LOCATION ANALYSIS: A STRATEGIC NETWORK FOR HOMELAND DEFENSE

John E. Bell, Department of Marketing & Logistics, University of Tennessee, Knoxville TN 37996, 478-235-2687, john.bell2@robins.af.mil
Stanley E. Griffis Department of Supply Chain Management, Michigan State University, East Lansing MI 48824, 517-432-4320, griffis@bus.msu.edu
William A. Cunningham III, Department of Operational Sciences, Air Force Institute of Technology, Wright-Patterson AFB OH 45433, william.cunningham@afit.edu
Jon A. Eberlan, Department of Operational Sciences, Air Force Institute of Technology, Wright-Patterson AFB OH 45433, jon.eberlan@maxwell.af.mil

ABSTRACT

This research uses location analysis for selecting aircraft alert sites for the defense of national areas of interest. Solutions are generated in a two step approach where the minimum number of sites is first identified using the Location Set Covering Problem and then the result is improved by finding the minimum aggregate network distance or p-median solution from the alternate optimal solutions to the LSCP. This approach also identifies the p-center solution to the problem ensuring equitable response to all areas of interest. Sensitivity analysis is performed to determine the impact of altering aircraft launch and flying times on the number of required alert sites and the amount of coverage provided by selecting fewer locations. This research points out significant implications about future basing decisions and the tradeoffs between cost and required response times of aircraft in a defense emergency.

Keywords: Locations, Optimization, Military, Homeland Security

INTRODUCTION

Throughout its history the United States has relied upon its geographic isolation to defend itself from enemies. Allies to the North and South, coupled with expansive oceans to the East and West, insulated the United States from potential dangers and mitigated the need for more active homeland defense measures. Strangely, while the collapse of the Soviet Union eliminates a known direct threat to the United States, it ushered in a change in the type of threats from conventional to unconventional adversaries, terrorism being chief among them. Terrorist tactics are unbounded by the traditional rules of warfare [33] that made threat planning much more manageable. The terrorist attacks on the World Trade Center and the Pentagon on September 11 brought homeland defense to the forefront of domestic policy in a manner it has never been in the history of the United States. The Office of Homeland Security was established to coordinate the executive branch's efforts…"to detect, prepare for, prevent, protect against, respond to, and recover from terrorist attacks within the United States" [3]. The importance of the joint United States and Canadian North American Aerospace Defense Command (NORAD) to homeland defense was central to the new organizations capabilities, particularly protecting the skies over both nations.

Previously, NORAD maintained 14 fighter aircraft, "on alert", ready for launch on a moments notice. On September 11 that number jumped to over 100 aircraft. By the next morning, more than 200 aircraft were on alert [28]. The events of September 11 led defense leaders to institute a program where the Air National Guard, Air Force Reserves, and active duty Air Force flew 24-hour, fully armed Close Air

Patrol (CAP) where aircraft orbited over areas of strategic interest within the United States, and placed scores more jets on alert status. By 2003 "… more than 29,000 CAP sorties were flown with more than 1,000 intercepts" [15]. It soon became evident that the demands of 24-hour CAP coverage would have a significant negative impact on military resources and logistics if sustained for extended periods of time [23]. Additionally, manpower and equipment issues were exacerbated by the additional demands placed on the Air Force by operations in Iraq and Afghanistan. Subsequently, many of the 24-hour patrols were scaled back in favor of a larger strip alert strategy, where air defense assets pre-positioned at alert sites or runways to respond to potential threats.

Prior to 2001, the USAF had reduced the number of active alert sites to 7 and the number of alert aircraft to 14 [13,28] as a cost containment issue. The locations that the DoD retained were around the periphery of the United States looking outward beyond the US's international borders for incoming danger [14,16], something shown to be too limited by the September 1tth attacks. When NORAD scrambled alert fighters to intercept hijacked airplanes over domestic airspace, the aircraft were not positioned to reach the hijacked aircraft in time Unfortunately, the events of September 11th illustrated how the basing and focus of the alert system had become out of step with post-Cold War needs. The threat as well as the network needed to be re-evaluated to develop a future structure to meet the security and logistics requirements to meet the new threat.

To address this problem, NORAD needed to reconsider the number of alert jets and the alert sites while considering both an inward and outward looking air defense philosophy. By February 2002 the USAF and NORAD had increased the number of alert bases to 26, with four fighter aircraft ready to go at each site [14,19]. The 24-hour CAPs continued until 2002, when it became evident that personnel availability and airframe serviceability would be severely impacted if the pace continued [23]. In 2003, RAND recommended that the Air Force adopt a strip alert network to become more operationally and cost effective. Additionally it was noted that the existing structure of the network did not necessarily translate to successful intercept of a threat due to the near infinite number of potential terrorist threats [23]. Subsequently, NORAD moved to an almost exclusive peacetime strip alert strategy with CAPs used only on a limited as-needed basis. However, the existing alert network was far from optimal.

Today, the number of jets on alert, as well as the number and location of CAPs, vary with the threat level maintained by the Department of Homeland Security. While specific NORAD alert postures in terms of numbers of aircraft, supporting forces, CAP coverage and current alert sites are classified, it can be said that current air defense network fluctuates in a spatial and temporal nature. Thus, NORAD is challenged to place aircraft at optimum locations to promote overall network effectiveness and efficiency. It is critically important to note that,this network was constrained to existing US military locations during a time when many US installations were being targeted for closure. To this end, a model was developed to facilitate decision making for placement of alert aircraft and decisions about the infrastructure and logistics network necessary to support the new alert strategy in the most efficient and effective manner. This study and its corresponding methods have implications for supply chain design research [12,18,21] particularly given the high levels of demand uncertainty. Despite it's defense focus, the research has more far reaching implications in the areas of disaster response [30] and humanitarian relief [17,25] which face similar challenges.

METHODOLOGY

Data for the study was provided by personnel at Headquarters Air Combat Command (ACC) Department of Homeland Security at Langley Virginia, and the Air Operations Center of 1st Air Force at Tyndall, Florida. ACC is the primary force provider for the alert aircraft network and 1st Air Force is charged with executing the alert operation. The overall strip alert network objectives were determined by the ACC Department of Homeland Security, and they helped establish the critical model parameters to aid in the location modeling method for this study.

Objectives of the Strip Alert Network

Personnel at the ACC Department of Homeland Security and the First Air Force AOC were interviewed to determine the system objectives and relative importance in the alert network. The following desired objectives of the strip alert network were delineated:

1. Minimize aircraft response time.
2. Protect all areas of interest with at least one alert site.
3. Minimize the cost by minimizing the number of strip alert locations.
4. Maximize protection capability by minimizing the overall or average distance per network location.
5. Maximize protection capability by minimizing the maximum travel time for an aircraft to any one location in the network.

Minimizing the required number of sites to cover all of the areas of interest was the overarching requirement of the model due to the logistical costs associated with maintaining facilities. All other objectives were secondary and were considered equally important. Aircraft response time is the amount of time (notification to arrival) it takes an aircraft to fly from a potential alert site to an area of interest. Areas of interest are those physical locations that merit special protection in the interest of National Security. Finally, a strip alert location is any candidate alert site which meets the criteria for operational capability.

Critical model parameters include the aircraft type, launch, operating characteristics, candidate site requirements, the list of areas of interest, and response time/distance to the areas of interest. A suitable candidate for a strip alert site must meet the following two criteria:

1. The candidate must be an existing military airfield in the continental US, to include any branch of the armed forces as well as any component (Guard, Active Duty, or Reserves).
2. A candidate site's runway must meet a minimum length as determined by the ACC Department of Homeland Security.

Once the criteria were established, 202 suitable candidates were identified. Each site was assigned a number to facilitate identification. The aircraft utilized in the model are of two types: F-15 and F-16. An 8-minute required launch time is used for all candidate alert sites, except for site 69, where a 5-minute launch time was used. Finally, a best case flight speed of 9 nautical miles (NM) per minute is used for both aircraft types.

One of the central model parameters is the areas of interest to be protected by the strip alert network. A list of 70 different areas of interest was obtained from the Air Force. As with other sensitive information, these sites are not divulged for security reasons. Each area of interest was assigned an identification number, and areas of interest are delineated by type. Type I areas require constant aerial coverage while Type II only require coverage upon request. Response times to each area of interest vary by area type and in some instances, specific area. Table 1 outlines the different response requirements.

Table 1 Desired Aircraft Response by Area Type and Exceptions

Area Type	Desired Response	Specific Area Exceptions
Type I (Areas 1-27 and 31-69)	≤ 20 minutes after notification	Area 13 response time is ≤ 12 minutes after notification
Type II (Areas 28, 29, 30, and 70)	≤ 12 minutes after notification	Area 70 response time is ≤ 20 minutes after notification

Note. Response time includes both launch and flight times in all instances.

The response times listed in Table 1 are notional, as the actual response times are classified. After obtaining the desired strip alert network objectives and the critical model parameters, network operation assumptions are made to simplify the model building process.

Assumptions

Since the objectives of the overall network are response time and coverage-oriented as opposed to cost, it was assumed that the inclusion criteria of active military flying at all candidate sites sufficiently addresses needed infrastructure and support network needs, including, but not limited to, personnel, ground support equipment, airborne tanker support, and hangar space. Furthermore, it was assumed that all sites met necessary explosive quantity-distance requirements for the types of munitions loaded on the jets, and that no airspace restrictions exist around any area of interest. It is also assumed that the number of aircraft at any alert site had no bearing on overall response time. Finally, political influence on basing decisions was assumed to play no part in site selection and each site had an equal probability of selection. Once site specific assumptions were made to simplify the operations of the candidate sites in the problem, assumptions were made regarding the network aircraft operating characteristics.

To limit the complexity of the model, it was assumed that the F-15 and F-16 aircraft perform similarly throughout the network. Furthermore, it was assumed that launched aircraft arrived successfully at the required area of interest. Essentially, this ignores the possibility of an aircraft aborting a mission for maintenance or other problems. Finally, it is inferred that the aircraft launch or scramble times follow historical trends. These assumptions reduce model complexity because infinite combinations of launch times and aircraft performance data would increase the number of possible network coverage schemes.

Model Formulations

For this research, the location set covering problem (LSCP), the p-median, and p-center methods were chosen, based on the five objectives of the overall strip alert network. Each are established location modeling techniques. The LSCP is effective at fulfilling objectives 2 and 3, the p-median problem is effective at meeting objective 4 and providing key input to fulfill objective 1, and the p-center has the ability to meet objective 5. Additionally, the candidate sites and areas of interest are each a set of discrete locations and these three techniques have proven to be effective in discrete location modeling.

Mathematical Formulation of the Location Set Covering Problem

The LSCP is designed to locate the minimum number of facilities within a distance or time constraint. It has been used previously in the area of supply chain disaster preparedness by [12] to make decisions about where to store emergency supplies. In this research, the required response time for the problem was converted into a critical distance by taking into account aircraft launch and flight times. The problem is formulated as an integer programming problem. Facility costs are assumed to be identical in this formulation and are not included in the objective function. Also, the model assumes the alert sites are uncapacitated and use single sourcing of demand. The original LSCP was developed by [31]; however, the formulation used here is from [26]. Given that the critical distance between areas of interest and candidate sites is varied in this research, the model requires that an adjustment be made to the maximum allowable distance notation. The notation used is stated as:

i, I = the index and set of areas of interest or nodes;
j, J = the index and set of candidate alert sites or nodes;
d_{ij} = the shortest distance or time between points or nodes i and j;

S_{ij} = the maximum allowable critical distance computed from response and launch times; an alert site located at node j within the standard of the area of interest node i *is* eligible to serve the area of interest;

$N_i = \{j | d_{ij} \le S_{ij}\}$ is the set of alert sites j within the critical distance S_{ij} of area of interest i;

$X_j \in \{0,1\}$ is 1 if an alert site is located at site j, and 0 otherwise.

The LSCP formulation used in this research is as follows:

$$\text{MINIMIZE} \quad \sum_{j \in J} X_j \qquad (1)$$

$$\text{SUBJECT TO:} \quad \sum_{j \in N_i} X_j \ge 1 \quad \forall i \in I \qquad (2)$$

$$X_j \in \{0, 1\} \quad \forall j \in J \qquad (3)$$

The objective function (1) minimizes the number of selected alert sites needed to cover each and every area of interest by at least one facility. Constraint (2) requires that each area of interest must be covered by at least one alert site within S distance or time units of it. Constraint (3) is the integrality constraint. The LSCP is classified as NP-hard [8].

Mathematical Formulation of the P-Median Problem

“The objective of the p-median model is to identify locations for p facilities in some space to serve n demand points so that the total weighted distance (or cost) between the facilities and the demand points they serve is minimized” [2]. In related research, an extension of the p-median problem was used by Scaparra and Church [27] to allocate resources among locations for homeland defense. As previously discussed, the number of facilities p utilized in this model is taken from the results obtained through the LSCP. While the first formulations of the p-median problem come from Cooper [4] and Hakimi [10,11], the formulation of Daskin [6] with a minor adjustment is utilized in this research. Daskin [6] was used as it removes the demand weight multiplier from the objective function. Given equal demand, as the issue at hand assumes, this was considered to be a suitable method. The formulation is as follows:

$$\text{MINIMIZE} \quad \sum_i \sum_j d_{ij} Y_{ij} \qquad (4)$$

$$\text{SUBJECT TO:} \quad \sum_j Y_{ij} = 1 \quad \forall i \qquad (5)$$

$$\sum_j X_j = P \qquad (6)$$

$$Y_{ij} - X_j \le 0 \quad \forall i, j \qquad (7)$$

$$X_j = 0,1 \quad \forall j \qquad (8)$$

$$Y_{ij} = 0,1 \quad \forall i, j \qquad (9)$$

where

X_j = 1 if we locate at candidate site j, 0 otherwise
Y_{ij} = 1 if area of interest i is served by candidate alert site j, 0 otherwise
d_{ij} = travel distance between area of interest i and candidate alert site j
P = number of alert sites to be located; taken from the LSCP results.

The objective function (4) minimizes travel distance between the areas of interest and each selected alert site. Constraint (5) requires that each area of interest be served by one alert site, (6) states that exactly P facilities are to be located, and (7) links the location variables (X_j) and the allocation variables (Y_{ij}). Constraints (8) and (9) are integrality constraints. The solution to this model identifies the locations of the alert sites, the allocation of areas of interest to the alert sites, and the overall alert network distance. This model also assumes uncapacitated alert sites, single trips to each area of interest, separate trips to each candidate site and area of interest pair, and single site sourcing of demand.

Mathematical Formulation of the P-Center Problem

The objective of the p-center model is to minimize the maximum response time or distance to any one demand site (objective 5). 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 alert sites can only be located on the candidate alert site nodes and not on the arcs of the network. As in previous modeling techniques used in this study, this modeling formulation assumes no limits on capacity at any candidate alert site. The original p-center problem was formulated by Hakimi [10,11]; however, the formulation used in this research is from Daskin [6] and Current et al. [5].

The formulation is as follows:

MINIMIZE
$$W \tag{10}$$
$$\sum_j Y_{ij} = 1 \qquad \forall i \tag{11}$$
$$\sum_j X_j = P \tag{12}$$
$$Y_{ij} \le X_j \qquad \forall i, j \tag{13}$$
$$W \ge \sum_j d_{ij} Y_{ij} \qquad \forall i \tag{14}$$
$$X_j = 0,1 \qquad \forall j \tag{15}$$
$$Y_{ij} \ge 0 \qquad \forall i, j \tag{16}$$

where

W = maximum distance between an area of interest and the nearest alert site
Y_{ij} = 1 if area of interest i is assigned to alert site candidate j, 0 otherwise
X_j = 1 if we locate at candidate alert site j, 0 otherwise
P = number of alert sites to locate; taken from LSCP results
d_{ij} = distance from area of interest i to candidate alert site j

The objective function (10) minimizes the maximum distance that any area of interest is from an open alert site. Constraint (11) requires that each area of interest be assigned to exactly one alert site, (12) stipulates that P alert sites be located or opened, (13) states that an area of interest i cannot be assigned to a candidate alert site j unless an alert site is located at j, and (14) states that the maximum distance between an area of interest and an alert site must be greater than or equal to the distance between any area of interest i and the alert site j to which it is assigned. Constraints (15) and (16) are the respective integrality and non-negativity constraints.

Distance Calculations

The latitude-longitude coordinates for the areas of interest and candidate alert sites were obtained. Once the coordinates were obtained, then, distances between areas of interest and candidate alert sites were computed using the Haversine (great circle) method [29]. In addition to the distances between locations, the calculation of the critical distance is important for the computation of the objective function in the LSCP. The critical distance for use in the LSCP in this research was calculated by the following formula:

$$S_{ij} = (MDRT - ACLT) * AS \tag{17}$$

where

S_{ij} = Critical distance from area of interest i to candidate alert site j
$MDRT$ = Maximum Desired Response Time (From Table 1)
$ACLT$ = Aircraft Launch Time (in minutes)
AS = Aircraft Speed (nautical miles per minute)

Essentially, S_{ij} is dependent on the values of the independent variables $ACLT$ and AS. $MDRT$ is a constant that changes based on user preference. Once all distances are calculated, the models are capable of generating solutions.

Generation of Solutions

When the LSCP is solved there exists a probability of alternate optimal solutions. Specifically, there is a chance of finding many different combinations of the minimum number of locations capable of covering the demand in the LSCP. For instance, if the LSCP found the minimum number of sites to cover the areas of interest to be 21 out of the 202 candidates, then there is the possibility of there being 8.71^{694} alternate optimal solutions [20].

As previously stated, any alternate optimal solution of the LSCP can meet objectives 2 and 3; however, an optimal solution is needed which also satisfies objectives 1 and 4, as well. Thus, the minimum number of locations computed from the LSCP is then used as "p" in the p-median problem. When solving the p-median problem following the LSCP, an optimal solution is found because there is only one minimum aggregate network distance. This technique was used by Dawson [7] and is similar to a military location model developed by Overholts [24].

Solutions to the problem were generated using Solver Add-In for the Microsoft Excel® spreadsheet package. Due to the size of the model, a commercial version of the Premium Solver Platform as well as a Large Scale Linear Program Add-In were obtained from Frontline Systems, Incorporated. The location modeling mathematical formulations used were generated on two primary spreadsheet models; one to generate solutions for the LSCP and p-center problem, and the second for the combined LSCP and p-median problem. The LSCP and p-center problem require one model because the maximum allowable distance constraint can be iteratively tightened on the LSCP, thus, minimizing the maximum distance between any area of interest and a candidate alert site. "Specifically, when the set covering problem equals p, the minimum associated coverage distance is the solution to the p-center problem" [5]. To ensure that the solution of each spreadsheet model was a global optimum solution and not a local optima, the integrality constraints were relaxed and the models re-run. When a relaxed LP produces the same integer solution as the ILP formulation, a matrix is said to be totally unimodular. Since all of the proposed networks used in these studies are bipartite, then, the LP relaxed solution should equal the ILP solution, because bipartite graphs have been proven to unimodular [34].

Table 2. Results for Model Set I

Results	Coverage Scheme	Critical Distance (S_{ij})
LSCP = 33 alert sites p-center = 163.8086 NM p-median = 3,512.511 NM	70 total areas--66 Type I and 4 Type II areas covered w/33 alert sites	108 NM (areas 1-12, 14-27, 31-37, 39-65, and 67-69); 56 NM (areas 13, 28-30); 142 NM (area 38); 126 NM (area 66); and 164 NM (area 70)
Alert Site	Area(s) Covered	# Areas Covered
1	64	1
2	45, 62	2
6	13, 14, 31	3
20	5, 35, 42, 67	4
23	33	1
24	10, 11	2
38	9, 68	2
47	7, 8, 47, 49, 50	5
49	37, 66	2
54	19	1
62	6, 69	2
67	27, 65, 70	3
69	23, 56	2
73	4, 40, 43	3
83	24	1
92	63	1
96	22, 54	2
98	30, 53	2
104	39, 58	2
105	34	1
111	20, 21	2
113	2, 3, 44	3
118	38	1
121	26, 46, 48	3
135	16, 28, 59	3
138	18	1
148	12, 36, 57	3
150	29	1
152	25, 41	2
159	1, 32	2
170	17	1
174	15, 51, 52, 55, 60	5
189	61	1

Results

The model found the LSCP, p-median, and p-center solutions for all Type I and Type II areas of interest combined for the 202 candidate alert sites. The model was run with a 9 NM per minute aircraft speed and 8-minute launch times. The computed critical distance, S_{ij} for the majority of locations was 108 NM given the notional (8-minute) launch and 9 NM aircraft flight speed. However there were exceptions, Area 13, 28, 29 and 30 had a critical distance of 56 NM based on their shorter 12 minute response time. Also, in order to solve the problem, the distance constraints on areas 38 and 66 needed to be increased to 142 NM and 126 NM respectively as no viable candidate sites existed within the computed critical distance. In addition to areas 38 and 66, the closest candidate site to area 70 is 163.8086 NM, therefore, the critical distance for area 70 was relaxed to 164 NM to allow the model to locate a candidate site. With these relaxations, the LSCP model was able to generate a solution with an objective function value of 33 minimum locations to cover all of the areas of interest. Ultimately, the objective function value for the p-center solution for this model is 163.8086 NM, the distance between area 70 and the closest candidate site in the network. Therefore, no "p-center" improvement could be gained in the spreadsheet model from the original solution generated for the LSCP. The solution to the P-median problem was generated using p=33 and results are presented in Table 2. The p-median solution gives an aggregate network distance of 3,512.51 NM. As can be seen in Table 2, Type II areas 28, 30, and 70 are covered by alert sites that also cover Type I areas of interest. The binding locations for this model set are shown in Table 3, which shows 13 binding locations, 9 for Type I areas and 4 for Type II areas. The generated solution to the p-median problem does not change the distance to any one location and is therefore also still considered an optimal solution to the p-center problem.

A closer look at the binding Type II alert sites shows that all sites covering Type II areas are binding; therefore, each Type II area can be served by only one candidate alert site given the input parameters. Although three of the four Type II alert sites can also cover Type I areas of interest as shown in Table 2, making the Type II alert sites permanent locations, as opposed to temporary, would degrade the performance of the permanent alert network. This occurs because the binding conditions on all Type II alert sites force the model to keep these candidate sites open. Specifically, each Type II area can only be served by one specific candidate site, therefore, the site must be selected.

Table 3. Binding Alert Sites for Model Set I

Binding Sites (13)	Area(s) Causing Binding Condition	Area Type(s)
47	7, 8, 49, 50	Type I
6	13	Type I
111	20, 21	Type I
23	33	Type I
105	34	Type I
118	38	Type I
73	40	Type I
92	63	Type I
49	66	Type I
135	28	Type II
150	29	Type II
98	30	Type II
67	70	Type II

FINDINGS AND RECOMMENDATIONS

The optimal alert network depends on available candidate sites, areas of interest requiring coverage, and the input parameters for the model. If all 202 candidate sites meeting the runway distance requirements set by the Air Force are used, the areas of interest explored in this research can be most efficiently covered by a minimum of 33 alert sites at a minimum aggregate network distance of 3,512.511 NM. Certain non-binding candidate alert sites are common to all model solutions, even though they are not required to be in the solution sets. These sites are important because no matter how the input parameters change in this research, the advantageous location of these sites causes them to almost always be in the generated solution. Also, certain sites must be in the solution and are considered binding. All Type II areas represent highly variable, non-repetitive demand, and force a binding alert site in each instance.

It was shown that the current network is incapable of meeting the response requirements to area 38 in every configuration, therefore, the critical distance for area 38 had to be relaxed to arrive at a feasible solution. Also, in many of the model runs, the critical distance for area 66 also had to be relaxed in order to find a solution. These findings are critical because the absence of an alert site within the critical distance for the two sites limits coverage options, and indicates a potential vulnerability in the network. Ultimately, the optimal alert network configuration depends on what defense planners constitute as suitable sites, what areas of interest they wish to cover, and what aircraft response times are deemed acceptable. This research showed that some areas could not be covered due to existing network resources. This suggests that continued analysis of the network structure, tanker refueling availability, and identification of the required funding for CAP support should be conducted. Other potential options include allowing candidate sites with minimum runway lengths below current restriction be considered, as well as the possibility of new construction of alert runways. New construction is the least attractive alternative due to high costs, but may be the only way to meet the required response times and distances.

MANAGERIAL IMPLICATIONS

The developed model allows planners to find alert aircraft basing solutions that are not obvious with other methods.. The model is flexible enough to facilitate future re-evaluation as new areas of interest require coverage or new candidate alert sites are introduced to produce a new optimal network. Numerous what-if scenarios can be posed to see how the optimal network configuration is affected. The location models used in this research can also be used to optimally locate aircraft based on desired proximity to the enemy, response requirements, and desired target coverage. Therefore extensions of this research have wide application to other areas of defense logistics including responding to natural disasters such as Hurricane Katrina [22] or bioterror attacks such as Anthrax [32]. In addition, the model produces solutions to economize the use of forces to prevent excessive overlap of resources. The model can be used in a greater-than distance scenario creating a p-dispersion model [6]. For instance, if the critical distance were used with a greater-than instead of a less-than constraint, policy makers could use the model to base aircraft away from the effective range of an adversary's conventional or nuclear weapons. Defense leaders can also take the actual results of the models generated in this research and make informed decisions about the current and future strip network of bases used for alert. The different network configurations could be tested based on historical launch times and differing aircraft speeds. Therefore, leaders who make decisions about Base Realignment and Closure actions mandated by Congress can use this model to evaluate of a base's suitability for supporting the air defense mission and prevent the inadvertent closure of a runway which for geographic purposes is critical to the Homeland Security mission. Additionally, the model can be used to make decisions based on allocation of limited funding for alert sites [27,1], and military planners can use the results of the sensitivity analysis to see how much demand would not be covered given limited funding for a fixed number of sites.

This research has shown how location modeling techniques can be applied to improve a network of U.S. military bases needed for the evolving Homeland Security mission. Additionally, it is believed that similar coverage and network design techniques can be used for strategic location decisions in supply chains facing uncertainty in demand or with customers who are extremely sensitive to a stock-out [18, 21]. Research for locating police stations and other public services has greatly benefited from improvements in location modeling in the past [9], and it is believed that similarly the challenges of emergency management for natural disasters and humanitarian relief efforts [25,17] around the globe can also benefit from designing optimal logistics and supply chain networks which can meet minimum response time distances and times in order to meet their mission of saving lives in a crisis situation.

References: are available on request from the author. Contact john.bell2@robins.af.mil