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**PLANNING COVERAGE OF POINTS OF INTEREST VIA MULTIPLE
IMAGING SURVEILLANCE ASSETS: A MULTI-MODAL APPROACH**

THESIS

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AFIT/GOR/ENS/03-11

**DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY**

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AFIT/GOR/ENS/03-11

PLANNING COVERAGE OF POINTS OF INTEREST VIA MULTIPLE IMAGING
SURVEILLANCE ASSETS: A MULTI-MODAL APPROACH

THESIS

Presented to the Faculty

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Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Operations Research

Sarah E. Jackson, B. S.

Captain, USAF

March 2003

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SURVEILLANCE ASSETS: A MULTI-MODAL APPROACH

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Abstract

For the United States to maintain information superiority, it is necessary to have a means of allocating intelligence-gathering assets to collect information on particular points of interest. In today's geopolitical environment, however, the number of points of interest is growing rapidly, whereas the number of available assets is not. To aid in maintaining information superiority, this research explores the use of a Multi-Modal Goal Programming Resource Constrained Project Scheduling approach for allocating imaging surveillance assets (land, air, sea, and space) to a set of points of interest for a given time period. The multiple objectives of this formulation are to minimize the number of points of interest not covered at any time during the required period, minimize the deviation from the minimum image resolution of each point of interest, and minimize the time between successive imaging assets imaging each point of interest.

PLANNING COVERAGE OF POINTS OF INTEREST VIA MULTIPLE IMAGING SURVEILLANCE ASSETS: A MULTI-MODAL APPROACH

I. Introduction

Background

It is said, “a picture is worth a thousand words”. In the fall of 1962, however, a picture may have been worth over three billion lives. In October of 1962, the U.S. was able to prove, contrary to claims made by the Soviet Union, that offensive weapons, medium-range and intercontinental ballistic missiles were being placed in Cuba by the Soviet Union. The images taken with a U-2 reconnaissance aircraft helped to disprove Soviet claims that the military build-up in Cuba was solely defensive in nature (30). This knowledge, along with other intelligence, aided in the avoiding of a potentially devastating nuclear war

Knowledge, along with the means to successfully implement it, is the key to preventing battles, if possible, and winning them if they prove unavoidable. Whether by the use of force or through passive means, knowledge of “enemy forces, their composition, disposition, intentions, their locations, direction, speed, and combat readiness” (38) is vital to the side that emerges as the victor. In today’s geopolitical environment, this knowledge, also referred to as information dominance, is a necessity to maintain security and assure victory.

Information dominance (ID), as defined by FM 100-6,

“is the degree of information superiority that allows the possessor to use information systems and capabilities to achieve an operational

advantage in a conflict or to control the situation in operations short of war, while denying those capabilities to the adversary.” (14:Glossary-7)

With information dominance the United States is able to “engage the adversary more precisely and with greater lethal / non-lethal effects, because of our information advantage and the enemy’s corresponding inability to move or protect itself” (46). In addition, information dominance allows the US to “create high performance units that use information in a manner that allows them to accomplish their missions more effectively and quickly with minimum casualties.” (46)

In a time where there is no longer a single superpower foe, but rather a plethora of potential adversaries spread across the globe, gaining and maintaining ID becomes a complex and time consuming task. This task drives the need to optimize coverage of prioritized points of interest using land, air, sea, and space assets in order to obtain knowledge that can best serve the appropriate decision-makers. Maintaining continual imaging of a point of interest in a critical pre-attack period is a complex task, involving both timing and allocation of key space, land, air, and sea intelligence, surveillance, and reconnaissance (ISR) assets. Given the quantity of assets and the array of possible locations that may require coverage, the problem of allocating the available resources can become a complex and time consuming task. The need to utilize scarce resources to image key areas of interest (POI) suggests the need to optimize the tasking of various existing assets to best serve the decision-makers.

An optimization approach is useful in this instance because there are limited resources to be divided among several potential POIs. “Optimization deals with problems of minimizing or maximizing a function of several variables, usually subject to

equality and/or inequality constraints.” (30:v) This allows the decision maker to utilize limited resources in a way that optimizes the resource’s usefulness in achieving an objective.

Problem Statement

During the Cold War, the United States primarily faced a single super power opponent. Maintaining continuous coverage of one principal foe and its allies was a complex task, but was comparatively simple compared with current surveillance requirements. In today’s political environment, there is no longer one primary foe; there are several potential alliances of foes and thus an array of points of interest (POI), some of which change rapidly. Allocating surveillance assets among several potential POIs is difficult. Maintaining continuous or near continuous 24-hour coverage over a multitude of potential POIs is an even more complex task. Continuous, 24-hour coverage of a POI, therefore, may not exist when relations between the POI and the United States begin to spiral towards conflict. The need arises to be able to allocate surveillance assets to provide the required coverage over a new POI.

There have been several attempts at optimizing coverage of a POI. The size of the problem often makes complete enumeration impractical. Branch and bound techniques have been used to reduce the number of possible solutions, however the size of the search space may still be great due to the number of assets being considered (33). The most popular technique for allocating resources is via a “greedy” heuristic in which “the targets are prioritized and then assigned for imaging.” (33:218) These approaches prove inadequate to allocate multiple asset types over multiple targets in a timely manner because the analysts have to accomplish independent runs for different imaging assets

and then combine the solutions. By not accounting for the integration of various asset types, in space, air, land and sea, as part of the original formulation, the optimal solutions obtained through the individual asset type allocating models tend to become sub-optimal when combined together.

The approach presented here allocates an array of surveillance asset types to multiple target areas. Given the need for a quick solution to allocate available resources to provide continuous 24-hour coverage of an area, the problem is initially modeled using multi-modal resource constrained techniques to specify all relevant optimization considerations.

Research Objectives

The United States maintains a limited number of surveillance assets. The need for methods to integrate assets over various domains (space, air, land, and sea), therefore, is critical to efficiently obtain imaging surveillance of areas of interest. Additionally, the number of potential adversaries is great. Porto suggests the number of possible solutions given N surveillance assets and T targets is $[(N/2) \times (T-1)!]$. (33:217) If, for example, the United States had five potential surveillance assets available to provide coverage of 20 POIs, there are 6.1×10^{17} possible ways to allocate the five surveillance assets to cover the 20 POIs assuming all assets were capable of observing all POIs. Should the United States have 10 assets available for allocation and 25 POIs, the number increases to 3.1×10^{24} possibilities.

The addition of time intervals expands the problem even further. Clearly the potential problem solution space increases rapidly with the addition of assets and POIs. To exhaustively enumerate all possible solutions would be prohibitive. Because the time

interval of interest in this research is the 72 hours preceding the initiation of actions, this research focuses on those assets that are available to the theater in question. The approach however can be expanded to multiple theaters.

A list of the intelligence assets in a particular theater is given in the Theater Intelligence Architecture Plan. However, for use in this thesis, an unclassified generic database has been used. It contains a fictitious number of space, air, land, and sea-based imagery surveillance assets along with capabilities based on unclassified sources. These assets were modeled using a program which has already been independently verified and validated for use in aerospace applications, Analytical Graphic, Inc's, Satellite Toolkit® (STK).

Assumptions

To aid in the completion of this research, some principal assumptions were made. The first assumption made was that all points of interests are terrestrial. No points of interest such as launched missiles, aircraft in flight, launched space vehicles, or other vehicles or objects already in flight are taken into consideration in this model.

Secondly, this model does not take into consideration the retasking of satellites. This could however be incorporated into the approach by some manipulation to the data and the addition of some constraints. This issue is addressed in Chapter 5.

The third major assumption is that times are all integers. For example, the duration of an access of an asset to a point of interest is an integer value, and the start times of the accesses are also integer in nature. This was done to simplify some of the calculations accomplished in the model. Chapter 5 suggests ways of adjusting this assumption for more realistic representation of access times and durations.

Finally, is it assumed that there exist some proposed routes for UAVs. These routes may not be all the possible routes, however they are assumed to represent the first choice routes for the UAVs. Sensitivity analysis can then be used to provide some constraints for routes that can then be generated with the appropriate route generation programs.

Methodology

To allocate surveillance assets to provide near-continuous to continuous coverage of a point(s) of interest, a modeling approach was developed based on Project Scheduling Program (PSP) principles. More specifically, a Multi-Modal Resource Constrained Project Scheduling Program (MMRCPSP) approach was extended to this surveillance allocation problem. The model at minimizes the uncovered time gaps between assets covering the point of interest. In order to take into consideration the priority of the various areas of interest, a Goal Programming (GP) approach was also incorporated into the model. This was done to ensure that the point of interest with the highest priority are covered prior to assigning assets to lower priority targets.

Summary

This chapter has given an overview of the background of the problem, the purpose of this research, the scope of the research accomplished, the fundamental assumptions made during the research, and a brief overview of the approach and methodology used to provide a model to solve the allocation of imagery surveillance assets. Chapter 2 provides a literature review in order to provide the reader with a background of the approaches used to develop the model. Chapter 3 presents the methodology of developing the model. Chapter 4 illustrates the approach by analyzing a notional

example and demonstrates how the results can be used by the decision makers. Chapter 5 gives the conclusions arrived from the research and recommendations for future studies.

II. Literature Review

Overview

In 2000 the Rand Corporation conducted a study to address the...

“ability of the Air Force to effectively attack time critical targets (TCTs) and the extent to which its successes and failures in this area can be attributed to dynamic command and control and battle management capabilities (or their lack)” (19:iii)

it was noted that

“a major shortfall to optimal allocation of scarce ISR (Intelligence, Surveillance, and Reconnaissance) resources and to cross-cued and / or simultaneous collections is the lack of agreed-upon (by DoD [Department of Defense] and the intelligence community) CONOPS [Concept of Operations], TTP[Tactics, Techniques, and Procedures], and automated tools for integrated tasking and battle management of (1) sensors from multiple intelligence disciplines (multi-INT), (2) sensors from multiple platform domains (cross-domain), and (3) the associated PEDS [Processing, Exploitation, and Disseminations Systems] to support military monitoring, assessment, planning, and execution processes and timelines.” (19: 28)

Multi-INT refers to signals, measurement and signature, human, and imagery intelligence disciplines (19:28). *Cross-domain* refers to the integration of land, sea, air, and space (19:28). This research focuses on imagery intelligence, which is obtained from electro-optical, radar, infrared, and photography systems (28:16). This research does, however, take into consideration cross-domain allocation of imagery surveillance assets.

The main focus of this research is to develop a mathematical formulation that integrates land, air, sea, and space imaging surveillance assets to provide near-continuous to continuous coverage of POIs. The integration of Multi-Modal Resource Constrained Project Scheduling and Goal Programming accomplished this.

In this section, a description of the Project Scheduling Problem (PSP) is given to provide an introduction to approaches used. This introduction leads into the necessary background of Resource Constrained Project Scheduling Problem (RCPSP), Generalized RCPSP (GRCPSP), and Multi-Modal RCPSP (MMRCPSP). Next, a description of Multiple-Criteria Decision Making (MCDM) is given and lends itself to the discussion of Goal Programming (GP). Concluding the chapter is an initial look at the result of integrating the approaches for the purpose of this research, a Multi-Modal Goal Programming Resource Constrained Project Scheduling Problem (MMGPRCPSP) formulation.

Project Scheduling

There are four primary objectives of Project Scheduling: 1) minimize the completion time of a project, 2) determine the capacities of the renewable resources so that a deadline is met and resource costs are minimized, 3) maximize the net present value of a project, and 4) minimize both the estimated rework times and costs (13:65). To better understand these objectives, and in turn the essence of the PSP, some definitions are required.

A *project* is a set of *activities* (tasks) that are performed under a set of *requirements* (constraints) in order to complete a process satisfying a particular objective, typically within some time horizon. For example, construction of a satellite could be a project. In terms of this thesis, the project is gathering imaging of a POI or of a set of POIs near continuously or continuously. The objective is to minimize the number of POIs not covered at any time during the observation period, minimize the deviation from the required image resolution of each POI, and minimize time gaps between successive

imaging surveillance assets. This objective, as will be seen, is accomplished using Goal Programming rather than through a standard PSP formulation.

An *activity* (task) is one of possibly several events, with a given duration, needed to accomplish the project. For the satellite construction project again, examples of some of the activities necessary for the project include the design phase, assembly of the parts, and testing. For the purpose of this research, the activity(s) is the collection of imaging from the POI(s).

A *resource* is something that is used during the activity. There are three types of resources: renewable, non-renewable, and doubly constrained. A *renewable resource* is something that can be re-used during the project. In the satellite example, one renewable resource is the people assembling the parts. The people work during a certain shift and after they have finished a shift return at the start of their next scheduled shift. The land, air, sea, and space imaging surveillance assets are the renewable resources in this research.

A *non-renewable resource* is a resource which can be used only once during an activity. For instance, in assembling the satellite, the individual parts are non-renewable. After a part is attached to one satellite, it will not return to be used on another satellite. For the purpose of this research, a nonrenewable resource would be a one-way mission for an imaging asset.

Doubly constrained resources are resources that are constrained by both activity and the project. The most common example of this is money. There could be an allotted amount of money to be used for each the design phase, assembly phase, and the test phase, and then a specific budget for the entire project. Each amount of monetary

allotment cannot be exceeded. For the purpose of this research, doubly constrained resources (*i.e.* a satellite that was tasked to different points of interest each orbit) are not used; however, could easily be incorporated at a later time if deemed necessary.

Fundamentally, the Project Scheduling Problem is to optimally schedule multiple activities, requiring various types of resources, which completes a project while achieving the objective defined by the decision-maker. In attempting to accomplish this, there typically are constraints on the resources. This type of PSP is called the Resource-Constrained PSP (RCPSPP). RCPSPP is used in this research and therefore is described in more detail in the following section.

Resource Constrained Project Scheduling Problem

In the majority of projects undertaken, there is some limit or constraint on the resources available. Due to the addition of such constraints, which are not taken into consideration in the basic Program Evaluation Review Technique (PERT) or Critical Path Method (CPM) approaches to PSP, an extension on the basic PSP needs to be included to compensate for the limited resources. When the constraints on the resources are considered, the basic PSP may not provide an optimal solution; therefore, the use of the Resource Constrained Project Scheduling Problem (RCPSPP) formulation is necessary. The RCPSPP formulation given is adapted from Pritsker, Watters, and Wolfe (1969).

The objective function of this formulation, expression [2.1], (one of several given in Pritsker, Watters, and Wolfe, 1969) is to minimize the total project throughput time. Minimizing the total throughput time is equivalent to maximizing “the number of time periods remaining after the project is completed” (34:96).

Table 1. Parameters and Variables for RCPSp formulation

| | |
|-------------|--|
| Parameters: | |
| i | project number, $i = 1, 2, \dots, I$; I = number of projects |
| j | job number, $j = 1, 2, \dots, N_i$; N_i = number of jobs in project i |
| t | time period, $t = 1, 2, \dots, \max G_i$; G_i is the absolute due date |
| g_i | desired due date of project i |
| e_i | earliest possible period by which project i could be completed |
| d_{ij} | number of periods required to perform job j of project i |
| l_{ij} | earliest possible period in which job j could be completed |
| u_{ij} | latest possible period in which job j could be completed |
| k | resource or facility number, $k = 1, 2, \dots, K$; K = number of different resource types |
| r_{ijk} | amount of type k resources required on job j of project i |
| R_{kt} | amount of type k resource available in period t |
| a_k | is the amount of resource k available for the project |
| Variables: | |
| x_{ijt} | 1 if job j of project i is completed in period t ; 0 otherwise |
| x_{it} | 1 in period t if all jobs of project i have been completed by period t , 0 otherwise |
| x_{int} | 0 for $t < \max \{a_{in} + d_{in} - 1; \max_{j \in P_m} (a_{ij} + d_{ij} + d_{in} - 1)\}$ where P_{in} is the set containing other jobs of project i that must precede job n , 1 otherwise |
| x_{imt} | 0 for $t > \min_{j \in F_{im}} \{G_i - d_{ij}\}$ where F_{im} is the set containing other jobs of project i that must follow job m , 1 otherwise |

$$\max \sum_{i=1}^I \sum_{t=e_i}^{G_i} x_{it} \quad [2.1]$$

subject to

$$\sum_{t=l_{ij}}^{u_{ij}} x_{ijt} = 1 \quad \text{for } i = 1, \dots, I; j = 1, \dots, N \quad [2.2]$$

$$x_{it} \leq (1/N_i) \sum_{j=1}^{N_i} \sum_{q=l_{ij}}^{t-1} x_{ijq} \quad \text{for } i = 1, \dots, I; t = e_i, e_i + 1, \dots, G_i \quad [2.3]$$

$$\sum_{t=l_{im}}^{u_{im}} t * x_{imt} + d_{in} \leq \sum_{t=l_{in}}^{u_{in}} t * x_{int} \quad [2.4]$$

$$\sum_{i=1}^I \sum_{j=1}^{N_i} \sum_{q=t}^{t+d_{ij}-1} r_{ijk} \cdot x_{ijq} \leq R_{kt} \quad \text{for } k = 1, \dots, K; t = \min a_{ij}, \dots, G_i \quad [2.5]$$

$$x_{ijt}, x_{it}, x_{int}, x_{imt} \in \{0, 1\}$$

This quantity of remaining time periods is represented by the summation of x_{it} as t varies from the earliest possible start of a project, e_i , to G_i , project i 's absolute due date. This objective is then subject to precedence and resource constraints.

The first constraint, expression [2.2], dictates each job having only one completion time for each project. In other words, the jobs, which are being used in the set of projects, are only to be accomplished once for each project.

Expression [2.3] prevents project i to be completed until all of the jobs are completed for that project. This is to ensure that the project is completed and no jobs are skipped that are required to be done.

The precedence constraint, given by expression [2.4], is to ensure that a job is not started prior to the completion of another job(s), if there exist such a requirement. For instance, in the construction of a building, it is required to have the walls in place prior to the roof being added.

Finally, expression [2.5] is a resource-constrained set, therefore, there must exist a constraint on the availability of resources in each time period. Suppose "a job is being processed in period t if the job is completed in period q ." (34:98) Then expression [2.3] limits the consumption of resource k by all jobs for time t to the amount of k available. The model forces activities to be shifted in the schedule if the resource limits are reached.

Generalized Resource Constrained Project Scheduling Problem

The Generalized Resource Constrained Project Scheduling Problem (GRCPSP) allows for more flexibility in the precedence requirements of the activities. Precedence requirements allow the user to define one of two time-lag requirements between two activities, minimal or maximum time-lag. The minimal time-lag denotes the minimum

time allowed between two activities. The maximal time-lag denotes the maximum time allowed between two activities.

There are three minimal / maximal time-lag classifications used in GRCPSP; 1) a finish-start relation dictates a minimal / maximal time must elapse between the finish of activity i and the start of activity j , 2) a finish-finish relation defines the requirement for an amount of time that must occur between the completion of activity i and the completion of activity j to allow for cope with the output of activity i , 3) a start-finish relation represents the requirement for a time-lag between the start of activity i and the completion of activity j . The minimal time-lag relations can be used in combination and the maximal time-lag relations can be used in combination if needed to accurately define the relations between activities i and j (13).

Multi-Modal Generalized Resource Constrained Project Scheduling Problem

In some instances, there may be more than one way to accomplish an activity. Such instances can be represented by a Multi-Modal Generalized Resource Constrained Project Scheduling Problem (MMGRCPSP) formulation. The RCPSP is actually a generalized formulation of a MMGRCPSP in that it assumes the existence of only one way to accomplish an activity. The formulation given is adapted from Sprecher (41:8)

Expression [2.6], the objective function, represents the desire to minimize the *makespan*, the duration of the project. This objective is subject to a set of constraints. Expression [2.7] constrains the problem by allowing only one mode assignment to each activity, and only one completion time of that mode. To ensure the usage (consumption) of renewable (non-renewable) resources do not exceed the per-period availability of each resource type, Expressions [2.8] and [2.9] are included in the formulation.

Table 2. Parameters and Variables for MMGRPSP formulation

| | |
|---|--|
| Parameters: | |
| J | number of jobs |
| M_j | set of modes in which job j can be performed |
| d_{jm} | duration of job j being performed in mode m |
| $R(N, D)$ | set of renewable (non-renewable, doubly constrained) resources |
| T | upper bound on the projects makespan |
| $K_r^v \geq 0$ ($K_r^\delta \geq 0$) | number of units of non-renewable (double constrained) resource r , r in R (r in D) |
| $K_{rt}^\rho \geq 0$ ($K_{rt}^\delta \geq 0$) | number of units of renewable (double constrained) resource r , r in R (r in D) available in period t , $t=1, \dots, T$ |
| EF_j (LF_j) | the earliest (latest) finish time of job j based on the modes with smallest duration |
| $k_{jmr}^\rho \geq 0$ ($k_{jmr}^\delta \geq 0$) | number of units of renewable (doubly constrained) resource r , r in R (r in D), used (consumed) by job j being performed in mode m at the period the job is in process |
| k_{jmr}^v | number of units of non renewable resource r , r in N , consumed by job j being performed in mode m |
| Variables: | |
| x_{jmt} | 1 if job j is performed by mode m and completed in period t ; 0 otherwise |

$$\min \sum_{m=1}^{M_j} \sum_{t=EF_j}^{LF_j} tx_{jmt} \quad [2.6]$$

subject to

$$\sum_{m=1}^{M_j} \sum_{t=EF_j}^{LF_j} x_{jmt} = 1 \quad j = 1, 2, \dots, J \quad [2.7]$$

$$\sum_{j=1}^J \sum_{m=1}^{M_j} k_{jmr}^\rho \sum_{q=t}^{t+d_{jm}-1} x_{jmq} \leq K_{rt}^\rho \quad r \in R; t = 1, 2, \dots, T \quad [2.8]$$

$$\sum_{j=1}^J \sum_{m=1}^{M_j} k_{jmr}^v \sum_{t=EF_j}^{LF_j} x_{jmt} \leq K_r^v \quad r \in N \quad [2.9]$$

$$x_{jmt} \in \{0, 1\}$$

Goal Programming

In the aforementioned formulations, each constraint was a hard constraint. In other words, each constraint must be satisfied as equal or less than the right hand side. However, what if the right-hand-side values were desired, but the decision maker would allow some deviation from these attainment levels? Goal programming allows the decision maker some flexibility in defining achievement levels or target values of various parameters in the problem. Within the appropriate constraints, a deviational variable is introduced to model whether or not the target value is obtained exactly, falls short or is exceeded. Allowing this controlled relaxation of the constraints opens up the possibility of a feasible solution where an infeasible solution previously existed when the constraints had to be met with strict regard to the inequality or equality specifications. “The overall purpose of GP is to minimize the deviations between the achievement of the goals and their aspirational levels.” (36:3)

There are three basic forms of GP: 1) Archimedean GP, 2) Chebyshev GP, and 3) non-Archimedean GP (21:12). The Archimedean form is used to minimize the sum or weighted sum of all deviations from the goals (21:12). This is also known as Weighted GP (WGP). The WGP formulation given here is adapted from Romero, 1991.

Table 3. Parameters and Variables for WGP and Chebyshev GP

| | |
|--------------------|--|
| Parameters: | |
| F | is the set of constraints |
| α_i | is the weighting factor for the negative deviation |
| β_i | is the weighting factor for the positive deviation |
| $f_i(\vec{x})$ | is the i th constraint function |
| b_i | is the target value of the i th constraint |
| d | is the maximum deviation |
| Variables: | |
| n_i | is the negative deviation from goal i |
| p_i | is the positive deviation from goal i |

$$\min \sum_{i=1}^k (\alpha_i * n_i + \beta_i p_i) \quad [2.10]$$

subject to

$$f_i(\vec{x}) + n_i - p_i = b_i \quad [2.11]$$

$$\vec{x} \in \{F\} \quad [2.12]$$

Ideally, in this formulation n_i and p_i will equal zero. However, if this is not possible, then the objective of the formulation is to minimize the positive and negative deviations, in proportional relation to the values of α_i and β_i .

Chebyshev GP, or minimax GP, is used to “minimize the ... maximum of the unwanted goal deviations.” (21:13) The following formulation is adapted from Romero 1991.

$$\min d \quad [2.13]$$

subject to

$$\alpha_i n_i + \beta_i p_i \leq d \quad [2.14]$$

$$f_i(\vec{x}) + n_i - p_i = b_i \quad [2.15]$$

$$\vec{x} \in \{F\} \quad [2.16]$$

The non-Archimedean form, also known as lexicographic goal programming, allows for prioritized goals. This concept of pre-emptive priorities lets the decision maker specify that one priority is preferred over another priority such that the goals should be fulfilled in a specific order, (*i.e.* “higher priority goals are satisfied first and it is only then that lower priorities are considered.” (36:4)) The LGP given is adapted from Ignizio 1985.

Table 4. Parameters for LGP model

| Parameters | |
|---------------------|---|
| \mathbf{u}^T | an ordered vector such that the k th, u_k term is of priority k |
| \mathbf{A} | coefficient matrix |
| \mathbf{b} | right hand side value/goal |
| \mathbf{v}^T | is the vector $[\mathbf{x} \ \mathbf{n} \ \mathbf{p}]$ where \mathbf{x} is the vector of variables, \mathbf{n} and \mathbf{p} are the vectors of negative and positive deviations from the goal |
| $\mathbf{c}^{(k)T}$ | the row vector of weights associated with deviations at rank k |

$$\text{subject to} \quad \text{lex min } \mathbf{u}^T = \{\mathbf{c}^{(1)T} \mathbf{v}, \dots, \mathbf{c}^{(k)T} \mathbf{v}\} \quad [2.17]$$

$$\begin{aligned} \mathbf{A}\mathbf{v} &= \mathbf{b} \\ \mathbf{v} &\geq 0 \end{aligned} \quad [2.18]$$

By utilizing one of the aforementioned GP models, it is possible to allow some controllable deviations from the desired right-hand-side values. This controllable deviation allows the decision maker to have some flexibility in the mathematical representation of the problem, which in turn gives some insight to alternate solutions.

Sensitivity Analysis

Sensitivity analysis of solutions to optimization problems gives the decision maker insight into the robustness of a solution. It tests the effect of model assumptions and assists in measuring sensitivity to the precision of the data. It also allows the

investigation of some limited variations in the operational conditions without the need for re-solving the model. Perhaps at the time of the formulation, circumstances were less stressed, (*i.e.* plentiful resources, no deadlines). Now, however, after the formulation is complete, circumstances have changed, resources have been depleted unexpectedly, time is now critical. The decision maker is not going to wait for a new formulation to be developed and solved. Utilizing sensitivity analysis on the original formulation and solution could provide adequate alternative solutions for the new circumstances.

Additionally, sensitivity analysis may be used to provide solutions to “what-if” scenarios; what if there were more resources or more time. By looking ahead to such “what if” scenarios, the decision maker might opt to make “minor” changes in certain values in order to gain higher benefits from the objective function.

In GP there are seven discrete changes that allow sensitivity analysis to be performed: 1) change in the weighting factor at priority level, 2) change in the weighting factor of the deviation variable, 3) change in the original right-hand-side goal, 4) change in the coefficients, 5) addition of a new goal, 6) addition of a new decision variable, and 7) reorder the original priority levels. (20:453; 39:62)

Utilizing such changes, being proactive in providing a list of suggested changes with corresponding benefits, allows the decision maker to have potential contingency plans if unforeseen circumstances arise. This is an extremely important edge if the decisions made, based on the results, mean life or death.

Previously Published Models

There have been two models, which have been developed recently, in an attempt to incorporate multiple asset types, Teledyne Brown Engineering (TBE) developed the

Sensor-Platform Allocation Analysis Tool (SPAAT) and ALPHATECH Inc. developed the Multi Asset Synchronizer (MAS). SPAAT utilizes mixed integer programming techniques to determine “the optimum mix of sensors, platforms, and ground stations” (35:37) to be used in various scenarios. SPAAT offers selection of simple objectives that can drive the model. These objective functions include: minimizing cost, maximizing area coverage, minimizing coverage, and feasibility goals (which “is used as a diagnostic tool” (35:39)).

MAS modifies a networking technique known as the Vehicle Routing Problem with Time Windows (VRPTW). This program, however, is used to allocate only airborne surveillance assets. Additionally, its primary goal is to “resolve tradeoffs in platform route planning, sensor resource allocation, and collection scheduling to construct highly efficient ISR [imaging, surveillance, and reconnaissance] plans.”(27:44)

Summary

The purpose of this chapter was to review the basic background in fundamental elements that were used in the development of the mathematical program used in this thesis. Chapter 3 describes the methodology used to achieve the mathematical formulation developed in this research to allocate imaging assets to cover various POIs.

III. Formulation

Introduction

The concept of determining an optimal mix of imaging assets to provide required coverage of a POI seems daunting. There is a finite number of imaging surveillance assets that are allocated to a theater. A theater itself could contain upwards of 50 countries. Each country alone can have many points of interests, be they military bases, military support factories, fighter squadrons, or even troops moving from one place to another. The vast array of possibilities complicates the process of allocating limited imaging surveillance assets.

Additionally, determining which objective function would best capture the decision-makers' needs and preferences is difficult. Should cost be minimized? Should area of coverage be maximized? Should time spent observing targets be maximized? Should assets used be minimized? Should the number of targets be maximized? These are just a few of an array of possible objective functions.

This chapter develops a mathematical formulation for allocating imaging assets over a fixed time horizon. First, a general approach for a Multi-Modal Goal Programming Resource Constrained Project Scheduling Problem (MMGPRCPSP) is given. Following the general formulation development, the specific formulation that was used in this research is given. The data needed for this formulation, the key assumptions made in this program, and computational effort follows the formulations.

The general problem being looked at is to observe a set of POIs with a finite set of assets for a fixed time. Additionally, there is a desired resolution for each POI, which is to be met by each asset imaging that POI.

General Approach

To optimize the allocation of resources to accomplish required tasks, the concept of Multi-Modal Resource Constrained Project Scheduling Goal Programming is used. The MMRCPSG allows for the scheduling of assets (constrained resources) in such a way that different assets (multiple modes) can be used to accomplish a task. The goal programming (GP) aspect of the formulation incorporates the various pre-emptive priorities assigned to different tasks.

The overall intent of the formulation is to allocate pre-assigned assets to accomplish a set of tasks during an established time window. Given such a setting, three main goals are addressed in this thesis: 1) minimize the number of POIs not imaged at any time during the required period, d_1 , 2) minimize the deviations from resolution requirements of the POIs, d_2 , and 3) minimize the time gap between assets imaging a POI, d_3 . The following sections discuss the constraints used to determine the value of these deviational variables.

Minimize POIs not Imaged During Time Horizon

As part of the objective function, it is necessary to minimize the number of POIs that are not imaged during the observation horizon. To assist in this goal, there must exist a means of counting the POIs not imaged. Expression [3.1] accomplishes this requirement. d_1 is a goal programming deviation variable that will equal one if no asset is

imaging a POI at any time during the planning period, *i.e.* $\sum \sum x_{mit} = 0$. d_i will be minimized in the objective function. There will be one such constraint for each POI.

$$d_i + \sum_{m \in M} \sum_{t \in ST_{mia}} x_{mit} \geq 1 \quad \forall i \in POI \quad [3.1]$$

Table 5. Parameter and Variable Definitions for General Formulation

| | |
|--------------------|--|
| Parameters: | |
| P | an ordered vector such that the k th term is of priority k |
| P_k | pre-emptive weight for priority k POIs |
| $\mathbf{w}^{(k)}$ | the vector of weights associated with deviations at rank k |
| w_{ij} | weight of deviation j for POI i |
| R | the set of possible routes for a particular asset |
| $NumSimulRts_R$ | number of simultaneous routes an asset in R can travel |
| M | set of all assets |
| POI | set of all POIs |
| ST_{mia} | set of access times for mode m imaging POI i |
| $Satellites$ | set of modes representing known satellites with known access times |
| MQ_i | minimum required image resolution for POI i |
| IQ_{mit} | image quality of mode m of POI i at time t |
| Variables: | |
| d | the is the vector of the deviation variables |
| d_{ij} | deviation variable j associated with POI i |
| $Routes_R$ | 1 if route c is chosen for UAV, 0 otherwise |
| DX_{mit} | 1 if mode m is imaging is imaging POI i at time t , 0 otherwise |
| DEV_{it} | 1 if no assets are imaging POI i at time t |
| F_{mit} | deviation from minimum required image quality of mode m on POI i at time t |

Minimize Deviations from Desired Resolution of each POI

It is also desirable to minimize the deviation from the minimum image quality desired by each asset imaging a particular POI. We must first determine the deviation from a particular requirement for each asset at every time the asset is imaging a POI.

Towards this, the expressions [3.2] and [3.3] are used. F_{mit} is the goal programming deviational variable. The number of constraints [3.2] in the formulization will be equal to the sum of all the durations of each access time of each asset to each POI.

$$x_{mit}IQ_{mit} - F_{mit} \leq x_{mit}MQ_i \quad \forall t \in ST[m, i, a], t' = t, \dots, t + Duration_{mia} \quad [3.2]$$

$$\sum_{m \in M} \sum_{t \in ST[m, i, a]} F_{mit} = d2_i \quad \forall i \in POI \quad [3.3]$$

Minimize the Time Gap Between Successive Imaging Assets

The final purpose of the objective function is to minimize the amount of time between successive assets imaging a particular POI. Constraints [3.4] and [3.5] work toward accomplishing this goal. Expression [3.4] introduces the deviational variable DEV_{it} , which is equal to one if there are no assets imaging task i at time t , to determine the times when no asset is imaging POI i at time t . Expression [3.5] then sums these deviations for each POI i . This sum, $d3_i$, is minimized in the objective function, thus selecting asset assignments that minimizes $d3_i$, the total time between assets imaging all POIs in the set. There will one constraint [3.4] for each time interval in *time* for each POI.

$$\sum_m DX_{mit} + DEV_{it} \geq 1 \quad \forall i \in POI, t \in time \quad [3.4]$$

$$\sum_{\forall j} DEV_{ij} = d3_i \quad \forall i \in POI \quad [3.5]$$

Additional Constraints

It is necessary to have a constraint that limits assets, which are only able to accomplish a set number of simultaneous routes. Equation [3.6] dictates that the sum of

the routes a particular asset travels must be less than or equal to the allowable number of simultaneous routes for that asset. Given a particular route, it is not possible for the resource to start a task at a time that is not in the route selected. This limitation is given by equation [3.7]. In the formulation, there will be a constraint [3.6] for each asset with more than one possible route, and a constraint [3.7] for each asset with multiple route possibilities, for each possible start time of that asset to image POI i at time t .

$$\sum_{c \in R} Routes_c \leq NumSimulRts_R \quad [3.6]$$

$$x_{cit} = Routes_c \quad \forall c \in R, i \in POI, t \in time \quad [3.7]$$

If there exists a set of assets that have unchangeable access times for each POI, then it is necessary to set x_{mit} equal one for those assets at the respective access times. This would be the acquire time of a satellite that is not to be re-established, for example. Mathematically, this is done via equation [3.8]:

$$x_{mit} = 1 \quad \forall t \in ST[m, i, a], m \in Satellites, i \in AOI, a \in access \quad [3.8]$$

In the overall formulization, there will be a constraint [3.3] for every asset with set start times, for every start time of that asset to image POI i at time t .

Objective Function

The goals in the objective function are numerically weighted, w_{ij} , within a priority class, and lexicographically weighted by priority class. As this is a pre-emptive goal program, lexicographic weights of the tasks to be accomplished control the prioritization. The tasks associated with the highest priority are required to be accomplished first; only after the first priority goals are attained does the solver consider accomplishing the tasks in the second highest priority. These pre-emptive weights are given as P_k , where

$k=1,2,\dots$, total number of priority classes and $P_1 \gg P_2 \gg \dots \gg P_k$. Mathematically, these goals and weights can be represented by the objective function given as expression [3.9]. Table 5 is a list of parameter and variable definitions used in this general formulation.

$$\text{lex min } \{P_1 \mathbf{w}^{(1)T} \mathbf{d}, \dots, P_k \mathbf{w}^{(k)T} \mathbf{d}\} \quad [3.9]$$

Specific Formulation

The following is a complete mathematical formulation used in this thesis. Table 5 gives the parameters and variables that are used in the specific formulation of this thesis. In this case, the project is to image a set of POIs for a given observation horizon. The resources are the different imaging surveillance assets and the tasks are the imaging of the various POIs. The objectives, in the example shown, are to minimize the number of POIs not imaged at all during the observation horizon, minimize the deviation from the minimum imaging resolution, and minimize the amount of time between each successive imaging asset for a particular POI. Of course, other objectives can be modeled with this approach.

The airborne imaging assets are only allowed to fly one route at a time. This requirement is adapted from expressions [3.2] and [3.3]. The special operations forces (SOF) team, also utilizes expressions [3.2] and [3.3], but the SOF team is allowed to image two POIs simultaneously, the equivalent of having two simultaneous routes.

Table 6. Parameters and Variables

| | |
|--------------------|--|
| Parameters: | |
| P_k | pre-emptive weight for priority k POIs |
| W_i | weight of having POI i imaged at any time during observation period |
| $W2_i$ | weight of having POI i imaged within minimum imaging requirements |
| $W3_i$ | weight of having POI i imaged with minimal time gaps |
| R | the set of possible routes for UAV |
| S | the set of 12-member SOF teams |
| ST_{mia} | set of access times for mode m imaging POI i |
| $Satellites$ | set of modes representing known satellites with known access times |
| MQ_i | minimum required image resolution for POI i |
| IQ_{mit} | image quality of mode m of POI i at time t |
| Variables: | |
| d_i | 1 if POI i is not imaged at any time during observing horizon, 0 otherwise |
| $Ftotal_i$ | total deviation form minimum image resolution for POI i |
| $TotGAP_i$ | total gap time deviation from allowable time gap for POI i |
| $RTUAV_i$ | 1 if route c is chosen for UAV, 0 otherwise |
| DX_{mit} | 1 if mode m is imaging is imaging POI i at time t , 0 otherwise |
| DEV_{it} | 1 if no assets are imaging POI i at time t |
| F_{mit} | deviation from minimum required image quality of mode m on POI i at time t |

$$lexmin\{P_1 \sum_{i \in POI \text{ in } P_1} W_i d_i + W2_i Ftotal_i + W3_i TotGAP_i, \dots, P_3 \sum_{i \in POI \text{ in } P_3} W_i d_i + W2_i Ftotal_i + W3_i TotGAP_i\} \quad [3.10]$$

subject to

$$\sum_{c \in R} RTUAV_c = 1 \quad [3.11]$$

$$x_{cit} = RTUAV_c \quad \forall c \in R, i \in POI, t \in time \quad [3.12]$$

$$\sum_m \sum_{t=1}^{432} x_{mit} \leq 2 \quad \forall m \in S, \forall i \in POI \quad [3.13]$$

$$x_{mit} = 1 \quad \forall t \in ST[m, i, a], m \in Satellites, i \in POI, a \in access \quad [3.14]$$

$$d_i + \sum_{m \in M} \sum_{t \in ST_{mia}} x_{mit} \geq 1 \quad \forall i \in POI \quad [3.15]$$

$$x_{mit} IQ_{mit'} - F_{mit} \leq x_{mit} MQ_i \quad \forall t \in ST[m, i, a], t' = t, \dots, t + Duration_{mia} \quad [3.16]$$

$$\sum_{m \in M} \sum_{t \in ST[m, i, a]} F_{mit} = Ftotal_i \quad \forall i \in POI \quad [3.17]$$

$$\sum_m DX_{mit} + DEV_{it} \geq 1 \quad \forall i \in POI, t \in time \quad [3.18]$$

$$\sum_{\forall j} DEV_{ij} = TotGAP_i \quad \forall i \in POI \quad [3.19]$$

$$Ftotal_i, TotGAP_i, F_{mit} \geq 0$$

$$d_i, x_{mit}, RTUAV_c, DX_{mit}, DEV_{it} \in \{0,1\}$$

Throughout this formulation, goal programming is used with both numeric and pre-emptive weighting purposes. The pre-emptive prioritization is to ensure the first priority set of tasks is accomplished before the second priority tasks are considered. The second priority set of tasks is then satisfied prior to considering the third priority set of tasks, and so forth. This is helpful if the higher priority tasks change. Pre-emptive weights are based on expert opinion, target values or other appropriate consideration.

The numeric weights, or differential weights, give precedence within the set of tasks at the same priority. They allow discrimination within a priority, just as they would in a regular linear program. This weighting can be done relative to within each priority class, or over all tasks. A simple example of the use of these weights is as follows; one scenario might require that the minimization of the time gap is of highest priority, then minimizing deviations from certain requirements, then tasks not accomplished at all during the observation period and in each case, the tasks need to be accomplished in a particular order. The numerical weights, however have to be determined using an acceptable scale. This formulation allows a great deal of flexibility to the analysis. It can accommodate a wide range of objectives and requirements, allowing the fine tuning of the model and the analysis.

The Dataset

Data needed to run this model includes:

- 1) desired objectives,
- 2) a list of POIs that are prioritized and weighted,
- 3) total length of observation time,
- 4) a list of all assets (i.e. satellite with IR imaging, UAV with SAR capabilities) available to theater, if there are multiple assets of the same type, they are listed individually, if choosing from potential routes, each route is listed as a separate entry,
- 5) access times of each asset to the POIs throughout the duration of the observation period,
- 6) the duration of the access each asset to each POI,
- 7) minimum required resolution of each POI, and
- 8) quality of images available from asset based on common scale

A list of POIs, the length of the observation horizon, and the minimal resolution requirements for each POI are inputs from the persons interested in gathering the imagery. This could be a Theater Commander, a CINC, national leadership, or other appropriate authority. Prioritization of the POIs is based on appropriate classes and scales developed by the interested party. Scales should be developed using appropriate decision analysis and measurement theory (see Burke, Kirkwood, and others), or another tested means of assigning unbiased weights to different POIs based on characteristics of the POI in question and the commander's intent. In the notional dataset used, the process of prioritizing and weighting the different POIs is assumed to have been accomplished based on one of the aforementioned methods.

The list of assets and the number of each asset type in each theater are given by the Theater Intelligence Architecture Plan (TIAP). The duration of access of each asset to each POI is known to the operators of the assets. The quality of the images available from each asset is based on a predetermined common scale. The acquisition time of each

asset can be calculated given a starting location. The number of assets of one type that can be used in one time period is based on the Theater Commander's doctrine. Finally, the objectives used in the analysis will be based on the Commander's operational requirements.

Key Assumptions

As mentioned in Chapter 1, there were four main assumptions made in this research: 1) terrestrial points of interest, 2) the retasking of satellites is not allowed, 3) all times are integers, and 4) there exists predetermined routes for the UAV(s) to choose. However these are not the only assumptions made during the process of this research.

The weighting of POIs is assumed to have been accomplished using an acceptable analytical method. Additionally, this model does not account for any potential breakdowns of equipment, or the retasking of satellites. If an asset is in the database as available to the theater in question, it is assumed to be fully operational.

If there exist multiple areas of interest in different theaters, then those POIs are considered as separate problems and can be handled independently. This is because the model considers only the assets available in one particular theater and not across theaters. With this basic model, however, a decomposition approach could be used to coordinate theaters.

Computational Effort

The MMGRCPSP is known to be *NP*-hard. (see Schirmer) *NP* is a class of *decision problems*. *Decision problems* are problems that ask the question "is there a feasible solution?" These decision problems are analogous to the optimization problem of finding a feasible solution. The decision problem "is not

computationally harder than the corresponding optimization problem.” (13:22).

However, the two problems are computationally similar; if the decision problem is computationally hard, then so is the optimization problem.

An *NP*-class of decision problems is a set of problems “for which no polynomial time algorithms are known but for which the ‘yes’ answer can be verified in polynomial time.” (13:23) The term *polynomial time* comes from complexity theory, a means of classifying computational problems as either easy or hard based on the runtime of the approach. Polynomial time is basically runtime that is a polynomial function (in the amount of steps required of the algorithm) dependent on time that bounds the time an algorithm works to solve a problem. If this bound is not present, then the function is considered an *exponential-time* algorithm.

NP-complete problems are the “hardest problem in NP” (13:23). If an optimization problem is *NP*-hard, then the decision problem is *NP*-complete. Due to this ‘hardness’, computing a solution using this approach could prove time consuming and/or difficult to find a feasible solution. In such cases, using a heuristic to find a starting solution can speed up the process. If the problem is large enough, it may require a solution via a heuristic approach. The concept of developing a usable heuristic for the formulation presented in this chapter is discussed in Chapter 5.

Summary

This chapter provided the methodology used to develop a mathematical formulation to optimally allocate imaging assets to cover particular POIs during an

observation period, subject to POI, imaging and time gap constraints. Chapter 4 will apply this methodology to a notional example and analyze the solutions provided.

IV. Illustrative Analysis

Introduction

This chapter demonstrates the methodology presented in Chapter 3 using a small notional dataset. First, an overview of the problem is given. The overview is followed by a description of how the notional dataset was created. Finally, the results and analysis based on the proposed methodology, is presented.

Problem

As tensions slowly begin to increase, Command desires to obtain imaging surveillance on ten points of interest for a 72-hour period. The 72-hour period is to be divided into 10-minute intervals. There are, however, only six imaging assets available for use in covering the ten POIs: four satellites, one UAV, and one 12-member special operations forces (SOF) team. The SOF team can be broken into two teams of six members each, bringing the potential number of imaging assets to seven.

Due to other commitments, the four satellites are unable to be retasked at this time; the access times from each satellite to each target and the duration of these accesses are, therefore, known and fixed. The use of a UAV route generator, such as one described in Grimm (1992) or Kinney (2000), has been employed to provide two potential routes for the UAV. The six-member special operations teams are currently able to monitor one POI each, and under current conditions, the teams have no restriction as to which POIs they can monitor.

The ten POIs have been weighted using Decision Analysis, Measurement Theory or some other appropriate method (see Kirkwood, 1997; Burke, 1999), which takes into

consideration the decision makers values concerning each POI, including the priority of the POI. Additionally, due to operational requirements, the decision maker has provided minimum image resolution requirements for each POI.

The requirement is to allocate the available imaging assets to cover as many of the POIs as possible for as much time as possible during the 72-hour observation horizon. If complete coverage is not possible, precedence will be given to the POIs with greater prioritized weights over the lesser-weighted POIs. Included in allotting the assets, a choice as to which route the UAV should use is determined based on the potential routes given.

Notional Dataset

The ten POIs used in the notional dataset were taken from Fuller (1997). Fuller has two unclassified scenarios; an Iraqi scenario and a Middle East scenario. The POIs used in this notional dataset were extracted from the Iraqi scenario. Included in the POI data were the latitudes, longitudes, and notional target or T-values of the individual POIs, which are given in Table 7. For more information on the POIs, latitudes, longitudes, and notional values, refer to Fuller (1997). Figure 1 is a map of the POIs and the starting location for the UAV.

Command has prioritized the POIs based on their T-values. If the POI has a T-value of eight or higher, it is considered a priority 1 POI; a value of four to seven corresponds to a priority of 2, and a target value of three or less was classified as a priority 3 target. Additionally, the notional weights for each POI are in the form of integers between 1 and 100.

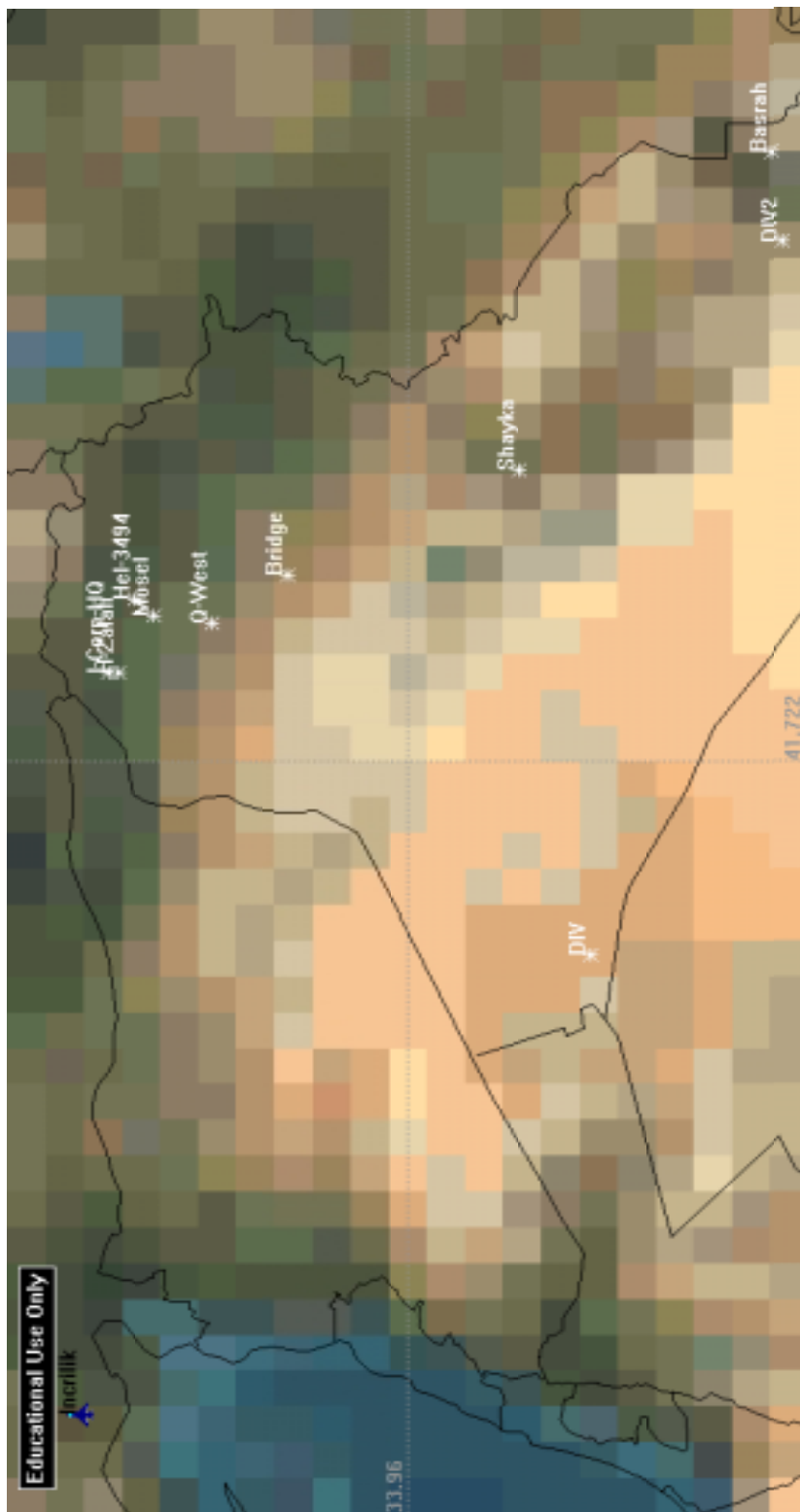


Figure 1. Map of POIs and starting position of UAV using STK®

Table 7. Notional POIs, Latitudes, Longitudes, T-Values, Priorities, and Weights

| Name | POI # | Latitude | Longitude | T-Value | Priorities | Weights |
|-----------|-------|----------|-----------|---------|------------|---------|
| Q-West | 1 | 35.79 | 43.09 | 10 | 1 | 98 |
| Basrah | 2 | 30.57 | 47.75 | 10 | 1 | 87 |
| Mosel | 3 | 36.33 | 43.16 | 8 | 1 | 70 |
| Shayka | 4 | 32.92 | 44.60 | 8 | 1 | 66 |
| H-Zalah | 5 | 36.66 | 42.60 | 6 | 2 | 52 |
| Hel-3494 | 6 | 36.50 | 43.33 | 6 | 2 | 51 |
| I-Corp-HQ | 7 | 36.75 | 42.60 | 3 | 3 | 50 |
| Bridge | 8 | 35.08 | 43.57 | 3 | 3 | 40 |
| DIV | 9 | 32.26 | 39.80 | 1 | 3 | 34 |
| DIV2 | 10 | 30.47 | 46.86 | 1 | 3 | 11 |

The minimum resolution required is dependent on operational requirements associated with the POIs. A resolution of six-meters allows the decision maker or image analyzer to recognize large buildings. Depending on the intended use of the imagery, different minimal requirements are assigned to each POI. For use in this notional dataset a priority 1 POI is assumed to require a minimal resolution of one meter, and no POI requires a resolution of less than six meters. These resolution requirements were arbitrarily chosen based on the capabilities of a certain resolution.

To determine the various access times of the assets to the POIs, data was collected using STK. One of the sponsors of this thesis provided orbital information for the notional set of satellites, as well as notional sensor data (including focal length and pixel pitch) for the satellites and UAV. COL William Klimack, USA, of the United States Military Academy, provided information concerning the special operations team (See Appendix A for details).

This information was programmed into STK and a three-day simulation was run. The simulation provided access times, the duration of each access, and the ground sampling distance (GSD) of each asset to each POI throughout the three-day period. The

GSD corresponds to the resolution obtainable from the sensors to the POI. This data is provided in Appendix B. In an actual operational setting this data would be obtained from various databases and analyses.

The data from STK was used as input to a Microsoft Excel® Worksheet. A code was written in Visual Basic Applications® to generate the coefficient and variable matrices for the optimization problem (see Appendix C). Those matrices were transferred to a worksheet for input to Frontline’s Premium Solver Platform™ to solve the problem. More specifically, the Large-Scale LP Solver of the Frontline Premium Solver Platform was used. Using a Dell INSPIRON 8100 laptop with a Pentium 3 processor, it took under two minutes for the solver to find an optimal solution.

In this notional example, there was no distinction between minimizing the number of POIs not imaged during the time horizon and minimizing the deviation from the desired image resolution nor minimizing the time between successive imaging assets for a particular POI. Each deviation for a given POI was weighted equally. Additionally, the POIs in the pre-emptive priority 1 set are weighted more heavily than the POIs in pre-emptive priority 2 and 3 sets. Expression [4.1] gives the objective function used in this particular formulation.

$$\begin{aligned} \min & P_1(98d_1 + 87d_2 + 70d_3 + 66d_4 + 98FTotal_1 + 87FTotal_2 + 70FTotal_3 + 66FTotal_4 + \\ & 98TotGAP_1 + 87TotGAP_2 + 70TotGAP_3 + 66TotGAP_4) + P_2(52d_5 + 51d_6 + 52FTotal_5 + \\ & 51FTotal_6 + 52TotGAP_5 + 51TotGAP_6) + P_3(50d_7 + 40d_8 + 34d_8 + 11d_{10} + 50FTotal_7 + \\ & 40FTotal_8 + 34FTotal_9 + 11FTotal_{10} + 50TotGAP_7 + 40TotGAP_8 + 34TotGAP_9 + 11TotGAP_{10}) \end{aligned} \quad [4.1]$$

Examining the Results

Running the Large-Scale LP Solver produced a solution for allocation of the seven assets. The solution assigned the UAV to route 2, the soft team was divided into

two teams; one covering Q-West, and the other covering Basrah. By reviewing the solution, the analyst is capable of determining when each POI is being imaged, for how long and at what resolution. Table 8 gives the allocation of assets for Q-west, the remaining POIs are given in Appendix D.

Additionally, the information provided by the solution shows the analyst when a POI is not being imaged. This could prove useful to show when coverage is limited, and the decision-maker can plan accordingly. For example, Figure 2 is a Gantt chart for a 3-hour period, utilizing data provided in the solution for the notional example (see Appendix E for complete Gantt chart from notional example).

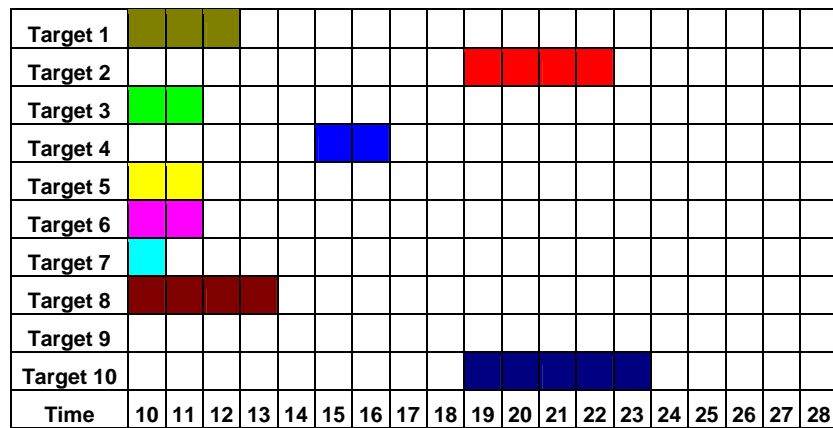


Figure 2. Sample Gantt chart for a 3-hour period (in 10 minute intervals)

This type of chart could be used by decision makers to determine how much coverage of a particular POI is available if a mission is planned for a particular time. Furthermore, if time allows, the analyst could give this information to the UAV route planners, so that another route could be planned or perhaps the decision-maker can deploy another soft team to provide additional coverage.

Table 8. Allocation for Q-west

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered | |
|----------|----------------|------------|----------|------------------|-----------------------|-----------------------------|--|
| Q-West | Quickbird 1 | 135 | 0 | 0.9481 | | 65 intervals | |
| | | 210 | 0 | 0.8498 | | | |
| | | 426 | 0 | 0.8979 | | | |
| | Quickbird 2 | 44 | 0 | 0.8836 | | | |
| | | 257 | 0 | 0.8503 | | | |
| | | 335 | 0 | 0.9683 | | | |
| | Quickbird 3 | 112 | 0 | 0.8882 | | | |
| | | 189 | 0 | 0.8697 | | | |
| | | 402 | 0 | 0.9199 | | | |
| | Quickbird 4 | 68 | 0 | 0.9066 | | | |
| | | 280 | 0 | 0.8610 | | | |
| | | 358 | 0 | 0.8989 | 1 to 9 | | |
| | UAV route 2 | 9 | 3 | 0.9126 | 13 to 36 | | |
| | | 37 | 2 | 1.1184 | 43 | | |
| | | 40 | 2 | 0.9307 | 45 to 67 | | |
| | | 68 | 2 | 1.1536 | 74 to 82 | | |
| | | 71 | 2 | 0.9270 | | | |
| | | 99 | 2 | 1.1678 | | | |
| | | 102 | 2 | 0.9425 | | | |
| | | | 130 | 2 | 1.1658 | | |
| | | | 134 | 2 | 0.9337 | | |
| | | | 161 | 2 | 1.2046 | | |
| | | | 165 | 2 | 0.9540 | | |
| | | | 193 | 2 | 1.1106 | | |
| | | | 196 | 3 | 0.9245 | | |
| | | | 224 | 2 | 1.1889 | | |
| | | | 227 | 3 | 0.8993 | | |
| | | 255 | 2 | 1.1446 | | | |
| | | 259 | 2 | 1.1555 | | | |
| SOF team | | 272 | 2 | 1.1996 | | | |
| | | 83 | 349 | 0.5000 | | | |

Figure 3 graphically demonstrates another way the data from the solution can be used. It shows the solution for the notional example color-coded to show how many intervals each POI is not being imaged. Figure 3 is used to graphically demonstrate the solution when the priorities are changed, discussed in the next section. These types of figures could be used to easily compare and contrast different alternative solutions, which could arise from goal programming sensitivity analysis described in the next section.

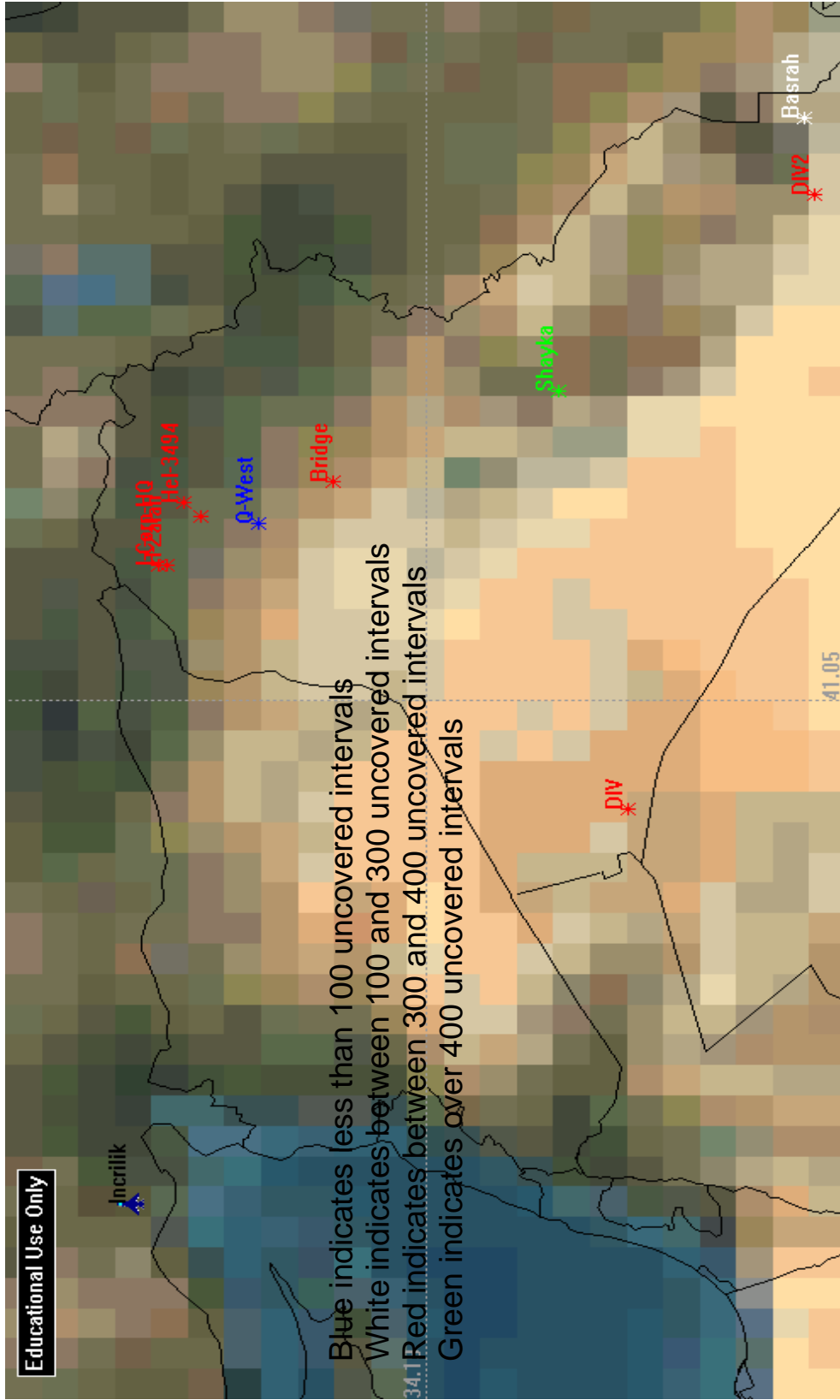


Figure 3. From STK®, graphical representation of solution

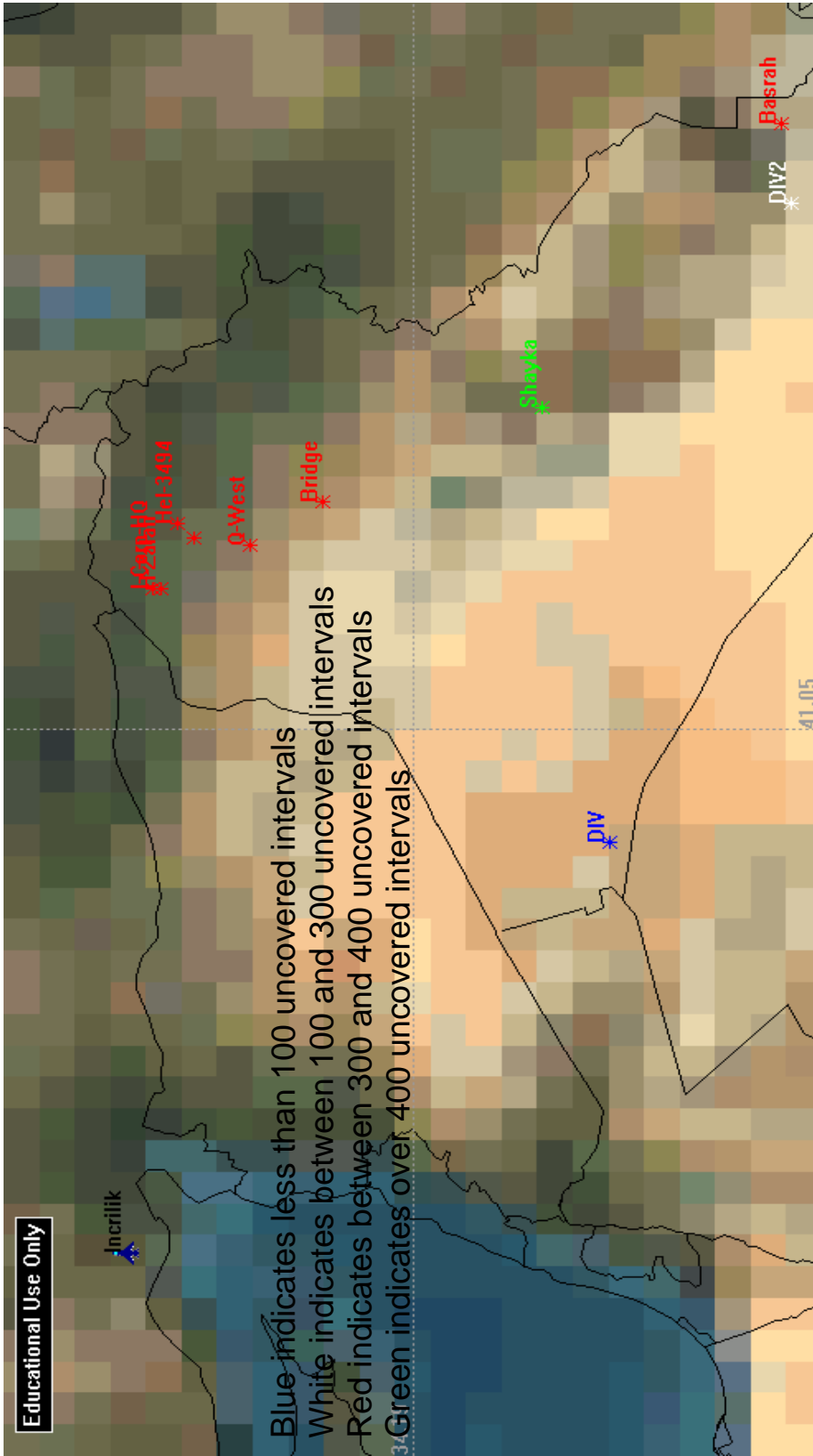


Figure 4. From STK®, changed priorities as part of sensitivity analysis

Goal Programming Sensitivity Analysis

One type of goal programming sensitivity analysis involves changing the priority weights - the pre-emptive weights. If the priorities of the targets change, causing the preferences for the POIs to change, this will change the solution. In this notional example, because it is small to illustrate the methodology and the capability of the formulation, such changes result in less dramatic impact. However, if the priorities are reversed, so that what was priority 3 is now priority 1, the solution changes to having the SOF team cover DIV and DIV2 instead of Q-west and Basrah. The route of the UAV stays the same because this route provides the most overall coverage of the POIs. The other route did not have as many access times of the various POIs.

In both examples the number of variables in the problem was 4853 and the number of constraints was 4833. This was just with seven imaging assets, 432 time intervals, and ten POIs. However, the number of variables and constraints is actually more. The \mathbf{A} matrix in the optimization problem, is sparse. To reduce the problem size, this characteristic was exploited. Through this manual pre-processing, the solver did not take into consideration any variable that was already a zero. To determine which variables could equal only zero, the times of each access were examined. If no asset started at time t , then it can be concluded that the corresponding x_{mit} cannot equal one, and those x_{mit} variables were not included in the actual solving of the problem. This kept the problem at a manageable number of variables and constraints for the solver to handle. Such pre-processing aids in limiting the size of the problem and will also reduce computational time.

Flexibility of the Formulation

This formulation can be used with any number of assets, POIs, and time intervals. Limits on the number of assets, POIs, and time intervals considered are dictated by the solver capability and the computer it is run on.

Retasking of assets

This formulation, with slight modifications to the constraints, could be used to help retask satellites and or help plan the routes of the UAVs. To accomplish this, the constraint:

$$d_i + \sum_{m \in M} \sum_{t \in ST_{mi}} x_{mit} \geq 1 \quad \forall i \in AOI \quad [4.2]$$

would be modified by simply changing the summation range for $t \in ST$ to $t = ES$ to LS where ES_{mi} (LS_{mi}) are simply the earliest (latest) start times of asset m imaging POI i . This would then have the formulation determine when to have asset m image POI i .

In doing this, however, constraints would need to be added to enforce any downtime, turn time, or reorbit time an asset would require after it completed imaging a particular POI. This constraint type would also ensure that an asset was not scheduled to start imaging a successive POI prior to completion of imaging of a previous POI. Suppose that dur_{mit} is the duration of asset m imaging POI i if it starts imaging at time interval t , and that RDT_{mi} is the required downtime, turn time, or reorbit time of asset m after imaging POI i . Then an example of the constraint needed could be:

$$\sum_{i \in POI} \left(x_{mit} + \sum_{t'=t+1}^{t+dur_{mit}+RDT_{mi}} x_{mit'} \right) \leq 1 \quad \forall t, m \quad [4.3]$$

This constraint says if $x_{mit} = 1$ (asset m starts imaging POI i at time t), then $x_{mit'} \neq 1$ if $t' < t + dur_{mit} + RDT_{mi}$.

The use of this modification to the original formulation unfortunately materially increases the size of the problem. This is because the model now considers every possible time t in the observation period, and adds an additional $t \cdot m$ constraints to the problem. It is recommended that efficient ways to implement this modification be investigated in future research. This would include only including assets that are likely to be candidates for re-tasking in this extension.

Bounding the time gap for each POI

Another modification that is possible is to place a lower bound the total time gap for each POI. Suppose the decision maker states there is some acceptable time gap, T_i , allowed between successive images of a POI assets. This condition could be incorporated into the problem by modifying constraint [3.11] to provide constraint [4.4] and adding another constraint [4.5]. This would change the deviational variable in the objective function from $TotGAP_i$ to $OVER_i$ to represent the amount over the allowable time gap each POI is over the allowed gap:

$$\sum_{j=t}^{t+T_i+2} DEV_{ij} - OVER_{iz} = T_i \quad \forall i \text{ and } \forall t \quad [4.4]$$

$$\sum_{\forall z} OVER_{iz} = OVER_i \quad \forall i \quad [4.5]$$

Again, this will increase the number of variables and constraints in the problem.

Given the basic formulation, a wide contingency of options can be modeled. The availability of such models provides a starting point to develop effective optimization and heuristic approaches.

Different goals for the objective function

In addition to easily modifying the constraints in the formulation, the objective function is also flexible in its ability to incorporate various decision-maker goals. For instance, suppose the decision-maker has five goals: 1) ensure that each priority one target has some coverage during the observing period, 2) minimize the time gap of priority one targets to a fixed number T_i , 3) provide required resolution of each target in each priority set where priority sets are weighted 3:2:1, 4) ensure all other targets are covered at least once during the observing period, and 5) minimize all the time gaps for all targets where the priority sets are weighted 3:2:1.

Constraints for objective function

For the first goal, it is necessary to have a constraint which counts the targets not covered in the priority 1 set of targets. Constraint [4.6], similar to constraint [3.15], is used to count the number of targets not covered.

$$d_i + \sum_{m \in M} \sum_{t \in ST_{mia}} x_{mit} \geq 1 \quad \forall i \in P1 \quad [4.6]$$

where

$P1$ is the set of priority 1 targets

x_{mit} is 1 if at time t , asset m is imaging target i

d_i is 1 if at no time during observation period is target i being imaged

The second goal incorporates one of the previously mentioned modifications given by expressions [4.4] and [4.5]. To minimize the gap between successive imaging assets to a given amount, expressions [4.4] and [4.5] are combined with expression [3.18]. The constraints are:

$$\sum_m DX_{mit} + DEV_{it} \geq 1 \quad \forall i \in P1, \forall t \quad [4.7]$$

$$\sum_{j=t}^{t+T_i+2} DEV_{ij} - OVER_{iz} = T_i \quad \forall i \in P1, \forall t \quad [4.8]$$

$$\sum_{\forall z} OVER_{iz} = MINTIMEGAP_i \quad \forall i \in P1 \quad [4.9]$$

where

DX_{mit} is 1 if mode m is imaging target i at time t

DEV_{it} is 1 if at time t no asset is imaging target i

T_i is the minimum time gap allowed between assets for target i

$OVER_{iz}$ is the amount over the minimum allowed time gap for a particular time period

$MINTIMEGAP_i$ is the total amount of time over the allowed time gap

For the goal of providing the required resolution, the constraints are unchanged from the ones given in the specific formulation. (See table 6 for variable definitions)

$$x_{mit} IQ_{mit'} - F_{mit} \leq x_{mit} MQ_i \quad \forall t \in ST[m, i, a], t' = t, \dots, t + Duration_{mia} \quad [4.10]$$

$$\sum_{m \in M} \sum_{t \in ST[m, i, a]} F_{mit} = Ftotal_i \quad \forall i \in POI \quad [4.11]$$

The fourth goal, to ensure all remaining targets are imaged at least once during the observing horizon, has a constraint very similar to [4.6]. The difference is that instead of only looking at the targets in priority one, it looks at the remaining targets in priorities two and three.

$$d_i + \sum_{m \in M} \sum_{t \in ST_{mia}} x_{mit} \geq 1 \quad \forall i \in P2 \text{ and } P3 \quad [4.12]$$

where

$P2(P3)$ are the set of priority two (three) targets

The final goal is to minimize all time gaps for all targets. For this goal, the constraints are the same as [3.18] and [3.19]. (See table 6 for variable definitions)

$$\sum_m DX_{mit} + DEV_{it} \geq 1 \quad \forall i \in POI, t \in time \quad [4.13]$$

$$\sum_{\forall j} DEV_{ij} = TotGAP_i \quad \forall i \in POI \quad [4.14]$$

Objective function

The objective function, which incorporates the five goals of the decision-maker, is given by:

$$\begin{aligned} lex \min \{ & P_1 \sum_{i \in P1} w_i d_i, P_2 \sum_{i \in P1} w_i MINTIMEGAP_i, P_3 \sum_{i \in P1} 3w_i Ftotal_i + P_3 \sum_{j \in P2} 2w_j Ftotal_j + \\ & P_3 \sum_{k \in P3} w_k Ftotal_k, P_4 \sum_{j \in P2 \& P3} d_j, P_5 \sum_{i \in P1} 3w_i TotGAP_i + P_5 \sum_{j \in P2} 2w_j TotGAP_j + P_5 \sum_{k \in P3} w_k TotGAP_k \} \end{aligned} \quad [4.15]$$

where

P_1, P_2, P_3, P_4, P_5 are the pre-emptive priorities for goals
 w_i is the weights associated for the particular deviations for each POI i

This formulation, given in its entirety below, is yet another demonstration of the flexibility and robustness of the general formulation given in Chapter 3. Utilization of the robustness, allows for a multitude of possible optimization problems to be solved and provide the necessary information to the decision maker.

The complete model:

$$\begin{aligned} \text{lex min } \{ & P_1 \sum_{i \in P1} w_i d_i, P_2 \sum_{i \in P1} w_i \text{MINTIMEGAP}_i, P_3 \sum_{i \in P1} 3w_i \text{Ftotal}_i + P_3 \sum_{j \in P2} 2w_j \text{Ftotal}_j + \\ & P_3 \sum_{k \in P3} w_k \text{Ftotal}_k, P_4 \sum_{j \in P2 \& P3} d_j, P_5 \sum_{i \in P1} 3w_i \text{TotGAP}_i + P_5 \sum_{j \in P2} 2w_j \text{TotGAP}_j + P_5 \sum_{k \in P3} w_k \text{TotGAP}_k \} \end{aligned} \quad [4.15]$$

subject to

$$d_i + \sum_{m \in M} \sum_{t \in ST_{mia}} x_{mit} \geq 1 \quad \forall i \in P1 \quad [4.6]$$

$$\sum_m DX_{mit} + DEV_{it} \geq 1 \quad \forall i \in P1, \forall t \quad [4.7]$$

$$\sum_{j=t}^{t+T_i+2} DEV_{ij} - OVER_{iz} = T_i \quad \forall i \in P1, \forall t \quad [4.8]$$

$$\sum_{\forall z} OVER_{iz} = \text{MINTIMEGAP}_i \quad \forall i \in P1 \quad [4.9]$$

$$x_{mit} IQ_{mit'} - F_{mit} \leq x_{mit} MQ_i \quad \forall t \in ST[m, i, a], t' = t, \dots, t + \text{Duration}_{mia} \quad [4.10]$$

$$\sum_{m \in M} \sum_{t \in ST[m, i, a]} F_{mit} = \text{Ftotal}_i \quad \forall i \in POI \quad [4.11]$$

$$d_i + \sum_{m \in M} \sum_{t \in ST_{mia}} x_{mit} \geq 1 \quad \forall i \in P2 \text{ and } P3 \quad [4.12]$$

$$\sum_m DX_{mit} + DEV_{it} \geq 1 \quad \forall i \in POI, t \in \text{time} \quad [4.13]$$

$$\sum_{\forall j} DEV_{ij} = \text{TotGAP}_i \quad \forall i \in POI \quad [4.14]$$

$$\text{Ftotal}_i, \text{TotGAP}_i, \text{MINTIMEGAP}_i, \text{OVER}_{iz}, F_{mit} \geq 0$$

$$d_i, x_{mit}, DX_{mit}, DEV_{it} \in \{0,1\}$$

Summary

A small notional example was used to demonstrate the model developed in Chapter 3. The formulation given in Chapter 3 was able to determine which

predetermined route for a UAV should be used and which POIs the SOF team should image. It also tells the analyst where there is no coverage of each POI available during the observation period. This is critical information for the decision-maker to have, especially in a planning environment. Using this information, the decision-maker could request more assets to fill gaps, develop alternate routes for the UAVs or other surveillance assets, or take other actions that would benefit the mission.

Additionally, this chapter described a couple of modifications that could be done to make this model more flexible. The main concern with the modifications given is that the number of variables and constraints increases dramatically, which limits the users choices in solvers to use to solve the problem.

Chapter 5 first reviews the research done for this thesis. Following the review, conclusions and recommendations based on this research are given.

V. Conclusions and Recommendations

Review

For the United States to maintain information dominance, it is necessary that surveillance and other information assets be allocated in the most efficient manner. Through efficient allocation, the necessary information can be obtained by analysts and passed to decision-makers for use in strategic and tactical planning. Towards this end, allocating available imaging surveillance assets to image points of interest becomes a vital tasking in the pre-critical timeframe. A means for optimizing the allocation of these assets in a timely fashion is of incredible importance.

Using a multi-modal resource constrained project scheduling approach along with goal programming is one way of optimizing the allocation of imaging assets. The formulation presented in Chapter 3 gives a means of optimizing surveillance assets in manner so as to minimize the number of POIs not covered at all, minimizing the deviation from a required imaging resolution for each POI, and minimizing the time gap between successive assets imaging a POI. These three objectives can be weighted to incorporate the decision-makers preferences as to the order of importance of the objectives. Using goal programming, the deviation variable associated with the most important objective is minimized first and then the second most important objective, and so forth.

The solution provided by solving the optimization problem suggests how to allocate the resources in a manner that maximizes coverage based on the three

objectives in the objective function. Additionally, the solution tells the analyst where there is a lack of imaging asset coverage. This information can be vital in the planning stages of a mission.

Recommendations

This approach works well when the data is of limited size. Unfortunately, as mentioned in Chapter 1, the problem exhibits combinatorial growth. In the small notional example presented in Chapter 4, there were over 4000 variables and over 4000 constraints, even with pre-processing during the problem generation phase. The methodology works, but the concern is how quickly the problem grows with additional POIs, assets, and time intervals.

To overcome the problem with dimensionality, it is suggested that a heuristic (or heuristics) be developed, to be used to generate feasible solutions, particularly in “quick turn” settings, and that can be used to generate starting solutions for the optimization, (see Calhoun 2000 and 2002), if an optimal solution is required. By providing a formulation of the problem, a first step has been taken in this process.

Furthermore, exploiting the potential structure in this problem of allocating assets could assist in limiting the dimensionality problems inherent to this problem. Different approaches could include formulating the problem as a set covering problem, a three-dimensional assignment problem, or a combination of decomposition approaches.

Conclusions

The need for accurate and timely information is a never-ending requirement for decision makers, especially for planning purposes. To provide this information, it is vital

to have a means of optimizing allocation of all imaging surveillance assets, be them land, sea, air, or space assets.

Keeping the problem manageable, in reference to size and computation time, while still providing the necessary information, is the key to creating useful optimization program. Unfortunately this kind of problem falls directly to the “curse of dimensionality”. It does not take much in the way of increasing POIs, assets, and time intervals to cause this problem to “explode”. The goal priority classes can assist, however, in limiting the search space.

The formulation presented is able to calculate an optimal allocation of resources and is robust and flexible so as to handle modifications and enhancements such as those addressed in Chapter 4. These modifications and enhancements, based on the decision maker’s needs and preferences, will provide the analyst with more information to better assist the decision-maker. The approach presented in this thesis is a firm foundation for future work in this area.

Appendix A. Information Used to Develop STK Model

All parameters for the satellites used in this model were provided by a sponsor. They were used to create an unclassified notional example to demonstrate the capability of the model. These parameters are given in Table 9.

Table 9. Satellite parameters used in STK model

| Satellite | Propagator | Apogee & Perigee Alt. | Inclination | RAAN |
|------------|----------------|-----------------------|----------------|----------------|
| Quickbird1 | J4Perturbation | 449.998960 km | 97.218774 deg | 279.276837 deg |
| Quickbird2 | J4Perturbation | 449.998960 km | 97.218774 deg | 219.276837 deg |
| Quickbird3 | J4Perturbation | 449.998960 km | 97.218774 deg | 219.276837 deg |
| Quickbird4 | J4Perturbation | 449.998960 km | 97.218774 deg | 279.276837 deg |
| Satellite | Coord. Type | Coord. System | True Anomaly | |
| Quickbird1 | Classical | J2000 | 0.0000000 deg | |
| Quickbird2 | Classical | J2000 | 0.0000000 deg | |
| Quickbird3 | Classical | J2000 | 180.000000 deg | |
| Quickbird4 | Classical | J2002 | 180.000000 deg | |

For the UAVs, the turn points, which mark each route in STK, were randomly selected for both Route 1 and Route 2. However, in the most general sense, the routes started from the same location (Incirlik AB, Turkey) and were designed to encompass the ten targets. Additionally, the altitude and speed of the UAV were based on the data for a RQ-4A Global Hawk. The notional parameters were provided by a sponsor, and meant to create an unclassified notional example. These parameters are given in Table 10.

Table 10. UAV Parameters used in STK model

| UAV Routes | Propagator | Starting/Finishing Latitude | Starting/Finishing Longitude | Altitude |
|------------|---------------|-----------------------------|------------------------------|----------|
| Route 1 | GreatArc | 37.00 deg | 35.26 deg | 3.048 km |
| Route 2 | GreatArc | 37.00 deg | 35.26 deg | 3.048 km |
| UAV Routes | Speed | Enroute Altitude | Enroute Speed | |
| Route 1 | 10.490 km/min | 19.812 km | 7.00 km/min | |
| Route 2 | 10.490 km/min | 19.812 km | 7.00 km/min | |

All parameters for the sensors used in this model were provided by a sponsor. They were used to create an unclassified notional example to demonstrate the capability of the model. These parameters are given in Table 11.

Table 11. Sensor parameters used in STK model

| Sensor Information | Satellites | UAVs |
|---------------------------|-------------------|---------------|
| Sensor Type | Simple Conic | Complex Conic |
| Outer Half Angles | N/A | 79.039 deg |
| Cone Angle | 45 deg | N/A |
| Focal Length | 10 m | 1.651m |
| Pixel Pitch | 12 μ m | 9 μ m |

The Special Operations Forces teams access start times are based on the time it would take for a ground vehicle traveling approximately 55 kph from Incirlik AB, Turkey to arrive at the POI location. The divisibility of the team is from information provided COL Klimack, as mentioned in Chapter 4.

Appendix B. Notional Dataset Obtained from STK

The data obtained from the notional model created in STK includes the access start times of each asset to each POI during the length of the simulation, 72 hours. Additionally, the ground sample distance (GSD) was calculated to determine the resolution of each asset was capable of for each access time for each POI. The GSD was calculated using:

$$GSD = \frac{SlantRange \cdot PixelPitch}{focallength \cdot \sqrt{\sin(ElevationAngle)}}$$

An Access Report, generated by STK, was used to determine the durations of each access period of each asset for each POI. These values were placed into a Microsoft Excel Worksheet. The duration, each access, resolution, and something else is given in Table 12. The values for duration and start of access times were made integer values, by rounding, and then, because the time intervals of the problem are 10-minute intervals, the duration and access start times were divided by ten. (The length of the observation, which is 4320 minutes, is 432 time intervals.) These modified values are given in Table 13. However, in actual practice, this data would be developed from classified and unclassified databases. Access time of a particular POI would be generated through runs of STK or another coverage model using the actual operational parameters of the appropriate models, as available and required.

Table 12. Actual values from STK model*

| Asset | Target Observing | 1st access | 2nd access | 3rd access | 4th access | 5th access | 6th access | 7th access | 8th access | 9th access |
|-------------|------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| UAV route 1 | 1 | 78.3416 | 360.613 | 663.5847 | 968.1017 | 1272.1504 | 1575.6869 | 1879.5857 | 2182.6243 | 2481.8098 |
| | 2 | 182.6977 | 486.0786 | 790.2973 | 1095.3882 | 1398.2245 | 1701.4919 | 2005.2699 | 2306.5384 | 2607.6767 |
| | 3 | 69.5426 | 366.5725 | 670.0166 | 974.3589 | 1278.6222 | 1582.116 | 1886.0333 | 2189.0446 | 2488.2237 |
| | 4 | 131.6416 | 437.4049 | 741.7479 | 1046.5692 | 1349.2325 | 1653.2967 | 1957.8298 | 2258.7881 | 2559.2372 |
| | 5 | 61.1315 | 367.5256 | 670.8185 | 974.8257 | 1279.5307 | 1583.0576 | 1887.0755 | 2190.1019 | 2489.148 |
| | 6 | 69.5223 | 370.244 | 673.6998 | 978.0715 | 1282.2916 | 1585.7626 | 1889.6619 | 2192.6611 | 2491.8695 |
| | 7 | 60.6882 | 368.9765 | 672.2583 | 976.2405 | 1280.98 | 1584.5161 | 1888.5462 | 2191.5785 | 2490.6059 |
| | 8 | 91.4114 | 396.0415 | 700.3452 | 1005.3158 | 1308.0499 | 1611.6886 | 1915.7944 | 2216.8188 | 2517.7748 |
| | 9 | 290.6748 | 594.1055 | 897.2395 | 1202.7782 | 1505.5382 | 1808.9971 | 2111.7329 | 2414.4886 | 2715.3998 |
| | 10 | 177.3689 | 481.217 | 785.41 | 1090.3321 | 1393.1426 | 1696.8291 | 2000.9713 | 2302.4171 | 2602.8494 |
| UAV route 2 | 1 | 91.2317 | 365.9763 | 401.80 | 676.0376 | 712.3539 | 987.0902 | 1023.199 | 1300.8575 | 1336.9713 |
| | 2 | 192.5971 | 502.739 | 813.33 | 1123.7655 | 1437.7601 | 1751.7264 | 2060.2899 | 2373.4763 | 100000 |
| | 3 | 82.0675 | 371.4406 | 681.33 | 992.2472 | 1306.0338 | 1618.5282 | 1931.2027 | 2243.1419 | 2554.0772 |
| | 4 | 146.787 | 457.8338 | 768.36 | 1080.7875 | 1393.5827 | 1708.3627 | 2016.6865 | 2329.7489 | 100000 |
| | 5 | 75.2101 | 370.3101 | 679.90 | 990.6984 | 1304.5013 | 1616.6095 | 1930.1599 | 2241.3917 | 2552.6826 |
| | 6 | 80.4366 | 375.4095 | 685.37 | 996.2771 | 1310.0647 | 1622.6724 | 1935.1119 | 2247.2334 | 2558.08 |
| | 7 | 73.6287 | 371.6143 | 681.19 | 991.9789 | 1305.7828 | 1617.8719 | 1931.4698 | 2242.662 | 2553.9717 |
| | 8 | 104.29 | 414.85 | 725.41 | 1036.34 | 1350.06 | 1664.30 | 1972.56 | 2285.59 | 100000.00 |
| | 9 | 300.163 | 609.7582 | 920.43 | 1232.7654 | 1546.8887 | 1860.386 | 2170.6531 | 2483.5019 | 2649.2098 |
| | 10 | 188.0424 | 498.416 | 809.00 | 1120.2104 | 1433.7658 | 1747.9399 | 2056.7457 | 2370.0689 | 100000 |
| Soft Team | 1 | 834.76 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 1606.707 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 834.9515 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 1134.3222 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 771.3942 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 857.544 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 771.3942 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 917.043 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 789.8641 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 1525.6904 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird1 | 1 | 1351 | 2101 | 4256 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 1349 | 3536 | 0 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 1351 | 2128 | 4256 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 1350 | 2129 | 4255 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 1352 | 2128 | 4256 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 1351 | 2128 | 4256 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 1352 | 2128 | 4256 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 1351 | 2129 | 4256 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 2130 | 4255 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 1349 | 2131 | 3536 | 4255 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird2 | 1 | 442 | 2569 | 3347 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 443 | 1850 | 2568 | 3974 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 442 | 2569 | 3347 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 442 | 2568 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |

| Asset | Target Observing | 1st access | 2nd access | 3rd access | 4th access | 5th access | 6th access | 7th access | 8th access | 9th access |
|------------|------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| | 5 | 442 | 2569 | 3347 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 442 | 2569 | 3347 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 442 | 2569 | 3347 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 442 | 2569 | 3347 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 443 | 1163 | 2569 | 3348 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 443 | 2568 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird3 | 1 | 1117 | 1894 | 4022 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 1115 | 3301 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 1117 | 1894 | 4022 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 1116 | 1895 | 3302 | 4021 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 1117 | 1894 | 4022 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 1117 | 1894 | 4022 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 1117 | 1894 | 4022 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 1116 | 1894 | 4021 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 1895 | 4021 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 1115 | 3302 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird4 | 1 | 676 | 2803 | 3581 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 677 | 2802 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 676 | 2803 | 3581 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 677 | 2802 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 676 | 2804 | 3581 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 676 | 2803 | 3581 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 676 | 2804 | 3581 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 676 | 2803 | 3581 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 1397 | 3582 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 677 | 2802 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |

| Asset | Target Observing | 10th access | 11th access | 12th access | 13th access | 14th access | 15th access | 16th access | 17th access | 18th access |
|-------------|------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| UAV route 1 | 1 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 2 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 3 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 4 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 6 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 7 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 8 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 9 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| | 10 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 10000 |
| UAV route 2 | 1 | 1613.5689 | 1651.2011 | 1925.7769 | 1959.3885 | 2238.0875 | 2272.3825 | 2548.8109 | 2585.3223 | 2717.5429 |
| | 2 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 2722.5512 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 2720.7316 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 2726.66 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 2721.9985 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |

| Asset | Target Observing | 10th access | 11th access | 12th access | 13th access | 14th access | 15th access | 16th access | 17th access | 18th access |
|-------|------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | 5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |

| Asset | Target Observing | duration1 | duration2 | duration3 | duration4 | duration5 | duration6 | duration7 | duration8 | duration9 |
|-------------|------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-----------|-----------|
| UAV route 1 | 1 | 30.13833333 | 51.29461667 | 51.90053333 | 52.41436667 | 51.25838333 | 51.07033333 | 50.98046667 | 49.52165 | 51.06865 |
| | 2 | 25.691 | 25.925 | 24.913 | 25.254 | 25.253 | 25.602 | 24.883 | 26.606 | 26.03 |
| | 3 | 32.272 | 39.047 | 39.798 | 40.455 | 39.021 | 39.009 | 39.028 | 37.396 | 39.001 |
| | 4 | 21.796 | 18.102 | 17.892 | 18.286 | 18.56 | 17.361 | 16.162 | 16.685 | 17.727 |
| | 5 | 32.573 | 29.38 | 30.231 | 31.236 | 29.406 | 29.288 | 29.137 | 27.646 | 29.303 |
| | 6 | 30.245 | 33.956 | 34.738 | 35.351 | 33.921 | 34.004 | 34.111 | 32.36 | 33.988 |
| | 7 | 31.826 | 26.887 | 27.76 | 28.787 | 26.913 | 26.803 | 26.657 | 25.125 | 26.816 |
| | 8 | 29.733 | 27.952 | 27.786 | 27.86 | 28.015 | 27.695 | 27.37 | 27.894 | 27.745 |
| | 9 | 26.86 | 26.913 | 28.129 | 26.893 | 27.866 | 28.439 | 28.832 | 25.048 | 29.329 |
| | 10 | 43.145 | 42.848 | 41.759 | 42.404 | 42.418 | 42.178 | 40.808 | 42.319 | 42.826 |
| UAV route 2 | 1 | 25.501 | 19.858 | 24.91 | 18.743 | 24.975 | 18.389 | 24.709 | 18.438 | 24.861 |
| | 2 | 25.784 | 25.373 | 25.38 | 27.552 | 27.328 | 26.893 | 28.743 | 28.292 | 0 |
| | 3 | 29.88 | 50.666 | 51.37 | 51.184 | 51.238 | 52.739 | 48.856 | 50.215 | 44.963 |
| | 4 | 13.38 | 11.853 | 11.96 | 8.438 | 10.6 | 9.151 | 9.556 | 9.756 | 0 |
| | 5 | 27.284 | 42.216 | 43.24 | 43.139 | 43.192 | 45.011 | 40.437 | 42.599 | 47.736 |
| | 6 | 30.648 | 45.925 | 46.56 | 46.429 | 46.451 | 47.891 | 44.138 | 45.259 | 36.956 |
| | 7 | 27.978 | 40.052 | 41.09 | 41.011 | 41.055 | 42.909 | 38.254 | 40.437 | 45.157 |
| | 8 | 25.19 | 24.61 | 24.67 | 24.21 | 24.47 | 24.11 | 24.75 | 25.08 | 0.00 |
| | 9 | 21.26 | 21.272 | 21.52 | 22.979 | 20.895 | 21.054 | 21.951 | 20.408 | 22.732 |
| | 10 | 42.086 | 41.269 | 41.27 | 42.587 | 42.947 | 42.112 | 43.854 | 43.033 | 0 |
| Soft Team | 1 | 3485.24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 2713.293 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 3485.0485 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 3185.6778 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 3548.6058 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 3462.456 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 3548.6058 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 3402.957 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 3530.1359 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 2794.3096 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird1 | 1 | 1.410466667 | 2.204883333 | 2.03045 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 2.168683333 | 1.845166667 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 1.520133333 | 2.2054 | 1.995866667 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 1.677183333 | 2.001733333 | 1.824433333 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 1.30225 | 2.183433333 | 2.078133333 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 1.6096 | 2.2065 | 1.9536 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 1.3182 | 2.18225 | 2.0752 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 1.527683333 | 2.1903 | 1.9677 | 0 | 0 | 0 | 0 | 0 | 0 |

| Asset | Target Observing | duration1 | duration2 | duration3 | duration4 | duration5 | duration6 | duration7 | duration8 | duration9 |
|------------|------------------|-------------|-------------|-------------|-------------|-----------|-----------|-----------|-----------|-----------|
| | 9 | 1.922216667 | 2.011866667 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 2.067516667 | 0.355966667 | 1.5324 | 0.906916667 | 0 | 0 | 0 | 0 | 0 |
| Quickbird2 | 1 | 2.080366667 | 2.19875 | 1.2426 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 1.251133333 | 1.03085 | 1.440683333 | 0.7041 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 2.073083333 | 2.191783333 | 1.302183333 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 2.19115 | 2.1398 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 1.959466667 | 2.206033333 | 1.605166667 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 2.091983333 | 2.18045 | 1.23685 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 1.955283333 | 2.20595 | 1.61595 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 2.15455 | 2.184233333 | 0.642183333 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 1.25915 | 0.7171 | 1.506616667 | 2.0146 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 1.66395 | 1.800133333 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird3 | 1 | 1.905316667 | 2.135033333 | 1.65575 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 2.1763 | 2.120933333 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 1.95745 | 2.144166667 | 1.58675 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 2.0425 | 1.598783333 | 0.495316667 | 1.194983333 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 1.84965 | 2.191916667 | 1.759583333 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 2.001433333 | 2.131866667 | 1.5007 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 1.856916667 | 2.193216667 | 1.75365 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 1.965 | 2.041983333 | 1.521466667 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 2.15065 | 2.1813 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 2.192116667 | 1.980666667 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird4 | 1 | 1.767366667 | 2.16405 | 1.819733333 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 1.845033333 | 1.941716667 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 1.753933333 | 2.1805 | 1.845616667 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 2.160433333 | 2.197116667 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 1.522466667 | 2.143316667 | 1.994883333 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 1.794683333 | 2.192533333 | 1.813733333 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 1.514516667 | 2.14595 | 2.00005 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 1.935116667 | 2.182616667 | 1.588416667 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 1.64825 | 2.1812 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 2.037983333 | 2.1042 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Asset | Target Observing | duration10 | duration11 | duration12 | duration13 | duration14 | duration15 | duration16 | duration17 | duration18 |
|-------------|------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| UAV route 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| UAV route 2 | 1 | 16.845 | 24.515 | 20.32 | 25.305 | 17.555 | 25.708 | 18.957 | 19.003 | 17.275 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Asset | Target Observing | duration10 | duration11 | duration12 | duration13 | duration14 | duration15 | duration16 | duration17 | duration18 |
|------------|------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| | 3 | 30.249 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 32.069 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 26.14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 30.802 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft Team | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Asset | Target Observing | duration10 | duration11 | duration12 | duration13 | duration14 | duration15 | duration16 | duration17 | duration18 |
|------------|------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Asset | Target Observing | Res 1 | Res 2 | Res 3 | Res 4 | Res 5 | Res 6 | Res 7 | Resn 8 | Res 9 |
|-------------|------------------|-------------|-------------|-------------|------------|-------------|-------------|-------------|-------------|-------------|
| UAV route 1 | 1 | 0.68264831 | 0.78957419 | 0.80428675 | 0.83459307 | 0.79051885 | 0.7958489 | 0.78642494 | 0.756029 | 0.795727226 |
| | 2 | 0.827979407 | 0.814697963 | 0.829269346 | 0.84783663 | 0.848018593 | 0.817425481 | 0.806409308 | 0.778995321 | 0.833777929 |
| | 3 | 0.74234474 | 0.60328988 | 0.58905941 | 0.60334469 | 0.60415539 | 0.60094983 | 0.59693941 | 0.59556338 | 0.60122832 |
| | 4 | 1.05246957 | 1.1775484 | 1.17393558 | 1.17023605 | 1.1589879 | 1.19411768 | 1.22640639 | 1.20755933 | 1.18024253 |
| | 5 | 0.66172135 | 0.71307229 | 0.70291038 | 0.68104979 | 0.71197926 | 0.72316952 | 0.73616139 | 0.74353697 | 0.72259758 |
| | 6 | 0.86138772 | 0.65644191 | 0.65368572 | 0.66596086 | 0.65766594 | 0.66799778 | 0.65658172 | 0.67777385 | 0.64694286 |
| | 7 | 0.65464852 | 0.74677489 | 0.73287952 | 0.70750167 | 0.74579314 | 0.75664475 | 0.76932725 | 0.80698893 | 0.75616529 |
| | 8 | 0.693061194 | 0.78734307 | 0.79922114 | 0.79398145 | 0.80383897 | 0.80563703 | 0.82839079 | 0.791311 | 0.80213024 |
| | 9 | 0.79354179 | 0.77917711 | 0.7663395 | 0.78003764 | 0.74583676 | 0.7418008 | 0.71468733 | 0.79829481 | 0.65941794 |
| | 10 | 0.58858546 | 0.58125341 | 0.58331937 | 0.58425843 | 0.58376111 | 0.59999239 | 0.60485036 | 0.61883714 | 0.58192016 |
| UAV route 2 | 1 | 0.91259763 | 1.11836433 | 0.93071377 | 1.15359125 | 0.92698004 | 1.1678256 | 0.94251573 | 1.16584895 | 0.93366362 |
| | 2 | 0.822241 | 0.827646 | 0.825369 | 0.763438 | 0.79098 | 0.791931 | 0.88782 | 0.74064 | 100000 |
| | 3 | 0.68138103 | 0.74833392 | 0.77630394 | 0.78252153 | 0.78033413 | 0.82248854 | 0.7125325 | 0.77047002 | 0.89682674 |
| | 4 | 1.285321 | 1.309913 | 1.307365 | 1.361172 | 1.331577 | 1.35425 | 1.346413 | 1.342504 | 100000 |
| | 5 | 0.83456759 | 0.63790807 | 0.63661633 | 0.63960707 | 0.6380342 | 0.65343109 | 0.62522288 | 0.61171332 | 0.51906669 |
| | 6 | 0.64057759 | 0.6953264 | 0.72154942 | 0.72446131 | 0.72385744 | 0.7549861 | 0.68722841 | 0.73176757 | 0.93042137 |
| | 7 | 0.78555852 | 0.62994245 | 0.62425712 | 0.62655014 | 0.62516998 | 0.61377911 | 0.625046125 | 0.60122252 | 0.528947 |
| | 8 | 0.93208756 | 0.94882127 | 0.94545327 | 0.97169323 | 0.95667077 | 0.97806219 | 0.9401965 | 0.93829763 | 100000 |
| | 9 | 0.87100074 | 0.87051252 | 0.85564313 | 0.8076515 | 0.86476068 | 0.87936687 | 0.83529709 | 0.88829814 | 0.83526421 |
| | 10 | 0.59852005 | 0.60427649 | 0.60449826 | 0.62186005 | 0.59791552 | 0.6232128 | 0.61696373 | 0.64163069 | 100000 |
| Soft Team | 1 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 0.5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird1 | 1 | 0.948054 | 0.84983075 | 0.8978625 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 0.85484375 | 0.891826333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |

| Asset | Target Observing | Res 1 | Res 2 | Res 3 | Res 4 | Res 5 | Res 6 | Res 7 | Resn 8 | Res 9 |
|------------|------------------|-------------|-------------|-------------|------------|--------|--------|--------|--------|--------|
| | 3 | 0.935915 | 0.8510745 | 0.90744625 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 0.913898333 | 0.90201975 | 0.896636333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 0.961879667 | 0.85751475 | 0.88587 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 0.925009667 | 0.850996 | 0.883629333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 0.960262667 | 0.8563445 | 0.88555975 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 0.934042667 | 0.85329675 | 0.880487 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 0.883643667 | 0.89959825 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 0.88251175 | 0.993293 | 0.930193667 | 0.9939455 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird2 | 1 | 0.883625 | 0.8502915 | 0.968275667 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 0.963376667 | 0.989767333 | 0.941857 | 0.993388 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 0.88654075 | 0.85233 | 0.961811333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 0.851557 | 0.86519175 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 0.883071 | 0.84865925 | 0.926124 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 0.88298275 | 0.85685375 | 0.969797333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 0.883715333 | 0.8502235 | 0.924639667 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 0.863979 | 0.85490175 | 0.996967 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 0.964172 | 0.995368 | 0.93374 | 0.89906625 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 0.913593667 | 0.897315 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird3 | 1 | 0.888166 | 0.86969465 | 0.919861333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 0.852167 | 0.86855025 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 0.882047333 | 0.86669 | 0.928555 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 0.89049125 | 0.923178 | 0.996213667 | 0.9602135 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 0.89594 | 0.85366605 | 0.907890333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 0.9059255 | 0.8693635 | 0.939140333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 0.895081 | 0.8543275 | 0.908904 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 0.879925 | 0.8941705 | 0.935255667 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 0.861262 | 0.85243025 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 0.8757756 | 0.8156455 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird4 | 1 | 0.906599 | 0.861034 | 0.898893667 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 0.891016667 | 0.879594333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 0.908779 | 0.85596075 | 0.89618 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 0.8598875 | 0.8476695 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 0.937406333 | 0.86743875 | 0.90778725 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 0.903524333 | 0.85342225 | 0.900357667 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 0.937636333 | 0.86612425 | 0.9050665 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 0.884617333 | 0.85417975 | 0.926663333 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 0.917833 | 0.85190175 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 0.8893925 | 0.87167975 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |

| Asset | Target Observing | Res 10 | Res 11 | Res 11 | Res 13 | Res 14 | Res 15 | Res 16 | Res 17 | Res 18 18 |
|-------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| UAV route 1 | 1 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |

| Asset | Target Observing | Res 10 | Res 11 | Res 11 | Res 13 | Res 14 | Res 15 | Res 16 | Res 17 | Res 18 18 |
|------------|------------------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
| | 3 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| Quickbird4 | 1 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 2 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 3 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 4 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 5 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 6 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 7 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 8 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 9 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |
| | 10 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 | 100000 |

* Access start times greater than 4320 indicate no access of that asset, Res numbers equal to 10000 indicate that there was no access therefore no resolution calculation was done.

Table 13. Modified values used in Frontline Premium Solver Platform

| Asset | Target Obs | 1st access | 2nd access | 3rd access | 4th access | 5th access | 6th access | 7th access | 8th access | 9th access |
|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| UAV route 1 | 1 | 8 | 36 | 66 | 97 | 127 | 158 | 188 | 218 | 248 |
| | 2 | 18 | 49 | 79 | 110 | 140 | 170 | 201 | 231 | 261 |
| | 3 | 7 | 37 | 67 | 97 | 128 | 158 | 189 | 219 | 249 |
| | 4 | 13 | 44 | 74 | 105 | 135 | 165 | 196 | 226 | 256 |
| | 5 | 6 | 37 | 67 | 98 | 128 | 158 | 189 | 219 | 249 |
| | 6 | 7 | 37 | 67 | 98 | 128 | 159 | 189 | 219 | 249 |
| | 7 | 6 | 37 | 67 | 98 | 128 | 159 | 189 | 219 | 249 |
| | 8 | 9 | 40 | 70 | 101 | 131 | 161 | 192 | 222 | 252 |
| | 9 | 29 | 59 | 90 | 120 | 151 | 181 | 211 | 241 | 272 |
| | 10 | 18 | 48 | 79 | 109 | 139 | 170 | 200 | 230 | 260 |
| UAV route 2 | 1 | 9 | 37 | 40 | 68 | 71 | 99 | 102 | 130 | 134 |
| | 2 | 19 | 50 | 81 | 112 | 144 | 175 | 206 | 237 | 10000 |
| | 3 | 8 | 37 | 68 | 99 | 131 | 162 | 193 | 224 | 255 |
| | 4 | 15 | 46 | 77 | 108 | 139 | 171 | 202 | 233 | 10000 |
| | 5 | 8 | 37 | 68 | 99 | 131 | 162 | 193 | 224 | 255 |
| | 6 | 8 | 38 | 69 | 100 | 131 | 162 | 194 | 225 | 256 |
| | 7 | 7 | 37 | 68 | 99 | 131 | 162 | 193 | 224 | 255 |
| | 8 | 10 | 42 | 73 | 104 | 135 | 166 | 197 | 229 | 10000 |
| | 9 | 30 | 61 | 92 | 123 | 155 | 186 | 217 | 248 | 265 |
| | 10 | 19 | 50 | 81 | 112 | 143 | 175 | 206 | 237 | 10000 |

| Asset | Target Obs | 1st access | 2nd access | 3rd access | 4th access | 5th access | 6th access | 7th access | 8th access | 9th access |
|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Soft Team | 1 | 84 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 161 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 84 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 113 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 77 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 86 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 77 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 92 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 79 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 153 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Quickbird1 | 1 | 135 | 210 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 135 | 354 | 0 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 135 | 213 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 135 | 213 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 135 | 213 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 135 | 213 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 135 | 213 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 135 | 213 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 213 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 135 | 213 | 354 | 426 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Quickbird2 | 1 | 44 | 257 | 335 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 44 | 185 | 257 | 397 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 44 | 257 | 335 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 44 | 257 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 44 | 257 | 335 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 44 | 257 | 335 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 44 | 257 | 335 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 44 | 257 | 335 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 44 | 116 | 257 | 335 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 44 | 257 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Quickbird3 | 1 | 112 | 189 | 402 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 112 | 330 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 112 | 189 | 402 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 112 | 190 | 330 | 402 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 112 | 189 | 402 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 112 | 189 | 402 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 112 | 189 | 402 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 112 | 189 | 402 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 190 | 402 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 112 | 330 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Quickbird4 | 1 | 68 | 280 | 358 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 68 | 280 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 68 | 280 | 358 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 68 | 280 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 68 | 280 | 358 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 68 | 280 | 358 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |

| Asset | Target Obs | 1st access | 2nd access | 3rd access | 4th access | 5th access | 6th access | 7th access | 8th access | 9th access |
|-------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| | 7 | 68 | 280 | 358 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 68 | 280 | 358 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 140 | 358 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 68 | 280 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |

| Asset | Target Obs | 10th access | 11th access | 12th access | 13th access | 14th access | 15th access | 16th access | 17th access | 18th access |
|-------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| UAV route 1 | 1 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 2 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 3 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 4 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 5 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 6 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 7 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 8 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 9 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| | 10 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 1000 |
| UAV route 2 | 1 | 161 | 165 | 193 | 196 | 224 | 227 | 255 | 259 | 272 |
| | 2 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 272 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 272 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 273 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 272 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Soft Team | 1 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Quickbird1 | 1 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |

| | | | | | | | | | | |
|------------|----|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Quickbird2 | 1 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Quickbird3 | 1 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| Quickbird4 | 1 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 2 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 3 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 4 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 5 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 6 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 7 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 8 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 9 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| | 10 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |

| Asset | Target Obs | dur1 | dur2 | dur3 | dur4 | dur5 | dur6 | dur7 | dur8 | dur9 |
|-------------|------------|------|------|------|------|------|------|------|------|------|
| UAV route 1 | 1 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 5 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 6 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3 |
| | 7 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 8 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 9 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 10 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| UAV route 2 | 1 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 |
| | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 0 |
| | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | 5 | 3 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 5 |

| Asset | Target Obs | dur1 | dur2 | dur3 | dur4 | dur5 | dur6 | dur7 | dur8 | dur9 |
|------------|------------|------|------|------|------|------|------|------|------|------|
| | 6 | 3 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 4 |
| | 7 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 |
| | 8 | 3 | 3 | 3 | 2 | 2 | 2 | 3 | 3 | 0 |
| | 9 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 10 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 |
| Soft Team | 1 | 349 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 271 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 349 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 319 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 355 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 346 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 355 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 340 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 353 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 279 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Asset | Target Obs | dur1 | dur2 | dur3 | dur4 | dur5 | dur6 | dur7 | dur8 | dur9 |
|-------|------------|------|------|------|------|------|------|------|------|------|
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Asset | Target Obs | dur10 | dur11 | dur12 | dur13 | dur14 | dur15 | dur16 | dur17 | dur18 |
|-------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| UAV route 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| UAV route 2 | 1 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 2 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft Team | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Asset | Target Obs | dur10 | dur11 | dur12 | dur13 | dur14 | dur15 | dur16 | dur17 | dur18 |
|------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quickbird4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix C. VBA Code

This VBA code was used to create the coefficient matrices used by Frontline Premium Platform Solver to accomplish the optimization. This code was designed to create every entry in the 3-dimensional matrices used. Three of these matrices are required, a duration matrix, an x matrix, and an image resolution matrix. Afterwards, the program exports the corresponding matrices to a worksheet for use in the constraints used in the solver.

```

Option Base 1

Sub RunSolver()
'need to dimension all of my variables
Dim xmit(7, 10, 432) As Integer, IQxmit(7, 10, 432) As Double, IQ(7, 10, 18) As Double, _
    m As Integer, I As Integer, a As Integer, t As Integer, _
    ST(7, 10, 18) As Integer, Duration(7, 10, 18) As Integer, DX(7, 10, 432) As Integer, p As
Integer
'fill ST matrix
For m = 1 To 7
    For I = 1 To 10
        For a = 1 To 18
            ST(m, I, a) = Worksheets("Sheet2").Range("E2").Offset((10 * (m - 1) + (I - 1)), (a -
1)).Value
        Next a
    Next I
Next m
'fill Duration matrix
For m = 1 To 7
    For I = 1 To 10
        For a = 1 To 18
            Duration(m, I, a) = Worksheets("Sheet2").Range("X2").Offset((10 * (m - 1) + (I - 1)), (a -
1)).Value
        Next a
    Next I
Next m
'fill IQ matrix
For m = 1 To 7
    For I = 1 To 10
        For a = 1 To 18
            IQ(m, I, a) = Worksheets("Sheet2").Range("AQ2").Offset((10 * (m - 1) + (I - 1)), (a -
1)).Value
        Next a
    Next I
Next m
'fill in IQx matrix
For m = 1 To 7

```

```

    For I = 1 To 10
      For a = 1 To 18
        If Worksheets("Sheet2").Range("E2").Offset((10 * (m - 1) + (I - 1)), (a - 1)).Value <> 0 Then
          IQxmit(m, I, (Worksheets("Sheet2").Range("E2").Offset((10 * (m - 1) + (I - 1)), (a - 1)).Value)) =
            IQ(m, I, a)
        End If
      Next a
    Next I
  Next m
  'print to worksheet3
  For m = 1 To 7
    For I = 1 To 10
      For t = 1 To 432
Worksheets("Sheet3").Range("b2").Offset(((t - 1) + 432 * (I - 1)), (2 * (m - 1))).Value = IQxmit(m, I, t)
      Next t
    Next I
  Next m
  'xmit 's and IQxmit's for satellites (modes 4-7)
  For m = 4 To 7
    For I = 1 To 10
      For a = 1 To 18
        For t = 1 To 432
          If t = ST(m, I, a) Then
            xmit(m, I, t) = 1
Worksheets("Sheet1").Range("j9").Offset(((t - 1) + 432 * (I - 1)), (2 * (m - 4))).Value = xmit(m, I, t)
          End If
        Next t
      Next a
    Next I
  Next m
  'create Dxmit matrix
  For m = 1 To 7
    For I = 1 To 10
      For a = 1 To 18
        For t = 1 To 432
          If t = ST(m, I, a) Then
            For p = t To t + Duration(m, I, a)
              DX(m, I, p) = 1
            Next p
          End If
        Next t
      Next a
    Next I
  Next m
  For m = 1 To 7
    For I = 1 To 10
      For t = 1 To 432
Worksheets("Sheet4").Range("b2").Offset(((t - 1) + 432 * (I - 1)), (m - 1)).Value = DX(m, I, t)
      Next t
    Next I
  Next m

```

After a solution was found, the DEV variables placed into one column. This column was then divided into multiple columns such that a column of data represented one POI. The following program was developed to create a Gantt chart from that data in Microsoft Excel. Due to the size of the graph, the time intervals are on the y-axis and the targets on the x-axis. In order to place these charts in this thesis, the axes were transposed.

```
Sub GHANTT()
```

```
'This is a subroutine to color code a gantt chart. It specifically looks at 10 targets
'and then colors in when there is an asset imaging that target at time t. one color for
'each target.
```

```
Dim i As Integer, j As Integer, k As Integer
```

```
For i = 2 To 11
```

```
  For j = 2 To 433
```

```
    If Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Value = 0 Then
```

```
      If i = 2 Then
```

```
        With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
```

```
          .ColorIndex = 12
```

```
          .Pattern = xlSolid
```

```
        End With
```

```
      End If
```

```
      If i = 3 Then
```

```
        With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
```

```
          .ColorIndex = 3
```

```
          .Pattern = xlSolid
```

```
        End With
```

```
      End If
```

```
      If i = 4 Then
```

```
        With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
```

```
          .ColorIndex = 4
```

```
          .Pattern = xlSolid
```

```
        End With
```

```
      End If
```

```
      If i = 5 Then
```

```
        With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
```

```
          .ColorIndex = 5
```

```
          .Pattern = xlSolid
```

```
        End With
```

```
      End If
```

```
      If i = 6 Then
```

```
        With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
```

```
          .ColorIndex = 6
```

```
          .Pattern = xlSolid
```

```
        End With
```

```

End If
If i = 7 Then
    With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
        .ColorIndex = 7
        .Pattern = xlSolid
    End With
End If
If i = 8 Then
    With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
        .ColorIndex = 8
        .Pattern = xlSolid
    End With
End If
If i = 9 Then
    With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
        .ColorIndex = 9
        .Pattern = xlSolid
    End With
End If
If i = 10 Then
    With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
        .ColorIndex = 10
        .Pattern = xlSolid
    End With
End If
If i = 11 Then
    With Worksheets("sheet5").Range("B1").Offset(j - 1, i - 2).Interior
        .ColorIndex = 11
        .Pattern = xlSolid
    End With
End If
End If
Next j
Next i
For k = 2 To 11
    For i = 2 To 433
        Worksheets("sheet5").Range("B1").Offset(i - 1, k - 2).Value = ""
    Next i
Next k
End Sub

```

Appendix D. Solution to Notional Example

The following tables summarizes the solution for the small notional example described in Chapter 4. There is one table for each POI.

Table 14. Allocation of assets for Q-West

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered | |
|--------|----------------|------------|----------|------------------|-----------------------|-----------------------------|--|
| Q-West | Quickbird 1 | 135 | 0 | 0.9481 | | 65 intervals | |
| | | 210 | 0 | 0.8498 | | | |
| | | 426 | 0 | 0.8979 | | | |
| | Quickbird 2 | 44 | 0 | 0.8836 | | | |
| | | 257 | 0 | 0.8503 | | | |
| | | 335 | 0 | 0.9683 | | | |
| | Quickbird 3 | 112 | 0 | 0.8882 | | | |
| | | 189 | 0 | 0.8697 | | | |
| | | 402 | 0 | 0.9199 | | | |
| | Quickbird 4 | 68 | 0 | 0.9066 | | | |
| | | 280 | 0 | 0.8610 | | | |
| | | 358 | 0 | 0.8989 | 1 to 9 | | |
| | UAV route 2 | 9 | 3 | 0.9126 | 13 to 36 | | |
| | | 37 | 2 | 1.1184 | 43 | | |
| | | 40 | 2 | 0.9307 | 45 to 67 | | |
| | | 68 | 2 | 1.1536 | 74 to 82 | | |
| | | 71 | 2 | 0.9270 | | | |
| | | | 99 | 2 | 1.1678 | | |
| | | | 102 | 2 | 0.9425 | | |
| | | | 130 | 2 | 1.1658 | | |
| | | | 134 | 2 | 0.9337 | | |
| | | | 161 | 2 | 1.2046 | | |
| | | | 165 | 2 | 0.9540 | | |
| | | | 193 | 2 | 1.1106 | | |
| | | | 196 | 3 | 0.9245 | | |
| | | | 224 | 2 | 1.1889 | | |
| | | | 227 | 3 | 0.8993 | | |
| | | | 255 | 2 | 1.1446 | | |
| | | | 259 | 2 | 1.1555 | | |
| | | | 272 | 2 | 1.1996 | | |
| | SOF team | 83 | 349 | 0.5000 | | | |

Table 15. Allocation of assets for Basrah

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered | |
|--------|----------------|------------|----------|------------------|-----------------------|-----------------------------|-----|
| Basrah | Quickbird 1 | 135 | 0 | 0.8548 | | | |
| | | 354 | 0 | 0.8918 | | | |
| | Quickbird 2 | 44 | 0 | 0.9633 | | | |
| | | 185 | 0 | 0.9897 | | | |
| | | 257 | 0 | 0.9418 | | | |
| | | 397 | 0 | 0.9933 | | | |
| | Quickbird 3 | 112 | 0 | 0.8521 | | | |
| | | 330 | 0 | 0.8685 | 1 to 18 | | |
| | Quickbird 4 | 68 | 0 | 0.8910 | 22 to 43 | | |
| | | 280 | 0 | 0.8795 | 44 to 49 | | |
| | UAV route 2 | 19 | 3 | 0.8222 | 54 to 67 | | |
| | | 50 | 3 | 0.8276 | 68 to 80 | | 137 |
| | | 81 | 3 | 0.8253 | 84 to 111 | | |
| | | 112 | 3 | 0.7634 | 115 to 134 | | |
| | 144 | 3 | 0.7909 | 135 to 143 | | | |
| | 175 | 3 | 0.7919 | 148 to 160 | | | |
| | 206 | 3 | 0.8878 | | | | |
| | 237 | 3 | 0.7406 | | | | |
| | SOF team | 161 | 271 | 0.5000 | | | |

Table 16. Allocation of Assets for Mosel

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered | |
|----------|----------------|------------|----------|------------------|-----------------------|-----------------------------|-----|
| Mosel | Quickbird 1 | 135 | 0 | 0.9359 | | | |
| | | 213 | 0 | 0.8510 | 1 to 7 | | |
| | | 426 | 0 | 0.9074 | 12 to 36 | | |
| | Quickbird 2 | 44 | 0 | 0.8865 | 43 | | |
| | | 257 | 0 | 0.8523 | 45 to 67 | | |
| | | 335 | 0 | 0.9618 | 74 to 98 | | |
| | Quickbird 3 | 112 | 0 | 0.8820 | 105 to 111 | | |
| | | 189 | 0 | 0.8666 | 113 to 130 | | |
| | | 402 | 0 | 0.9285 | 137 to 161 | | |
| | Quickbird 4 | 68 | 0 | 0.9087 | 168 to 188 | | |
| | | 280 | 0 | 0.8559 | 190 to 192 | | |
| | | 358 | 0 | 0.8961 | 199 to 212 | | |
| | | | | | | | 368 |
| | UAV route 2 | 8 | 3 | 0.6813 | 214 to 223 | | |
| | | 37 | 5 | 0.7483 | 230 to 254 | | |
| | | 68 | 5 | 0.7763 | 260 to 271 | | |
| | | 99 | 5 | 0.7825 | 276 to 279 | | |
| | | 131 | 5 | 0.7803 | 281 to 334 | | |
| | | 162 | 5 | 0.8224 | 336 to 357 | | |
| | | 193 | 5 | 0.7125 | 359 to 401 | | |
| 224 | | 5 | 0.7704 | 403 to 425 | | | |
| 255 | | 4 | 0.8968 | 427 to 432 | | | |
| 272 | | 3 | 1.8685 | | | | |
| SOF team | 83 | 349 | 0.5000 | | | | |

Table 17. Allocation of Assets for Shayka

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered | |
|--------|----------------|------------|----------|------------------|-----------------------|-----------------------------|-----|
| Shayka | Quickbird 1 | 135 | 0 | 0.9138 | 1 to 14 | | |
| | | 213 | 0 | 0.9020 | 17 to 43 | | |
| | | 426 | 0 | 0.8966 | 45 | | |
| | Quickbird 2 | 44 | 0 | 0.8515 | 48 to 67 | | |
| | | 257 | 0 | 0.8651 | 69 to 76 | | |
| | Quickbird 3 | 112 | 0 | 0.8904 | 79 to 107 | | |
| | | 190 | 0 | 0.9231 | 110 to 111 | | |
| | | 330 | 0 | 0.9962 | 113 to 134 | | |
| | | 402 | 0 | 0.9602 | 136 to 138 | | |
| | Quickbird 4 | 68 | 0 | 0.8598 | 141 to 170 | | |
| | | 280 | 0 | 0.8476 | 173 to 189 | | |
| | UAV route 2 | 15 | 1 | 1.2853 | 191 to 201 | | 405 |
| | | 46 | 1 | 1.3099 | 203 to 211 | | |
| | | 77 | 1 | 1.3073 | 213 to 231 | | |
| | | 108 | 1 | 1.3611 | 234 to 255 | | |
| | | 139 | 1 | 1.3315 | 257 to 278 | | |
| | | 171 | 1 | 1.3542 | 280 to 328 | | |
| | | 202 | 1 | 1.3464 | 330 to 400 | | |
| | | 233 | 1 | 1.3425 | 402 to 424 | | |
| | SOF team | 113 | 319 | 0.5000 | 426 to 432 | | |

Table 18. Allocation of Asset for H-Zalah

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered | |
|----------|----------------|------------|----------|------------------|-----------------------|-----------------------------|-----|
| H-Zalah | Quickbird 1 | 135 | 0 | 0.9618 | | | |
| | | 213 | 0 | 0.8575 | 1 to 7 | | |
| | | 426 | 0 | 0.8858 | 12 to 36 | | |
| | Quickbird 2 | 44 | 0 | 0.8830 | 42 to 43 | | |
| | | 257 | 0 | 0.8486 | 45 to 67 | | |
| | | 335 | 0 | 0.9261 | 73 to 98 | | |
| | Quickbird 3 | 112 | 0 | 0.8959 | 104 to 111 | | |
| | | 189 | 0 | 0.8536 | 113 to 129 | | |
| | | 402 | 0 | 0.9078 | 136 to 161 | | |
| | Quickbird 4 | 68 | 0 | 0.9374 | 168 to 188 | | |
| | | 280 | 0 | 0.8674 | 190 to 192 | | |
| | | 358 | 0 | 0.9077 | 198 to 212 | | |
| | UAV route 2 | 8 | 3 | 0.8345 | 214 to 223 | | 373 |
| | | 37 | 4 | 0.6379 | 229 to 254 | | |
| | | 68 | 4 | 0.6366 | 261 to 271 | | |
| | | 99 | 4 | 0.6396 | 276 to 279 | | |
| | | 130 | 4 | 0.6380 | 281 to 334 | | |
| | | 162 | 5 | 0.6534 | 336 to 357 | | |
| | | 193 | 4 | 0.6252 | 359 to 401 | | |
| | | 224 | 4 | 0.6117 | 403 to 425 | | |
| 255 | | 5 | 0.5190 | 427 to 432 | | | |
| 272 | | 3 | 0.9288 | | | | |
| SOF team | 77 | 355 | 0.5000 | | | | |

Table 19. Allocation of Assets for Hel-3494

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered |
|----------|----------------|------------|----------|------------------|--|-----------------------------|
| Hel-3494 | Quickbird 1 | 135 | 0 | 0.9250 | 1 to 7 12 to 37 45 to 67 75 to 99 106 to 111 113 to 130 137 to 161 168 to 188 190 to 193 199 to 212 214 to 224 231 to 255 261 to 272 277 to 279 281 to 334 336 to 357 359 to 401 403 to 425 427 to 432 | 368 |
| | | 213 | 0 | 0.8510 | | |
| | | 426 | 0 | 0.8836 | | |
| | Quickbird 2 | 44 | 0 | 0.8830 | | |
| | | 257 | 0 | 0.8569 | | |
| | | 335 | 0 | 0.9698 | | |
| | Quickbird 3 | 112 | 0 | 0.9059 | | |
| | | 189 | 0 | 0.8694 | | |
| | | 402 | 0 | 0.9391 | | |
| | Quickbird 4 | 68 | 0 | 0.9035 | | |
| | | 280 | 0 | 0.8534 | | |
| | UAV route 2 | 8 | 3 | 0.6406 | | |
| | | 38 | 5 | 0.6953 | | |
| | | 69 | 5 | 0.7215 | | |
| | | 100 | 5 | 0.7245 | | |
| | | 131 | 5 | 0.7239 | | |
| | | 162 | 5 | 0.7550 | | |
| | | 194 | 4 | 0.6872 | | |
| | | 225 | 5 | 0.7318 | | |
| | | 256 | 4 | 0.9304 | | |
| | | 273 | 3 | 1.8568 | | |
| | SOF team | 86 | 346 | 0.5000 | | |

Table 21. Allocation of Assets for I-Corp-HQ

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered |
|-----------|----------------|------------|----------|------------------|-----------------------|-----------------------------|
| I-Corp-HQ | Quickbird 1 | 135 | 0 | 0.9602 | | |
| | | 213 | 0 | 0.8563 | 1 to 6 | |
| | | 426 | 0 | 0.8855 | 11 to 36 | |
| | Quickbird 2 | 44 | 0 | 0.8837 | 42 to 43 | |
| | | 257 | 0 | 0.8502 | 45 to 67 | |
| | | 335 | 0 | 0.9246 | 73 to 98 | |
| | Quickbird 3 | 112 | 0 | 0.8950 | 104 to 111 | |
| | | 189 | 0 | 0.8543 | 113 to 130 | |
| | | 402 | 0 | 0.9089 | 136 to 161 | |
| | Quickbird 4 | 68 | 0 | 0.9376 | 167 to 188 | |
| | | 280 | 0 | 0.8661 | 190 to 192 | |
| | | 358 | 0 | 0.9050 | 198 to 212 | |
| | UAV route 2 | 7 | 3 | 0.7855 | 214 to 223 | |
| | | 37 | 4 | 0.6299 | 229 to 254 | |
| | | 68 | 4 | 0.6242 | 261 to 271 | |
| | | 99 | 4 | 0.6265 | 276 to 279 | |
| | | 131 | 4 | 0.6251 | 281 to 334 | |
| | | 162 | 4 | 0.6137 | 336 to 357 | |
| | | 193 | 4 | 0.6250 | 359 to 401 | |
| | | 224 | 4 | 0.6012 | 403 to 425 | |
| | | 255 | 5 | 0.5289 | 427 to 432 | |
| | | 272 | 3 | 0.7745 | | |
| | SOF team | 77 | 355 | 0.5000 | | |

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Table 22. Allocation of Assets for Bridge

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered |
|--------|----------------|------------|----------|------------------|-----------------------|-----------------------------|
| Bridge | Quickbird 1 | 135 | 0 | 0.9340 | | |
| | | 213 | 0 | 0.8532 | 1 to 9 | |
| | | 426 | 0 | 0.8804 | 14 to 40 | |
| | Quickbird 2 | 44 | 0 | 0.8639 | 45 to 67 | |
| | | 257 | 0 | 0.8549 | 69 to 72 | |
| | | 335 | 0 | 0.9969 | 76 to 103 | |
| | Quickbird 3 | 112 | 0 | 0.8799 | 107 to 111 | |
| | | 189 | 0 | 0.8941 | 113 to 124 | |
| | | 402 | 0 | 0.9352 | 128 to 155 | |
| | Quickbird 4 | 68 | 0 | 0.8846 | 159 to 178 | |
| | | 280 | 0 | 0.8541 | 180 to 186 | |
| | | 358 | 0 | 0.9266 | 190 to 202 | |
| | UAV route 2 | 10 | 3 | 0.9320 | 204 to 218 | |
| | | 41 | 2 | 0.9488 | 223 to 246 | |
| | | 73 | 2 | 0.9454 | 248 to 269 | |
| | | 104 | 2 | 0.9716 | 271 to 324 | |
| | | 135 | 2 | 0.9566 | 326 to 347 | |
| | | 166 | 2 | 0.9780 | 349 to 401 | |
| | | 197 | 2 | 0.9401 | 203 to 425 | |
| | | 229 | 3 | 0.9382 | 427 to 432 | |
| | SOF team | 92 | 340 | 0.5000 | | |

Table 23. Allocation of Assets for DIV

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered |
|-----|----------------|------------|----------|------------------|-----------------------|-----------------------------|
| DIV | Quickbird 1 | 213 | 0 | 0.8836 | 1 to 29 | |
| | | 426 | 0 | 0.8995 | 33 to 43 | |
| | Quickbird 2 | 44 | 0 | 0.9641 | 45 to 60 | |
| | | 116 | 0 | 0.9953 | 64 to 91 | |
| | | 257 | 0 | 0.9337 | 95 to 115 | |
| | | 335 | 0 | 0.8990 | 117 to 122 | |
| | Quickbird 3 | 190 | 0 | 0.8612 | 126 to 139 | |
| | | 402 | 0 | 0.8524 | 141 to 154 | |
| | Quickbird 4 | 140 | 0 | 0.9178 | 158 to 185 | |
| | | 358 | 0 | 0.8519 | 189 | |
| | UAV route 2 | 30 | 2 | 0.8710 | 191 to 212 | |
| | | 61 | 2 | 0.8705 | 214 to 216 | |
| | | 92 | 2 | 0.8556 | 220 to 247 | |
| | | 123 | 2 | 0.8076 | 251 to 256 | |
| | | 155 | 2 | 0.8647 | 258 to 264 | |
| | | 186 | 2 | 0.8793 | 268 to 334 | |
| | | 217 | 2 | 0.8352 | 336 to 357 | |
| | | 248 | 2 | 0.8882 | 359 to 401 | |
| | | 265 | 2 | 0.8352 | 403 to 425 | |
| | | SOF team | 79 | 353 | 0.5000 | 427 to 432 |

Table 24. Allocation of Assets for DIV2

| POI | Asset covering | Start time | Duration | Image Resolution | Intervals not covered | Total intervals not covered |
|------|----------------|------------|----------|------------------|-----------------------|-----------------------------|
| DIV2 | Quickbird 1 | 135 | 0 | 0.8825 | 1 to 18 | |
| | | 213 | 0 | 0.9932 | 24 to 43 | |
| | | 354 | 0 | 0.9301 | 45 to 49 | |
| | | 425 | 0 | 0.9939 | 55 to 67 | |
| | Quickbird 2 | 44 | 0 | 0.9135 | 69 to 80 | |
| | | 257 | 0 | 0.8973 | 86 to 111 | |
| | Quickbird 3 | 112 | 0 | 0.8757 | 117 to 134 | |
| | | 330 | 0 | 0.8156 | 136 to 142 | |
| | Quickbird 4 | 68 | 0 | 0.8893 | 148 to 174 | |
| | | 280 | 0 | 0.8716 | 180 to 205 | |
| | UAV route 2 | 19 | 4 | 0.5985 | 211 to 212 | 383 |
| | | 50 | 4 | 0.6042 | 214 to 236 | |
| | | 81 | 4 | 0.6044 | 242 to 256 | |
| | | 112 | 4 | 0.6218 | 258 to 279 | |
| | | 143 | 4 | 0.5979 | 281 to 329 | |
| | | 175 | 4 | 0.6232 | 331 to 353 | |
| | | 206 | 4 | 0.6169 | 355 to 424 | |
| | | 237 | 4 | 0.6416 | 426 to 432 | |
| | SOF team | 153 | 279 | 0.5000 | | |

Appendix E. Gantt Charts from Notional Example

Using the VBA code described in Appendix C, the following Gantt charts were developed. For each target, if the time interval is colored, that corresponds to the target being imaged at that time.

| | | | | | | | | | | | | | | | | | | | |
|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|--|--|--|--|
| Target 1 | | | | | | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | | | | | | |
| Time | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | | | | | |

| | | | | | | | | | | | | | | | | | | | |
|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|--|--|--|--|
| Target 1 | | | | | | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | | | | | | |
| Time | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | | | | | |

| | | | | | | | | | | | | | | | | | | | |
|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|--|--|--|--|
| Target 1 | | | | | | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | | | | | | |
| Time | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | | | | | |

| | | | | | | | | | | | | | | |
|-----------|--------|---------|---------|---------|---------|---------|---------|-------|-----|------|------|-----|-----|-----------|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | Red |
| Target 3 | Green | Green | Green | Green | Green | | | | | | | | | Green |
| Target 4 | | | | | | | | | | Blue | Blue | | | Blue |
| Target 5 | Yellow | Yellow | Yellow | Yellow | Yellow | | | | | | | | | Yellow |
| Target 6 | | Magenta | Magenta | Magenta | Magenta | Magenta | Magenta | | | | | | | Magenta |
| Target 7 | Cyan | Cyan | Cyan | Cyan | | | | | | | | | | Cyan |
| Target 8 | | | | | | Brown | Brown | Brown | | | | | | Brown |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | Dark Blue |
| Time | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 |

| | | | | | | | | | | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----|-----|-----|-----|-----|-----|-------|-------|-------|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | Red | Red | Red | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | Green | | | | | | | Green | Green | Green | |
| Target 10 | Dark Blue | Dark Blue | Dark Blue | Dark Blue | | | | | | | | | | |
| Time | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|---------|---------|---------|---------|---------|-----------|-------|-------|-----|------|-------|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | Red | | | | | |
| Target 3 | | | | Green | Green | Green | Green | Green | Green | | | | | |
| Target 4 | | | | | | | | | Blue | | | | Blue | Blue |
| Target 5 | | | | Yellow | Yellow | Yellow | Yellow | Yellow | | | | | | |
| Target 6 | | | | Magenta | Magenta | Magenta | Magenta | Magenta | Magenta | | | | | |
| Target 7 | | | | Cyan | Cyan | Cyan | Cyan | Cyan | | | | | | |
| Target 8 | | | | | | | | | Brown | Brown | Brown | | | |
| Target 9 | | | | | | | | | | | | | | Green |
| Target 10 | | | | | | | | | Dark Blue | | | | | |
| Time | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 | 138 | 139 | 140 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | 209 | 210 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 225 | 226 | 227 | 228 | 229 | 230 | 231 | 232 | 233 | 234 | 235 | 236 | 237 | 238 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 239 | 240 | 241 | 242 | 243 | 244 | 245 | 246 | 247 | 248 | 249 | 250 | 251 | 252 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 253 | 254 | 255 | 256 | 257 | 258 | 259 | 260 | 261 | 262 | 263 | 264 | 265 | 266 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 267 | 268 | 269 | 270 | 271 | 272 | 273 | 274 | 275 | 276 | 277 | 278 | 279 | 280 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 281 | 282 | 283 | 284 | 285 | 286 | 287 | 288 | 289 | 290 | 291 | 292 | 293 | 294 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 295 | 296 | 297 | 298 | 299 | 300 | 301 | 302 | 303 | 304 | 305 | 306 | 307 | 308 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 309 | 310 | 311 | 312 | 313 | 314 | 315 | 316 | 317 | 318 | 319 | 320 | 321 | 322 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 323 | 324 | 325 | 326 | 327 | 328 | 329 | 330 | 331 | 332 | 333 | 334 | 335 | 336 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 337 | 338 | 339 | 340 | 341 | 342 | 343 | 344 | 345 | 346 | 347 | 348 | 349 | 350 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 351 | 352 | 353 | 354 | 355 | 356 | 357 | 358 | 359 | 360 | 361 | 362 | 363 | 364 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 365 | 366 | 367 | 368 | 369 | 370 | 371 | 372 | 373 | 374 | 375 | 376 | 377 | 378 |

| | | | | | | | | | | | | | | |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 379 | 380 | 381 | 382 | 383 | 384 | 385 | 386 | 387 | 388 | 389 | 390 | 391 | 392 |

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|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 393 | 394 | 395 | 396 | 397 | 398 | 399 | 400 | 401 | 402 | 403 | 404 | 405 | 406 |

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|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
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| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 407 | 408 | 409 | 410 | 411 | 412 | 413 | 414 | 415 | 416 | 417 | 418 | 419 | 420 |

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|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|--|
| Target 1 | | | | | | | | | | | | | | |
| Target 2 | | | | | | | | | | | | | | |
| Target 3 | | | | | | | | | | | | | | |
| Target 4 | | | | | | | | | | | | | | |
| Target 5 | | | | | | | | | | | | | | |
| Target 6 | | | | | | | | | | | | | | |
| Target 7 | | | | | | | | | | | | | | |
| Target 8 | | | | | | | | | | | | | | |
| Target 9 | | | | | | | | | | | | | | |
| Target 10 | | | | | | | | | | | | | | |
| Time | 421 | 422 | 423 | 424 | 425 | 426 | 427 | 428 | 429 | 430 | 431 | 432 | | |

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| 14. ABSTRACT For the United States to maintain information superiority, it is necessary to have a means of allocating intelligence-gathering assets to collect information on particular points of interest. In today's geopolitical environment, however, the number of points of interest is growing rapidly, where as the number of available assets is not. To aid in maintaining information superiority, this research explores the use of a Multi-Modal Goal Programming Resource Constrained Project Scheduling approach for allocating imaging surveillance assets (land, air, sea, and space) to image a set of points of interest for a set time period. The objective of this formulation is to minimize the number of points of interest not covered at any time during the required period, minimize the deviation from the minimum image resolution of each point of interest, and minimize the time between successive imaging assets imaging each point of interest. | | | | | |
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