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An Optimization of the Hub-and-Spoke Distribution Network in United States European Command

THESIS

Joseph B. Skipper, Captain, USAF

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Abstract

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> "To laugh often and much; to win the respect of intelligent people and the affection of children; to earn the appreciation of honest critics and endure the betrayal of false friends; to appreciate beauty, to find the best in others; to leave the world a little better; whether by a healthy child, a garden patch or a redeemed social condition; to know even one life has breathed easier because you have lived. This is the meaning of success."
>
> *-Ralph Waldo Emerson*

First, I would like to thank the Lord for providing me with the opportunity to expand my horizons both personally and professionally. He has led me through life's trials even when I did not deserve the benefit and grace that lay on the other side.

I would like to thank my wife for her devotion, understanding, and patience. She stands beside me providing the encouragement and love that keep me going. She also provided me with the most wonderful gift of all, our beautiful daughter. Thank you does not begin to cover the appreciation I have for both of you.

I would be remiss if I did not include my sincere gratitude to my advisor and readers. Dr. Cunningham listened through many longs sessions and provided the "words of wisdom" necessary to get this Southern boy back on track. Lt. Col. Brady provided the encouragement to take my study to the next level, and listened when I needed to vent built-up frustration. Lt. Col. Hill took the additional time to provide the technical sophistication that was so badly needed in the course of this study.

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Ben Skipper

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Abstract

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An Optimization of the Hub-and-Spoke Distribution Network in United States European Command

I. Introduction

Introduction

This chapter introduces the purpose and relevance of the study. It provides the research question, forming basis for the investigative questions underlying the research. The chapter continues with a brief description of the methodology and the assumptions that were used in the study. Next, the data used are discussed. Finally, the section ends with a review of the limitations of the study.

Purpose

The current hub-and-spoke network in the European Theater is made up of locations built and organized around a Cold War threat. Since the end of the Cold War, many changes in the political and military environment have brought new challenges and demands. The threat of large-scale attrition warfare seems to have passed, and the threat of multiple smaller scale contingencies has placed greater demands on the US military's ability to transport equipment and personnel to multiple locations simultaneously. The threat of multiple small-scale contingencies against unknown or previously unlikely aggressors requires an efficient and effective peacetime network of locations for reception and forward movement of material. This network must be flexible enough to handle peacetime operations and to support unknown contingency, peacekeeping, peace enforcement, or humanitarian efforts. These challenges have strained the existing network, and a new network may be more efficient and effective for time definite transportation of equipment and personnel.

The sponsor for this thesis is the Theater Distribution Management Cell (TDMC) located at Ramstein AB, Germany. The TDMC is responsible for tracking and managing the movement of personnel and cargo throughout United States European Command (USEUCOM) from the Aerial Port of Embarkation (APOE) to the Forward Operating Location (FOL), or destination. The TDMC needs a model to help determine optimality of a hub-and-spoke system given certain political and geographical constraints. This model will also be used as a contingency planning tool for both strategic and tactical airlift planning.

Problem Statement

The TDMC needs to know if a more efficient and effective hub-and-spoke network is feasible in the European Theater. Efficiency is defined as the ability of a network to meet requirements in a timely manner. In effect, how long it takes for the network to meet demand. Effectiveness concerns the ability of the network to deliver requirements to the necessary locations. The current network may not be the most efficient for meeting the demands of recent and future contingencies. Cost and time values are used to compare the efficiency and effectiveness of the current versus alternative networks. This research provides the TDMC with an analysis of the current and potential hub locations and how efficiently and effectively these locations meet the demand placed on the system in an effort to find an optimal network.

Research Question

What is the optimal hub-and-spoke network configuration in USEUCOM to meet peacetime operational requirements? Peacetime efforts are those efforts not directly in support of contingency operations. Peacetime operational requirements include the transport of personnel and equipment used to supply, resupply, or replace forces within the theater.

Investigative Questions

This research provides a model to optimize the network of locations and the corresponding flow of equipment and personnel between stations in to meet delivery deadlines. This model focuses on the location for hub placement in the network. Using a Multiple Objective Linear Program (MOLP). This research validates the model, runs it with an emphasis on meeting delivery deadlines using the lowest cost mode of transportation between nodes in the network, and analyzes the results, compared to the current network, to determine potential improvements in efficiency and/or effectiveness.

There were also several additional investigative questions:

a. Selection/validation of methodology (MOLP vs. historically proven method).

b. What requirement must be met for a location to be included in the hub-and-spoke network?

c. What equipment and personnel should support peacetime operations?

d. What locations are considered active in support of peacetime operations?

e. What, where, and who determines the definition of on time delivery?

f. Why is on time delivery important?

g. What is a hub-and-spoke and why is it preferred over other distribution systems?

h. What is the difference between the hub and the spokes in an optimized network and the current network configuration?

Methodology

This research determines if a more efficient network of transportation nodes is available in the European Theater, which would enable the Air Mobility Command (AMC) and USEUCOM to more efficiently meet demand. The research focuses on the timeliness of delivery of equipment and personnel and the cost of that delivery. The research measures the effect of changing the current hub from which cargo and personnel are introduced into the network transportation system to a new proposed system.

This study considers all locations that might be used to deliver equipment and personnel by AMC and USEUCOM components to forward operating locations in the USEUCOM Area of Responsibility (AOR). A sampling of operating locations that fit given characteristics in the European Theater (managed or shared by USEUCOM) will be used. Archival data, provided by TDMC, is used and includes a record of the time required to deliver equipment and personnel to all of its current operating locations and the cost of moving cargo from the APOD to forward operating locations.

Data

The data required for this study was provided by the TDMC. This data includes the weight of each increment as well as a description of the hazardous material, if any, included in the increment. An increment is a standardized unit used throughout the DoD and a measurement of cargo. Increments are either a loaded 463L pallet or rolling stock.

Pallets are used to make the transportation of loose cargo organized and more efficient. An increment may also be rolling stock. Rolling stock is any piece of equipment that may be self driven or towed on to an aircraft. An itemized listing of the ready to ship date from the APOE and arrival date at the Aerial Port of Debarkation (APOD), and FOL was provided for a minimum of six months for each location in the study. This listing was provided with daily entries whenever possible. Data representing cargo or personnel not supporting of peacetime operations was removed from the study. All data was compiled in Microsoft Excel format for ease of sorting and statistical analysis.

Assumptions

This study makes several crucial assumptions. The first concerns the use of peacetime data. In order to construct an optimal network based on minimizing cost, it was necessary to collect data from a time-period of relatively fixed, non-dynamic demand. After careful consideration and discussion, it was decided to use data from a small selection of bases in USEUCOM that form the peacetime core of the current distribution network. The underlying assumption was that an optimal peacetime network can be adapted to meet the initial demands of a contingency scenario. The second assumption is that after an initial warm-up period, the cost of operating each spoke, or route, will normalize. This means that after given a period of time, contracts are negotiated for ground transportation, and that the cost per flying hour, if air transport is used, is consistent. If rates were dynamic for the same route with no known trend, the changes would make any model or forecast extremely difficult and reduce the validity of the model. This assumption means contracts and cost-per-flying hour will remain constant for a minimum of one year. It is assumed that the use of current facilities and basing rights will continue to be in effect for the locations used in this study. This study also assumes that the cost of establishing the basic capabilities necessary for a location to act as a hub are relatively the same and constant regardless of which location is chosen so that the cost of operating the hub location was can be omitted from the cost calculations. Cost calculations in this study include only the transportation cost of equipment and personnel. The final overarching assumption deals with the time required to transport cargo, or personnel, over a given route. This means that the route, or tour, schedule has been established and the time requirement is known and relatively fixed. Delays due to weather and maintenance of aircraft outside of the USEUCOM Theater are not included.

Scope/Limitations

This study is limited to the USEUCOM Theater and has been structured to meet a specific request. The assumptions and methodology used may not be appropriate for all scenarios. Geopolitical concerns have not been addressed, as they are beyond the level of concern for this study.

After numerous discussions with the sponsor, the decision was made to make this model as user friendly as possible, keeping in mind that USAF personnel in the field would use the results of the model as an operational tool. Due to the fact that future support may not be available, it was decided to use Commercial-off-the-Shelf (COTS) software that would be readily available to users and would be supported by the commercial marketplace. Therefore, the sponsor and future users identified the level of detail and modeling complexity as an important concern. This model does not replace more detailed studies conducted in this field. The model's ultimate purpose is to provide a useful tool to field personnel to build an initial network. With this background on the users and potential use of the system, it was decided to limit the capability of the model. Determining the use of facilities or bases that are not currently being used by USEUCOM activities is beyond the scope of this study.

II. Literature Review

Introduction

This chapter is a general overview of the literature available related to hub-and-spoke problems. The USEUCOM Theater has many methods available to design their distribution system. These range from direct delivery to a fully developed hub-and-spoke system. These models all include some variation of the vehicle routing problem, facility location problem, or the combined location problem.

Increasing the efficiency and effectiveness of the USEUCOM theater distribution system is a key objective of the United States Air Force (USAF). In light of current increasing demand and stress on existing transportation assets, while defense budgets continue to decrease, and a smaller number of personnel and available airlifters, each distribution network must operate as efficiently as possible. At the same time, a reduction in materiel inventory and increased operations tempo drives the requirement for improved time definite delivery, or increased effectiveness of the system. These two considerations often directly conflict with one another. These areas are so important that "increasing efficiency and effectiveness" has been listed as one of the six AMC air mobility strategies (HQ AMC, 1998).

Direct Delivery

The direct delivery, or point to point, method of cargo distribution involves the movement of cargo from an origin, warehouse or depot, to a destination without or combination with other cargo. This method has the advantage of speed and in-transit visibility; however, it entails the inefficient use of assets and is extremely costly. Direct delivery also places a limited, vital asset into scenarios where the risk of losing the asset is high. Using this method, strategic airlifters would deliver cargo and personnel to the FOL. In the process of delivery the strategic airlifter must fly and land in areas that may be unsecured, thereby placing the asset in unnecessary danger. For these reasons, the USAF moved away from direct delivery except under those circumstances where the mission requirement is deemed to be worth the risk, or when the area is known to be secure.

Hub-and-Spoke

Hubs, or transshipment nodes, allow the construction of a network where large numbers of direct connections are replaced with fewer indirect connections. The hub-and-spoke method of distribution involves the centralization of routes. Cargo and personnel are moved from outlying areas to a central location and then to a final destination. Hub-and-spoke configurations reduce and simplify network construction costs, centralize commodity handling and sorting, and allow transportation providers to take advantage of economies of scale through consolidation of flows between network nodes. These networks have widespread application in both civilian and military transportation. In order to determine the applicability of a hub-and-spoke network, three critical design questions must be considered: (O'Kelly and Miller, 1994)

a. Are the nodes in the network assigned exclusively to a single hub?
b. Are direct node-to-node- linkages permitted to bypass the hub facilities?
c. Are the hub facilities fully interconnected?

In the case of USEUCOM, cargo from CONUS is moved to a centralized point, a hub referred to as an APOE. The cargo is transported to the USEUCOM theater to another hub, an APOD, and is then split for forward movement to it final destination, the FOL. The term APOE is also commonly referred to as a supply point in this study, and the term APOD represents the hub in theater. Due to political, fiscal, and policy constraints USEUCOM is restricted to the use of a single hub for peacetime supply and resupply efforts. Node-to-node linkages are allowed for missions involving other than routine deliveries, but are minimal in number and are primarily used for the repositioning of equipment and personnel. Since there is only one hub in theater, hub facility connection is not a concern.

Multi-modes of transportation may be used to include air, water, land, or rail, in order to make the best use of the modes that make up the system. Strategic airlift is not used beyond the APOD. Tactical airlift is used to move smaller shipments to the forward locations. This reduces the risk to high value assets such as the strategic airlifters. "The use of a major hub or many hub—depending on the size of the market—enables a carrier to reduce fuel and labor expenses and allows for more flexibility in scheduling flights" (Lambert et al, 1992). The hub-and-spoke network design problem involves the determination of the route, or tour, structure for transporting cargo and personnel between nodes, and the placement of the hub to minimize total cost. Cost can be a measure of actual monetary cost or a measure of time.

Many studies have been conducted using heuristics to determine the appropriate placement of the hub and the spokes. There are many constraints that confound the planning and implementation of a hub-and-spoke distribution system. In the USEUCOM scenario, as in many other military and civilian scenarios, these constraints include cost of constructing new facilities, political considerations, and available assets.

Vehicle Routing Problem

Vehicle Routing Problems (VRPs) are based on the classic Traveling Salesman Problem (TSP). The TSP is summarized as: given a salesman, or in this case a vehicle, a defined, finite set of N nodes, or destinations, and distances between these nodes, find the routing schedule that begins at a set node, visits all the other nodes once, and returns to the original node, in the shortest total distance (Gass, 1970). At first glance this problem sounds relatively easy to solve, however, when the previously mentioned constraints are added the problem becomes much more difficult. This problem assumes that the beginning node is known, defined, and will not change. The problem also assumes that the demand of cargo and personnel transported along the routes is fixed. The complexity is increased if multiple salesmen, or vehicles, are added to the problem, making it a multiple TSP. The VRP adds "demand" to the standard TSP or multiple TSP.

The VRP becomes a problem of determining the optimal route (spokes) from the origin (hub) to the destination while ensuring that each destination is visited exactly once, while meeting the demand of each destination. Costs, measured in the form of monetary cost, time, or distance are placed on each spoke, or arc, and the optimal solution minimizes the total cost while meeting all defined constraints. In addition to a cost measurement, capacity constraints may be added to each arc. This measurement relates the maximum capacity that may be transported over a given arc at one time.

One of the critical assumptions made for the VRP is that all destinations will be visited only once. This assumption may be invalid in military, or civilian, scenarios. Mission requirements may drive the necessity of visiting some nodes more than others, and in some cases not visiting specific nodes at all. If demand at a node fluctuates drastically, or if a node has no demand, there may be no requirement to visit that node at a given point in time. This fact must be recognized in the organization and implementation of a hub-and-spoke network. In the case of peacetime operations where demand is less dynamic, routing schedules can be planned on a routine schedule. In times of war, or contingency, this schedule must be analyzed closely to avoid waste or loss of efficiency.

Facility Location Problems

Another related problem to the hub-and-spoke is the Facility Location Problem (FLP). In this type of problem, we seek for the hub location, which best serves customers, or spokes. There are many examples of facility location problems in the civilian market place. These models are designed to determine the optimal location for warehousing, manufacturing, or distribution. The objective of these models is to minimize the cost associated with transportation between the nodes in the network. Again, this cost can represent either a monetary cost, time, or distance between nodes.

Cost not only depends on the distance between nodes, but also with the interactions with other facilities. In this case, the model attempts to determine which units to assign to a fixed set of nodes, or bases, in order to minimize the movement of supplies. This scenario is commonly played out in theater beddown decisions, where the placement of units is determined. In order to solve location problems linear programs have been adapted. The characteristics of the location problem lend itself to the solving capabilities of linear programming, or quadratic assignment problems. One problem that exists with quadratic assignment problems is the shear number of connections between nodes. "A full enumeration would involve the solution of a large number of quadratic assignment problems, which is by no means an easy computational task" (O'Kelly, 1987).

Even though there are many facility location, or warehouse models, there is very little existing research on hub location. Joseph Campbell, states, "Recent surveys of facility location research testify to the breadth of problems considered. One area that has so far received limited attention is hub location problems." (Campbell, 1994). Campbell also tells us that, "This type of problem can be classified by the way in which demand points are assigned, or allocated, to hubs". Each node may have its own servicing hub, single allocation, or a node may be serviced by multiple hubs, multiple allocation.

The limited research accomplished concerning hub location has focused on the civilian airline system and the small package delivery industry. These models make the assumption that travelers, whether business or pleasure, or cargo will move among all the various destination in multiple directions. In the civilian marketplace, almost every airport is an initiation point, or origin, for some travelers and at the same time a final destination for others. In the USEUCOM, or other military scenario, this assumption does not always hold. In most cases, the origin and destination are separable and distinct from one another. The shipment of cargo and personnel in military applications generally has a distinct shipment, from supply point to using location. This is different from the multiple route scenario found in the civilian marketplace. This difference makes the application of civilian models to military applications difficult because most civilian models are unnecessarily complicated for military purposes.

A Combined Model

In some cases, it is necessary to find both the optimal hub location and the best routing schedule between the hub, or hubs, and the destinations. In these situations, it is natural to find the hub location first, using FLP, and then determine the optimal routing schedule between locations, using VRP. This method appears logical, and in fact works well in scenarios where each location is visited and then the vehicle returns to the hub without visiting multiple locations. However, if a vehicle must visit multiple locations on one tour, or route, the total cost of the route must include the "customer service cost". "The sequential solution of a classical facility location and a vehicle routing model can therefore lead to a sub optimal design for the distribution system" (Balakrishnan, A. et al, 1987).

Even though the sub-optimality of the combined method is a problem, there is a current movement toward constructing models that use a dual goal. These dual goal models are known as combined facility location/vehicle routing problems, or Location Routing Problems (LRPs). "LRPs are VRPs in which the set of depots is not known *a priori*. Instead, depot sites with given operating costs must be determined from a candidate set, simultaneously with the optimal delivery routes" (LaPorte, Louveaux and Mercure, 1989). These LRP models, however, are complex and require careful consideration of the combination of relatively near-term operational decisions, such as routing and schedules, and long-term strategic decision, such as hub location. This means that the planner must carefully consider the trade-offs between optimizing hub location and scheduling. An optimal hub location for the long term may result in increased short-term deficiencies, or vice versa.

In USEUCOM, peacetime operating locations and their demand levels are relatively fixed. Because the mission dictates the demand level, opportunities for optimization are limited to optimizing the network through hub selection. Hub-and-spoke networks are used in virtually every mode of transportation; particularly airline passenger networks, overnight package delivery, and rail sorting yards. While these networks are similar in nature, it is difficult to generalize one network model that meets the requirements of every situation for each type of mode.

A review of available literature concerning hub placement in networks reveals that early studies in management science and operations research often classified hubs as being synonymous with a central warehouse or storage facility (Minas and Mitten, 1958). By using this definition, a hub becomes simply a warehouse, or depot, located in the center of a demand area. In contrast, later studies argued that a hub should actually be located to minimize the sum of transportation cost between the nodes of a network (Goldman, 1969). This definition addresses the possibility that demand could be higher at some nodes and less at others. If demand is higher and therefore more shipments are necessary, the optimal hub location may be closer to that node.

Within the transportation industry, the term hub denotes different meanings. In the passenger airline industry, the Federal Aviation Administration (FAA) the term hub is classified as the basis of the percentage of total passengers enplaned in that area. “Air traffic hubs are geographical areas, and are based on the percentage of total passengers enplaned in the area" (Federal Aviation Administration, 1996). An airline hub may contain more than one airport. This definition should not be confused with the definition used by the airlines in describing their "hub and spoke" structures. The hubs constitute a primary focal point for the transportation research programs of the FAA, and the analyses of individual cities within an area are treated in relationship to the entire area. Within the package delivery market, the term hub represents a major sorting center. This definition of hub is most similar to that used in this study. The important point is that the flow of cargo and personnel between a supply point, or origin, and a demand point, or destination, passes through a hub.

The hub network design problem involves finding the optimal location for hub facilities, assigning non-hub origins and destinations to the hubs, determining linkages between the hubs, and routing flows through the network (O'Kelly, et al, 1996). This involves a large number of decision variables, and the multiple solutions that are possible are all interdependent on each other. In order to combat the complexity of the problem, there are three initial possibilities. The first involves the adoption of a partial approach, where some aspects of the decision variables are simplified. For example, the researcher could make the assumption that transportation costs are independent of flow volume (Campbell, 1990). Unfortunately, this assumption eliminates part of the economies of scale that make hub-and-spoke networks attractive. The second simplifying possibility is to break the network down into smaller sub-networks (Chung et al., 1992). This action reduces the number of possible solutions and reduces the interdependency of demand nodes; however, the hub interdependency may increase substantially. In cases of a single hub network, this disadvantage is eliminated. The final possibility for reducing complexity involves the recognition of the inherent mathematical difficulty, and to seek a local optimal solution rather than a provable global optimal solution (O'Kelly, et al., 1995). Local optimization may be perfectly acceptable in some circumstances, but must be identified as a local solution and not representative of global circumstances.

A set of assumptions has been accepted as a standard in order to manage the hub design problem. These assumptions address issues such as the number of hubs, the interconnectivity between hubs, and the interconnectivity between demand nodes within the network (O'Kelly and Miller, 1994). The standard hub network makeup, Protocol A, consists of a relatively large number of nodes each directly connected to only one of a small number of completely interconnected hubs. This is commonly referred to as "pure hub and spoke configuration". Protocol A serves as the basis for many efforts to solve the hub network design problem and provides the basis for the methodology of this study. The methodology of Protocol A and this study are discussed further in Chapter 3.

In addition to Protocol A, seven additional protocols have been defined, B through H. Each successive protocol includes an additional level of complexity within the network. Selection of the protocol used for a specific network problem involves a determination of the variables measured within that network and an analysis of the nodes within the network. For example, one must determine the number of hubs utilized within the network. If multiple hubs are used, one must then determine whether these hubs are linked. In addition, a determination must be made as to the connectivity between demand nodes. This is important in determining the routes used to service the demand nodes. Table 1 lists all eight protocols, provides the variables that should be measured and an example of where these protocols are employed.

Table 1. Hub Network Design Protocols

Design Class	Design Variables	Empirical Examples
Protocol A	Hub Location Node-Single Hub Assignment	Interplant communications
Protocol B	Hub Location Node-Single Hub Assignment Hub-Hub Links	Satellite Communications
Protocol C	Hub Location Node-Single Hub Assignment Node-Node Links	Financial Networks
Protocol D	Hub Location Node-Single Hub Assignments Node-Node Links	Financial Networks
Protocol E	Hub Location Node-Multiple Hub Assignments	Air Passenger Networks
Protocol F	Hub Location Node-Multiple Hub Assignments Hub-Hub Links	Ground Delivery Service
Protocol G	Hub Location Node-Multiple Hub Assignment Node-Node Links	Air Passenger Networks
Protocol H	Hub Location Node-Multiple Hub Assignment Hub-Hub Links Node-Node Links	Air Passenger Networks

Summary

No one answer fits every scenario for the distribution network problem. Each scenario brings its own individual needs that must be carefully analyzed. It is important to note that the same scenario may have different requirements and therefore demand a new model at different times. For example, peacetime operations produce less dynamic demands, and typically have a relatively fixed number of operating locations. In this case, a simple model may be used to determine the optimal operating schedule. In wartime, however, demand is very dynamic, and new, previously unconsidered locations may be required. In this case, a new or additional hub may be required in addition to new operating locations. Given that every scenario is different, the best solution may be to adapt a standard model to a scenario based on carefully defined assumptions. This may also include the "borrowing" of the features that fit the scenario from different models.

III. Methodology

Research Question

The research question in this study is to determine if there is a more efficient network of transportation nodes available in the European Theater available to Air Mobility Command (AMC) and United States European Command (USEUCOM). The measures utilized in this study are the timeliness of delivery of equipment and personnel and the cost of that delivery. Currently, AMC uses only a few APODs. This research effort attempts to determine if a better mix of APODs, or hubs, would be more efficient and effective in the timely delivery of cargo and personnel at lower cost. Included in this network are the transshipment points where equipment and personnel are matched for further movement to forward locations. Since contingency scenarios change, a peacetime scenario is modeled for both groups.

As introduced in Chapter 2 of this study, Protocol A acts as the cornerstone of current hub selection problem models. This protocol is defined as the product of three simplifying assumptions:

a. All hubs are fully interconnected.
b. All nodes are connected to only one hub.
c. There are no direct non-hub connections.

These assumptions have led this protocol to be commonly referred to as 'strict hubbing policy' (O'Kelly and Miller, 1994).

Protocol A designs have two important properties. The first involves deterministic routing, or connections, between nodes. If a hub location is fixed, the allocation of non-hubs and the triangle of inequality with respect to distance, there is only one shortest path between any supply-demand pair in the network. Since each non-hub origin and destination is connected to only one hub (assumption 2), and all hubs are interconnected (assumption 1), the triangular distance inequality means that the shortest path can be found simply by choosing the direct connections between a non-hub origin or destination and its hub (O'Kelly, 1986). Thus, the distance between two points is always smaller or equal to the distance between these points and a third point. The second property is a p-median problem constraint set. For the purposes of this model, the p-median problem is used to minimize the distance (cost or time) in order to meet demand. Protocol A network characteristics allow the hub network design problem to be stated in similar format to a traditional optimal location problem. Facility location research has loaned itself to hub location research by supplying algorithms. These two properties allow the hub location design problem to be stated as a more traditional facility location problem (O'Kelly and Miller, 1994).

The Quadratic Single Assignment Model

The quadratic single assignment model was developed to linearize the model. This model seeks the solution for networks with a single hub allocated to service multiple demand locations. This model differs from previous single hub assignment models because of the quadratic terms included in the objective function. This quadratic term is used if a cost is incurred inside a hub, meaning costs are incurred as equipment or personnel are moved inter-hub. By including the quadratic term the model becomes more inclusive of the cost incurred by the network. If there is no cost 'inter-hub' the quadratic term drops out. This development allows the use of linear programming to find optimal solutions (Campbell, 1994). Ideally, a linearization will provide integer solutions such as the case of a study seeking to find the number of hubs required to service a network. This model has been adapted to meet a number of programming needs and has also been adapted for use in all eight protocols. The following formulation is the model (Bryan and O'Kelly, 1999).

Objective Function

$$Min \sum_{i} \sum_{j} W_{ij} \left(\sum_{k} Z_{ik} C_{ik} + \sum_{m} Z_{jm} C_{jm} + \alpha \sum_{k} \sum_{m} Z_{ik} Z_{jm} C_{km} \right) \tag{1}$$

Subject to

$$(n - p + 1) Z_{kk} - \sum_{i} Z_{ik} \geq 0 \quad \forall k \tag{2}$$

$$\sum_{k} Z_{ik} = 1 \quad \forall i \tag{3}$$

$$\sum_{k} Z_{kk} = p \tag{4}$$

$$Z_{ik} \in \{0,1\} \quad \forall i, k$$

where

n = the number of nodes in a network
p = the number of hubs to be located
α = the interhub discount factor $0 \leq \alpha \leq 1$
i = the index of origin
j = the destination
k = the selected hub
m = the alternative hub set
W_{ij} = the amount of flow traveling between i and j
C_{ik} = the per unit cost of traveling between i and k

C_{jm} = the per unit cost of traveling between j and m
C_{km} = the per unit cost of traveling between k and m
Z_{ik} = 1 if node i is allocated to hub k
0 otherwise
Z_{jm} = 1 if destination j is allocated to hub m
0 otherwise
Z_{kk} = Represents the limit on hub selection

The objective function (1) minimizes total network costs. Constraint (2) requires a hub to be open before a node is assigned to it. Constraint (3) constrains each node to be assigned to a single hub. Constraint (4) requires that p hubs be open. The final line of the equation restricts the number of routes between the origin to the hub to zero or one. This means that only one route will be used from the origin to the hub.

A comparison is conducted using a between-subject design, by measuring the effect of changing the network design by changing the hub location and then comparing the original network and the new network. Efficiency is defined as a measure of average deliveries of equipment and personnel on the specified date. The time measurement will be based on the standard that the sponsor has placed on the current network, specified for delivery of all equipment and personnel assigned by theater planners. The TDMC has established a 96-hour standard for delivery of cargo to the EUCOM AOR. The length of time required to deliver cargo to a specific location from a hub will be restricted by the established 96 hour standard. Cost is measured using data provided by TDMC for each of its operating locations in the theater of operations. Where data was unavailable for a selected location, cost estimates of similar locations was used instead.

In order to accurately compare the two networks, a level playing field is maintained. By eliminating outside effects on the system and using the same workload factors on the system, a true comparison of the actual network locations involved should result in a determination of which network best meets the requirements of theater demand.

Populations and Sampling Frame

This study considers all locations that might be used to deliver equipment and personnel by AMC and USEUCOM to forward operating locations in the EUCOM Theater of Operations. These sites include all locations with a sufficiently long runway, parking spaces for aircraft, aircraft refuel capability, equipment storage and personnel billeting, material handling equipment for the downloading of equipment, potable water, and availability of ground transportation. The AMC Airfield Summary Report provides the requirements necessary to land and operate large aircraft. The requirements discussed above are but a few of the many requirements necessary for the landing, loading/ unloading, and eventual takeoff of large aircraft. This type of information is available for locations that AMC has operated from or used as an alternate landing site in case of emergency. Unfortunately, while the locations may be listed, random portions of the pertinent data may be missing. The enumeration of the population would be quite lengthy and tedious to analyze. In order to make the analysis more efficient, the sponsor was asked to provide a list of the potential locations that might serve as a hub in the network design. These locations are all in the European Theater, and are managed or shared by USEUCOM units. These locations are required to meet established aircraft beddown standards and have data available for analysis. As mentioned previously, if for any reason data is unavailable, an estimate, using a similar location's capabilities, is used in order to compute an overall comparison of efficiency and cost. This method risks a level of error due to the selection of the estimate. In order to combat this error an expert panel will select the substitute locations and the sponsor will approve the estimate before use.

Nature of the Data

The current model uses archival data provided by TDMC and re-formatted for the model. This data includes a record of the time required to deliver equipment and personnel to all of its current operating locations and the cost of moving cargo from the APOD to FOLs This is the same type of data that might be used in the USAF budgeting process and should be reasonably accurate. To minimize any error in data entry, the data was reviewed before use.

There are many confounding factors, in fact too many to model accurately, that occur to cause delays in the delivery of equipment and personnel to their demand locations. Many of these factors have nothing to do with the efficiency or effectiveness of the network and will therefore be intentionally removed from consideration in the model. For instance, delays caused by maintenance problems before entering the theater are not be included in the study. Delays due to weather are also not considered. By eliminating the uncontrollable causes of inefficiency, the model will focus on the limitations of the actual network design. This is done in an effort to reduce the number of outside effects on the network itself in the model.

When data is not available for a location, suitable substitutes will be used instead. For example, Sembach Annex has some base facilities but the runway has been closed for several years. Since data may not be available for this location, a location of similar size and upkeep may have data that could be substituted and used for modeling purposes. Another example is Spangdalhem AB. This location has an active flight line operation and might be used to handle overflow operations from the current hub, or added as an independent hub. The determination of what is or is not a suitable substitute will be left to experts' opinion provided by TDMC.

In an effort to reduce experimental construct validity problems the model was reviewed by the sponsor to ensure that data was interpreted properly and that the correct questions were asked. This step also ensured that the model matched the real system in use, thereby increasing the validity of the model. Since the possibility exists that differences in the system in use at a given time would result in data that is not directly comparable, only data collected in the January 2001 to June 2001 interval was used. Data collected during contingency operations during this period will be examined for the purpose of removing contingency support operations. This provides only non-contingency demands and cost for the system.

Statistical Analysis

Complex statistical analysis is not necessary in this research. Since the analysis of this data will only involve the comparison of two independent outcomes, complex statistics are not expected to be necessary. In order to attain the results for this model, we used Excel Solver. For an example of the actual model and a description of the model please see Appendix A.

Multiple Objective Linear Programming

Multiple Objective Linear Programming (MOLP) models seek to solve for two, or more, potentially conflicting objective functions. In our case, to minimize the time requirement and the cost of the network. Transportation by air is generally faster than transportation via ground modes. However, air transport is also normally more expensive. Finding the right mix of air and ground transportation is one of the considerations in hub selection. Each proposed hub location may have a different capacity of the two types of transportation modes available. This capacity will affect the hub's ability to meet demand in both cost and time considerations. MOLP problems require analyzing the trade-offs among different objectives. The model for this study will support decision makers and planners by providing quantifiable data representing the cost and time requirements in hub placement options.

The Hub Location Model

Constructing this model required identifying the current network including the supply node, the current hub location, and the demand nodes. After lengthy discussions, it was determined that the supply node is Dover AFB, DE. This location acts as the sole supply point for channel missions delivering non-contingency support. It is also the supply point for all Strategic Defense Management Initiative (SDMI) items. SDMI will be further discussed in Chapter 5 of this study. The consolidation of multiple supply points into one allows AMC to benefit from the streamlining and economies of scale of strategic airlift. It also allows AMC to consolidate much of the personnel and equipment necessary to support large APOD operations. Figure 1 depicts the current network, with each node numbered for ease of reference.

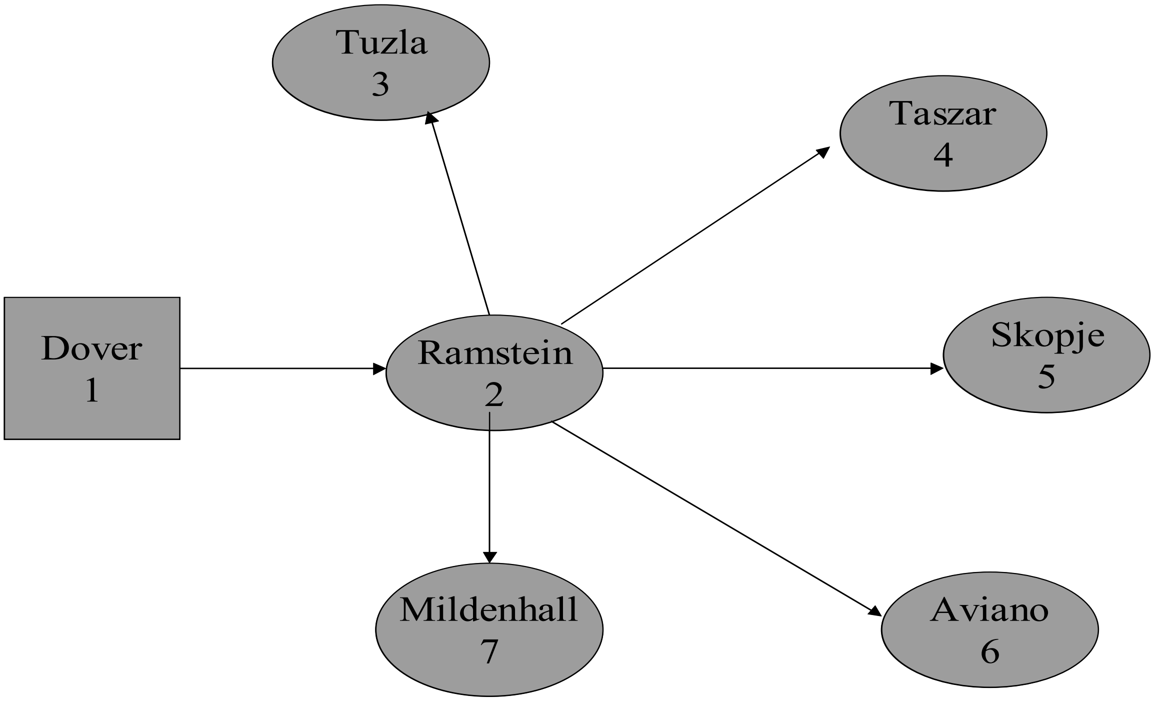


Figure 1. Network Representation

Each arc represents the direction of travel used to deliver cargo and personnel to the hub and demand nodes. In reality, each arrow represents two modes of travel, air and ground. While other modes may be used, these two are by far the predominate modes utilized in the EUCOM theater. The modes have separate capacity and cost.

Arc costs were provided by TDMC and represent the average cost of transporting equipment and personnel to forward operating locations from a transshipment point or APOD. The cost figures for ground modal transportation were taken from existing contracts and existing tenders. Costs for the air modal arcs represent the average cost per flying hour, and were provided by AMC. The capacities represent the average number of increments transported via the respective mode. Again, contingency scenarios and their corresponding cost and capacity were not included.

Minimum Cost Model

The minimum cost network formulation meeting the requirements of the demand locations is:

Objective Function

$$\text{Min} \quad \sum_{i} \sum_{j} X_{ij} * C_{ij}$$

Subject to:

$$X_{ij} \le Avail_{ij} \qquad \forall i, j \qquad (6)$$

$$\sum_{i} X_{ij} * CA_{ij} \ge Demand_{j} \qquad \forall j \qquad (7)$$

$$X_{ij} \ge 0 \qquad (8)$$

$$X_{ij} = Integer \qquad (9)$$

where

C = Cost of movement
i = Node I
j = Destination j
X = Number of missions
$Avail$ = Available missions
$Demand$ = Demand at location in increments
CA = Per Mission load

Constraint (6) deals with the number of available missions from the hub to the demand location. Missions denote both air missions flown by C-130 aircraft and contract trucking ground missions. The number of available missions for each transportation mode for the EUCOM Theater was provided by TDMC. Each demand location has a limited number of missions available to service them. For this case, the number of ground missions was limited to 200 and the number of air missions was limited to 50. These estimates represent a maximum capability without deploying additional assets to the USEUCOM, or adding additional contracts for ground transportation.

Constraint (7) deals with the available capacity of each arc linking the nodes. There are only a certain number of missions available to each location via either transportation mode. The number of missions is constrained by organic capability such as the number of intratheater airlift assets, the C-130, assigned to a location, or the number of truck mission that can be produced organically or contracted from the civilian marketplace. The sponsor for this study provided estimates.

The final constraints (8) and (9) limit the model to non-negative results and provide for integer solutions only.

Minimum Time Model

The second objective used in this study concerns the minimal time necessary to meet the requirements of the demand locations. The mathematical formula for this objective is very similar to the one used for the minimum cost objective, the difference being that the objective is to minimize the time required to meet demand.

Objective Function

$$\text{Min} \quad \sum_i \sum_j X_{ij} * T_{ij}$$

Subject to:

$$X_{ij} \leq Avail_{ij} \qquad \forall i, j \quad (10)$$

$$\sum_i X_{ij} * CA_{ij} \geq Demand_j \qquad \forall j \quad (11)$$

$$X_{ij} \geq 0 \tag{12}$$

$$X_{ij} = Integer \tag{13}$$

where:

T = Time required for movement
i = Node I
j = Destination j
X = Number of missions
$Avail$ = Available missions
$Demand$ = Demand at location in increments
CA = Per Mission load

The two minimal solutions, found by solving for minimum cost and time, serve as the target values for the goal-programming model. In this model, the researcher will use the MINI-MAX objective discussed previously.

MINI-MAX Model

This model allows the researcher to minimize the maximum deviation from the target objectives found in the minimum cost and time models. This requires the introduction of an additional variable ‘Q’ to the model. In order to construct this model several additional constraints are required. These additional constraints will allow the researcher apply ‘weights’, or values, to the target objectives that were already in use. In order to find the actual cost and time, the model performs a deviation calculation. The calculations start with two definitional constraints.

$$\sum_{i}\sum_{j} X_{ij} * C_{ij} = Actual\,Cost \tag{14}$$

$$\sum_{i}\sum_{j} X_{ij} * T_{ij} = Actual\ Time \tag{15}$$

Constraints (14) and (15) provide variable values to compute percent deviations using:

$$\text{(actual value – target value) / target value} \qquad (16)$$

These percentage deviations are weighted to form a weighted combination. This new objective function helps to find the trade-off point where both cost and time are minimized and the requirements of the demand locations are met.

MIN: Q

Subject to:

$$w1^{*}\ \text{(actual cost – target value)/target value} \leq Q \qquad (17)$$

$$w2^{*}\ \text{(actual time – target value)/target value} \leq Q \qquad (18)$$

Constraint (17) indicates that the weighted percentage deviations from the target network cost must be less than or equal to Q. Constraint (18) indicates that the weighted percentage deviation from the target level of network time must be less than or equal to Q. Thus, if the model minimizes Q, it is also minimizing the percentage deviation from the target values for each of the objectives. In this way, the maximum weighted deviation from any of the goals is minimized. Changing w1 or w2 provides a means to examine a wide range of potential solutions.

Summary

The research question for this study is whether there is a more efficient hub location and network of transportation nodes available in the European Theater available to Air Mobility Command (AMC) and USEUCOM than are currently being utilized. The constructs studied are the timeliness of delivery of equipment and personnel and the cost of that delivery.

This study considers all locations that might be used to deliver equipment and personnel by AMC to FOLs in the European Theater of Operations. Data pertaining to these locations was provided by TDMC and includes a record of the time required to deliver equipment and personnel to all of its current operating locations and an established standard for delivery. This data also includes the cost of moving cargo from the APOD to FOLs.

The goal of this study is to determine which system of nodes and arcs provide the most efficient system for delivery of equipment and personnel to the final destination at the lowest acceptable cost. In order to assess this question, a Multiple Objective Linear Programming (MOLP) technique involving network flow is used.

IV. Results

Introduction

This chapter will summarize the results of the research. Each alternate hub location was used along with its corresponding time and cost values. A table and explanation for each set of results is provided to clarify the results.

Analysis

The following sections describe the results of each model. For comparison sake, the model results are provided in sets of three. The first table provided in each section represents the results of a model run with equal weights. The second represents the results when time is given a higher weight than cost. Finally, the last table in each section represents the results from the model when cost is given a higher value than time. A table with all values for all location is provided in the summary. The target values listed within each table represent the minimum time required to meet demand given the constraints used in the model.

During the initial run of this model a problem was encountered. This problem resulted in Solver being unable to find a feasible solution. The researcher was forced to reanalyze the data, formulations, and constraints used in the model and found one constraint that caused the problem. The constraint that created the error forced the model to make the ‘Hours Used’ less than or equal to ‘Hours Goal’. In this case, the ground route from Ramstein to Skopje, Macedonia requires a total of 60 hours. The combination of the ‘Shipment Hours’ and the ‘Average Port Hold Time’ make the ‘Hours Used’ greater than the ‘Hours Goal’ of 96. This problem was found again in the Spangdahlem to Skopje model. This constraint was forcing the model to return an error even if the route, Skopje Ground, was not used.

After lengthy discussion with the sponsor and the advisory team for this study, the researcher made the decision to remove the ‘Hours Goal’ constraint from the effected routes only. This decision was made after it was determined that in the real world execution of this system the goal is often waved. A phone conversation with the sponsor related that in some cases, where it is known in advance that the use of ground transportation to the problem demand location will result in a ‘time bust’, or not meeting the ‘Hours Goal’, the goal is waved. This decision is made based on the fact, in part, that in order to meet the time goal, internal business rules must be broken. In order to meet the 96-hour goal, the TDMC must schedule the ground transportation to arrive at the hub a minimum of 12 hours earlier. This reduces the port hold time and results in the shipment meeting the 96-hour goal.

After identification of the problem, the researcher discussed the possible solutions with the sponsor. Two solutions became quickly apparent. The first was to reduce the average port hold time at the hub location to 12 hours. If ground transportation could be arranged 12 hours in advance, then the time required to meet the ‘Hours Goal’ would be within the 96-hour window. This alternative would result in the restructuring of some existing policy and management guidelines, and may incur additional cost. This alternative was rejected.

The second alternative discussed was to simply waive the ‘Hours Goal’ in cases where actual requirement could not be met given current management direction and established policy. This alternative results in no increased cost to the current system.

This alternative would require an increase in the coordination between APOE and APOD, but is possible at little additional cost, if any, and would not require additional resources. The change would appear to be a procedural change, not a physical change to the network or the organization that manages the network activities.

Either alternative would cause the planners of this network to break a management policy. The first results in planners being forced to arrange ground transportation well in advance of receiving the equipment to be moved to the demand location. There is a narrow window when the requirements can be finalized at the supply location and forwarded to the hub for follow on movement. By moving the arrangement of ground transportation up 12 hours, planners would require the finalized list of equipment that will be received at the hub earlier than it is currently feasible to acquire. The change would result in equipment being received, prepared, finalized, and a listing forwarded to the hub from the supply location earlier than can be accomplished at this time. This change in policy offers a “free” increase in efficiency and effectiveness.

The following sections of the paper provide the results of the model. These results were found by removing the ‘Hours Goal’ constraint from the routes that were known to be incapable of meeting the 96-hour goal.

Ramstein as Hub

The first model used the existing network configuration with Ramstein AB as the hub. The results of this model run state that minimum cost is $6,742,144 and the minimum for time is 17,218.2 hours. Note that the Target Value represents the minimum cost or time necessary to meet the requirements of the demand location. The value represents the goal, or absolute best performance, that the network can achieve. This value was determined using the MOLP techniques discussed in Ch 3 of this study. The trade-off cost, or actual cost, given the constraints discussed in Chapter 3 of this study is $7,354,974. This cost is slightly higher than the Target Value. The same is true for the actual time requirement, 18,779.8. The ‘weight’ column represents a user-defined precedence for either cost or time. In this case, the weight is the same for both categories. Additional runs of the model are provided later in this study to demonstrate the results of unequal weights. Table 2 lists the results of the model run with Ramstein AB as the hub with equal weight for both time and cost. Table 3 provides the results for the model run when time has precedence over cost. Finally, Table 4 demonstrates the results of the model solution when cost has precedence over time. For all three tables, time is measured in hours.

It is important to note that as priorities change the number and type of mission’s change as well as the cost and time values. The number of missions to each location by mode is provided in detail in Appendix A.

Table 2. Ramstein Results—Equal Weight

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	18,779.8	**17,218.2**	9.07%	**1**
Cost	$7,354,974	**$6,742,144**	9.09%	**1**

Table 3. Ramstein Results – Time Precedence

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	18,250.2	**17,233.0**	5.90%	**2**
Cost	$7,541,410	**$6,742,144**	11.85%	**1**

Table 4. Ramstein Results – Cost Precedence

	Total	Target Value	% Deviation	Weight
Time (hrs)	19,670.8	**17,233.0**	14.15%	**1**
Cost	$7,218,490	**$6,742,144**	7.07%	**2**

Spangdahlem as Hub

The next model represents a network configured with Spangdahlem AB as the hub. Since this location is geographically very close to the current hub location of Ramstein AB, it was expected that the results would be very similar to the original values. Table 5 provides the results for the equal weight model. Table 6 represents the results for time precedence, and Table 7 provides the results for cost precedence. The columns represent the same values previously provided.

Table 5. Spangdahlem Results – Equal Weight

	Total	Target Value	% Deviation	Weight
Time (hrs)	19,682.4	**18,249.7**	7.85%	**1**
Cost	$7,664,036	**$7,108,323**	7.82%	**1**

Table 6. Spangdahlem Results – Time Precedence

	Total	Target Value	% Deviation	Weight
Time (hrs)	19,102.0	**18,249.7**	4.67%	**2**
Cost	$7,781,234	**$7,108,323**	9.47%	**1**

Table 7. Spangdahlem Results – Cost Precedence

	Total	Target Value	% Deviation	Weight
Time (hrs)	20,528.5	**18,249.7**	12.49%	**1**
Cost	$7,555,560	**$7,108,323**	6.29%	**2**

Here again, the trade-off forces both the cost and time requirements higher than the absolute minimums for each.

Sigonella as Hub

The next model represents a network configured with Sigonella Naval Air Station as the hub. Since this location is geographically very distant from the current hub location of Ramstein AB, it was expected that the results would differ from the original values. Table 8 provides the results for the equal weight model. Tables 9 and 10 provide the results of the time and cost precedence, respectively. The columns represent the same values previously provided.

Table 8. Sigonella Results – Equal Weight

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	19,246.1	**17,314.6**	11.16%	**1**
Cost	$8,252,408	**$7,416,795**	11.27%	**1**

Table 9. Sigonella Results – Time Precedence

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	18,963.1	**17,818.6**	6.42%	**2**
Cost	$8,385,472	**$7,416,795**	13.06%	**1**

Table 10. Sigonella Results – Cost Precedence

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	20,926.1	**17,818.6**	17.44%	**1**
Cost	$8,061,666	**$7,416,795**	8.69%	**2**

Here the model shows that the target value for cost is higher than in the previous models.

Aviano as Hub

The next model represents a network configured with Aviano AB as the hub. Since this location is geographically very distant from the current hub location of Ramstein AB, it was expected that the results would be somewhat different from the original values. In addition, since Aviano is also one of the demand locations it was expected that a large portion of the actual time and cost figures would be reduced. If Aviano is the hub, there is not requirement to forward deploy to that location via ground or intratheater airlift. Table 11 provides the results for this equal weight model. Tables 12 and 13 provide the results for time and cost precedence models with Aviano as the hub in the network. The columns represent the same values previously provided.

Table 11. Aviano Results -- Equal Weight

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	14,161.5	**12,371.4**	14.47%	**1**
Cost	$6,687,501	**$5,839,685**	14.52%	**1**

Table 12. Aviano Results – Time Precedence

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	13,407.8	**12,371.4**	8.38%	**2**
Cost	$6,831,674	**$5,839,685**	16.99%	**1**

Table 13. Aviano Results – Cost Precedence

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	15,132.1	**12,371.4**	22.32%	**1**
Cost	$6,496,464	**$5,839,685**	11.25%	**2**

The Target Values in this case are the least so far.

Hub Location Comparison

A summary of the time and cost requirements is provided in Table 14 and graphically depicted in Figures 2 and 3.

Table 14. Cost and Time Requirements Summary

Hub		Total	Target Value	% Deviation	Weight
Ramstein-- Equal Weight (1)	*Time (hrs)*	18780	17218	9.069%	1
	Cost	$7,354,974	$6,742,144	9.090%	1
Ramstein-- Time Precedence (2)	*Time (hrs)*	18,250.2	17,233.0	5.903%	2
	Cost	$7,541,410	$6,742,144	11.855%	1
Ramstein-- Cost Precedence (3)	*Time (hrs)*	19671	17233	14.146%	1
	Cost	$7,218,490	$6,742,144	7.065%	2
Spangdahlem-- Equal Weight (4)	*Time (hrs)*	19682	18250	7.851%	1
	Cost	$7,664,036	$7,108,323	7.818%	1
Spangdahlem-- Time Precedence (5)	*Time (hrs)*	19102	18250	4.670%	2
	Cost	$7,781,234	$7,108,323	9.467%	1
Spangdahlem-- Cost Precedence (6)	*Time (hrs)*	20529	18250	12.487%	1
	Cost	$7,555,560	$7,108,323	6.292%	2
Sigonella-- Equal Weight (7)	*Time (hrs)*	19246	17315	11.155%	1
	Cost	$8,252,408	$7,416,795	11.266%	1
Sigonella-- Time Precedence (8)	*Time (hrs)*	18963	17819	6.423%	2
	Cost	$8,385,472	$7,416,795	13.061%	1
Sigonella-- Cost Precedence (9)	*Time (hrs)*	20926	17819	17.440%	1
	Cost	$8,061,666	$7,416,795	8.695%	2
Aviano-- Equal Weight (10)	*Time (hrs)*	14162	12371	14.470%	1
	Cost	$6,687,501	$5,839,685	14.518%	1
Aviano-- Time Precedence (11)	*Time (hrs)*	13408	12371	8.377%	2
	Cost	$6,831,674	$5,839,685	16.987%	1
Aviano-- Cost Precedence (12)	*Time (hrs)*	15,132.1	12,371.4	22.315%	1
	Cost	$6,496,464	$5,839,685	11.247%	2

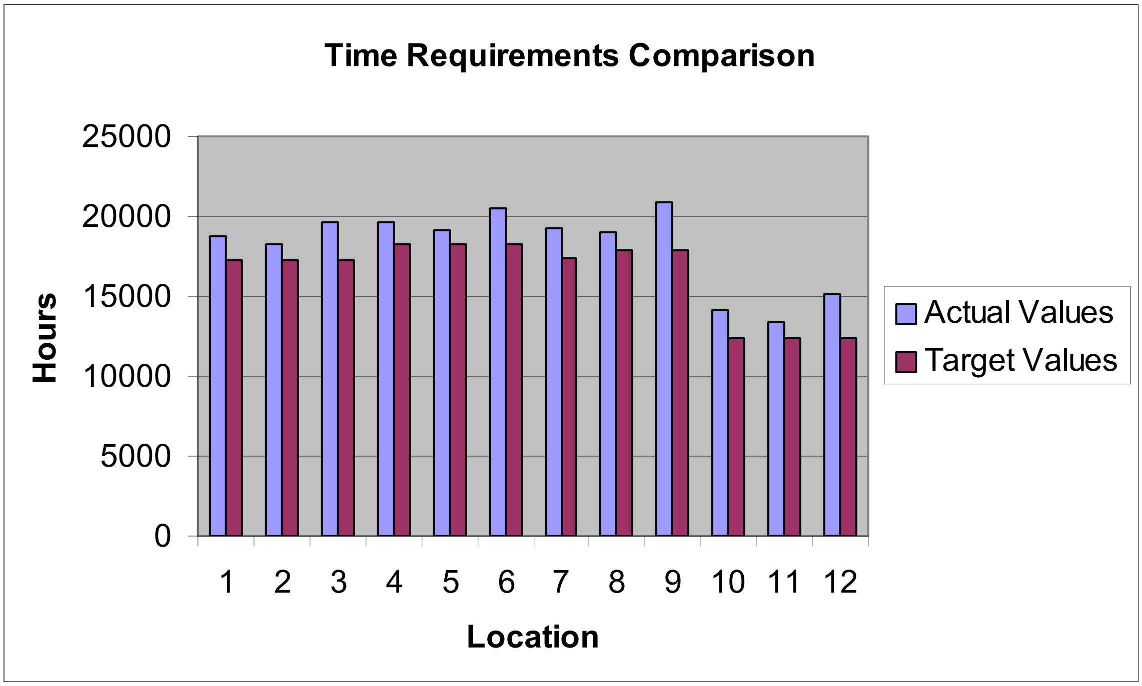


Figure 2. Time Requirement Comparison

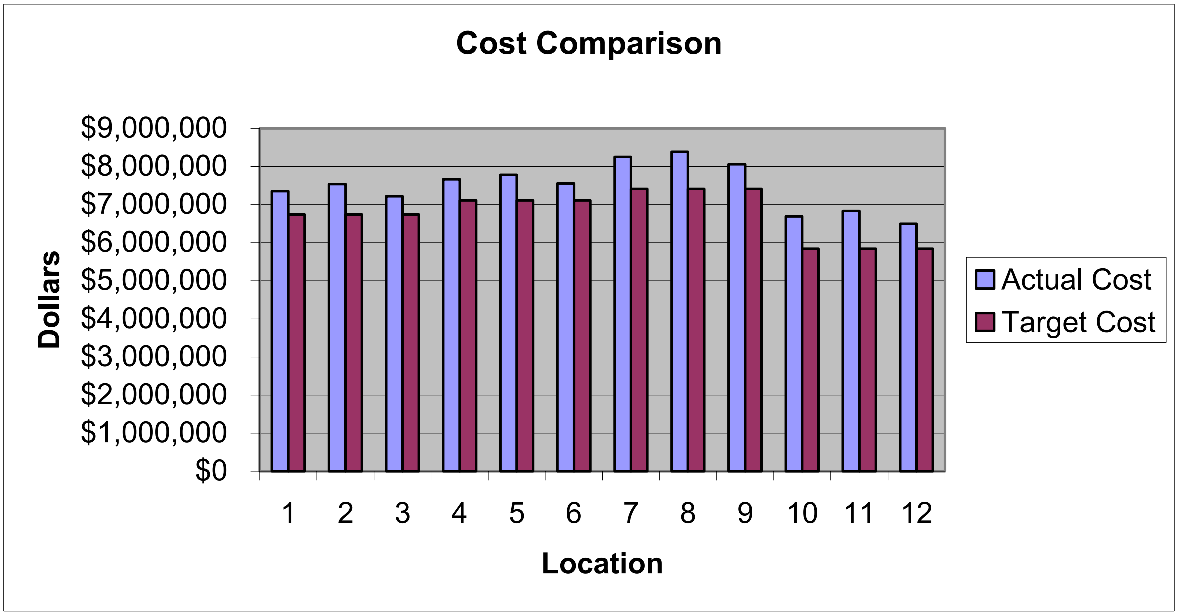


Figure 3. Cost Requirement Comparison

In order to provide a comparison of models that share the same weight characteristics the following sections review the results of each model that shared equal weight, then time precedence, and finally cost precedence. The reordering of the results should provide a planner, or decision maker, with the necessary information to choose the optimal hub location for a hub-and-spoke network.

The following summarizes the results of the ‘Equal Weight’ models. These models gave both time and cost having the same level of importance. These results represent the trade-off point between minimum cost and the minimum time necessary to meet the requirements of a demand location. Table 15 provides this comparison.

Table 15. Equal Weight Comparison

Hub		**Total**	**Target Value**	**% Deviation**	**Weight**
Ramstein-- Equal Weight (1)	*Time (hrs)*	18,780	17,218	9.069%	1
	Cost	$7,354,974	$6,742,144	9.090%	1
Spangdahlem-- Equal Weight (4)	*Time (hrs)*	19,682	18,250	7.851%	1
	Cost	$7,664,036	$7,108,323	7.818%	1
Sigonella-- Equal Weight (7)	*Time (hrs)*	19,246	17,315	11.155%	1
	Cost	$8,252,408	$7,416,795	11.266%	1
Aviano-- Equal Weight (10)	*Time (hrs)*	**14,162**	12,371	14.470%	1
	Cost	**$6,687,501**	$5,839,685	14.518%	1

These results show that the Aviano hub provides both the lowest cost and lowest time requirements. This is largely due to the fact that in this scenario, Aviano is both the hub and one of the demand locations. When the additional time and cost requirements of forward movement from the hub to the demand locations are removed, the result is a much lower total cost and time requirement for the hub. It is important to note on this chart that the Aviano hub provides the lowest cost and time totals.

We next study the model runs in which time has precedence over cost. In some scenarios, a network may be forced to operate in conditions where time is more important than cost. Such situations include contingency or humanitarian support. Planners must be aware of the trade-offs inherent in trading time for cost. Table 16 provides the results of the four hub locations when time is given precedence over cost.

Table 16. Time Precedence Comparison

Hub		**Total**	**Target Value**	**% Deviation**	**Weight**
Ramstein-- Time Precedence (2)	*Time (hrs)*	18,250.2	17,233.0	5.903%	2
	Cost	$7,541,410	$6,742,144	11.855%	1
Spangdahlem-- Time Precedence (5)	*Time (hrs)*	19,102	18,250	4.670%	2
	Cost	$7,781,234	$7,108,323	9.467%	1
Sigonella-- Time Precedence (8)	*Time (hrs)*	18,963	17,819	6.423%	2
	Cost	$8,385,472	$7,416,795	13.061%	1
Aviano-- Time Precedence (11)	*Time (hrs)*	**13,408**	12,371	8.377%%	2
	Cost	**$6,831,674**	$5,839,685	16.987%	1

Here again, the Aviano hub seems to be the least expensive and least time consuming.

Finally, cost precedence model runs are examined. Similar to the previous comparison, there are times when planners must be primarily concerned with cost. Table 17 provides a comparison of the models run with cost as the higher weighting factor.

Table 17. Cost Precedence Comparison

Hub		Total	Target Value	% Deviation	Weight
Ramstein-- Cost Precedence (3)	*Time (hrs)*	19,671	17,233	14.146%	1
	Cost	$7,218,490	$6,742,144	7.965%	2
Spangdahlem-- Cost Precedence (6)	*Time (hrs)*	20,529	18,250	12.487%	1
	Cost	$7,555,580	$7,108,323	6.292%	2
Sigonella-- Cost Precedence (9)	*Time (hrs)*	20,926	17,819	17.440%	1
	Cost	$8,061,666	$7,416,795	8.695%	2
Aviano-- Cost Precedence (12)	*Time (hrs)*	**15,132**	12,371	23.315%	1
	Cost	**$6,496,464**	$5,839,685	11.247%	2

Once again, the Aviano hub location provides the least cost and the least time consuming solution.

Least Time Consuming Option Cost

This section will discuss the cost associated with the lowest possible time requirements for each hub alternative. Planners and decision makers are often forced to select the hub that provides the quickest service to demand locations. Table 18 provides the results of the model run to minimize time and provides the actual cost associated with the solution.

Table 18. Cost for Minimized Time Comparison

Hub	Target Time Value	Cost
Ramstein-- Time Precedence (2)	17,233	$7,776,636
Spangdahlem-- Time Precedence (5)	19,102	$7,781,234
Sigonella-- Time Precedence (8)	17,819	$8,957,829
Aviano-- Time Precedence (11)	12,371	$7,033,639

This table illustrates that the Aviano Hub alternative provides the lowest target value for time, at the lowest cost. Note here that the cost is higher than in the previous results. This is due to the fact that the network was forced to maximize the use of air transport and was not forced to trade-off cost.

This version of the model will allow the planner, or decision maker, to forecast the 'best case' time requirement and understand the cost incurred in order to achieve the quickest delivery. Users of the model and of the information collected from this study would need this information in times where a transition from peacetime demand to wartime demand is expected, or in the construction of a new network where multiple alternatives are being analyzed.

Summary

This chapter of the study presented the results of 36 individual model runs. A problem in the model was identified (Hours Goal constraint), and a recommended solution to the problem was provided. Once the solution to the problem was implemented, the results were provided by location with an explanation of percentage deviation and weighted values. The results of the individual runs were then listed in table format in order to provide a summary of the initial results. The results were reported by weighted category, i.e. equal weight, time precedence, and cost precedence, in an effort to provide planners and decision makers a means to compare like items. This was done to allow for an 'apples-to-apples' comparison. Finally, the results of the time precedence models were provided with the actual cost incurred in accomplishing the minimum time required to meet demands. This analysis allows the user to understand what cost will be incurred if the minimal time requirement network is used. In all three categories, it appears that the Avaino hub alternative provides the optimal hub location when considering time and cost. Further discussion as to the implications of these results and the implication removing the 'Hours Goal' will be discussed in Ch 5 of this study.

V. Conclusion

Introduction

This section of the paper will provide conclusions on the results of the study. It will continue by revisiting the limitations that were known in an advance and those that were discovered in the process of conducting the study. Recommendations for action are discussed, to include changes in the current process. This section is followed by recommendations for future research. This research would be necessary in order to implement any of the recommendations provided.

Conclusions

The results of the multiple model runs show that the Aviano hub alternative provides the least expensive and least time consuming option of the four alternatives considered. This came as no surprise. The use of a hub location that coincides with one of the demand locations eliminates the need for forward movement from the hub to the demand location. The elimination of the cost and time factors should result in an overall savings to the entire network transportation cost. This was the case in this study.

As discussed in Chapter 4, the cost and time factors for the Aviano hub location provided the least expensive and least time consuming alternative for equal weight, time precedence, and cost precedence results. If conditions arise that stress the networks capability, such as a dramatic increase in demand or the implementation of a contingency scenario, the planner should be aware that the savings that were apparent in a peace time scenario may not be realized. This issue will be discussed further in the Limitations section of this chapter.

Limitations

This study is based on the movement of channel cargo under the constant watch of the sponsor, the TDMC. The movement of this cargo has been managed under an innovative new program called the Strategic Distribution Management Initiative (SDMI). SDMI is a program managed in the USEUCOM Theater by the TDMC. The program's goals include transporting equipment from a depot to the forward demand location in a time efficient and cost effective manner. Due to the fact that the sample of data was taken from a population completely managed under the close eye of the TDMC and operated under SDMI guidance, the results of the models may not be generalized to other situations and conditions. It is hoped that with minor modifications, such as adjusting the 'Hours Goal', 'Capacity Available', and 'Avg Port Hold', the model may be used in other scenarios. These minor modifications would make this model capable of performing 'first-cut' analyses thereby saving hours of effort and frustration for planners.

The model was built to analyze only one hub location at a time with only a single supply location, and up to ten demand locations. If more than one supply location is used, or if multiple hubs are required, then the model will require extensive modification. Changes to the model would also be necessary if more than ten demand locations are required. It is possible to determine hub optimality to more than ten demand locations by simply running the model through multiple iterations with changes to the demand locations in each run.

This study is limited to the USEUCOM Theater and was structured to meet a specific request. The assumptions and methodology used may not be appropriate for all scenarios. Geopolitical concerns were not addressed, as they are beyond the level of concern for this study.

After numerous discussions with the sponsor, the decision was made to make this model as user friendly as possible, keeping in mind that USAF personnel in the field would use the results of the model as an operational tool. Because future support may not be available, it was decided to use Commercial-off-the-Shelf (COTS) software that would be readily available to users and would be supported by the commercial marketplace. Therefore, the sponsor and future users identified the level of detail and modeling complexity as an important concern. This model does not replace other studies conducted in this field that are more detailed. The model's ultimate purpose is to provide a useful tool to field personnel and may be used to build an initial network. With this background on the users and use of the system, it was decided to limit the capability of the model. Determining the use of facilities or bases that are not currently being used by USEUCOM activities is beyond the scope of this study.

Finally, this model, like any other, is only as good as the data provided. In order to analyze the network and provide an optimal hub location, correct and current data must be entered for processing. As stated previously, this model was constructed in an attempt to simplify the tedious task of developing a network by hand. The adage "Garbage In, Garbage Out" is especially true in this case.

Recommendations

Unfortunately, choosing the second option means that the system will never be able to reach the 96-hour goal. If the 96-hour goal were to be strictly enforced, or all of the requirements for items at the demand location were shipped via air mode, then a severe cost penalty will be paid. Table 19 provides the results of the equal weight model run to represent the mandatory meeting of a maximum 96-hour goal from Ramstein to Skopje. This would be the result if the 'Hours Goal' was mandatory and average port hold time was not reduced. This scenario forces the use of air transportation in order to meet goal and requires 151 air missions to be flown to this single location.

Table 19. Ramstein—Skopje with 96-hour constraint

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	7,531.1	**17,218.2**	-56.26%	**1**
Cost	$9,109,991	**$6,742,144**	35.12%	**1**

It is important to note the drastic reduction in the total time required. By forcing the demand location to be serviced strictly via the air mode, the model shows a dramatic reduction in time, however the cost increases by almost $2.5 million. The 10,000 hours reduction is due to the elimination of over 198 ground missions that were previously used. Table 20 and 21 provide the results of the Spangdahlem and Sigonella results with the same conditions.

Table 20. Spangdahlem—Skopje with 96-hour constraint

	Total	**Target Value**	**% Deviation**	**Weight**
Time (hrs)	8,390.3	**18,249.7**	-54.02%	**1**
Cost	$9,286,176	**$7,108,323**	30.64%	**1**

Here again, 151 air missions are required. The time requirement drops significantly and the cost increases by over $2 million.

Table 21. Sigonella—Mildenhall with 96-hour constraint

	Total	Target Value	% Deviation	Weight
Time (hrs)	14,896.8	**17,314.6**	-13.96%	**1**
Cost	$9,140,167	**$7,416,795**	23.24%	**1**

In this case, the model shows that the network will save over 3000 hours in time, but will incur an additional $1.7 million in cost to meet the requirements of the demand location.

If a current practice must be broken in order to provide a feasible solution, it would seem to be more cost efficient to reduce the average port hold time requirement of 24 hours to 12 hours. This would result in meeting the 96-hour goal and reap the benefits of cost savings from the use of ground transportation to the demand locations. This assumes that the changes required in the current system that would provide the necessary information to the planners would cost less than the cost incurred through the forced use of air transportation.

By reducing the port-hold time where possible to a maximum of 12 hours, the network might be able to use the less costly mode of transportation, ground, and still meet the demand requirements placed on the network. An example of this change and it's effect can be seen in the model run with Ramstein as the hub of the network. The time required to service Skopje is 104 hours. With a minimized port hold time of 12 hours, cargo can be delivered in 92 hours. This would meet the goal of 96 established for the theater.

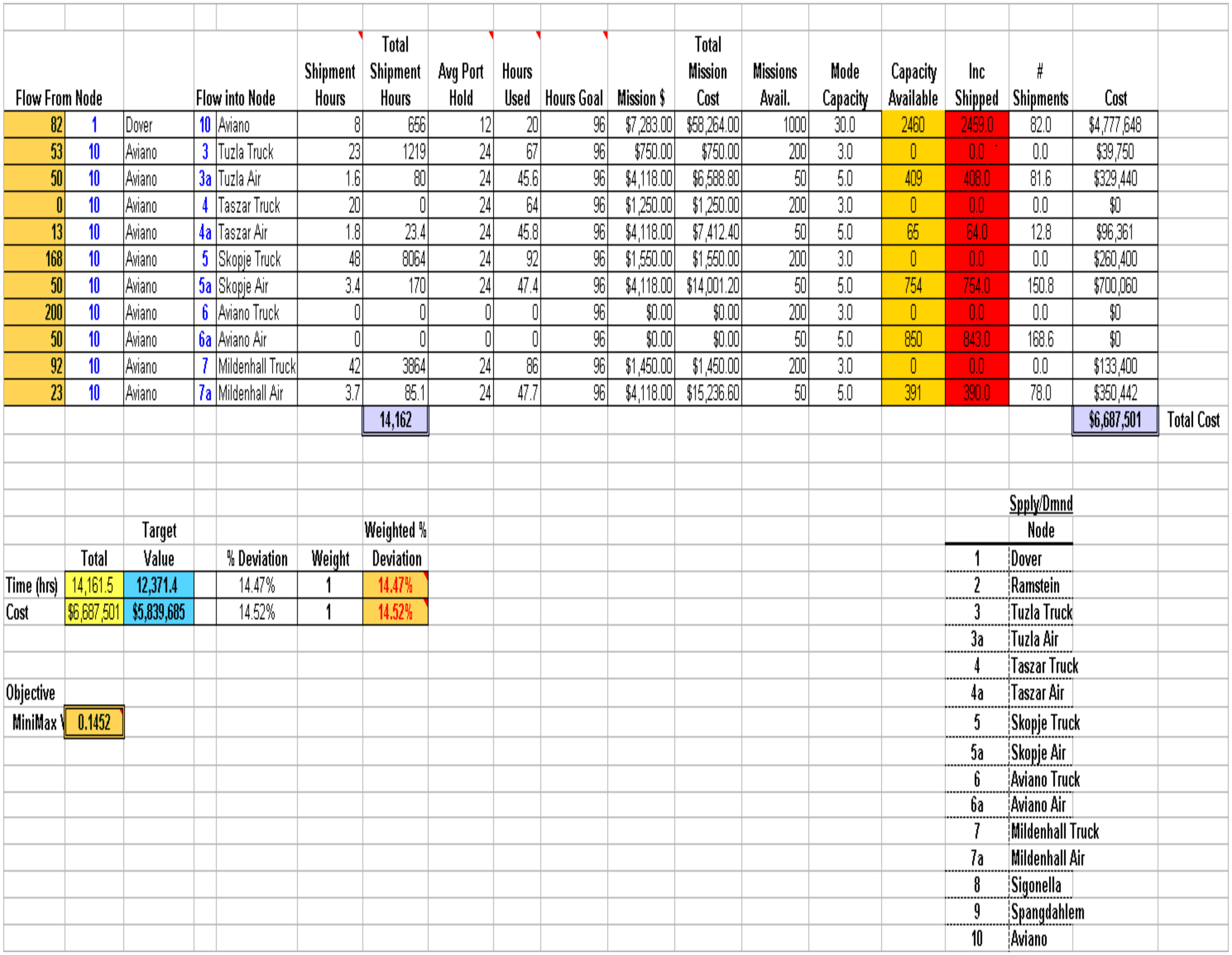
Future Research

Further research is warranted in this area. The researcher was only able to skim the very surface of the multifaceted topic. Additional research using more advanced modeling techniques may result in the optimizing both the hub location and the routing involved in the network. Additional research may also be warranted in the shipment of non-channel cargo.

It may be possible to improve the interface between model and user. This would reduce the occurrence of the mistakes in the entry of data, which would result in accurate results.

Appendix A. Model By Location

Aviano Model



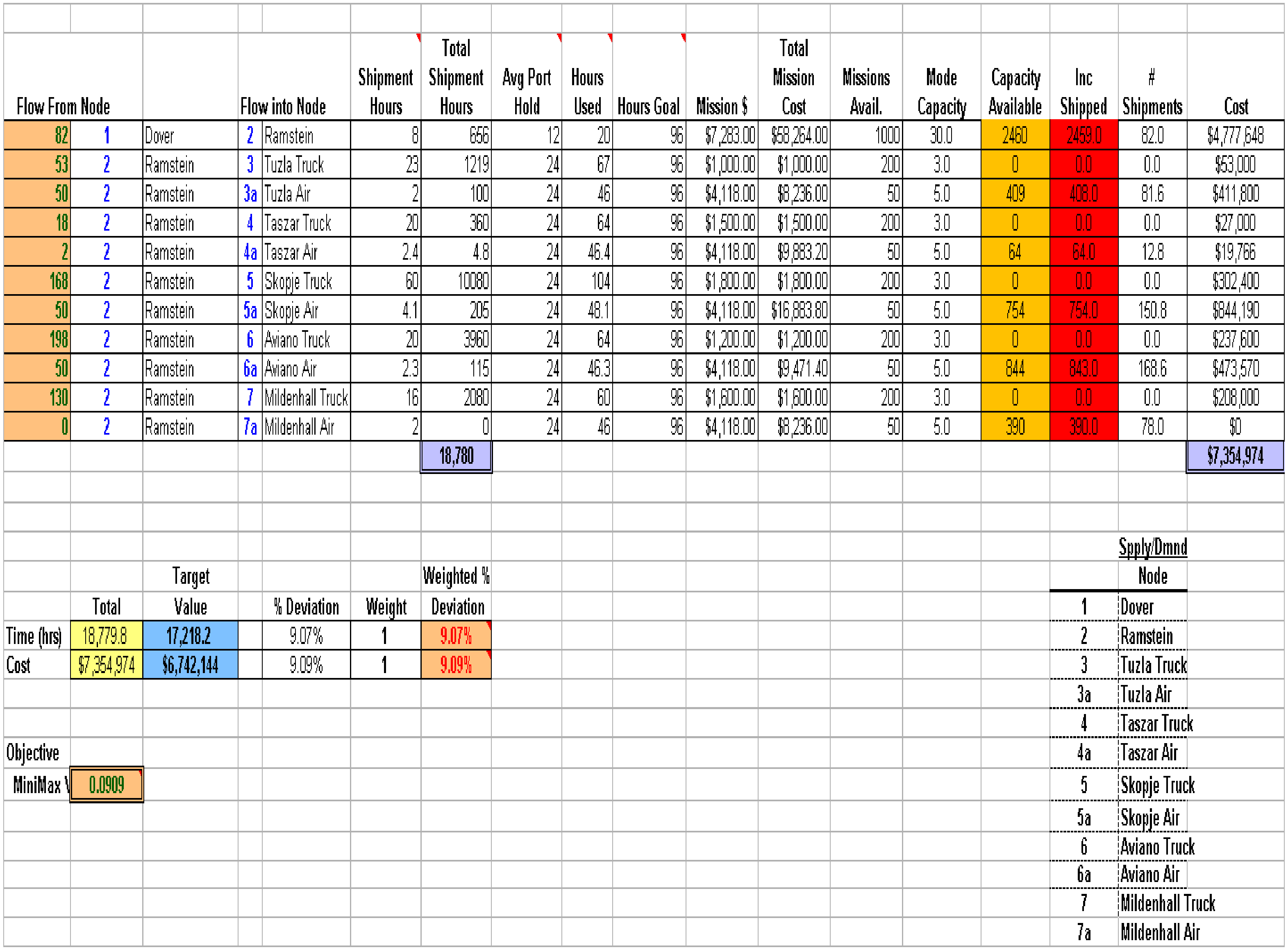
Flow From Node			Flow into Node		Shipment Hours	Total Shipment Hours	Avg Port Hold	Hours Used	Hours Goal	Mission $	Total Mission Cost	Missions Avail.	Mode Capacity	Capacity Available	Inc Shipped	# Shipments	Cost	
82	1	Dover	10	Aviano	8	656	12	20	96	$7,283.00	$58,264.00	1000	30.0	2460	2459.0	82.0	$4,777,648	
53	10	Aviano	3	Tuzla Truck	23	1219	24	67	96	$750.00	$750.00	200	3.0	0	0.0	0.0	$39,750	
50	10	Aviano	3a	Tuzla Air	1.6	80	24	45.6	96	$4,118.00	$6,588.80	50	5.0	409	408.0	81.6	$329,440	
0	10	Aviano	4	Taszar Truck	20	0	24	64	96	$1,250.00	$1,250.00	200	3.0	0	0.0	0.0	$0	
13	10	Aviano	4a	Taszar Air	1.8	23.4	24	45.8	96	$4,118.00	$7,412.40	50	5.0	65	64.0	12.8	$96,361	
168	10	Aviano	5	Skopje Truck	48	8064	24	92	96	$1,550.00	$1,550.00	200	3.0	0	0.0	0.0	$260,400	
50	10	Aviano	5a	Skopje Air	3.4	170	24	47.4	96	$4,118.00	$14,001.20	50	5.0	754	754.0	150.8	$700,060	
200	10	Aviano	6	Aviano Truck	0	0	0	0	96	$0.00	$0.00	200	3.0	0	0.0	0.0	$0	
50	10	Aviano	6a	Aviano Air	0	0	0	0	96	$0.00	$0.00	50	5.0	850	843.0	168.6	$0	
92	10	Aviano	7	Mildenhall Truck	42	3864	24	86	96	$1,450.00	$1,450.00	200	3.0	0	0.0	0.0	$133,400	
23	10	Aviano	7a	Mildenhall Air	3.7	85.1	24	47.7	96	$4,118.00	$15,236.60	50	5.0	391	390.0	78.0	$350,442	
						14,162											$6,687,501	Total Cost

	Total	Target Value	% Deviation	Weight	Weighted % Deviation
Time (hrs)	14,161.5	12,371.4	14.47%	1	14.47%
Cost	$6,687,501	$5,839,685	14.52%	1	14.52%

Objective	
MiniMax \	0.1452

Spply/Dmnd	Node
1	Dover
2	Ramstein
3	Tuzla Truck
3a	Tuzla Air
4	Taszar Truck
4a	Taszar Air
5	Skopje Truck
5a	Skopje Air
6	Aviano Truck
6a	Aviano Air
7	Mildenhall Truck
7a	Mildenhall Air
8	Sigonella
9	Spangdahlem
10	Aviano

Ramstein Model



Flow From Node			Flow into Node		Shipment Hours	Total Shipment Hours	Avg Port Hold	Hours Used	Hours Goal	Mission $	Total Mission Cost	Missions Avail.	Mode Capacity	Capacity Available	Inc Shipped	# Shipments	Cost
82	1	Dover	2	Ramstein	8	656	12	20	96	$7,283.00	$58,264.00	1000	30.0	2460	2459.0	82.0	$4,777,648
53	2	Ramstein	3	Tuzla Truck	23	1219	24	67	96	$1,000.00	$1,000.00	200	3.0	0	0.0	0.0	$53,000
50	2	Ramstein	3a	Tuzla Air	2	100	24	46	96	$4,118.00	$8,236.00	50	5.0	409	408.0	81.6	$411,800
18	2	Ramstein	4	Taszar Truck	20	360	24	64	96	$1,500.00	$1,500.00	200	3.0	0	0.0	0.0	$27,000
2	2	Ramstein	4a	Taszar Air	2.4	4.8	24	46.4	96	$4,118.00	$9,883.20	50	5.0	64	64.0	12.8	$19,766
168	2	Ramstein	5	Skopje Truck	60	10080	24	104	96	$1,800.00	$1,800.00	200	3.0	0	0.0	0.0	$302,400
50	2	Ramstein	5a	Skopje Air	4.1	205	24	48.1	96	$4,118.00	$16,883.80	50	5.0	754	754.0	150.8	$844,190
198	2	Ramstein	6	Aviano Truck	20	3960	24	64	96	$1,200.00	$1,200.00	200	3.0	0	0.0	0.0	$237,600
50	2	Ramstein	6a	Aviano Air	2.3	115	24	46.3	96	$4,118.00	$9,471.40	50	5.0	844	843.0	168.6	$473,570
130	2	Ramstein	7	Mildenhall Truck	16	2080	24	60	96	$1,600.00	$1,600.00	200	3.0	0	0.0	0.0	$208,000
0	2	Ramstein	7a	Mildenhall Air	2	0	24	46	96	$4,118.00	$8,236.00	50	5.0	390	390.0	78.0	$0
						18,780											$7,354,974

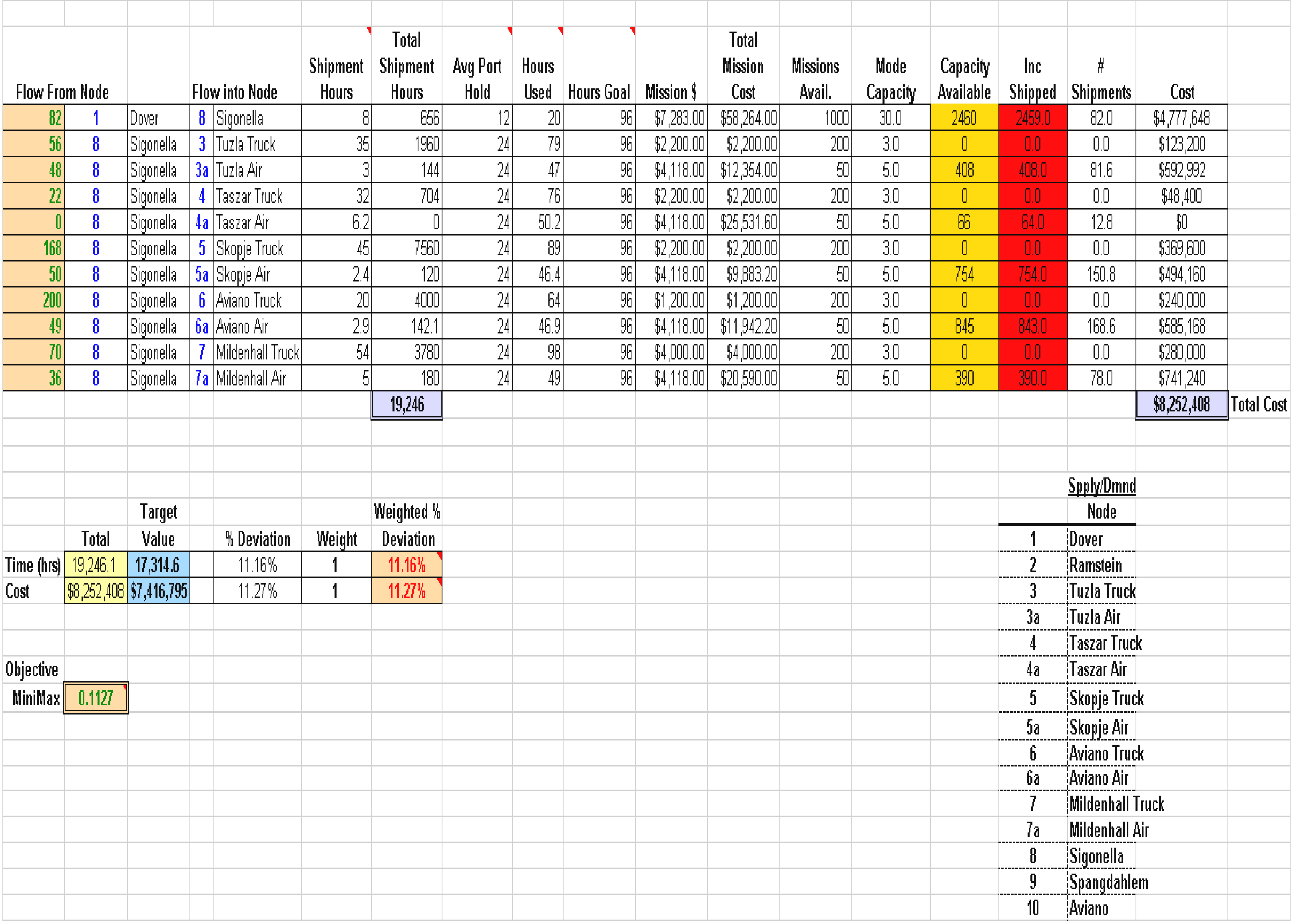
	Total	Target Value	% Deviation	Weight	Weighted % Deviation
Time (hrs)	18,779.8	17,218.2	9.07%	1	9.07%
Cost	$7,354,974	$6,742,144	9.09%	1	9.09%

Objective

MiniMax \	0.0909

Spply/Dmnd Node	
1	Dover
2	Ramstein
3	Tuzla Truck
3a	Tuzla Air
4	Taszar Truck
4a	Taszar Air
5	Skopje Truck
5a	Skopje Air
6	Aviano Truck
6a	Aviano Air
7	Mildenhall Truck
7a	Mildenhall Air

Sigonella Model



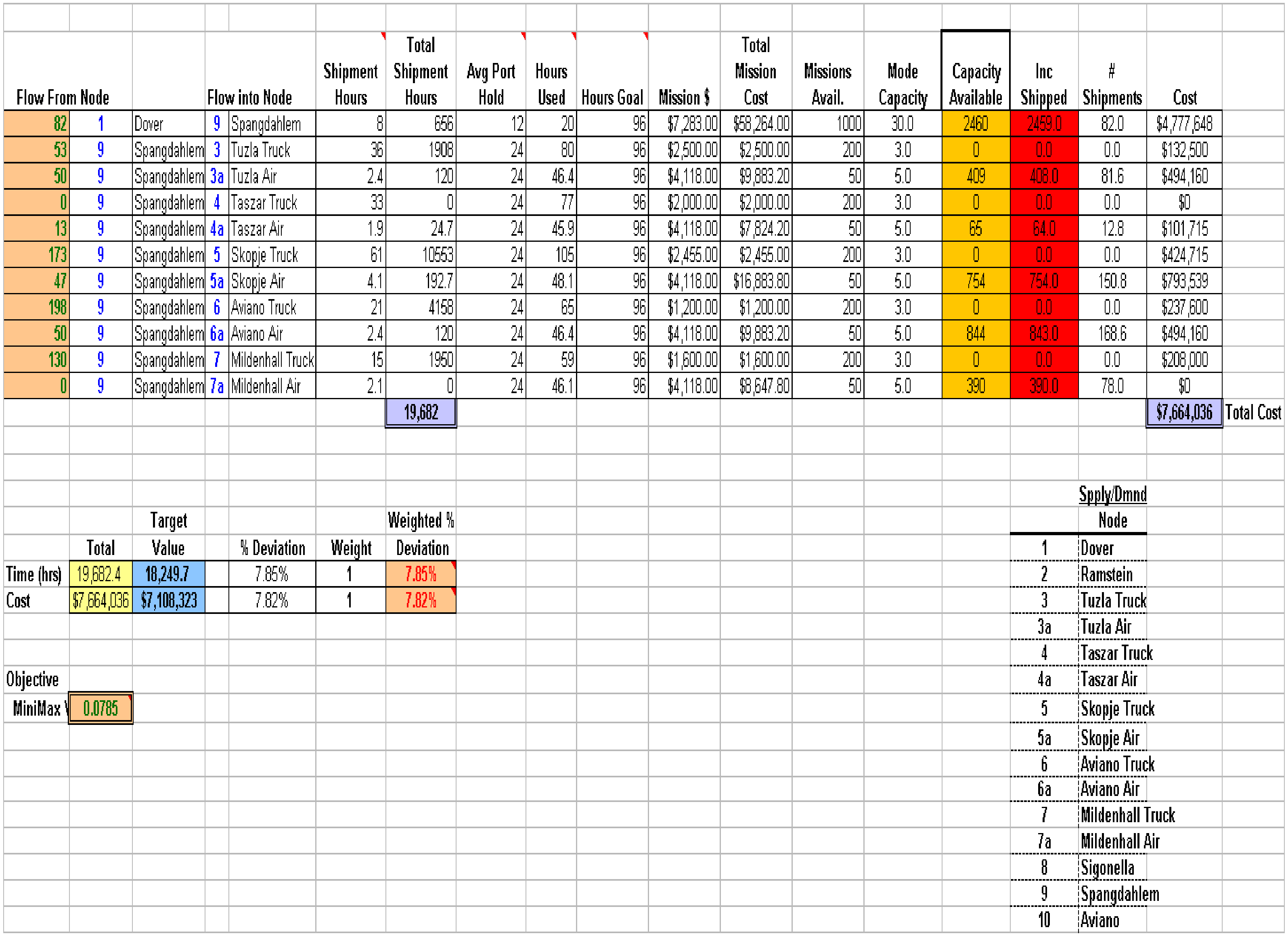
Flow From Node			Flow into Node		Shipment Hours	Total Shipment Hours	Avg Port Hold	Hours Used	Hours Goal	Mission $	Total Mission Cost	Missions Avail.	Mode Capacity	Capacity Available	Inc Shipped	# Shipments	Cost	
82	1	Dover	8	Sigonella	8	656	12	20	96	$7,283.00	$58,264.00	1000	30.0	2460	2459.0	82.0	$4,777,648	
56	8	Sigonella	3	Tuzla Truck	35	1960	24	79	96	$2,200.00	$2,200.00	200	3.0	0	0.0	0.0	$123,200	
48	8	Sigonella	3a	Tuzla Air	3	144	24	47	96	$4,118.00	$12,354.00	50	5.0	408	408.0	81.6	$592,992	
22	8	Sigonella	4	Taszar Truck	32	704	24	76	96	$2,200.00	$2,200.00	200	3.0	0	0.0	0.0	$48,400	
0	8	Sigonella	4a	Taszar Air	6.2	0	24	50.2	96	$4,118.00	$25,531.60	50	5.0	66	64.0	12.8	$0	
168	8	Sigonella	5	Skopje Truck	45	7560	24	89	96	$2,200.00	$2,200.00	200	3.0	0	0.0	0.0	$369,600	
50	8	Sigonella	5a	Skopje Air	2.4	120	24	46.4	96	$4,118.00	$9,883.20	50	5.0	754	754.0	150.8	$494,160	
200	8	Sigonella	6	Aviano Truck	20	4000	24	64	96	$1,200.00	$1,200.00	200	3.0	0	0.0	0.0	$240,000	
49	8	Sigonella	6a	Aviano Air	2.9	142.1	24	46.9	96	$4,118.00	$11,942.20	50	5.0	845	843.0	168.6	$585,168	
70	8	Sigonella	7	Mildenhall Truck	54	3780	24	98	96	$4,000.00	$4,000.00	200	3.0	0	0.0	0.0	$280,000	
36	8	Sigonella	7a	Mildenhall Air	5	180	24	49	96	$4,118.00	$20,590.00	50	5.0	390	390.0	78.0	$741,240	
						19,246											$8,252,408	Total Cost

	Total	Target Value	% Deviation	Weight	Weighted % Deviation
Time (hrs)	19,246.1	17,314.6	11.16%	1	11.16%
Cost	$8,252,408	$7,416,795	11.27%	1	11.27%

Objective	
MiniMax	0.1127

Spply/Dmnd Node	
1	Dover
2	Ramstein
3	Tuzla Truck
3a	Tuzla Air
4	Taszar Truck
4a	Taszar Air
5	Skopje Truck
5a	Skopje Air
6	Aviano Truck
6a	Aviano Air
7	Mildenhall Truck
7a	Mildenhall Air
8	Sigonella
9	Spangdahlem
10	Aviano

Spangdahlem Model



Flow From Node			Flow into Node		Shipment Hours	Total Shipment Hours	Avg Port Hold	Hours Used	Hours Goal	Mission $	Total Mission Cost	Missions Avail.	Mode Capacity	Capacity Available	Inc Shipped	# Shipments	Cost	
82	1	Dover	9	Spangdahlem	8	656	12	20	96	$7,283.00	$58,264.00	1000	30.0	2460	2459.0	82.0	$4,777,648	
53	9	Spangdahlem	3	Tuzla Truck	36	1908	24	80	96	$2,500.00	$2,500.00	200	3.0	0	0.0	0.0	$132,500	
50	9	Spangdahlem	3a	Tuzla Air	2.4	120	24	46.4	96	$4,118.00	$9,883.20	50	5.0	409	408.0	81.6	$494,160	
0	9	Spangdahlem	4	Taszar Truck	33	0	24	77	96	$2,000.00	$2,000.00	200	3.0	0	0.0	0.0	$0	
13	9	Spangdahlem	4a	Taszar Air	1.9	24.7	24	45.9	96	$4,118.00	$7,824.20	50	5.0	65	64.0	12.8	$101,715	
173	9	Spangdahlem	5	Skopje Truck	61	10553	24	105	96	$2,455.00	$2,455.00	200	3.0	0	0.0	0.0	$424,715	
47	9	Spangdahlem	5a	Skopje Air	4.1	192.7	24	48.1	96	$4,118.00	$16,883.80	50	5.0	754	754.0	150.8	$793,539	
198	9	Spangdahlem	6	Aviano Truck	21	4158	24	65	96	$1,200.00	$1,200.00	200	3.0	0	0.0	0.0	$237,600	
50	9	Spangdahlem	6a	Aviano Air	2.4	120	24	46.4	96	$4,118.00	$9,883.20	50	5.0	844	843.0	168.6	$494,160	
130	9	Spangdahlem	7	Mildenhall Truck	15	1950	24	59	96	$1,600.00	$1,600.00	200	3.0	0	0.0	0.0	$208,000	
0	9	Spangdahlem	7a	Mildenhall Air	2.1	0	24	46.1	96	$4,118.00	$8,647.80	50	5.0	390	390.0	78.0	$0	
						19,682											$7,664,036	Total Cost

	Total	Target Value	% Deviation	Weight	Weighted % Deviation
Time (hrs)	19,682.4	18,249.7	7.85%	1	7.85%
Cost	$7,664,036	$7,108,323	7.82%	1	7.82%

Objective	
MiniMax \	0.0785

Spply/Dmnd Node	
1	Dover
2	Ramstein
3	Tuzla Truck
3a	Tuzla Air
4	Taszar Truck
4a	Taszar Air
5	Skopje Truck
5a	Skopje Air
6	Aviano Truck
6a	Aviano Air
7	Mildenhall Truck
7a	Mildenhall Air
8	Sigonella
9	Spangdahlem
10	Aviano

Model Description

In order to assess this data, a Multiple Objective Linear Programming (MOLP) technique involving network flow will be used. This model is designed relatively easily using Microsoft Excel's solver. In the network, nodes will represent transshipment points, APODs, and the end destination. The nodes will be assigned certain capabilities, capacities, and limitations, each corresponding to the data collected from the archival records.

In the Excel model, each node will be assigned a cell. The constraints for each node will also be placed in a cell. These cell constraints will be summed and compared to the limit of that asset. Arcs will represent the connection between these nodes. Each arc represents a mode of transportation whether by air or ground. The arcs will have a corresponding capacity and cost, also provided by the archival records. The arcs also represent the direction of flow. For example, we may only ship to a location. In order to flow the model most efficiently, any equipment returning to the node of origin may be required to travel through a star network. This depends on priority, size, and weight of the cargo that will be moved between the different nodes.

The goal of this network flow model is to determine which system of nodes and arcs provide the most efficient system for delivery of equipment and personnel to the final destination at the lowest acceptable cost. The number of items that could be moved across each of the arcs represents the capacity. Each node is assigned constraints, such as the capacity of the aircraft or ground transportation, that may used to transport equipment or personnel from the hub to the demand location. In hub consideration, each location must meet criteria as to the number of aircraft it can safely handle at one time. This constraint is known as Maximum on Ground (MOG) and refers to the maximum number of aircraft that can be held at a given location at a point in time. Locations considered to be possible alternative hubs must meet a minimum MOG of three aircraft. Together with other relevant factors, these constraints affect the timely delivery of cargo. A comparison of total time requirements for the current hub and alternate hub locations was used to determine which hub provided the most efficient service. This comparison measured the time required to meet FOL demand requirements in the least amount of time.

In order to measure cost for the current system the design will use cost data provided by the sponsor. These cost are measured in US dollars. The alternate model will use real cost whenever possible and will use estimates of similar locations if actual data is not available. Each arc that represents a transportation flow will be assigned a cost according to actual or estimated cost. The totals for each system will be compared against each other and the lesser of the two will obviously be considered less expensive. This model does not include the operating cost of a location, just the cost of transportation involved between the origin and the destination. It was determined that the costs incurred in the operation of aerial port activities of a hub location are relative at locations that are already in use. This means that the actual cost of performing the aerial port mission is relatively constant across locations.

The trade-off between the two measured constructs, time and cost, requires expert evaluation. For example, the new system may deliver equipment and personnel to their final destination an average of five days faster than the current real world system, but at a cost of an additional $2.5 million dollars. The sponsor of course would be the ultimate decision maker in determining if this improved efficiency is worth the additional expense.

This Missions Available constraint, when used in Excel Solver, will limit the number of missions to each location by the number of available mission to a location. The number of missions to a demand location will be seen as a changing, or variable cell. In other words, the missions to a location must be less than or equal to the available missions to that location. Each modal arc will require its own constraint.

In the model, this information is represented in column form. Each arc has been listed with its ‘Missions Available’. The next column represents the number of increments that may be transported on each mission. For air arcs, the average number of increments transported is five (via C-130). For ground arcs, the average number of increments transported is three (via truck). These averages were provided by the TDMC. This information is provided in column format as well. The product of these two columns represents the ‘Capacity Available’ column in the model. This column shows the total number of increments that can be moved using both air and ground transportation modes. The final column, ‘Inc Shipped’, in this section represents the total number of increments that must be transported in order to meet the requirements at the demand locations.

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Vita

Captain Joseph B. Skipper was born in Apalachicola, Florida. After graduating from Apalachicola High School in 1988 he went on to earn his Associates Degree in Business Management from Andrew College in Cuthbert, Georgia. This was followed by the successful completion of his undergraduate work in Marketing at Troy State University, Troy, Alabama, in 1992. After two years in the commercial business world, he joined the USAF on 26 September 1994 and was commissioned from Officer Training School, Class 95-02, in January of 1995.

In his first assignment at Pope Air Force Base, North Carolina, then Second Lieutenant Skipper was assigned to the 23 Logistics Support Squadron, Logistics Plans Branch and acted as the Assistant Installation Deployment Officer and War Reserve Materiel Officer for the "Flying Tigers". In May of 1997 First Lieutenant Skipper was assigned to Headquarters Eighth Air Force, Barksdale, Louisiana. While at the "Mighty Eighth", Captain Skipper helped shape the force structure required for the management of component theater management as Chief, Logistics Plans and Programs.

In August 2000, he entered the Graduate Logistics Management program at the Air Force Institute of Technology. Upon graduation, he will be assigned to the Air Force Logistics Management Agency (AFLMA), Gunter Annex, Maxwell AFB, Alabama.

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14. ABSTRACT

The current hub-and-spoke network in the European Theater is made up of locations built and organized around a Cold War threat. The threat of large-scale attrition warfare seems to have passed, and the threat of multiple, smaller scale contingencies has placed greater demands on the US military's ability to transport equipment and personnel to multiple locations simultaneously.

This research effort utilizes a Multiple Objective Linear Programming (MOLP) model to analyze optimal hub locations in USEUCOM. The model used to analyze the network was developed in Microsoft Excel and followed MOLP techniques to determine the trade-offs between the two constructs of importance time and cost.

The results of the multiple model runs show that the Aviano hub alternative provides the least expensive and least time consuming option of the four alternatives considered. This came as no surprise. The use of a hub location that coincides with one of the demand locations eliminates the need for forward movement from the hub to the demand location. The reduction of cost and time in the optimal network should result in an overall savings to the entire network cost.

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