3	63.87	18.21	, J-5
5/3/2004	3	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	23.50	3	125.33	19.67	, M-8	18.26	3	85.20	17.26	, M-8, B-11
5/4/2004	3	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	23.97	3	175.78	19.95		20.43	3	136.23	18.21	, G-7
5/5/2004	3	, O-4, G-7, M-8, B-6, C-9, N-9	22.98	3	91.92	19.66		17.79	3	71.17	18.21	
5/9/2004	3	, O-4, G-7, A-11, C-8, G-2	23.99	3	79.96	17.51		19.04	3	63.46	17.51	
5/10/2004	3	, O-4, G-7, A-11, C-8, G-2	23.99	3	79.96	17.51		19.04	3	63.46	17.51	
Total:	159	Averages and Total number of FTs Used:	20.69	140	95.73	18.49		16.39	151	72.43	16.63	
			% FTs used	88.05%				% FTs used	94.97%			
			Max.		Max.	Max.		Max.		Max.	Max.	
			26.14		202.64	19.96		21.10		143.60	19.69	
			Min.		Min.	Min.		Min.		Min.	Min.	
			14.57		29.92	15.92		10.78		15.79	8.07	

Appendix K. p-median Results, Full Data Set w/Reduced Fire Teams

			P-Median									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	3	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	11.27	3	52.60	23.07		14.38	3	67.11	18.56	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	9.22	3	43.05	13.96		14.36	3	67.04	17.64	
1/12/2004	3	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	10.42	3	62.54	18.87		14.90	3	89.39	19.29	
1/13/2004	3	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	12.27	3	65.42	26.31		17.85	3	95.21	26.82	
1/14/2004	3	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	8.38	3	39.11	14.48		14.66	3	68.39	19.29	
1/20/2004	3	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	15.86	3	116.32	25.90		19.01	3	139.44	22.50	
1/21/2004	3	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	12.58	3	92.28	19.47		15.65	3	114.80	22.50	
1/22/2004	3	, A-3, A-8, B-3, C-9, G-10	8.17	3	27.23	16.35		13.59	3	45.29	10.52	
1/27/2004	3	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	15.20	3	101.35	23.61		18.16	3	121.07	24.77	
1/28/2004	3	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	10.18	3	47.51	18.10		12.24	3	57.14	12.71	
1/29/2004	3	, E-7, G-2, A-2, I-9, A-8, A-11	9.47	3	37.87	18.10		11.66	3	46.64	12.71	
2/3/2004	3	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	12.91	3	86.09	21.81		15.88	3	105.88	22.50	
2/4/2004	3	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	12.27	3	81.78	17.87		15.29	3	101.96	22.50	
2/5/2004	3	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	12.40	3	90.90	17.19		17.03	3	124.87	19.69	
2/9/2004	3	, E-11, G-2, C-5, A-5, O-11, E-9	7.63	3	30.54	16.09		13.24	3	52.96	14.71	
2/10/2004	3	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	10.74	3	71.59	15.49		14.91	3	99.38	27.35	
2/11/2004	3	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	13.09	3	95.98	16.09		16.93	3	124.17	27.35	
2/12/2004	3	, E-11, D-7, B-4, D-10	2.85	3	7.60	7.60		10.67	3	28.45	10.05	
2/17/2004	3	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	18.50	3	160.36	29.91		20.16	3	174.75	30.18	
2/18/2004	3	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	17.61	3	164.35	26.21		19.52	3	182.15	24.71	
2/19/2004	3	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	12.70	3	84.66	19.57		18.10	3	120.67	24.67	
2/23/2004	3	, E-9, G-3, A-9, A-11, K-10, N-8	15.26	3	61.05	25.26		18.52	3	74.09	27.71	
2/24/2004	3	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	13.76	3	82.59	22.26		17.30	3	103.82	23.30	
2/25/2004	3	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	12.56	3	66.97	27.08		17.71	3	94.44	24.47	
2/26/2004	3	, E-9, G-3, D-7, L-10, E-8	6.13	3	20.42	15.82		12.02	3	40.07	11.67	
3/2/2004	3	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	17.44	3	81.37	22.99		19.90	3	92.87	22.94	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	6.86	3	32.02	10.50		10.58	3	49.39	10.50	
3/4/2004	3	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	7.95	3	37.09	13.29		12.06	3	56.28	10.50	
3/8/2004	3	, E-6, G-4, A-8, B-7	8.21	3	21.90	21.90		13.53	3	36.09	11.84	
3/9/2004	3	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	10.96	3	58.44	25.51		15.16	3	80.88	22.93	
3/10/2004	3	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	11.32	3	52.84	25.51		14.79	3	69.04	22.93	
3/11/2004	3	, A-9, E-6, G-4, H-9, A-8	3.09	3	10.30	5.59		10.54	3	35.15	10.15	
3/15/2004	3	, D-5, G-4, A-5, E-8	7.76	3	20.70	16.09		14.55	3	38.79	14.71	
3/16/2004	3	, G-4, E-8	0.00	2	0.00	0.00		11.84	2	15.79	8.07	
3/17/2004	3	, G-4, E-8, A-8, G-6	3.33	3	8.88	8.88		13.36	3	35.63	10.15	
3/18/2004	3	, G-4, E-6, A-5, A-8	6.45	3	17.19	17.19		12.78	3	34.08	10.15	
3/22/2004	3	, E-6, E-8, G-9, A-5, B-4	8.28	3	27.58	18.40		12.24	3	40.81	14.71	
3/23/2004	3	, E-6, A-5, G-9, G-11, E-8	6.67	3	22.23	9.18		12.36	3	41.21	10.12	
3/24/2004	3	, E-6, E-8, A-6, I-8, C-4	8.51	3	28.36	19.18		13.93	3	46.42	17.00	
3/25/2004	3	, E-8, I-8, A-6	0.00	3	0.00	0.00		11.41	3	22.82	8.74	
3/29/2004	3	, E-6, E-10, M-5, M-6	3.46	3	9.24	9.24		10.78	3	28.76	10.50	
3/30/2004	3	, E-6, E-10, M-5, M-6	3.46	3	9.24	9.24		10.78	3	28.76	10.50	
4/5/2004	3	, E-10, B-4, M-9, J-11, N-6, G-6	17.51	3	70.03	25.51		18.64	3	74.57	30.98	
4/6/2004	3	, D-9, E-10, B-6, B-7, B-9, F-4	8.87	3	35.47	21.41		16.29	3	65.17	16.37	
4/7/2004	3	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	17.71	3	94.44	33.36		21.86	3	116.60	30.98	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	10.54	3	49.19	18.15		14.10	3	65.79	17.30	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	6.36	3	25.42	15.13		9.78	3	39.12	10.15	
4/29/2004	3	, O-4, M-9, C-3, A-9, J-5, O-9	15.10	3	60.38	30.22		19.84	3	79.35	33.32	
5/3/2004	3	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	19.07	3	114.39	29.62		21.45	3	128.68	36.38	
5/4/2004	3	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	16.65	3	122.11	24.00		19.79	3	145.12	36.38	
5/5/2004	3	, O-4, G-7, M-8, B-6, C-9, N-9	12.25	3	48.98	18.07		17.79	3	71.17	18.21	
5/9/2004	3	, O-4, G-7, A-11, C-8, G-2	14.08	3	46.92	33.20		16.32	3	54.41	17.51	
5/10/2004	3	, O-4, G-7, A-11, C-8, G-2	14.08	3	46.92	33.20		16.32	3	54.41	17.51	
Total:	159	Averages and Total number of FTs Used:	10.52	158	55.51	19.08		15.22	158	75.21	19.05	
			% FTs used	99.37%				% FTs used	99.37%			
			Max.		Max.	Max.		Max.		Max.	Max.	
			19.07		164.35	33.36		21.86		182.15	36.38	
			Min.		Min.	Min.		Min.		Min.	Min.	
			0.00		0.00	0.00		9.78		15.79	8.07	

Appendix L. p-center Results, Full Data Set w/Reduced Fire Teams

			P-Center									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	3	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	15.46	3	72.16	12.47		18.57	3	86.65	17.64	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	12.35	3	57.62	10.50		14.36	3	67.04	17.64	
1/12/2004	3	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	16.02	3	96.15	13.60		14.90	3	89.39	19.29	
1/13/2004	3	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	17.79	3	94.88	16.31		24.31	3	129.68	22.00	
1/14/2004	3	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	10.55	3	49.21	10.03		18.80	3	87.73	17.64	
1/20/2004	3	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	18.73	3	137.38	17.87		21.00	3	154.01	20.62	
1/21/2004	3	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	14.21	3	104.22	14.77		23.81	3	174.64	21.68	
1/22/2004	3	, A-3, A-8, B-3, C-9, G-10	13.23	3	44.11	10.52		13.59	3	45.29	10.52	
1/27/2004	3	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	18.67	3	124.45	16.33		20.13	3	134.21	22.79	
1/28/2004	3	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	11.40	3	53.21	10.15		12.24	3	57.14	12.71	
1/29/2004	3	, E-7, G-2, A-2, I-9, A-8, A-11	13.09	3	52.35	10.17		13.04	3	52.17	12.71	
2/3/2004	3	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	16.81	3	112.10	15.99		19.13	3	127.50	18.68	
2/4/2004	3	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	15.79	3	105.29	14.48		20.50	3	136.69	18.68	
2/5/2004	3	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	16.49	3	120.91	15.99		18.85	3	138.24	19.69	
2/9/2004	3	, E-11, G-2, C-5, A-5, O-11, E-9	18.55	3	74.21	14.48		15.20	3	60.82	14.71	
2/10/2004	3	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	14.26	3	95.06	15.49		17.10	3	114.03	20.80	
2/11/2004	3	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	18.12	3	132.85	15.44		17.54	3	128.64	20.62	
2/12/2004	3	, E-11, D-7, B-4, D-10	6.43	3	17.15	4.59		10.67	3	28.45	10.05	
2/17/2004	3	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	22.97	3	199.06	19.22		25.62	3	222.03	23.92	
2/18/2004	3	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	21.31	3	198.88	18.15		22.20	3	207.19	23.43	
2/19/2004	3	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	15.64	3	104.25	13.72		22.98	3	153.22	20.94	
2/23/2004	3	, E-9, G-3, A-9, A-11, K-10, N-8	19.68	3	78.74	16.26		19.75	3	78.99	23.30	
2/24/2004	3	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	14.13	3	84.80	15.96		17.87	3	107.23	20.62	
2/25/2004	3	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	17.71	3	94.44	17.00		21.08	3	112.40	20.62	
2/26/2004	3	, E-9, G-3, D-7, L-10, E-8	10.06	3	33.53	10.13		14.41	3	48.04	11.67	
3/2/2004	3	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	23.18	3	108.18	17.11		23.37	3	109.04	22.38	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	8.70	3	40.58	9.26		11.01	3	51.40	10.50	
3/4/2004	3	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	9.60	3	44.81	7.98		12.06	3	56.28	10.50	
3/8/2004	3	, E-6, G-4, A-8, B-7	13.53	3	36.09	11.84		14.02	3	37.38	11.84	
3/9/2004	3	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	15.27	3	81.43	15.14		17.11	3	91.26	22.25	
3/10/2004	3	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	14.91	3	69.60	15.14		17.02	3	79.43	22.25	
3/11/2004	3	, A-9, E-6, G-4, H-9, A-8	4.77	3	15.91	4.71		10.54	3	35.15	10.15	
3/15/2004	3	, D-5, G-4, A-5, E-8	13.40	3	35.73	11.48		15.73	3	41.94	14.71	
3/16/2004	3	, G-4, E-8	0.00	2	0.00	0.00		11.84	2	15.79	8.07	
3/17/2004	3	, G-4, E-8, A-8, G-6	4.68	3	12.48	5.16		13.66	3	36.42	10.15	
3/18/2004	3	, G-4, E-6, A-5, A-8	11.76	3	31.35	9.89		13.26	3	35.37	10.15	
3/22/2004	3	, E-6, E-8, G-9, A-5, B-4	9.91	3	33.02	9.74		16.74	3	55.78	14.71	
3/23/2004	3	, E-6, A-5, G-9, G-11, E-8	8.24	3	27.48	7.49		12.36	3	41.21	10.12	
3/24/2004	3	, E-6, E-8, A-6, I-8, C-4	15.21	3	50.71	12.30		17.18	3	57.28	17.00	
3/25/2004	3	, E-8, I-8, A-6	0.00	3	0.00	0.00		11.41	3	22.82	8.74	
3/29/2004	3	, E-6, E-10, M-5, M-6	6.15	3	16.41	6.71		10.78	2	28.76	10.50	
3/30/2004	3	, E-6, E-10, M-5, M-6	6.15	3	16.41	6.71		10.78	2	28.76	10.50	
4/5/2004	3	, E-10, B-4, M-9, J-11, N-6, G-6	18.52	3	74.07	18.15		25.38	3	101.54	22.41	
4/6/2004	3	, D-9, E-10, B-6, B-7, B-9, F-4	16.15	3	64.62	14.45		16.76	3	67.04	16.37	
4/7/2004	3	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	25.32	3	135.04	21.57		27.57	3	147.05	24.01	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	16.15	3	75.39	13.32		15.34	3	71.57	16.51	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	9.74	3	38.97	7.86		9.78	3	39.12	10.15	
4/29/2004	3	, O-4, M-9, C-3, A-9, J-5, O-9	22.36	3	89.44	19.54		25.77	3	103.09	22.94	
5/3/2004	3	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	25.32	3	151.90	21.40		25.10	3	150.61	27.31	
5/4/2004	3	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	20.19	3	148.03	18.81		25.73	3	188.66	26.86	
5/5/2004	3	, O-4, G-7, M-8, B-6, C-9, N-9	17.54	3	70.18	13.97		18.43	3	73.73	18.21	
5/9/2004	3	, O-4, G-7, A-11, C-8, G-2	23.72	3	79.06	17.51		17.39	3	57.98	17.51	
5/10/2004	3	, O-4, G-7, A-11, C-8, G-2	23.72	3	79.06	17.51		17.39	3	57.98	17.51	
Total:	159	Averages and Total number of FTs Used:	14.60	158	74.77	12.91		17.38	156	87.24	17.12	
			% FTs used	99.37%				% FTs used	98.11%			
			Max.		Max.	Max.		Max.		Max.	Max.	
			25.32		199.06	21.57		27.57		222.03	27.31	
			Min.		Min.	Min.		Min.		Min.	Min.	
			0.00		0.00	0.00		9.78		15.79	8.07	

Appendix M. Hybrid Results, Full Data Set w/Reduced Fire Teams

			Hybrid									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	3	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	14.58	3	68.03	12.47		17.30	3	80.73	17.64	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	11.45	3	53.41	10.50		14.36	3	67.04	17.64	
1/12/2004	3	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	12.26	3	73.58	13.60		14.90	3	89.39	19.29	
1/13/2004	3	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	14.43	3	76.96	16.31		22.42	3	119.59	22.00	
1/14/2004	3	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	10.55	3	49.21	10.03		17.64	3	82.30	17.64	
1/20/2004	3	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	17.78	3	130.39	17.87		19.34	3	141.85	20.62	
1/21/2004	3	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	14.03	3	102.89	14.73		18.47	3	135.48	21.68	
1/22/2004	3	, A-3, A-8, B-3, C-9, G-10	9.53	3	31.76	10.52		13.59	3	45.29	10.52	
1/27/2004	3	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	18.49	3	123.25	16.28		20.13	3	134.21	22.79	
1/28/2004	3	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	11.40	3	53.21	10.15		12.24	3	57.14	12.71	
1/29/2004	3	, E-7, G-2, A-2, I-9, A-8, A-11	10.54	3	42.18	10.15		11.66	3	46.64	12.71	
2/3/2004	3	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	16.37	3	109.16	15.99		18.89	3	125.96	18.68	
2/4/2004	3	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	12.83	3	85.54	14.48		19.33	3	128.83	18.68	
2/5/2004	3	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	13.01	3	95.44	15.99		17.03	3	124.87	19.69	
2/9/2004	3	, E-11, G-2, C-5, A-5, O-11, E-9	7.64	3	30.57	14.43		13.24	3	52.96	14.71	
2/10/2004	3	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	10.74	3	71.59	15.49		16.82	3	112.10	20.80	
2/11/2004	3	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	15.30	3	112.23	15.44		17.54	3	128.64	20.62	
2/12/2004	3	, E-11, D-7, B-4, D-10	3.40	3	9.06	4.59		10.67	3	28.45	10.05	
2/17/2004	3	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	21.13	3	183.13	19.22		23.08	3	200.00	23.92	
2/18/2004	3	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	21.31	3	198.88	18.15		21.88	3	204.21	23.43	
2/19/2004	3	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	15.64	3	104.25	13.72		19.19	3	127.94	20.94	
2/23/2004	3	, E-9, G-3, A-9, A-11, K-10, N-8	16.36	3	65.45	16.26		19.10	3	76.40	23.30	
2/24/2004	3	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	14.13	3	84.77	15.96		17.41	3	104.46	20.62	
2/25/2004	3	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	14.97	3	79.83	17.00		20.96	3	111.78	20.62	
2/26/2004	3	, E-9, G-3, D-7, L-10, E-8	10.06	3	33.53	10.13		12.02	3	40.07	11.67	
3/2/2004	3	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	19.96	3	93.15	17.11		23.36	3	109.00	22.38	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	7.21	3	33.67	9.26		10.58	3	49.39	10.50	
3/4/2004	3	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	9.60	3	44.81	7.98		12.06	3	56.28	10.50	
3/8/2004	3	, E-6, G-4, A-8, B-7	8.25	3	21.99	11.84		13.53	3	36.09	11.84	
3/9/2004	3	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	12.84	3	68.46	15.14		17.11	3	91.26	22.25	
3/10/2004	3	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	12.13	3	56.62	15.14		17.02	3	79.43	22.25	
3/11/2004	3	, A-9, E-6, G-4, H-9, A-8	3.37	3	11.22	4.71		10.54	3	35.15	10.15	
3/15/2004	3	, D-5, G-4, A-5, E-8	7.77	3	20.73	11.48		14.55	3	38.79	14.71	
3/16/2004	3	, G-4, E-8	0.00	2	0.00	0.00		11.84	2	15.79	8.07	
3/17/2004	3	, G-4, E-8, A-8, G-6	4.68	3	12.48	5.16		13.36	3	35.63	10.15	
3/18/2004	3	, G-4, E-6, A-5, A-8	6.47	3	17.25	9.89		12.78	3	34.08	10.15	
3/22/2004	3	, E-6, E-8, G-9, A-5, B-4	8.29	3	27.63	9.74		12.24	3	40.81	14.71	
3/23/2004	3	, E-6, A-5, G-9, G-11, E-8	6.73	3	22.42	7.49		12.36	3	41.21	10.12	
3/24/2004	3	, E-6, E-8, A-6, I-8, C-4	9.77	3	32.58	12.30		13.93	3	46.42	17.00	
3/25/2004	3	, E-8, I-8, A-6	0.00	3	0.00	0.00		11.41	3	22.82	8.74	
3/29/2004	3	, E-6, E-10, M-5, M-6	4.45	3	11.88	6.71		10.78	3	28.76	10.50	
3/30/2004	3	, E-6, E-10, M-5, M-6	4.45	3	11.88	6.71		10.78	3	28.76	10.50	
4/5/2004	3	, E-10, B-4, M-9, J-11, N-6, G-6	17.77	3	71.07	18.15		21.39	3	85.57	22.41	
4/6/2004	3	, D-9, E-10, B-6, B-7, B-9, F-4	12.89	3	51.54	14.45		16.29	3	65.17	16.37	
4/7/2004	3	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	23.31	3	124.35	21.57		25.35	3	135.19	24.01	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	12.87	3	60.05	13.32		15.34	3	71.57	16.51	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	6.37	3	25.50	7.86		9.78	3	39.12	10.15	
4/29/2004	3	, O-4, M-9, C-3, A-9, J-5, O-9	20.07	3	80.28	19.54		23.16	3	92.65	22.94	
5/3/2004	3	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	22.20	3	133.23	21.40		22.78	3	136.65	27.31	
5/4/2004	3	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	18.38	3	134.80	18.81		23.63	3	173.30	26.86	
5/5/2004	3	, O-4, G-7, M-8, B-6, C-9, N-9	12.87	3	51.49	13.97		17.79	3	71.17	18.21	
5/9/2004	3	, O-4, G-7, A-11, C-8, G-2	14.26	3	47.52	17.51		16.32	3	54.41	17.51	
5/10/2004	3	, O-4, G-7, A-11, C-8, G-2	14.26	3	47.52	17.51		16.32	3	54.41	17.51	
Total:	159	Averages and Total number of FTs Used:	12.06	158	63.82	12.91		16.33	158	81.80	17.12	
			% FTs used	99.37%				% FTs used	99.37%			
			Max.		Max.	Max.		Max.		Max.	Max.	
			23.31		198.88	21.57		25.35		204.21	27.31	
			Min.		Min.	Min.		Min.		Min.	Min.	
			0.00		0.00	0.00		9.78		15.79	8.07	

Appendix N. MCLP Results, Reduced Data Set w/Reduced Fire Teams

			Max Cover				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	3	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	23.80	3	111.07	19.58	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	20.32	3	94.82	19.54	
1/12/2004	3	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	21.98	2	131.87	19.10	
1/13/2004	3	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	18.90	3	100.81	19.10	
1/14/2004	3	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	17.57	3	82.02	19.54	
1/20/2004	3	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	20.23	3	148.39	19.29	
1/21/2004	3	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	19.14	3	140.39	19.17	
1/22/2004	3	, A-3, A-8, B-3, C-9, G-10	17.82	3	59.39	18.65	
1/27/2004	3	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	17.25	3	115.01	19.96	
1/28/2004	3	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	17.09	3	79.74	19.47	
1/29/2004	3	, E-7, G-2, A-2, I-9, A-8, A-11	21.02	2	84.10	19.96	
2/3/2004	3	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	15.26	3	101.75	17.19	
2/4/2004	3	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	19.24	2	128.27	17.19	
2/5/2004	3	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	18.35	3	134.56	17.57	
2/9/2004	3	, E-11, G-2, C-5, A-5, O-11, E-9	18.91	2	75.64	18.41	
2/10/2004	3	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	16.19	3	107.94	19.22	
2/11/2004	3	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	16.77	3	123.00	19.32	
2/12/2004	3	, E-11, D-7, B-4, D-10	17.09	1	45.57	18.40	
2/17/2004	3	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	21.36	3	185.09	19.22	
2/18/2004	3	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	21.71	3	202.64	19.60	
2/19/2004	3	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	14.57	3	97.15	17.23	
2/23/2004	3	, E-9, G-3, A-9, A-11, K-10, N-8	20.85	3	83.41	16.26	
2/24/2004	3	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	20.95	2	125.73	18.03	
2/25/2004	3	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	17.48	3	93.23	18.32	
2/26/2004	3	, E-9, G-3, D-7, L-10, E-8	19.49	2	64.98	19.45	
3/2/2004	3	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	22.59	3	105.40	17.81	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	21.78	2	101.66	17.13	
3/4/2004	3	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	21.77	2	101.58	17.13	
3/8/2004	3	, E-6, G-4, A-8, B-7	17.44	3	46.50	17.13	
3/9/2004	3	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	24.41	3	130.18	18.57	
3/10/2004	3	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	23.40	3	109.21	18.57	
3/11/2004	3	, A-9, E-6, G-4, H-9, A-8	24.40	3	81.34	19.65	
3/15/2004	3	, D-5, G-4, A-5, E-8	21.83	3	58.22	18.56	
3/17/2004	3	, G-4, E-8, A-8, G-6	20.69	2	55.16	18.75	
3/18/2004	3	, G-4, E-6, A-5, A-8	21.80	2	58.14	15.92	
3/22/2004	3	, E-6, E-8, G-9, A-5, B-4	22.41	2	74.70	19.54	
3/23/2004	3	, E-6, A-5, G-9, G-11, E-8	22.94	2	76.45	19.70	
3/24/2004	3	, E-6, E-8, A-6, I-8, C-4	26.14	3	87.14	19.54	
3/29/2004	3	, E-6, E-10, M-5, M-6	23.58	2	62.87	17.13	
3/30/2004	3	, E-6, E-10, M-5, M-6	23.58	2	62.87	17.13	
4/5/2004	3	, E-10, B-4, M-9, J-11, N-6, G-6	23.18	3	92.72	19.71	
4/6/2004	3	, D-9, E-10, B-6, B-7, B-9, F-4	16.52	3	66.08	16.37	
4/7/2004	3	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	22.09	3	103.09	19.71	, E-10
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	19.68	2	91.86	16.66	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	19.99	3	79.94	18.33	
4/29/2004	3	, O-4, M-9, C-3, A-9, J-5, O-9	22.36	3	89.44	19.54	
5/3/2004	3	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	23.50	3	125.33	19.67	, M-8
5/4/2004	3	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	23.97	3	175.78	19.95	
5/5/2004	3	, O-4, G-7, M-8, B-6, C-9, N-9	22.98	3	91.92	19.66	
5/9/2004	3	, O-4, G-7, A-11, C-8, G-2	23.99	3	79.9574	17.51	
5/10/2004	3	, O-4, G-7, A-11, C-8, G-2	23.99	3	79.96	17.51	
Total:	153	**Averages and Total number of FTs Used:**	20.67	136	98.12	18.54	
			% FTs used	88.89%			
			Max.		**Max.**	**Max.**	
			26.14		202.64	19.96	
			Min.		**Min.**	**Min.**	
			14.57		45.57	15.92	

Appendix O. p-median Results, Reduced Data Set w/Reduced Fire Teams

			P-Median				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	3	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	11.27	3	52.60	23.07	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	9.22	3	43.05	13.96	
1/12/2004	3	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	10.42	3	62.54	18.87	
1/13/2004	3	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	12.27	3	65.42	26.31	
1/14/2004	3	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	8.38	3	39.11	14.48	
1/20/2004	3	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	15.86	3	116.32	25.90	
1/21/2004	3	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	12.58	3	92.28	19.47	
1/22/2004	3	, A-3, A-8, B-3, C-9, G-10	8.17	3	27.23	16.35	
1/27/2004	3	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	15.20	3	101.35	23.61	
1/28/2004	3	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	10.18	3	47.51	18.10	
1/29/2004	3	, E-7, G-2, A-2, I-9, A-8, A-11	9.47	3	37.87	18.10	
2/3/2004	3	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	12.91	3	86.09	21.81	
2/4/2004	3	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	12.27	3	81.78	17.87	
2/5/2004	3	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	12.40	3	90.90	17.19	
2/9/2004	3	, E-11, G-2, C-5, A-5, O-11, E-9	7.63	3	30.54	16.09	
2/10/2004	3	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	10.74	3	71.59	15.49	
2/11/2004	3	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	13.09	3	95.98	16.09	
2/12/2004	3	, E-11, D-7, B-4, D-10	2.85	3	7.60	7.60	
2/17/2004	3	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	18.50	3	160.36	29.91	
2/18/2004	3	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	17.61	3	164.35	26.21	
2/19/2004	3	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	12.70	3	84.66	19.57	
2/23/2004	3	, E-9, G-3, A-9, A-11, K-10, N-8	15.26	3	61.05	25.26	
2/24/2004	3	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	13.76	3	82.59	22.26	
2/25/2004	3	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	12.56	3	66.97	27.08	
2/26/2004	3	, E-9, G-3, D-7, L-10, E-8	6.13	3	20.42	15.82	
3/2/2004	3	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	17.03	3	79.48	22.99	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	6.86	3	32.02	10.50	
3/4/2004	3	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	7.95	3	37.09	13.29	
3/8/2004	3	, E-6, G-4, A-8, B-7	8.21	3	21.90	21.90	
3/9/2004	3	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	10.96	3	58.44	25.51	
3/10/2004	3	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	11.32	3	52.84	25.51	
3/11/2004	3	, A-9, E-6, G-4, H-9, A-8	3.09	3	10.30	5.59	
3/15/2004	3	, D-5, G-4, A-5, E-8	7.76	3	20.70	16.09	
3/17/2004	3	, G-4, E-8, A-8, G-6	3.33	3	8.88	8.88	
3/18/2004	3	, G-4, E-6, A-5, A-8	6.45	3	17.19	17.19	
3/22/2004	3	, E-6, E-8, G-9, A-5, B-4	8.28	3	27.58	18.40	
3/23/2004	3	, E-6, A-5, G-9, G-11, E-8	6.67	3	22.23	9.18	
3/24/2004	3	, E-6, E-8, A-6, I-8, C-4	8.51	3	28.36	19.18	
3/29/2004	3	, E-6, E-10, M-5, M-6	3.46	3	9.24	9.24	
3/30/2004	3	, E-6, E-10, M-5, M-6	3.46	3	9.24	9.24	
4/5/2004	3	, E-10, B-4, M-9, J-11, N-6, G-6	17.51	3	70.03	25.51	
4/6/2004	3	, D-9, E-10, B-6, B-7, B-9, F-4	8.87	3	35.47	21.41	
4/7/2004	3	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	17.78	3	94.81	33.47	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	10.54	3	49.19	18.15	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	6.36	3	25.42	15.13	
4/29/2004	3	, O-4, M-9, C-3, A-9, J-5, O-9	15.10	3	60.38	30.22	
5/3/2004	3	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	19.07	3	114.39	29.62	
5/4/2004	3	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	16.65	3	122.11	24.00	
5/5/2004	3	, O-4, G-7, M-8, B-6, C-9, N-9	12.25	3	48.98	18.07	
5/9/2004	3	, O-4, G-7, A-11, C-8, G-2	14.08	3	46.9221	33.20	
5/10/2004	3	, O-4, G-7, A-11, C-8, G-2	14.08	3	46.92	33.20	
Total:	153	**Averages and Total number of FTs Used:**	10.92	153	57.65	19.83	
			% FTs used	100.00%			
			Max.		**Max.**	**Max.**	
			19.07		164.35	33.47	
			Min.		**Min.**	**Min.**	
			2.85		7.60	5.59	

Appendix P. p-center Results, Reduced Data Set w/Reduced Fire Teams

			P-Center				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	3	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	15.46	3	72.16	12.47	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	12.35	3	57.62	10.50	
1/12/2004	3	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	16.02	3	96.15	13.60	
1/13/2004	3	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	17.79	3	94.88	16.31	
1/14/2004	3	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	10.55	3	49.21	10.03	
1/20/2004	3	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	18.73	3	137.38	17.87	
1/21/2004	3	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	14.21	3	104.22	14.77	
1/22/2004	3	, A-3, A-8, B-3, C-9, G-10	13.23	3	44.11	10.52	
1/27/2004	3	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	18.67	3	124.45	16.33	
1/28/2004	3	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	11.40	3	53.21	10.15	
1/29/2004	3	, E-7, G-2, A-2, I-9, A-8, A-11	13.09	3	52.35	10.17	
2/3/2004	3	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	16.81	3	112.10	15.99	
2/4/2004	3	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	15.79	3	105.29	14.48	
2/5/2004	3	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	16.49	3	120.91	15.99	
2/9/2004	3	, E-11, G-2, C-5, A-5, O-11, E-9	18.55	3	74.21	14.48	
2/10/2004	3	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	14.26	3	95.06	15.49	
2/11/2004	3	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	18.12	3	132.85	15.44	
2/12/2004	3	, E-11, D-7, B-4, D-10	6.43	3	17.15	4.59	
2/17/2004	3	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	22.97	3	199.06	19.22	
2/18/2004	3	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	21.31	3	198.88	18.15	
2/19/2004	3	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	15.64	3	104.25	13.72	
2/23/2004	3	, E-9, G-3, A-9, A-11, K-10, N-8	19.68	3	78.74	16.26	
2/24/2004	3	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	14.13	3	84.80	15.96	
2/25/2004	3	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	17.71	3	94.44	17.00	
2/26/2004	3	, E-9, G-3, D-7, L-10, E-8	10.06	3	33.53	10.13	
3/2/2004	3	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	23.18	3	108.18	17.11	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	8.70	3	40.58	9.26	
3/4/2004	3	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	9.60	3	44.81	7.98	
3/8/2004	3	, E-6, G-4, A-8, B-7	13.53	3	36.09	11.84	
3/9/2004	3	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	15.27	3	81.43	15.14	
3/10/2004	3	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	14.91	3	69.60	15.14	
3/11/2004	3	, A-9, E-6, G-4, H-9, A-8	4.77	3	15.91	4.71	
3/15/2004	3	, D-5, G-4, A-5, E-8	13.40	3	35.73	11.48	
3/17/2004	3	, G-4, E-8, A-8, G-6	4.68	3	12.48	5.16	
3/18/2004	3	, G-4, E-6, A-5, A-8	11.76	3	31.35	9.89	
3/22/2004	3	, E-6, E-8, G-9, A-5, B-4	9.91	3	33.02	9.74	
3/23/2004	3	, E-6, A-5, G-9, G-11, E-8	8.24	3	27.48	7.49	
3/24/2004	3	, E-6, E-8, A-6, I-8, C-4	15.21	3	50.71	12.30	
3/29/2004	3	, E-6, E-10, M-5, M-6	6.15	3	16.41	6.71	
3/30/2004	3	, E-6, E-10, M-5, M-6	6.15	3	16.41	6.71	
4/5/2004	3	, E-10, B-4, M-9, J-11, N-6, G-6	18.52	3	74.07	18.15	
4/6/2004	3	, D-9, E-10, B-6, B-7, B-9, F-4	16.15	3	64.62	14.45	
4/7/2004	3	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	25.32	3	135.04	21.57	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	16.15	3	75.39	13.32	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	9.74	3	38.97	7.86	
4/29/2004	3	, O-4, M-9, C-3, A-9, J-5, O-9	22.36	3	89.44	19.54	
5/3/2004	3	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	25.32	3	151.90	21.40	
5/4/2004	3	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	20.19	3	148.03	18.81	
5/5/2004	3	, O-4, G-7, M-8, B-6, C-9, N-9	17.54	3	70.18	13.97	
5/9/2004	3	, O-4, G-7, A-11, C-8, G-2	23.72	3	79.0649	17.51	
5/10/2004	3	, O-4, G-7, A-11, C-8, G-2	23.72	3	79.06	17.51	
Total:	153	**Averages and Total number of FTs Used:**	15.17	153	77.71	13.42	
			% FTs used	100.00%			
			Max.		**Max.**	**Max.**	
			25.32		199.06	21.57	
			Min.		**Min.**	**Min.**	
			4.68		12.48	4.59	

Appendix Q. Hybrid Results, Reduced Data Set w/Reduced Fire Teams

			Hybrid				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	3	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	14.58	3	68.03	12.47	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	11.45	3	53.41	10.50	
1/12/2004	3	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	12.26	3	73.58	13.60	
1/13/2004	3	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	14.43	3	76.96	16.31	
1/14/2004	3	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	10.55	3	49.21	10.03	
1/20/2004	3	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	17.78	3	130.39	17.87	
1/21/2004	3	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	14.03	3	102.89	14.73	
1/22/2004	3	, A-3, A-8, B-3, C-9, G-10	9.53	3	31.76	10.52	
1/27/2004	3	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	18.49	3	123.25	16.28	
1/28/2004	3	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	11.40	3	53.21	10.15	
1/29/2004	3	, E-7, G-2, A-2, I-9, A-8, A-11	10.54	3	42.18	10.15	
2/3/2004	3	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	16.37	3	109.16	15.99	
2/4/2004	3	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	12.83	3	85.54	14.48	
2/5/2004	3	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	13.01	3	95.44	15.99	
2/9/2004	3	, E-11, G-2, C-5, A-5, O-11, E-9	7.64	3	30.57	14.43	
2/10/2004	3	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	10.74	3	71.59	15.49	
2/11/2004	3	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	15.30	3	112.23	15.44	
2/12/2004	3	, E-11, D-7, B-4, D-10	3.40	3	9.06	4.59	
2/17/2004	3	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	21.13	3	183.13	19.22	
2/18/2004	3	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	21.31	3	198.88	18.15	
2/19/2004	3	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	15.64	3	104.25	13.72	
2/23/2004	3	, E-9, G-3, A-9, A-11, K-10, N-8	16.36	3	65.45	16.26	
2/24/2004	3	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	14.13	3	84.77	15.96	
2/25/2004	3	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	14.97	3	79.83	17.00	
2/26/2004	3	, E-9, G-3, D-7, L-10, E-8	10.06	3	33.53	10.13	
3/2/2004	3	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	19.96	3	93.15	17.11	
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	7.21	3	33.67	9.26	
3/4/2004	3	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	9.60	3	44.81	7.98	
3/8/2004	3	, E-6, G-4, A-8, B-7	8.25	3	21.99	11.84	
3/9/2004	3	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	12.84	3	68.46	15.14	
3/10/2004	3	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	12.13	3	56.62	15.14	
3/11/2004	3	, A-9, E-6, G-4, H-9, A-8	3.37	3	11.22	4.71	
3/15/2004	3	, D-5, G-4, A-5, E-8	7.77	3	20.73	11.48	
3/17/2004	3	, G-4, E-8, A-8, G-6	4.68	3	12.48	5.16	
3/18/2004	3	, G-4, E-6, A-5, A-8	6.47	3	17.25	9.89	
3/22/2004	3	, E-6, E-8, G-9, A-5, B-4	8.29	3	27.63	9.74	
3/23/2004	3	, E-6, A-5, G-9, G-11, E-8	6.73	3	22.42	7.49	
3/24/2004	3	, E-6, E-8, A-6, I-8, C-4	9.77	3	32.58	12.30	
3/29/2004	3	, E-6, E-10, M-5, M-6	4.45	3	11.88	6.71	
3/30/2004	3	, E-6, E-10, M-5, M-6	4.45	3	11.88	6.71	
4/5/2004	3	, E-10, B-4, M-9, J-11, N-6, G-6	17.77	3	71.07	18.15	
4/6/2004	3	, D-9, E-10, B-6, B-7, B-9, F-4	12.89	3	51.54	14.45	
4/7/2004	3	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	23.31	3	124.35	21.57	
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	12.87	3	60.05	13.32	
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	6.37	3	25.50	7.86	
4/29/2004	3	, O-4, M-9, C-3, A-9, J-5, O-9	20.07	3	80.28	19.54	
5/3/2004	3	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	22.20	3	133.23	21.40	
5/4/2004	3	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	18.38	3	134.80	18.81	
5/5/2004	3	, O-4, G-7, M-8, B-6, C-9, N-9	12.87	3	51.49	13.97	
5/9/2004	3	, O-4, G-7, A-11, C-8, G-2	14.26	3	47.52	17.51	
5/10/2004	3	, O-4, G-7, A-11, C-8, G-2	14.26	3	47.52	17.51	
Total:	153	**Averages and Total number of FTs Used:**	12.53	153	66.32	13.42	
			% FTs used	100.00%			
			Max.		**Max.**	**Max.**	
			23.31		198.88	21.57	
			Min.		**Min.**	**Min.**	
			3.37		9.06	4.59	

Appendix R. MCLP Results, Full Data Set w/ Reduced Maximum Distance

			Max Cover									
			All SAs					MAFs Only				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	9.20	5	42.94	9.23		11.72	4	46.86	9.23	, E-10
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	13.43	3	53.72	9.93	, E-10	11.52	3	30.73	9.03	, E-10, K-11, N-5
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	11.99	5	71.96	9.93		9.65	5	45.05	9.96	, K-7, K-9
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	10.75	5	57.35	9.98		10.82	5	50.50	9.17	, K-7
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	8.41	5	39.26	9.18		11.25	5	52.51	9.66	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	10.86	5	65.18	9.83	, A-8, B-3	11.43	5	53.35	9.64	, A-8, G-10, J-6, K-9
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	10.08	5	73.93	9.62		9.71	5	51.80	9.56	, A-8, E-10, K-9
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	8.65	4	28.83	9.64		12.82	3	34.18	9.64	, A-8
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	10.43	4	55.63	8.96	, I-10, K-5	9.35	4	37.38	9.69	, A-8, E-10, I-10, K-5
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	7.76	4	36.19	9.80		9.74	4	32.46	8.68	, A-8, E-10
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	7.49	5	29.94	8.56		9.74	4	32.46	8.68	, A-8
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	9.55	5	63.70	9.58		9.74	5	45.43	8.85	, D-8, A-8, C-5
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	10.23	5	68.19	9.62		9.33	4	37.32	8.85	, D-8, E-10, A-8, C-5
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	10.37	5	76.03	9.94		8.57	5	40.01	7.13	, D-8, A-8, C-5, G-11
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	11.08	4	44.32	9.94		8.89	4	29.63	9.82	, C-5
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	10.55	5	70.33	9.84		9.15	3	42.68	8.85	, D-10, G-11, M-4
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	10.94	5	80.25	9.94		10.58	5	56.41	9.82	, G-11, M-4, D-10
2/12/2004	5	, E-11, D-7, B-4, D-10	11.55	4	30.79	9.02		9.20	3	18.40	8.85	, D-10
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	10.75	4	71.67	9.90	, A-6, J-6, K-8	9.41	4	50.17	9.96	, F-4, G-11, J-6, K-7, K-8
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	8.48	4	56.52	9.90	, A-6, J-6, K-8, N-11	9.34	4	49.82	9.96	, G-11, F-4, J-6, K-7, K-8, N-11
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	11.55	4	61.59	9.93	, G-11, H-2	8.24	4	32.98	7.69	, G-11, H-2, A-8, F-4
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	10.72	4	35.72	9.38	, K-10	9.22	4	30.72	8.13	, G-3
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	10.67	4	56.90	9.73	, E-9	10.58	4	28.23	9.89	, G-3, K-10, F-4, A-7, A-8
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	10.00	4	53.33	9.89		10.37	4	34.57	9.95	, G-3, A-7, A-8
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	9.58	4	31.93	9.28		10.05	3	26.79	8.85	, G-3
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	8.33	4	27.76	9.64	, J-3, N-7	8.21	4	27.36	6.38	, G-3, N-7
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	8.70	3	40.58	9.26		8.53	2	28.44	6.91	, G-3, E-10
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	9.37	3	43.73	9.95		9.28	3	30.92	8.93	, G-3, E-10
3/8/2004	4	, E-6, G-4, A-8, B-7	8.66	4	23.08	9.64		10.57	3	21.14	7.72	, A-8
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	8.28	4	38.64	6.91	, E-6	10.75	4	43.00	9.01	, E-6, A-8
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	7.17	4	28.69	6.91	, E-6	10.58	4	42.33	9.01	, A-8
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	10.47	3	34.90	9.64		9.37	3	24.99	9.01	, A-8
3/15/2004	4	, D-5, G-4, A-5, E-8	12.53	4	33.43	9.94		12.71	4	33.90	9.82	
3/16/2004	3	, G-4, E-8	10.23	2	13.65	9.18		11.84	2	15.79	8.07	
3/17/2004	4	, G-4, E-8, A-8, G-6	8.80	3	23.46	9.18		12.74	2	25.48	9.69	, A-8
3/18/2004	5	, G-4, E-6, A-5, A-8	10.96	4	29.24	9.74		11.96	3	23.92	9.82	, A-8
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	9.27	4	30.90	9.44		10.78	4	35.93	9.82	
3/23/2004	5	, E-6, A-5, G-9, G-11, E-8	8.87	4	29.57	9.94		11.66	3	31.09	9.82	, G-11
3/24/2004	5	, E-6, E-8, A-6, I-8, C-4	10.16	4	33.87	9.39		10.63	4	35.43	8.74	
3/25/2004	5	, E-8, I-8, A-6	12.24	3	24.48	9.18		11.41	3	22.82	8.74	
3/29/2004	4	, E-6, E-10, M-5, M-6	9.24	2	24.64	9.28		9.13	2	18.26	6.71	, E-10
3/30/2004	4	, E-6, E-10, M-5, M-6	9.24	2	24.64	9.28		9.13	2	18.26	6.71	, E-10
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	12.02	4	32.06	8.88	, M-9, N-6	11.74	4	31.31	9.69	, E-10, N-6
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	8.42	4	33.68	8.42		9.59	2	19.18	7.05	, E-10, B-9, F-4
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	9.12	5	42.55	9.99	, N-6	10.63	4	28.34	9.69	, E-10, B-9, B-10, F-4
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	9.57	3	38.28	9.47	, M-5	9.14	3	18.29	7.05	, E-10, A-8, M-5, O-3
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	9.53	3	38.12	9.82		8.69	3	28.96	6.33	, A-8
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	11.77	5	47.09	9.17		9.83	5	39.33	9.16	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	10.74	5	57.27	9.20	, M-8	11.56	5	53.93	9.98	, M-8, A-7
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	8.16	5	48.97	9.60	, G-7, M-8	10.64	5	56.74	9.30	, M-8, A-7, N-9
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	10.40	5	41.60	9.38		11.54	5	38.46	9.98	, N-9
5/9/2004	5	, O-4, G-7, A-11, C-8, G-2	9.71	4	32.37	9.20		10.50	4	35.00	9.98	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	9.71	4	32.37	9.20		10.50	4	35.00	9.98	
Total:	232	Averages and Total number of FTs Used:	9.94	215	43.51	9.42		10.27	199	34.98	8.92	
			% FTs used	92.67%				% FTs used	85.78%			
			Max.		Max.	Max.		Max.		Max.	Max.	
			13.43		80.25	9.99		12.82		56.74	9.98	
			Min.		Min.	Min.		Min.		Min.	Min.	
			7.17		13.65	6.91		8.21		15.79	6.33	

Appendix S. MCLP Results, Reduced Data Set w/ Reduced Maximum Distance

			Max Cover				
			All SAs				
Date	Number of Fire Teams Available	Scheduled Sites	Avg. Response Time (Minutes)	Number of Fire Teams Used	Total Distance	Maximum Distance of any Fire Team to a Penetrated LF	LFs not covered
1/7/2004	5	, E-3, E-8, E-10, G-10, J-6, K-8, K-11	9.20	5	42.94	9.23	
1/8/2004	3	, E-3, E-8, E-10, F-6, G-10, K-11, N-5	13.43	3	53.72	9.93	, E-10
1/12/2004	5	, D-11, E-2, G-10, J-4, K-2, K-5, K-7, K-9, K-11	11.99	5	71.96	9.93	
1/13/2004	5	, B-2, E-5, E-8, G-10, J-4, K-2, K-7, K-11	10.75	5	57.35	9.98	
1/14/2004	5	, B-2, E-5, E-8, G-10, K-11, K-2, K-7	8.41	5	39.26	9.18	
1/20/2004	5	, A-3, A-8, B-3, D-6, D-7, E-9, G-10, J-6, K-4, K-9, K-11	10.86	5	65.18	9.83	, A-8, B-3
1/21/2004	5	, A-3, A-8, C-9, D-6, E-7, E-9, E-10, G-2, G-10, K-9, K-11	10.08	5	73.93	9.62	
1/22/2004	4	, A-3, A-8, B-3, C-9, G-10	8.65	4	28.83	9.64	
1/27/2004	4	, A-11, A-8, D-2, D-6, E-10, E-7, G-2, G-6, I-10, K-5	10.43	4	55.63	8.96	, I-10, K-5
1/28/2004	4	, A-2, A-8, A-11, E-7, E-10, G-2, I-9	7.76	4	36.19	9.80	
1/29/2004	5	, E-7, G-2, A-2, I-9, A-8, A-11	7.49	5	29.94	8.56	
2/3/2004	5	, D-8, E-11, G-2, E-2, A-8, K-11, D-4, H-7, C-5, D-7	9.55	5	63.70	9.58	
2/4/2004	5	, D-8, E-11, G-2, E-10, E-2, A-8, K-11, D-4, C-5, D-7	10.23	5	68.19	9.62	
2/5/2004	5	, D-8, E-11, G-2, C-4, A-2, A-8, A-10, C-5, D-9, E-2, G-11	10.37	5	76.03	9.94	
2/9/2004	4	, E-11, G-2, C-5, A-5, O-11, E-9	11.08	4	44.32	9.94	
2/10/2004	5	, E-11, B-4, D-5, D-7, D-9, D-10, D-11, E-4, G-11, M-4	10.55	5	70.33	9.84	
2/11/2004	5	, J-10, E-11, G-11, M-4, A-5, A-10, A-4, J-6, E-9, D-10, F-9	10.94	5	80.25	9.94	
2/17/2004	4	, A-6, B-4, D-11, E-11, E-6, E-9, F-4, G-11, J-6, K-7, K-8, N-11, N-7	10.75	4	71.67	9.90	, A-6, J-6, K-8
2/18/2004	4	, G-11, E-9, A-6, B-4, C-6, D-11, E-6, E-11, F-4, F-11, J-6, K-7, K-8, N-11	8.48	4	56.52	9.90	, A-6, J-6, K-8, N-11
2/19/2004	4	, G-11, E-9, H-2, A-4, A-6, A-8, B-4, C-6, E-11, F-4	11.55	4	61.59	9.93	, G-11, H-2
2/23/2004	4	, E-9, G-3, A-9, A-11, K-10, N-8	10.72	4	35.72	9.38	, K-10
2/24/2004	4	, E-9, G-3, K-10, A-11, F-4, A-7, A-8, B-7, D-3	10.67	4	56.90	9.73	, E-9
2/25/2004	4	, E-9, G-3, A-7, A-8, E-7, O-9, L-4, A-5	10.00	4	53.33	9.89	
2/26/2004	4	, E-9, G-3, D-7, L-10, E-8	9.58	4	31.93	9.28	
3/2/2004	4	, A-9, G-3, J-3, N-7, E-2, K-11, E-6	8.33	4	27.76	9.64	, J-3, N-7
3/3/2004	3	, G-3, E-6, E-2, E-7, D-4, E-10, E-11	8.70	3	40.58	9.26	
3/4/2004	5	, G-3, E-6, F-11, D-4, E-10, E-11, K-11	9.37	3	43.73	9.95	
3/9/2004	4	, E-6, G-4, H-9, B-7, A-2, A-8, D-4, H-10	8.28	4	38.64	6.91	, E-6
3/10/2004	4	, E-6, G-4, H-9, A-2, A-8, D-4, H-10	7.17	4	28.69	6.91	, E-6
3/11/2004	4	, A-9, E-6, G-4, H-9, A-8	10.47	3	34.90	9.64	
3/22/2004	4	, E-6, E-8, G-9, A-5, B-4	9.27	4	30.90	9.44	
4/5/2004	4	, E-10, B-4, M-9, J-11, N-6, G-6	12.02	4	32.06	8.88	, M-9, N-6
4/6/2004	5	, D-9, E-10, B-6, B-7, B-9, F-4	8.42	4	33.68	8.42	
4/7/2004	5	, E-10, N-6, B-9, B-10, B-11, F-4, G-6, M-5	9.12	5	42.55	9.99	, N-6
4/12/2004	3	, E-10, A-8, A-11, B-7, L-10, M-5, O-3	9.57	3	38.28	9.47	, M-5
4/14/2004	3	, H-11, B-4, B-5, A-11, A-8, B-6	9.53	3	38.12	9.82	
4/29/2004	5	, O-4, M-9, C-3, A-9, J-5, O-9	11.77	5	47.09	9.17	
5/3/2004	5	, G-7, O-4, C-3, M-8, A-7, B-11, E-11, L-2, L-11	10.74	5	57.27	9.20	, M-8
5/4/2004	5	, O-4, G-7, M-8, B-11, L-2, L-11, A-7, B-6, C-9, N-9, O-9	8.16	5	48.97	9.60	, G-7, M-8
5/5/2004	5	, O-4, G-7, M-8, B-6, C-9, N-9	10.40	5	41.60	9.38	
5/10/2004	4	, O-4, G-7, A-11, C-8, G-2	9.71	4	32.37	9.20	
Total:	179	**Averages and Total number of FTs Used:**	9.87	175	48.36	9.42	
			% FTs used	97.77%			
			Max.		**Max.**	**Max.**	
			13.43		80.25	9.99	
			Min.		**Min.**	**Min.**	
			7.17		27.76	6.91	

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Vita

Senior Master Sergeant Michael C. Dawson graduated from Kenmore High School, Akron, Ohio, in June 1982. He enlisted in 1983 as a Missile Maintenance Specialist. After being selected as an Honor Graduate at Basic Military Training School, he received technical training at Chanute AFB, Illinois, before his first assignment to Whiteman AFB, Missouri from January 1984 through August 1994. While there, he earned several Airman and NCO of the Quarter awards and was a Distinguished Graduate at NCO Leadership School and a Distinguished Graduate and the Academic Achievement Award recipient at the NCO Academy.

In August 1994, Senior Master Sergeant Dawson was selected as an evaluator for Twentieth Air Force at F. E. Warren AFB, Wyoming, performing inspections and evaluations of all ICBM units and the 576th FLTS. He graduated *Summa Cum Laude* with a double-major Bachelor of Science degree in Management/Accounting and Management/Computer Information Systems from Park College in 1995.In 1998, he became a member of the 90th Space Wing at F. E. Warren AFB and was the NCOIC of the Pneudraulics Section, NCOIC of the Peacekeeper Maintenance Section, Superintendent of Quality Assurance, and Superintendent of the Facilities Maintenance Flight. In 2001, he was again recognized as a Distinguished Graduate at the Senior NCO Academy.

In August 2003, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology as a member of only the second group of enlisted personnel selected to attend. Upon graduation, he will be assigned to Maxwell AFB, Alabama. Senior Master Sergeant Dawson is married and has one daughter.

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14. ABSTRACT

Since the events of September 11, 2001, security for the nation's Intercontinental Ballistic Missile force has become a prominent concern for personnel in the highest levels of government. This has resulted in many physical security upgrades and new methods to counter hostile activities. This research seeks to find the optimal placement for one layer of the security net protecting these crucial assets, the daily-deployed security forces Fire Teams. The problem of finding the optimal placement for these forces is modeled as a facility location problem. Of the methods of locating facilities available in the literature, three are selected to solve this problem. The maximum covering location problem strives to cover the maximum demand possible with a predetermined, finite number of facilities. The p-center problem covers all demand and seeks to minimize the maximum distance between a demand point and a servicing facility. The p-median problem intends to minimize the demand-weighted total distance between demand sites and servicing facilities. A hybrid model is also developed to first employ a p-center solution and then attempt to reduce the total distance using the p-median solution. Comparison of the four models is based on Fire Team usage, the average response time calculated from the placement of Fire Teams, the average total distance, and the average maximum distance any Fire Team is located from a penetrated Launch Facility.

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