Urgent Aeromedical Evacuation Network Capacity Planning

Scott C. Finkbeiner

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URGENT AEROMEDICAL EVACUATION NETWORK CAPACITY PLANNING

THESIS

Scott C. Finkbeiner, 2nd Lieutenant, USAF

AFIT-ENS-13-M-04

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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URGENT AEROMEDICAL EVACUATION NETWORK CAPACITY PLANNING

THESIS

Presented to the Faculty
Department of Operational Sciences
Graduate School of Engineering and Management
Air Force Institute of Technology
Air University
Air Education and Training Command
In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Operations Research

Scott C. Finkbeiner, BS
2nd Lieutenant, USAF

March 2013

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URGENT AEROMEDICAL EVACUATION NETWORK CAPACITY PLANNING

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Abstract

Aeromedical Evacuation (AE) has been steadily utilized during Operation Iraqi Freedom and Operation Enduring Freedom. AE is a global enterprise. The current structure of AE is facing changes as forces scale down from operations in Iraq and Afghanistan. AE will, however, continue to be important in its domestic use in the continental USA (CONUS). Current practice is to pull aircraft (e.g. C-17, C-130 or KC-135) from their normal operations to meet Urgent and Priority patient needs when local alternatives are infeasible. An alternative to the current system would be having a centralized "bed-down" location for AE operations that would house dedicated aircraft as well as AE personnel. In this thesis, a hybrid queuing and discrete-event simulation approach is used to determine how many aircraft are needed for a given level of AE patient care and an integer programming model is used to locate aircraft within the provider network. The high costs associated with operating current aircraft drive this research to look for solutions that better represent the future of Urgent and Priority patient movement operations whether CONUS or global.
Acknowledgments

I am grateful to my sponsors, Col Faubion and Mr. Hannan for taking the time to teach me about AE. Also, the coordination of visits around Scott AFB, frequent clarifying questions and ensuring I had the necessary resources propelled this work through to completion.

It has been an honor for me to have worked with Dr. Cochran. My initial expectations have been exceeded by his fervent ability to guide an advisee. He fueled the total experience and without doubt advanced my academic level in Operations Research.

Finally, this thesis would not be possible without the support of my wife (and luck charm) as well as my daughter whose positive energy is contagious even on the dreariest Ohio day.
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I. Introduction

The proposed topic aims at giving Air Mobility Command (AMC) insight into the future of Urgent and Priority AE operations within the continental US. The current flexible system operates well but isn’t tailored for small scale AE needs. The financial future of the Air Force also dictates the testing of other alternatives. There exists a need to evaluate alternatives that would save the AF while at the same time provide the equivalent level of care. An alternative to pulling aircraft (C-17, C-130 and KC-135) to meet AE needs would be having a centralized hub with designated aircraft. Specifically testing out what the potential benefits of having an AF owned asset or a contracted one would be. To do so, several angles to the alternatives will be tested out.

Some of the data required would be flying hour cost, speed of aircraft and also the frequencies of Urgent and Priority demands. Urgent patients are emergency cases that must be moved to save life or limb, or prevent complications of serious illness (Army Medical). Priority patients require prompt medical attention that cannot be acquired locally and must be delivered with least possible delay within 24 hours. The work will focus on the Continental US Urgent and Priority AE mission. Several alternatives will be developed to make comparisons to the current AC being utilized. To model alternatives, several Operations Research disciplines will be used.
II. Literature Review

History of AE

AE has been an evolving process since the inception of the idea to use airplane for transporting patients. In 1910, Capt Gosman and 1st Lt Rhoades had the idea however not the support of the Army; that would come in 1918 when the director of the Army Air Service ordered every Army airfield to have their own air ambulance (Elliot, 2010). Soon, in 1922, the French Army air evaced “over 2200 during the Riffian war in Morrocco” (Austin, 2002). The idea of medical practioners onboard started with the formation of the Australian Aerial Medical Services (AAMS) in 1934 (Royal Flying Doctor Service, 2013). During the course of WWII 1.34 million air evacuations were carried out by all sides (Nanney, 1998). During the Korean War, Combat Cargo transported 311,673 wounded personnel within theater and Military Air Transport Service (MATS) sent back 43,196 to the US (National Museum of the USAF). In fiscal year (FY) 1966, MATS was recorded as performing 97,422 AE mission in the US (including trips from overseas hospitals to US aerial ports) in a Airlight Service Management Report (Reiter, 1993).

Figure 1: C-9A Nightingale
In 1968 the first “AE specialized” C-9A was delivered to Military Airlift Command (MAC) which would be the AE workhorse for more than 30 years (Air Mobility Command Museum). During the Vietnam War, MAC evacuated 7,436 patients out of Vietnam in March 1969 alone (Clingman, 1989). The entire duration of the Gulf War had 12,500 successful transports utilizing converted cargo AC (Howell & Brannon, 2000). AE missions within the continental US were at 70,000 as of 1995 (Diamond, 2003) however the complete implementation of TRICARE (military healthcare program) in May 1997 would drop the number (Health, Education, and Human Services Division, 1995).

![The drop in peacetime aeromedical evacuations](image)

**Figure 2: Diamond’s AE Chart**

Numbers of AE missions dropped down to 20,000 in 1999 and 15,000 in 2000 due to the TRICARE’s network of local providers capturing cases that in the past would require AF AE (Diamond, 2003). The need for a dedicated AC to blanket the total AE mission ceased. With TRICARE fully online and the C-9A aging, Air Mobility
Command (AMC) shifted from a “capacity-based system” to a “requirements-based system” and retired the C-9A on July 23rd 2003.

The new “requirements-based system” would essentially pull either a C-17, C-130 or KC-135 (pictured in that order) and equip it with the appropriate equipment and personnel. This system has been a great asset for recent conflicts; in 2010 AE was delivering patients from Afghanistan and Iraq in 3 days which is 7 days faster than Operation Desert Storm and 40 days faster than the Vietnam War (AFA News, 2010). The current set-up is ideal for times of conflict, especially since the AC used are adaptable to the unique operational demands of forward AE missions (both C-130 and C-17 can utilized un-improved runways).
The C-17 (pictured left), the typical AE airframe for inter-theater transportation can hold up to 36 litter and 54 ambulatory patients (Guerdan, 2011). The C-130 (pictured center), best equipped for intra-theater demands can accommodate up to 74 litters and finally the KC-135 (pictured right), known for its longer range can handle up to 15 litters and 8 ambulatory patients. It must be pointed out that these capacities are just one of many configurations. These aircraft are suited well for missions that can deliver either cargo, fuel or a large volume of patients.

**Defining AE**

AE can be broken into three categories as from an article of the American Journal of Medicine (Bruce R. Guerdan, 2011).

<table>
<thead>
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<tr>
<td><strong>Typical Branch</strong></td>
</tr>
<tr>
<td>Army, Marines</td>
</tr>
<tr>
<td><strong>Type of Transport</strong></td>
</tr>
<tr>
<td><strong>Typical Movement</strong></td>
</tr>
<tr>
<td><strong>Level of Care</strong></td>
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Casualty Evacuation (Case-Evac) supports patients from the initial point of injury (POI) which is currently accomplished using AC like the MV-22 Osprey. A Naval Post-Graduate School (NPS) thesis looked at unmanned aerial systems (UAS) using simulation to determining optimal factors like number of litters per system (Featherstone, 2009). Another recent study from the Journal of Defense Modeling and Simulation (JDMS) utilized simulation to test the MV-22 against the same nascent technology of
autonomous aircraft or UAS (Anderson, Konaske, & Davis, 2010). An article, again from JDMS, looked at how different methods like Case-Evac from the POI affected soldier mortality rates (Mitchell, Parker, Galarneau, & Konaske, 2010).

Medical Evacuation (Medevac), primarily a mission of Army helicopters, is best defined as patient/casualty evacuation when time is sensitive (O'Shea, 2011). The following figure from the Army Field Manual (FM) summarizes their area of interest (Army, 2009).

![Figure 5: Army Field Manual Diagram](image)

Helicopter Medevac came to maturity during the Vietnam War being known as DUSTOFF (from literally dusting of those to be evacuated by a rotary wing AC). A 1990 US Army War College project advocated for medical assets to be dedicated to Medevac missions due to their inherent time sensitive nature (Miles, 1990). A study of past Medevac missions stressed for the future helicopter units to know the lessons learned from evacuation efforts during the Korean and Vietnam War (Howard, 2003).
Operations during current times feature single units performing over 1500 Medevac missions in a year like in Operation Iraqi Freedom (OIF) II (Kneeland, Risio, Fulton, & Goodman, 2005). An article from JDMS featured work done using stochastic optimization goal-planning to determine the minimum number of helicopters in-theater to meet demand while minimizing their vulnerability to attack (Bastian, A Robust, Multi-criteria Modeling Approach for Optimizing Aeromedical Evacuation Asset Emplacement, 2010). Another JDMS article presented the results of a DOTMLPF (Doctrine, Organization, Training, Maintenance, Leadership, Personnel, and Facilities) assessment which found the problem areas of Medevac to be maintenance and manpower (Bastian, Fulton, Mitchell, Pollard, & Wilson, 2012).

Aeromedical Evacuation (Air-Evac or AE) has had many aspects researched over the years. AF operations on average encompass the bottom two items of Figure 4, Theater Hospitalization Capability and Definitive Care Capability. Several studies focus on patient safety like finding that obstetrics patients can be evacuated (air) at any gestational period despite USAF policy that doesn’t recommend it after 34 weeks (Connor & Lyons, 1995). Others focus on inflight oxygen saturation decrements (Bendrick, Nicolas, Krause, & Castillo, 1995) or the feasibility of ear acupuncture inflight for pain management of which posted positive results (Walter, York, Thati, Niemtzow, & Burns, 2012). A recent study focused on determining when a patient with a traumatic brain injury is safe to fly (Goodman, et al., 2010). Simulated AE using mice found that hemorrhagic shock did not worsen systemic inflammation or organ injury compared to controls (Makley, et al., 2012). Another work on Operation Desert Storm found designated AE crews important to mission success (Mabry, Munson, &
Richardson, 1993). Biosafety containment during AE with the Aeromedical Isolation Team is described in detail in a 1999 report (Christopher & Eitzen Jr., 1999) and in a 2000 report, AE is deemed safe and effective for contagious biological warfare patients (Withers & Christopher, 2000). In 2005, demographics of patients from OIF found that 94% of evacuees were of routine nature (Harman, Hooper, & Gackstetter, 2005). Patient information was a focus of a 2009 study emphasizing a need for standardized scoring to determine when to evacuate international travelers (Duchateau, Verner, Cha, & Corder, 2009).

A 1976 article titled “Five-Year Study of Emergency Aeromedical Evacuation in the United States” showed how extensive the Urgent or Priority AE mission was before TRICARE (Johnson Jr., Cooper, & Ellegood, 1976). During this time the AE mission was responsible for upholding the DOD policy that the movement of armed forces patients would be accomplished by military AC. This equated to 7056 patient movements (PMs) between 1 July 1969 and 30 June 1974. The chart below summarizes some of the results found in the article (over five year period).

<table>
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<tr>
<td>July</td>
<td>26</td>
<td>69</td>
</tr>
<tr>
<td>August</td>
<td>25</td>
<td>66</td>
</tr>
<tr>
<td>September</td>
<td>23</td>
<td>54</td>
</tr>
<tr>
<td>October</td>
<td>21</td>
<td>58</td>
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<tr>
<td>November</td>
<td>21</td>
<td>52</td>
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<td>December</td>
<td>19</td>
<td>53</td>
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<td>January</td>
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<td>February</td>
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<td>March</td>
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<td>April</td>
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<td>50</td>
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<tr>
<td>May</td>
<td>25</td>
<td>69</td>
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<tr>
<td>June</td>
<td>19</td>
<td>58</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>254</strong></td>
<td><strong>715</strong></td>
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The article also noted 1032 diversions of C-9A’s from their pre-planned “routine patient” missions to pick up Urgent patients (over the five years). Other aspects of the article focused on where the patients were coming from in which the numbers suggested that the C-9A, which was housed at Scott AFB should rather be located in the South West or South East area (where 52 % of the Urgent patients were airlifted from). An edited map from the article is presented below to define these areas.

![Figure 6: Map of Regions from 1976 Article](image)

Their suggested area for a dedicated asset contains the weighted mean center (WMC) based off of the current AF population presented later. They found that the distances between medical facilities in the Far West and North East were within acceptable automobile driving ranges to meet acute medical requirements; this was well before the Defense Base Closure and Realignment Commission which downgraded many military hospitals to clinics in 2005 (BRAC Commission, 2005). Another aspect of interest in the article was which type of patient was being moved. Pediatrics and Burns each
represented 20 % of Urgent patient movements over the 5 year period followed by Neuro Surgery at 15 % and Thoracic Surgery at 12 %.

One final excerpt from the article was the following, quoted below.

“Less than 6 h after the request for urgent help was received in the Patient Airlift Center at Scott AFB, IL, the patient was delivered to his destination hospital for definitive care.”

Less than 6 hours, even in 2013 would be invaluable in ensuring patients reached advanced military medical care. Patients seen in-house (military) benefit from providers who are familiar with military medical concerns and have easy access to Electronic Medical Records (EHRs) through the AHLTA or Armed Forces Health Longitudinal Technology Application (AHLTA, 2013).

Reviewing Air Mobility Operations Joint Publication 3-17 highlighted the current philosophy and desire for a flexible system (USAF, 2 Oct 2009). The following excerpt is from an AE success story within the publication.

“The ability to use virtually any aircraft on-site or in-system (vice the old system of dedicated AE aircraft) provided a quick response to casualty movement requirements.”

The idea of dedicated AE aircraft lends itself to the notion of decreased flexibility. This is problematic for theater operations where the unyielding performance measure (and rightly so) is patient lives. However in a more stable stateside setting, using a dedicated aircraft could potentially reduce costs without jeopardizing patient survivability. Options to reduce cost are challenged by the desire to have AF assets accomplish AE missions. Several benefits exist with such a notion, one being that by
keeping missions in house allows AE medical personnel to keep up their clinical skills. This however may not be the best financial based option with high flying hour costs associated with aircraft like the C-17. To decide what means to transport a patient the following Patient Movement Planning and Execution Algorithm from AFTTP 3-42.5 is used.

Figure 7: AFTTP 3-42.5 Flowchart

The process starts when a Patient Movement Request (PMR) is submitted to the Patient Movements Requirement Center (PMRC) by the requesting Medical Treatment Facility (MTF); PM is defined as “process of moving sick, injured, wounded, or other person to obtain medical, dental, or other treatment” (Department of Defense Instruction,
Planning begins when the PMRC processes the PMR and decides if the PMR is validated. Validation refers to determining if care is needed during the move and can the Tanker/Airlift Control Center (TACC) support the PMR. If the PMR is not validated then it is sent back to the MTF for modification for resubmittal. If care is not needed in-flight then the local MTF is notified to execute the PMR with local resources; the PRMC maintains In-Transit Visibility (ITV) until the request is completed. If the TACC cannot support the PMR then all options are evaluated by the Validating Flight Surgeon (VFS) and the Senior Mission Clinical Coordinator (MCC). From this node (5) a PMR can either be performed using local resources or other service AE options (Army or Navy) with or without an AE crew. If planned without an AE crew, ITV is maintained until the PM completes. If other services are selected with an AE crew then the TACC plans and executes the AE; this is the same if the TACC originally supports the PMR. If clinical issues arise during the move the Patient Movement Clinical Coordinator (PMCC) and VFS have a conference call to resolve the issue. If not ITV is maintained through to completion.

Figure 8: AFTTP 3-42.5 Visual Diagram
The above figure also located in AFTTP 3-42.5 provides an overview of the process. The figure highlights how AE is not a rigid system but instead one that is flexible to patient demands and the availability of different types of transport. One aspect that lacks any presence in these two figures is cost.

An article in the Air Force Times highlighted one situation where potential savings exist (Ricks, 2011). The story was of a C-17 loaded with 3 critically injured patients making the “eight-hour flight across the Atlantic”. If an AC with flying hour costs closer to the C-37B (aka G550) was used (assuming equivalent levels of care), the savings would have been $74,768; using flying hour costs from AMC spreadsheet (AMC, 2012).

\textbf{Equation 1: Cost Difference}

\[ 8 \times (C17 \text{ Flying Hour Cost} - C37B \text{ Flying Hour Cost}) = 74,768 \]

The C-17 carries an $11,415 flying hour cost as compared to the C-37B’s cost of $2,069. This simple look at flying hour costs highlights the potential benefit of having an asset tailored to the Urgent and Priority mission. Despite the savings, a large fleet of C-37B’s could not avert situations where non-specialized AC would be used to accomplish movements due to the random nature of Urgent and Priority patient requests (unless every airman had their own AC!).

A figure (below) from the 9 September 1998 DODI 6000.11 summarizes the cost decision process of AE (Department of Defense Instruction, 1998).
Before TRICARE the two steps to send patients to local providers would not be an option. One aspect of the final decision process to be noted is that the flying hour costs will be 0 $ if scheduled using available readiness baseline flying hours since they are already funded. This idea would be interesting if applicable to a dedicated or designated AC that would service as the Urgent/Priority AC of the continental US. This could be optimized to ensure maximum use of training flying hours for AE.

Further investigation involving HQ AMC produced the “Aeromedical Evacuation / En Route Care Capabilities-Based Assessment Report” (USAF, 31 July 2012). Upon review of the report it was clear that current economic climate was calling for efficient
improvements to AE. Systemic Gap number 22 “AF needs to determine how to utilize/optimize all airlift assets in support of PM requirements” identified that AMC is driven to optimize AE by increasing flexibility. The assessment also called for determining the feasibility of dedicated contracting (AE) support which further backed up the notion of having a “dedicated” asset for the process (albeit support in this case refers to personnel). Having a contract like the one proposed to AFRICOM would include all costs from maintenance, crew and fuel wrapped up in the total cost. The one downside to such a contract would be that it takes away the training platform for AE crews to maintain their clinical currency.

**Past AFIT Research**

An AFIT thesis from 1995 was aimed at giving the Global Patient Movement Requirements Center (GPMRC) a tool to efficiently forecast AE assets in the “lift-bed” process; “lift-bed” refers to ensuring that an airlifted patient will have a hospital bed available to them at the end of their mission (Kimminau, 1995). The tool was a mixed integer linear program (MILP) model built in FORTRAN giving solutions for the number of dedicated C-141s needed to complete the AE mission (Fortran). Getting patients to where they belong had been an issue during the Persian Gulf War which led to the creation of the decision support system, TRAC2ES (TRANSCOM regulating and command and control evacuation system) (Kott, Saks, & Mercer, 1999). Currently still in use, TRAC2ES tracks patients from initial care until they reach their destination hospital reacting along the way to airport closures and changes to hospital bed availability.
The thesis titled “An Analytical Tool to Assess Aeromedical Evacuation Systems for the Department of Defense” was aimed at giving insight into whether the AF should keep the McDonnell-Douglas C-9A Nightingale or find a replacement (Wilhelm, March 1998). The value function used in the work was as follows.

\[ Go * \sum w_i V(x_i) \]  

Here \( w_i \) is the weight assigned to the evaluation measure \( i \), \( V(x_i) \) is the value assessed from the evaluation measure and “Go” is either 0 or 1 if the alternative passes all NO-GO/GO criteria. Some of the evaluation measures range from Speed, Capacity to Temperature Control (all 31 are summarized in a table below).

### Table 3: Evaluation Measures

<table>
<thead>
<tr>
<th><strong>Aircraft Performance</strong></th>
<th><strong>Mission Performance</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>Capacity, Litter</td>
</tr>
<tr>
<td>Speed</td>
<td>Capacity, Ambulatory</td>
</tr>
<tr>
<td>Range</td>
<td>Capacity, Medical Crew Seats</td>
</tr>
<tr>
<td>2\textsuperscript{nd} Role</td>
<td>Integral Litter Ramp</td>
</tr>
<tr>
<td>Aerial Refuel Capability</td>
<td>Ability to Reconfigure</td>
</tr>
<tr>
<td>Survivability</td>
<td>Temperature Control</td>
</tr>
<tr>
<td>Logistics Tail</td>
<td>Isolation Area</td>
</tr>
<tr>
<td>Comm/Nav Capability</td>
<td>Central Monitoring</td>
</tr>
<tr>
<td>Runway Required, Hard Surface</td>
<td>Galley</td>
</tr>
<tr>
<td>Runway Required, Unprepared Strip</td>
<td>Comfort Pallet</td>
</tr>
<tr>
<td>Self-Start</td>
<td>Noise and Vibration</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td>Ground Refuel Without Stands</td>
<td>Medical Work Space and Equipment Storage</td>
</tr>
<tr>
<td>Unassisted Maneuverability</td>
<td>Electricity, Configuration</td>
</tr>
<tr>
<td></td>
<td>Vacuum System, Configuration and Built-In O₂, O₂, Oxygen Outlets</td>
</tr>
<tr>
<td></td>
<td>Electricity, Back and Vacuum System, Back-Up</td>
</tr>
<tr>
<td></td>
<td>Built-In O₂, Liquid Quantity</td>
</tr>
<tr>
<td></td>
<td>Lighting, Illumination</td>
</tr>
<tr>
<td></td>
<td>Lighting, Blackout</td>
</tr>
</tbody>
</table>

The scores generated placed the C-9A (both modified and baseline) at the bottom of a list of aircraft including the C-17. This was not surprising since at the time the C-9A was a dated aircraft in need of modification to meet FAA requirements. The C-17 faltered when operating costs were factored into the analysis. Below is an excerpt from the study.

“Of the larger aircraft, the C-17 in particular provided overall high value that was significantly curtailed by its surprisingly low litter capacity. When LCC (Life Cycle Costs) were considered, however, the extreme expense of the system forced it to the bottom of the alternatives list.”

The flexibility of the C-17 makes it an ideal “theater” asset however within the continental US it is over-qualified for Urgent and Priority AE missions. Such missions occur randomly within the continental US and being that the C-17 is one of the
workhorses of the fleet its availability is better than cheaper options like the C-130 and KC-135.

A thesis by W. Tod Whetstone, USAF “A Heuristic Approach for Aeromedical Evacuation System Scheduling and Routing” developed the idea of optimizing the use of dedicated aircraft (Whetstone, December 1988). The work first looked at a weekly scheduling problem utilizing a patient demand matrix that split the continental U.S. into 6 regions.

\[ P_{ijk} = \text{Patient demand from region } i \text{ to region } j \text{ on day } k \]

The matrix was “based primarily on the historical frequency of patient demands” and led to the use of a heuristic algorithm to solve the problem. Several contraints like capacity and number of vehicles available were used to find an optimal schedule.

The second discipline of the thesis by Whetstone took aim at the daily routing problem of the aircraft. The main objective was to minimize the total distance traveled subjected to constraints.

**Equation 3: Whetstone’s Objective Function**

\[
z = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} d_{ijk} x_{ijk} \quad \text{for } i \neq j
\]

The above is the objective function of the model where \(d_{ijk}\) is the distance from node \(i\) to node \(j\) on leg \(k\) of the route. By finding the arcs traveled in the model the \((x_{ijk} = 1)\) total distance can be minimized.

A thesis that expanded on Whetstone’s work was “A Dynamic Programming Approach to The Daily Routing of Aeromedical Evacuation System Missions” by David C. Mullen, USAF (Mullen, June 1989). The routing problem was modified to
incorporate time constraints; time window constraints, origin/destination precedence requirements and flow/time relationships. This problem was motivated by the fact that AE schedulers were manually selecting stops to meet mission requirements like the 16 hour crew-duty-day restriction. A dynamic programming algorithm was developed and its performance was compared to actual scheduled AE missions (using the same information).

Going further back to a 1993 thesis by Micheal J. Loftus, USAF aimed at giving AMC insight into how they assign patients that need aeromedical attention (Loftus, 1993). The objective of the study was to minimize the total patient wait time. This was done by assigning patients to AE AC and routing them to a single airport using a heuristic algorithm. Routing was a key factor of a fleet of C-9A’s that were dedicated to the AE mission.

Another work from AFIT on AE was an article “The Use of Simulation to Evaluate Strategic Aeromedical Evacuation Policy and Planning” by Charles W. Wolfe, Jr., USAF focused on the Civil Reserve Air Fleet (CRAF) (Charles W. Wolfe, 1993). The work utilized simulation and multivariate analysis to analyze measures like how long a patient spends in the AE system. The work found that “resource located at the departure point to CONUS missions”, “regulation policy used” and “number of AC available” significantly affected strategic AE operations.

**Research Questions**

What if the AF had a dedicated, specialized AC (either owned or contracted) that could be tasked first before looking into the current fleet of non-specialized AC? In
Australia, fixed-wing aeromedical services need to be able to cover vast distances to reach different pockets of indigenous communities (Margolis & Ypinazar, 2009). Their aircraft can carry 2 patients on stretchers which is similar to the capacity of the C-37B (aka G550). The similarities between isolated Indigenous populations in Australia is very similar to scattered military personnel within the US.

Secondly, what if the intention of a dedicated asset was not to cover the entire Urgent and Priority mission but rather a significant portion as compared to the current fleet? There would be a dual purpose to such a system. This would optimize costs associated with the AC involved and also ensure that AC best suited for times of conflict (C-17, C-130 and KC-135) would get training experience. These questions are some that inspired this work.
III. Methodology

The Methodology to this work is framed below.

![Diagram of Methodology]

**Figure 10: Methodology Chart**

Four alternatives are the basis of the study. The first alternative will be the AC utilized from the current system (As-Is) of C-17, C-130 and KC-135; the flying costs of these AC will be used on the simulation output to develop comparison costs. The second and third scenario will focus on the idea of AMC having an assigned and dedicated C-37B or C-40C (redistributed from the current AF fleet) for AE patients, utilizing the current system only when busy. The final alternative will only differ (from the second and third) in how the costs are generated since utilizing a contracted asset (G550).

HQ/AMC provided several references regarding flying hour cost that were used for the comparison of the alternatives (FY2013 data). The individual Latitude and
Longitudes of the different bases in the study were attained from a website (geohack) as well as the different base Active Duty populations (Military Zone).

**Location**

A CONUS map of AF installations was used to develop the idea of sections of responsibility. This assumes that the placement of AF bases is a good means to determine appropriate coverage for the notional AE Discrete-Event Simulation (DES) model. AF AE services all branches of the military so the results may not accurately reflect coverage for all military personnel. Also, this assumes that bases that do not have an active runway can utilize local airports for transferring patients. The Air Force Bases (AFBs) from the map minus the endpoints of care (EPCs) are listed in the table below.
with longitude and latitude as well as population; locations within 50 miles of an EPC are not included. This 50 mile radius assumes that the military EPCs do not have their own air ambulance.

Table 4: Base Locations and Populations

<table>
<thead>
<tr>
<th>Installation</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Base Population</th>
<th>Installation</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Base Population</th>
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<td>Offutt</td>
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<tr>
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<td>35.34</td>
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</tr>
<tr>
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<td>4481</td>
<td>Shaw</td>
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<td>80.47</td>
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<td>106.11</td>
<td>3955</td>
<td>Sheppard</td>
<td>33.99</td>
<td>98.49</td>
<td>10985</td>
</tr>
<tr>
<td>Hurlburt Field</td>
<td>30.43</td>
<td>86.69</td>
<td>7798</td>
<td>Tinker</td>
<td>35.42</td>
<td>97.39</td>
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<td>Keeler</td>
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<td>88.92</td>
<td>6081</td>
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<td>Kirtland</td>
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<td>106.61</td>
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<td>34.73</td>
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<td>3297</td>
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<td>92.15</td>
<td>4375</td>
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<td>38.73</td>
<td>93.55</td>
<td>3347</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>33.92</td>
<td>118.37</td>
<td>1405</td>
<td>Wright-Patterson</td>
<td>39.82</td>
<td>84.05</td>
<td>6274</td>
</tr>
</tbody>
</table>

From this data, locations were addressed for the idea of utilizing a dedicated AC to handle Urgent and Priority PMRs. If AMC utilized a resource whose primary mission was AE, location would play an important role in factors like response times and costs. For the continental US, 4 different location arrangements were developed using disciplines like Integer Programming (IP).
The first would be having one AE AC bed-down location to service the entire US. In this scenario, requests (Urgent or Priority) would utilize AC from a single hub that would deliver patients to the EPC nearest to the pick-up location based on mileage only.

Second would be a 2 region model using Travis AFB and Andrews AFB to split the US in two. Each region would have its own AE AC hub and would deliver patients to the nearest EPC from the pick-up location.

A 3 region model would make up the third scenario splitting up the bases based on the EPCs. The difference in regards to the previous 2 scenarios would be that patients would be delivered to the EPC that their region is defined by versus the closest based off of mileage.

Finally a 4 region model would introduce a 4\textsuperscript{th} possible EPC, the United States Air Force Academy (USAFA). The Colorado Springs area has the 10\textsuperscript{th} Medical Group operating the USAFA hospital and Ft. Carson hosting the Evans Army Community Hospital offering advanced medical care. USAFA was also mentioned by members of AMC as a possible future EPC. In this 4 region design, patients are delivered to their assigned EPC unlike the first two scenarios based of mileage alone. Since Buckley AFB, Peterson AFB and Schriever AFB are close to the USAFA, they are removed from the 4 region model since they fall within 50 miles.

<table>
<thead>
<tr>
<th>Table 5: Summary of Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPC determination</td>
</tr>
<tr>
<td># of EPC's</td>
</tr>
<tr>
<td>Sectioned by</td>
</tr>
</tbody>
</table>

24
Determining how to section the US into different regions of responsibility was accomplished by developing a simple IP (except for the Whole US model which did not require any sectioning). The objective of the IP was to minimize distances traveled from potential patient location to EPC while maintaining relatively even coverage of bases and population per each endpoint. The IP is featured below.

**Inputs and sets:**
- $I$: Set of patient bases, indexed by $i$
- $J$: Set of EPC, indexed by $j$
- $a_i$: Airman population for base $i \in I$
- $p$: Total airman population of bases
- $d_{ij}$: Distance from base $i \in I$ to EPC $j \in J$

**Decision variables:**
- $z_{ij}$: \begin{align*}
    z_{ij} &= \begin{cases}
        1, & \text{if base } i \in I \text{ assigned to EPC } j \in J \\
        0, & \text{if not}
    \end{cases}
\end{align*}

Using this notation the problem is formulated below (Daskin, Snyder, & Berger, 2005):

**Equation 4: Location IP**

$$
\min \sum_i \sum_j d_{ij} z_{ij} \\
\text{s.t.} \\
\sum_j z_{ij} = 1 \quad i \in I \\
\text{IF number of bases divided by EPC is an integer} \\
\quad \sum_i z_{ij} = \text{number of base assignments} \quad j \in J \\
\text{ELSE} \\
\quad \sum_i z_{ij} \geq \text{Minimum number of base assignments} \quad j \in J
$$
\[
\sum_{i} z_{ij} \leq \text{Maximum number of base assignments} \quad j \in J
\]

\[
\text{END IF}
\]

\[
\sum_{i} \frac{a_{ij}z_{ij}}{p} \geq \text{Minimum percent of population coverage} \quad j \in J
\]

\[
\sum_{i} \frac{a_{ij}z_{ij}}{p} \leq \text{Maximum percent of population coverage} \quad j \in J
\]

\[
z_{ij} \in \{0,1\} \quad i \in I
\]

This difference between how the models were implemented is captured in the table below.

<table>
<thead>
<tr>
<th>Number of Base Assignments</th>
<th>2 Regions</th>
<th>3 Regions</th>
<th>4 Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>28</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Maximum</td>
<td>28</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Percent of Population</td>
<td>Minimum</td>
<td>0.49</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.51</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Since the 2 and 4 regions model could be split up evenly, their respective minimum and maximum number of base assignments are equal. The intention was to relax the number of assignments per AE AC hub however solutions were feasible with these constraints in place. The percent of population constraints ensure that one AE AC hub does not have a disproportional amount of coverage based on population.

To solve these IPs, LINGO a linear program solving application was utilized (LINDO System INC., 2013). The results provided the foundation to find the different WMCs for the different regions. The code and results from LINGO are included in the appendix.
The population WMC was used to determine the best location within a region for locating dedicated assets (Sahoo). Latitude, Longitude and Population were utilized to find each WMC.

**Equation 5: WMC Formulation**

\[
\begin{align*}
    n &= \text{number of bases in region} \\
    x_i &= \text{latitude reading for base } i \ (N) \\
    y_i &= \text{longitude reading for base } i \ (W) \\
    a_i &= \text{population for base } i \\
    \bar{X} &= \frac{\sum_{i=1}^{n} a_i x_i}{\sum_{i=1}^{n} a_i} \\
    \tilde{Y} &= \frac{\sum_{i=1}^{n} a_i y_i}{\sum_{i=1}^{n} a_i}
\end{align*}
\]

*weighted latitude coordinate*

*weighted longitude coordinate*

Once each WMC for the different regions is found, the nearest base is deemed the candidate site to locate AE AC. To find the distances needed for comparison, the haversine formula is implemented using MATLAB (MathWorks, 2013); actual code can be found in the appendix (Peyrad, 2011). The following table summarizes the candidate sites for the model.

**Table 7: Nearest Locations to WMC**

<table>
<thead>
<tr>
<th>Whole US</th>
<th>Whole US</th>
<th>Tinker AFB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travis AFB Region</td>
<td>USAFA Region</td>
<td>Brooks AFB Region</td>
</tr>
<tr>
<td>2 region</td>
<td>USAFA</td>
<td></td>
</tr>
<tr>
<td>3 region</td>
<td>Hill AFB</td>
<td>Barksdale AFB</td>
</tr>
<tr>
<td>4 region</td>
<td>Nellis AFB</td>
<td>McConnell AFB</td>
</tr>
</tbody>
</table>
The haversine formula was also used to find the EPC that was closest to the potential patient locations. These distances were needed for the Whole and 2 region scenarios.

MATLAB also generated average and maximum distances for the WMC’s and candidate sites of the different regions. The table below relates to the candidate sites for AE.

Table 8: Distances to Patient

<table>
<thead>
<tr>
<th>Region</th>
<th>Whole US</th>
<th>Travis AFB Region</th>
<th>USAFA Region</th>
<th>Brooks AFB Region</th>
<th>Andrews AFB Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>744.31</td>
<td>508.64</td>
<td>497.93</td>
<td>465.69</td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>1574.09</td>
<td>1049.34</td>
<td>834.78</td>
<td>988.91</td>
<td></td>
</tr>
</tbody>
</table>

As the number of AE locations increase, the average distances decrease. This is highlighted below by taking the averages from above.

Table 9: Average Distances to Patient

<table>
<thead>
<tr>
<th>Region</th>
<th>Whole US</th>
<th>Travis AFB Region</th>
<th>USAFA Region</th>
<th>Brooks AFB Region</th>
<th>Andrews AFB Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>744.31</td>
<td>486.87</td>
<td>441.35</td>
<td>390.08</td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>1574.09</td>
<td>1045.45</td>
<td>977.21</td>
<td>782.27</td>
<td></td>
</tr>
</tbody>
</table>

Having the mileage “to the patient” is the first step followed by finding the average distances “to the EPC”. The following table summarizes the average distances and maximum distances for the different regions.

Table 10: Distances to EPC

<table>
<thead>
<tr>
<th>Region</th>
<th>Whole US</th>
<th>Travis AFB Region</th>
<th>USAFA Region</th>
<th>Brooks AFB Region</th>
<th>Andrews AFB Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>913.18</td>
<td>619.33</td>
<td>699.34</td>
<td>562.21</td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>1779.69</td>
<td>1242.98</td>
<td>1392.06</td>
<td>1367.30</td>
<td>1242.98</td>
</tr>
<tr>
<td>Avg</td>
<td>481.26</td>
<td>505.54</td>
<td>506.33</td>
<td>533.59</td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>824.30</td>
<td>800.43</td>
<td>1204.11</td>
<td>823.55</td>
<td></td>
</tr>
</tbody>
</table>

28
The averages per each scenario are summarized in the following table.

Table 11: Average Distances to EPC

<table>
<thead>
<tr>
<th></th>
<th>To Endpoint of Care</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg Dist</td>
<td>Max Dist</td>
<td></td>
</tr>
<tr>
<td>Whole US</td>
<td>550.29</td>
<td>1242.98</td>
<td></td>
</tr>
<tr>
<td>2 region</td>
<td>550.29</td>
<td>1242.98</td>
<td></td>
</tr>
<tr>
<td>3 region</td>
<td>570.40</td>
<td>1132.20</td>
<td></td>
</tr>
<tr>
<td>4 region</td>
<td>495.67</td>
<td>957.98</td>
<td></td>
</tr>
</tbody>
</table>

Since the first two scenarios take patients to the nearest EPC based solely on mileage, their respective averages are equal. The 3 and 4 region models utilize the IP’s solution to send patients to the EPC. The main reason is that it would not be realistic (based on AMC information) to have a single EPC. The use of Travis AFB Area, Brook AFB Area and Andrews AFB Area were used based on AMC input for current EPCs. The United States Air Force Academy (USAFA) and Wright Patterson Air Force base (WPAFB) were also mentioned as possible EPCs for AE missions. To expand the idea of having a 4 region network, USAFA was chosen over WPAFB as the 4th EPC since WPAFB is closer to another EPC (Andrews AFB).

The total distance for the notional AE Urgent/Priority mission is summarized in the following table.

Table 12: Mission Distances

<table>
<thead>
<tr>
<th></th>
<th>Average Distance</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>To Patient</td>
<td>To Endpoint</td>
<td>To Hub</td>
<td>Total</td>
</tr>
<tr>
<td>Whole US</td>
<td>744.31</td>
<td>550.29</td>
<td>864.03</td>
<td>2158.64</td>
</tr>
<tr>
<td>2 region</td>
<td>486.87</td>
<td>550.29</td>
<td>745.19</td>
<td>1782.36</td>
</tr>
<tr>
<td>3 region</td>
<td>441.35</td>
<td>570.40</td>
<td>437.20</td>
<td>1448.95</td>
</tr>
<tr>
<td>4 region</td>
<td>390.08</td>
<td>495.67</td>
<td>419.66</td>
<td>1305.41</td>
</tr>
</tbody>
</table>

The total average distance represents the trip from the AE AC hub to the patient location, then delivery to EPC and finally the return trip to the hub. These numbers are
per mission hence the reduction in mileage as the US is split into more regions. To utilize this information data was needed from the AE system which is summarized below.

Table 13: AE Data Utilized

<table>
<thead>
<tr>
<th>Amount</th>
<th>Value Measure</th>
<th>Derived From</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise Speed</td>
<td>609 mph</td>
<td>G550 &amp; C-40 handouts</td>
</tr>
<tr>
<td>Onload and Offload times</td>
<td>0.50 hours each</td>
<td>AFPAM10-1403 for C-130</td>
</tr>
<tr>
<td>Takeoff factor</td>
<td>0.33 hours</td>
<td>estimate</td>
</tr>
<tr>
<td>Landing factor</td>
<td>0.17 hours</td>
<td>estimate</td>
</tr>
<tr>
<td>Minimum Crew Rest Times</td>
<td>16.00 hours</td>
<td>AFPAM10-1403 for C-130</td>
</tr>
</tbody>
</table>

The table above was produced from various AE sources, starting with cruise speed (Mach 0.80) which was pulled from an informational handout of the G550 AC (Gulfstream Aerospace Corporation, 2010). The Mach speed range of 0.78 to 0.82 associated with the C-40 AC was taken from a Boeing document (Bartlett & Gossett, 2011) and verified by the relevant AF fact sheet (AF.MIL, 2011). The Mach speed of 0.80 was used for the speed of both AC which when converted (used Wolfram Alpha (A Wolfram Research Company, 2013)) equates to roughly 609 miles per hour. Onload and offload times are estimated based on information from an Air Force Pamphlet (AFPAM 10-1403) regarding AE. The times of one hour and thirty minutes from the C-130 are used as a guide to estimate what the G550 times would be. Takeoff and Landing factors are to account for reduced speeds during both events; these times were loosely based off of what was found in Mullen’s Thesis (Mullen, June 1989). Minimum Crew Rest Times (MCRTs) were added based again off of the C-130; this assumes only one crew is available for AE. In the absence of data, the Annual number of Urgent/Priority missions will come from the number of patient redistributions in 2011 (AMC, 2011).
The C-37B and C-40C flying hour costs come directly from an AMC handout (AMC, 2012). The initial drive for the study focused on the high costs related to the C-17 which is pulled at times for missions where a smaller AC could be utilized. The final section lists numbers related to having a G550 contract; these numbers were found in a Cost Comparison Analysis for Pacific Command (PACAF).

Using the information from the table above, response times and utilization rates were found. To get mission times, the formula below (within the box) was used.

**Equation 6: Mission Times**

$$MT = \frac{TAD}{CP} + 2 \cdot OOT + 3 \cdot (TF + LF) + MCRT$$

Here mission times (MT) are an average number generated from the total average distances (TAD) divided by cruise speed (CP) and adding 2 onload and offload times (OOT), 3 takeoff (TF) and landings (LF) and finally adding the minimum crew rest times (MCRT). Once these times were collected (for each of the different regions) the utilization rates could be determined using Queueing theory.
Queueing

For the Urgent/Priority AE mission, the interarrival times (\( \lambda \) for arrival rate) of PMRs would assume to follow an exponential distribution. The exponential has the Markov memoryless property that in this case means a cardiac patient request at Tyndall AFB has no influence on the occurrence of a trauma patient request at Holloman AFB (Gross, Shortle, Thompson, & Harris, 2008). The service times (\( \mu \)) found earlier typically do not follow an exponential distribution but rather possibly an Erlang type-6. However, since the focus here is on utilization rates or traffic intensity (\( \rho \)), the formula for finding these rates are the same (\( \rho = \frac{\lambda}{\mu} \) for exponentially distributed interarrival times, generally distributed service times and of one server denoted with Kendall-Lee notation M/G/1). The utilization results from Queueing Theory Software (QTS) plus, an Excel Queueing solving tool (Shortle, 2008), are as follows.

Table 14: M/M/1 Results

<table>
<thead>
<tr>
<th></th>
<th>Total Mission Time</th>
<th>Service Rate</th>
<th>Arrival Rate</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole US</td>
<td>22.0446</td>
<td>1.0887</td>
<td>0.4382</td>
<td>0.4025</td>
</tr>
<tr>
<td>2 region</td>
<td>21.4267</td>
<td>1.1201</td>
<td>0.2191</td>
<td>0.1956</td>
</tr>
<tr>
<td>3 region</td>
<td>20.8792</td>
<td>1.1495</td>
<td>0.1461</td>
<td>0.1271</td>
</tr>
<tr>
<td>4 region</td>
<td>20.6435</td>
<td>1.1626</td>
<td>0.1096</td>
<td>0.0942</td>
</tr>
</tbody>
</table>

Based on current information regarding AE, a single dedicated resource would only be utilized roughly 40% of the time. Splitting the US into regions only drops utilization rates and thus increasing the amount of time these resources (AC) would be idle. To further illustrate these rates, a table was created to see the effects of increasing the amount of annual PMRs and available AC (below).
Table 15: Queueing Utilization Table

<table>
<thead>
<tr>
<th>Annual Flights</th>
<th>Servers</th>
<th>CONUS</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>156</td>
<td>1</td>
<td>0.4025</td>
<td>0.2012</td>
<td>0.1342</td>
<td>0.1006</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.1956</td>
<td>0.1001</td>
<td>0.0667</td>
<td>0.0500</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.1271</td>
<td>0.0648</td>
<td>0.0432</td>
<td>0.0324</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.0942</td>
<td>0.0480</td>
<td>0.0320</td>
<td>0.0240</td>
</tr>
<tr>
<td>312</td>
<td>1</td>
<td>0.8050</td>
<td>0.4025</td>
<td>0.2683</td>
<td>0.2012</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.4004</td>
<td>0.2002</td>
<td>0.1335</td>
<td>0.1001</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.2591</td>
<td>0.1296</td>
<td>0.0864</td>
<td>0.0648</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.1918</td>
<td>0.0959</td>
<td>0.0639</td>
<td>0.0480</td>
</tr>
<tr>
<td>468</td>
<td>1</td>
<td>1.2075</td>
<td>0.6037</td>
<td>0.4025</td>
<td>0.3019</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.6005</td>
<td>0.3003</td>
<td>0.2002</td>
<td>0.1501</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.3887</td>
<td>0.1943</td>
<td>0.1296</td>
<td>0.0972</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.2877</td>
<td>0.1439</td>
<td>0.0959</td>
<td>0.0719</td>
</tr>
<tr>
<td>624</td>
<td>1</td>
<td>1.6100</td>
<td>0.8050</td>
<td>0.5367</td>
<td>0.4025</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.8007</td>
<td>0.4004</td>
<td>0.2669</td>
<td>0.2002</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.5182</td>
<td>0.2591</td>
<td>0.1727</td>
<td>0.1296</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.3836</td>
<td>0.1918</td>
<td>0.1279</td>
<td>0.0959</td>
</tr>
</tbody>
</table>

Here, servers represent AC at an AE AC hub and utilization rates are based on each AC (therefore in the 4 region model with 4 servers there would be a total of 16 AC). Utilization rates over 50 % are highlighted to showcase reasonable ranges for this value measure. Rates over 100 % would indicate a situation where the current system (C-17, C-130 and KC-135) was relied on more heavily to fill the overflow. To get an idea at how often the as-is system would be utilized in such a scenario, a simulation model was developed to glean insight.

**Simulation**

“Simulation is the imitation of the operation of a real-world process or system over time” and in this case the AE Urgent operation (Banks, Carson II, Nelson, & Nicol, 2010). DES Simulation “is the modeling of systems in which the state variable changes only at a discrete set of points in time”. Events that drive the AE process are PMRs that are well suited for the nature of DES. AE DES conceptualization was done using Arena.
simulation software which is well equipped for handling DES problems (Rockwell Software). Translating the proposed system into a model was aided by using Arena. Arena utilizes a Graphical User Interface (GUI) allowing users to easily build models while following their progress. Verification is easier since the GUI provides an easier visual representation than lines of code. Validation can also be easier due to the visual construct of Arena; sponsors at AMC were able to give face validity to the model from the GUI. Qualification can be easier as well in Arena; it involves finding that the math agrees with the nature of what is being modeled (Cochran, 1987). These principles are important to Simulation models since it is not the intent to model reality exactly. Most real world problems under study are complex and modeling aims to find a balance between assumptions and the random nature of systems.

The experimental design (decisions to be made when running a model) for the AE DES needed to be addressed before moving forward. First, the simulation will be terminating instead of a steady-state model due to the fact that queues (for Urgent and Priority requests) are expected to be empty. Also since queues are not expected to form, the model will not utilize a warm-up period. Each replication will run for 365 days to ensure more random behavior across the replications since the model is relatively simple and non-steady-state. The model will make 30 independent replications allowing for classical statistics to be applied to the performance measures (Kelton, A Tutorial on Design and Analysis of Simulation Experiments).

From the utilization rates found in the Queueing results earlier, the first modeling decision is to only have one dedicated asset. The second decision will be to remove the
MCRT and instead assume that alternate pilots and AE personnel will be available in the event that rest times are comprised. This will decrease the utilization even further however the next decision will be to add the “redistribution” of patients to the dedicated assets AE mission.

Connected to the AE mission is the redistribution of patients once their advanced treatment ends. An example would be a severely injured patient moved from Bagram to the burn center in the San Antonio area. The AE mission encompasses this movement, ending in San Antonio. After treatment has been completed at the burn and rehab center, the patient then needs transportation back to their home station. This is just one of many examples that are known as the redistribution of patients.

![Redistribution Visual Aid](image)

**Figure 12: Redistribution Visual Aid**

This movement alone cost AMC roughly 28.5 million dollars in 2011. Efforts are made to optimize these movements however subject matter experts at AMC indicate that these missions are typically carrying only one patient. Airframes such as the KC-135 and C-17 carry a heavy price tag for a movement that could be accomplished with a smaller AC. The costs from the 2011 AMC spreadsheet are summarized below (AMC, 2011).
Comparing this to the C-37B FY 2013 flying hour cost of $2,069 would result in a cost difference of close to 23 million dollars less than current operations.

### Table 17: C-37B Example Costs

<table>
<thead>
<tr>
<th>AC Type</th>
<th>Flying Hour Cost</th>
<th>Total Fly Time</th>
<th>Cost</th>
<th>Cost Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-37B</td>
<td>$2,069.00</td>
<td>2652</td>
<td>$5,486,988.00</td>
<td>$(23,060,544.00)</td>
</tr>
</tbody>
</table>

This is a rough estimate, however if these large and expensive AC are being used for single patient movements then room exists to optimize cost. To model this scenario, the average distance from the patient’s care location to their home base and back to Tinker AFB (WMC-based location of dedicated asset) is the same as the total mileage found earlier for AE missions (in a different order).

### Table 18: Redistribution Mileage

<table>
<thead>
<tr>
<th>Average “Redistribution” Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>To Patient Care Location</td>
</tr>
<tr>
<td>864.03</td>
</tr>
</tbody>
</table>

Being that the total average distance is the same as PMRs, redistribution requests will be assumed to have the same service times. Redistribution requests per year will be centered on the amount found in 2011 of 156.

**Notional Simulation Model**

What if AMC had one strategically positioned AC for the Urgent / Priority AE mission and the redistribution needs they encounter? This idea stems from the initial
impression of the Queueing model that a single asset would have a low utilization. The proposed simulation model will incorporate create nodes within Arena that will generate Urgent / Priority requests, “redistribution” requests as well as requests for non-routine “milestone” maintenance (that which occurs with mileage and hours on different types of hardware). The “redistribution” requests (in hours) will be processed by the same node as the Urgent / Priority missions since both are similar in nature. Time for refueling and maintenance (between flights) occurs once the AC arrives back at Tinker AFB using a triangular distribution (1 hour minimum, 1.5 hour average and 2 hour maximum). A picture of the model is featured below.

![Simulation Model Diagram](image)

**Figure 13: Simulation Model**

A PMR will preempt a redistribution request that is currently in process. The time remaining for the redistribution request will be stored internally until the completion of the PMR, at which point will resume service. This in effect translates to a redistribution patient riding along with the PMR patient. Although the redistribution patient would be
traveling back to the EPC, the service time does not reset; this could be modeled with more detail however on average, the redistribution request would be preempted near to the EPC. The two situations within the model where PMRs are not processed by the dedicated asset are when the AC is with another Urgent / Priority request or is busy with milestone maintenance. When unavailable, PMRs are picked up by either a C-17 or KC-135 randomly (with the C-17 being selected two-thirds of the time and the remaining by the KC-135; this is based off the 2011 AMC report). Urgent and Priority requests will wait for the refueling and maintenance needs that are required between missions. Redistribution requests will only be serviced by the dedicated asset in the model. If the AC is busy with either redistribution request or PMR, a new redistribution request will wait until the asset returns and accomplishes refueling and maintenance. The table below summarizes the model.

<table>
<thead>
<tr>
<th>Entities</th>
<th>Process</th>
<th>Type of Process</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient Movement Requests (PMR)</td>
<td>Dedicated Asset</td>
<td>Delay Release</td>
<td>Dedicated Asset</td>
</tr>
<tr>
<td></td>
<td>C-17</td>
<td>Seize Delay Release</td>
<td>C-17</td>
</tr>
<tr>
<td></td>
<td>KC-135</td>
<td>Seize Delay Release</td>
<td>KC-135</td>
</tr>
<tr>
<td></td>
<td>Refuel and Maintenance</td>
<td>Seize Delay Release</td>
<td>Dedicated Asset</td>
</tr>
<tr>
<td></td>
<td>Wait Till Refuel and MX Complete</td>
<td>Delay Release</td>
<td></td>
</tr>
<tr>
<td>Redistribution Requests</td>
<td>Dedicated Asset</td>
<td>Delay Release</td>
<td>Dedicated Asset</td>
</tr>
<tr>
<td></td>
<td>Refuel and Maintenance</td>
<td>Seize Delay Release</td>
<td>Dedicated Asset</td>
</tr>
<tr>
<td></td>
<td>Wait for Dedicated Asset</td>
<td>Delay Release</td>
<td></td>
</tr>
<tr>
<td>Milestone Maintenance Requests</td>
<td>Milestone Maintenance Work</td>
<td>Delay</td>
<td></td>
</tr>
</tbody>
</table>

Table 19: Components of Simulation Model
The benefit of using a simulation model (over Queuing) in this scenario is that it will capture those instances where the dedicated resource is unavailable and the current as-is system AC would be utilized. The different arrival rates ($\lambda$) within the model will follow the exponential distributions. The service rates ($\mu$) however would need some attention since the exponential distribution would not be appropriate since service times of 0 or over 48 hours would be unrealistic for this example. Arena’s Input Analyzer was used to determine a distribution adequate for the service times. The following service times (without MCRT) were fed into Input Analyzer.

<table>
<thead>
<tr>
<th>Installation</th>
<th>Service Time</th>
<th>Installation</th>
<th>Service Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altus</td>
<td>4.0000</td>
<td>Luke</td>
<td>7.190</td>
</tr>
<tr>
<td>Arnold</td>
<td>6.3558</td>
<td>MacDill</td>
<td>7.416</td>
</tr>
<tr>
<td>Barksdale</td>
<td>4.2646</td>
<td>Malmstrom</td>
<td>7.919</td>
</tr>
<tr>
<td>Beale</td>
<td>7.0582</td>
<td>Maxwell</td>
<td>6.624</td>
</tr>
<tr>
<td>Buckley</td>
<td>5.3322</td>
<td>McChord</td>
<td>8.257</td>
</tr>
<tr>
<td>Cannon</td>
<td>4.5015</td>
<td>McConnell</td>
<td>4.393</td>
</tr>
<tr>
<td>Charleston</td>
<td>6.7302</td>
<td>McGuire</td>
<td>6.750</td>
</tr>
<tr>
<td>Columbus</td>
<td>5.1379</td>
<td>Minot</td>
<td>8.298</td>
</tr>
<tr>
<td>Davis- Monthan</td>
<td>7.3027</td>
<td>Moody</td>
<td>6.896</td>
</tr>
<tr>
<td>Dover</td>
<td>6.5390</td>
<td>Mountain Home</td>
<td>7.332</td>
</tr>
<tr>
<td>Dyess</td>
<td>3.9836</td>
<td>Nellis</td>
<td>7.032</td>
</tr>
<tr>
<td>Edwards</td>
<td>7.1734</td>
<td>Offutt</td>
<td>5.213</td>
</tr>
<tr>
<td>Eglin</td>
<td>5.5476</td>
<td>Patrick</td>
<td>7.450</td>
</tr>
<tr>
<td>Ellsworth</td>
<td>6.0361</td>
<td>Peterson</td>
<td>5.187</td>
</tr>
<tr>
<td>Fairchild</td>
<td>8.0610</td>
<td>Pope Army Airfield</td>
<td>6.546</td>
</tr>
<tr>
<td>Francis E. Warren</td>
<td>5.5891</td>
<td>Robins</td>
<td>6.660</td>
</tr>
<tr>
<td>Goodfellow</td>
<td>4.0341</td>
<td>Schriever</td>
<td>5.163</td>
</tr>
<tr>
<td>Grand Forks</td>
<td>7.7921</td>
<td>Scott</td>
<td>6.311</td>
</tr>
<tr>
<td>Hanscom</td>
<td>7.4530</td>
<td>Seymour Johnson</td>
<td>6.592</td>
</tr>
<tr>
<td>Hill</td>
<td>7.1212</td>
<td>Shaw</td>
<td>6.616</td>
</tr>
<tr>
<td>Holloman</td>
<td>4.9096</td>
<td>Sheppard</td>
<td>3.915</td>
</tr>
<tr>
<td>Hurlburt Field</td>
<td>5.5223</td>
<td>Tinker</td>
<td>3.893</td>
</tr>
<tr>
<td>Keesler</td>
<td>5.1249</td>
<td>Tyndall</td>
<td>5.744</td>
</tr>
<tr>
<td>Kirtland</td>
<td>5.0679</td>
<td>USAF Academy</td>
<td>5.232</td>
</tr>
<tr>
<td>Langley</td>
<td>6.5223</td>
<td>Vance</td>
<td>4.107</td>
</tr>
<tr>
<td>Laughlin</td>
<td>4.1879</td>
<td>Vandenberg</td>
<td>7.313</td>
</tr>
<tr>
<td>Little Rock</td>
<td>4.5601</td>
<td>Whiteman</td>
<td>4.868</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>7.2975</td>
<td>Wright-Patterson</td>
<td>6.330</td>
</tr>
</tbody>
</table>

Table 20: Service Times
These times represent the total time for a dedicated asset to complete an AE mission including the time to return to the Tinker AFB hub. The average time for the patient to reach their EPC is 4.626 hours. The suggested distribution for the data was a Beta Distribution, which is known for its flexibility and use for bounded random variables (Banks, Carson II, Nelson, & Nicol, 2010). Input Analyzer suggests distributions by finding the theoretical distribution with the smallest mean square error (table below).

<table>
<thead>
<tr>
<th>Function</th>
<th>Sq Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta</td>
<td>0.0231</td>
</tr>
<tr>
<td>Triangular</td>
<td>0.0281</td>
</tr>
<tr>
<td>Uniform</td>
<td>0.0313</td>
</tr>
<tr>
<td>Normal</td>
<td>0.0340</td>
</tr>
<tr>
<td>Weibull</td>
<td>0.0398</td>
</tr>
<tr>
<td>Erlang</td>
<td>0.0484</td>
</tr>
<tr>
<td>Gamma</td>
<td>0.0487</td>
</tr>
<tr>
<td>Lognormal</td>
<td>0.0629</td>
</tr>
<tr>
<td>Exponential</td>
<td>0.0725</td>
</tr>
</tbody>
</table>

The mean square error (MSE) is the average of the square error terms for each histogram cell between the observations and the theoretical distribution (Kelton, Sadowski, & Swets, Simulation with Arena: Fifth Edition, 2010). To ensure there wasn’t a large gap in performance between the different distributions, the simulation was run with the top three distributions above (Beta, Triangular and Uniform). The model was run using 30 replications, each 365 days long and having interarrival times for PMRs of 1 day.

A summary of the key value measures of the dedicated asset are below.
All these distributions are bounded and therefore have similar results. Bounded is preferred since the “resource” in all the alternatives is assumed to be ready when available. Also, the patient is assumed to be ready when the resource lands. Combining this with the fact that flight times typically have low variance makes service times relatively constant. The main difference between the value measures is that the dedicated asset resource tasking (average amount of PMRs that are accomplished by the Dedicated Asset versus the C-17 and KC-135) had subtle increases in half-widths from Beta across to Uniform. While the performance within the model was similar, the Beta was selected over the Triangular and Uniform since it tested better in Input Analyzer. The results from Input Analyzer are presented below.

![Figure 14: Input Analyzer Results](image)
The Kolmogorov-Smirnov (KS) test above shows the corresponding p-value was greater than 0.15 meaning there isn’t enough evidence to reject the null hypothesis that the observed and theoretical distribution are different.

With the inputs in place the simulation could be run to get the desired outputs highlighted in the following figure.

**Figure 15: Simulation Overview**

The purpose of the simulation was to retrieve outputs that would allow cost comparisons to be attained as well as insights regarding utilization. Resource tasking in this study is focused on how many of the Urgent and Priority PMRs are accomplished with the dedicated asset versus the overflow AC (C-17 and KC-135). With the numbers regarding resource tasking and flying hour costs, total costs can be derived of the different systems (Dedicated or Contracted). The utilization of the dedicated asset would help AMC determine if having such an AC would be plausible. Having a resource with a low utilization may or may not be advisable; low utilization may be viewed as increased readiness or alternatively inefficient use of an AC. To best extract the information desired, a Design of Experiment (DOE) was developed.
Design of Experiment

To best understand the costs associated with a system that only utilized one dedicated asset, a DOE was implemented. The two factors that would be varied are the redistribution requests and PMRs; a 3 level by 2 factor \((3^2)\) factorial experiment yielding 9 scenarios. The 2 factors involved are the arrival rates of the entities Redistribution and PMR. A summary table of the different levels of interarrival times along with the corresponding numbers per year is presented below.

Table 23: DOE inputs

<table>
<thead>
<tr>
<th>Average Requests</th>
<th>Days Between</th>
<th>Number Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Mid</td>
</tr>
<tr>
<td>Redistribution</td>
<td>4.5641</td>
<td>2.2821</td>
</tr>
<tr>
<td>PMR</td>
<td>2.3576</td>
<td>1.1788</td>
</tr>
</tbody>
</table>

The number of redistribution requests is based on an AMC report, centered on 156 as the mid-level; low (78) is half the mid-level and high (312) is double the amount. The days between arrivals are simply 356 divided by “Number per Year”. For the PMR row, the average number per year of 1411.2 from the 1976 journal article was utilized (Johnson Jr., Cooper, & Ellegood, 1976) along with the 78.57 % decrease caused by TRICARE in the late 90’s (70,000 mission in 1995 dropped to 15,000 in 2000 (Diamond, 2003)) to come up with the number of 302 Urgent / Priority AE Missions per year. The low (151) and high (604) numbers again represent half and double the value respectively. Although this is only a crude estimate it provides a basis to gain insight on the notional system.
IV. Analysis and Results

The results of the DOE are as follows.

Table 24: DOE results

<table>
<thead>
<tr>
<th>Scenario (Redistribution/PMR)</th>
<th>Percent of Missions Completed by Dedicated Asset</th>
<th>Dedicated Asset Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Min</td>
</tr>
<tr>
<td>L/L</td>
<td>0.903</td>
<td>0.874</td>
</tr>
<tr>
<td>L/M</td>
<td>0.810</td>
<td>0.773</td>
</tr>
<tr>
<td>L/H</td>
<td>0.689</td>
<td>0.660</td>
</tr>
<tr>
<td>M/L</td>
<td>0.883</td>
<td>0.812</td>
</tr>
<tr>
<td>M/M</td>
<td>0.811</td>
<td>0.771</td>
</tr>
<tr>
<td>M/H</td>
<td>0.695</td>
<td>0.660</td>
</tr>
<tr>
<td>H/L</td>
<td>0.903</td>
<td>0.873</td>
</tr>
<tr>
<td>H/M</td>
<td>0.812</td>
<td>0.777</td>
</tr>
<tr>
<td>H/H</td>
<td>0.692</td>
<td>0.668</td>
</tr>
</tbody>
</table>

Here each scenario represents 30 replications of the simulation model with the controls set at the levels from Table 23: DOE inputs. The responses show that when the days between arrivals is the lowest (4.5641 for Redistribution and 2.3576 for PMR), the dedicated asset captures 90.3 % of the Urgent / Priority AE missions and has a utilization rate of 18.9%. When at their highest, the dedicated asset still captures 69.2 % of the specified AE missions and has a utilization rate of 62.3 %. The half-widths of the different estimates show that they are relatively precise. The model is most sensitive to alteration of PMRs since they have a higher volume and also redistribution requests have a lower priority (their more of an additional “flexible” work-flow to better utilize the asset). Regression analysis was done on these results in JMP (SAS Institute Inc., 2013 ) to see what effects the different levels of redistributions and PMRs had on the responses (below).
Table 25: JMP results

### Utilization

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>2</td>
<td>0.1317</td>
<td>0.0659</td>
<td>23.4306</td>
<td>0.0015</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>0.0169</td>
<td>0.0028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>8</td>
<td>0.1486</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Parameter Estimates

| Term          | Estimate | Std Error | t Ratio | Prob>|t| |
|---------------|----------|-----------|---------|------|
| Intercept     | 0.7088   | 0.0500    | 14.1800 | <.0001|
| Redistribution| -0.0531  | 0.0124    | -4.2800 | 0.0052|
| PMR           | -0.1285  | 0.0240    | -5.3400 | 0.0018|

### Percent Accomplished by DA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>2</td>
<td>0.058</td>
<td>0.029</td>
<td>33.065</td>
<td>0.001</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>0.005</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>8</td>
<td>0.063</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Parameter Estimates

| Term          | Estimate | Std Error | t Ratio | Prob>|t| |
|---------------|----------|-----------|---------|------|
| Intercept     | 0.6497   | 0.0280    | 23.2300 | <.0001|
| Redistribution| -0.0001  | 0.0069    | -0.0200 | 0.9899|
| PMR           | 0.1094   | 0.0135    | 8.1300  | 0.0002|

The results from JMP for utilization indicate that both the levels of redistributions and PMRs are significant to the regression. For the percent accomplished by the dedicated asset (DA), PMRs are significant however redistributions have relatively no impact on the percentage. This is not surprising since they are preempted when an Urgent/Priority request is generated.

The following figure summarizes the two performance measures.
When both PMRs and redistribution requests are low, the utilization rate of the AC is only 19%. This equates to the dedicated asset being idle 80% of the year. This can be viewed two ways; for one, it is available for other transportation movements (Distinguished Visitor travel for example) or oppositely that the low utilization represents increased readiness/availability.

When both requests are high, the utilization rate of the dedicated asset is close to ideal at 62.3%. This also can have two interpretations. For one, it possibly indicates a need for analysis to determine the feasibility of a second dedicated asset (since the fleet of C-17s, KC-135s are taking up roughly 31% of missions that could be covered by a more cost-effective airframe). Alternatively, it could be viewed as providing enough use of the current system to satisfy training requirements. When forces draw down so too does the “forward” AE system that has been honing the skills of AE personnel.

The table below includes the information that will be used when generating the costing information for the different scenarios.
Table 26: Data for Developing Costs

<table>
<thead>
<tr>
<th>Average Trip Distance</th>
<th>Miles</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2158.64</td>
<td>WMC results</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Flying Hour Cost</th>
<th>Reference</th>
<th>Cruise Speed (MPH)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-37B (G550)</td>
<td>$2,069.00</td>
<td></td>
<td>609</td>
<td>G550 handout</td>
</tr>
<tr>
<td>C-40C</td>
<td>$2,901.00</td>
<td></td>
<td>609</td>
<td></td>
</tr>
<tr>
<td>C-17</td>
<td>$11,145.00</td>
<td>AMC handout</td>
<td>563</td>
<td>AF Fact Sheet</td>
</tr>
<tr>
<td>KC-135</td>
<td>$6,851.00</td>
<td></td>
<td>530</td>
<td></td>
</tr>
<tr>
<td>C-130</td>
<td>$5,368.00</td>
<td></td>
<td>366</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contract Costs</th>
<th>Cost</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Runway Cost</td>
<td>$3,708,000.00</td>
<td>CCA handout</td>
</tr>
<tr>
<td>per Mile up to 200K</td>
<td>$8.15</td>
<td></td>
</tr>
<tr>
<td>per Mile 200K-400K</td>
<td>$7.00</td>
<td></td>
</tr>
<tr>
<td>per Mile over 400K</td>
<td>$5.15</td>
<td></td>
</tr>
</tbody>
</table>

With the above table the numbers that pertain to which AC complete the Urgent and Priority missions can be used to determine flying hours for the different airframes (below)

Table 27: DOE Flying Hours

<table>
<thead>
<tr>
<th>Scenario (Redistribution/PMR)</th>
<th>Notional Model Flying Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DA</td>
</tr>
<tr>
<td>L/L</td>
<td>484.07</td>
</tr>
<tr>
<td>L/M</td>
<td>880.35</td>
</tr>
<tr>
<td>L/H</td>
<td>1492.73</td>
</tr>
<tr>
<td>M/L</td>
<td>472.73</td>
</tr>
<tr>
<td>M/M</td>
<td>881.89</td>
</tr>
<tr>
<td>M/H</td>
<td>1483.05</td>
</tr>
<tr>
<td>H/L</td>
<td>473.91</td>
</tr>
<tr>
<td>H/M</td>
<td>865.47</td>
</tr>
<tr>
<td>H/H</td>
<td>1489.90</td>
</tr>
</tbody>
</table>

With flying hours, cost estimates can be drawn for the different alternatives.
Redistribution needs to be addressed for a total cost to be derived for the different scenarios (below).

The redistribution of patients is assumed to be viable with the civilian contracted G550. With all the previous numbers the total costs are generated for the different systems.
Table 30: DOE Total Costs

<table>
<thead>
<tr>
<th>Scenario (Redistribution/PMR)</th>
<th>Total Costs per System</th>
<th>Comparative Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C-37B</td>
<td>C-40C</td>
</tr>
<tr>
<td>L/L</td>
<td>$2.27</td>
<td>$2.90</td>
</tr>
<tr>
<td>L/M</td>
<td>$4.50</td>
<td>$5.46</td>
</tr>
<tr>
<td>L/H</td>
<td>$10.92</td>
<td>$12.40</td>
</tr>
<tr>
<td>M/L</td>
<td>$2.76</td>
<td>$3.61</td>
</tr>
<tr>
<td>M/M</td>
<td>$5.18</td>
<td>$6.38</td>
</tr>
<tr>
<td>M/H</td>
<td>$11.52</td>
<td>$13.22</td>
</tr>
<tr>
<td>H/L</td>
<td>$3.91</td>
<td>$5.23</td>
</tr>
<tr>
<td>H/M</td>
<td>$6.25</td>
<td>$7.89</td>
</tr>
<tr>
<td>H/H</td>
<td>$12.47</td>
<td>$14.64</td>
</tr>
</tbody>
</table>

Here the results include the comparative values if one of the current airframes completes all PMRs and redistribution requests. Taking the most practical current AC, the KC-135 (higher flying hour cost than the C-130 is offset by its faster speed) that of the C-37B and C-40C hybrid systems. This rides on the assumption that AMC can acquired one of the AC from the AF’s current inventory and station AE crews at Tinker AFB. On average (across all scenario’s), the C-37B comes in at 58 % lower than the KC-135. In the most stressed scenario 9 (604 PMRs and 312 redistribution requests) the C-37B is 51% lower in cost than the KC-135; this even when using the C-17 (for overflow) 13.2 % of the time. The C-40C hybrid system comes in at 49.2 % of the KC-135 annual average cost across all scenarios.

The contracted G550 hybrid system alternative, which utilizes the C-17 and KC-135 for PMR overflows and completes all redistribution moves, competed slightly well against the KC-135 alone. On average it came in at 3.7 % lower than the cost of the KC-135 across all scenarios. Although the result is higher, the costs associated with a contracted AC include “Crew/Gas/Maintenance”. If these costs were factored in for the KC-135, it would be assumed that the contracted G550 would have the advantage.
Costs suggest the pursuit of an AC more tailored to the Urgent and Priority AE mission. When comparing the different AC from a patient care perspective, the current AE arrangement is more engineered for supporting combat operations. The following table summarizes attributes pertaining to patient care.

**Table 31: Patient Care Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Onboard Oxygen</th>
<th>Comfort Level</th>
<th>Easy On &amp; Off Loading</th>
<th>Mass Casualty Support</th>
<th>Speed of Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-130</td>
<td>N</td>
<td>L</td>
<td>Y</td>
<td>Y</td>
<td>L</td>
</tr>
<tr>
<td>KC-135</td>
<td>N</td>
<td>L</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
</tr>
<tr>
<td>C-17</td>
<td>Y</td>
<td>M</td>
<td>Y</td>
<td>Y</td>
<td>M</td>
</tr>
<tr>
<td><em>C-37B</em></td>
<td>Y</td>
<td>H</td>
<td>N</td>
<td>N</td>
<td>H</td>
</tr>
<tr>
<td><em>C-40C</em></td>
<td>Y</td>
<td>H</td>
<td>Y</td>
<td>Y</td>
<td>H</td>
</tr>
<tr>
<td>Contract G550</td>
<td>Y</td>
<td>H</td>
<td>N</td>
<td>N</td>
<td>H</td>
</tr>
</tbody>
</table>

*Assuming remodeled for Dedicated AE Mission*

The C-130 and KC-135 are not noted as being comfortable AC for patients. The pair also lack onboard oxygen and the C-130 is the slowest of all AC featured with a cruise speed of 366 mph. These airframes are best suited as AC of opportunity in times of conflict and during natural disaster events. This applies to the C-17 also; however, the C-17 is noted as being the most patient care friendly set-up in the current arrangement.

A G550 under contract would be specifically dedicated to the AE mission. Patient comfort would be high and only hampered by not being considered and easy on & off AC (Air Mobility Command, 2011). Another issue with the G550 is that it would not be very effective during a mass casualty event with a capacity of 12 passengers; which leaves little room when considering space for AE medical providers and litter patients. The speed of a contracted dedicated asset would not be an issue as well as the interior being specifically made for patient care. The C-37B could assume to be equivalent to the asset
under contract since if assigned to AMC it would be assumed to be remodeled for the AE mission.

The C-40C possibly presents the most interesting possibilities. The assumption is that if assigned to AMC, it also would be remodeled for patient care. With a larger remodeled C-40C, the AE mission would have a versatile asset ready for a wide variety of missions. Patient care would be high with features like onboard oxygen and climate control. The speed would be equivalent to the C-37B and the interior would potentially be able to accommodate more patients than any of the current AE AC.

V. Conclusion, Recommendation and Future Study

After looking at different arrangements of a hybrid dedicated AE system, it is the conclusion that the C-40C is best suited for the Urgent and Priority AE mission. Based on flying hour costs, it is recommended to pursue a C-40C from the AF inventory and retrofit a large cargo door like in Figure 17: US Navy’s C-40A Clipper (Defense Industry Daily Staff, 2012). Having a single dedicated asset would take a large portion of work away from non-specialized expensive AC like the C-17. The overflow from the C-40C (situations when busy) would give platforms like the C-17 and C-130 AE practice for times of conflict. This would still maintain the “Train like we fight” mentality while optimizing costs.
Future Work

This study of the AE process focused on the continental Urgent / Priority piece, which is just a small part of the total AE mission. The whole AE mission encompasses US military personnel across the entire globe. The heaviest tasked section during current times is those supporting operations abroad. When patients are in-theater, there is not a TRICARE option so transport for all AE (including all routine) must be routed out of country. The workhorse for these missions is the C-17 leaving room for retroactive studies to show if investment in a dedicated platform would have been operationally feasible and optimal.

The simulation could be expanded to explore the outer-bounds of the range of newer aircraft, servicing possibly Alaska, Hawaii and other distant US military locations from a centralized stateside location. The G550 has a 6,750 nautical mile range, thus having the ability to fly non-stop from Washington D.C. to Dubai (Gulfstream, 2012). Ranges could
be set within the model where movement of a Priority patient in Northern Africa would have the option of returning to the US versus heading to Landstuhl AB.

Mass evacuation events and how they factor into the AE mission are absent from this study. Modeling such events would be helpful in determining how dedicated and non-dedicated AC would perform. Events could range from natural disaster to ones requiring patient decontamination. Such a simulation model could give valuable insights into both arrangements.

The decision to either airlift patients or have them seen by local civilian providers could be tested with the idea of dedicated assets. Like the decision flowchart in Figure 9: DODI 6000.11 Decision Flowchart, an AF AE mission is only tasked when associated costs fall lower than local civilian care. A dedicated asset that has a lower flying hour cost then would potentially capture more AE missions. A study to determine the optimal proportion of dedicated asset missions to those sent to local civilian care could be done. Included could be a value focused thinking approach for costs and non-costs of military versus civilian care.
# VI. Appendix

## Acronym List

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAMS</td>
<td>Australian Aerial Medical Services</td>
</tr>
<tr>
<td>AC</td>
<td>Aircraft</td>
</tr>
<tr>
<td>AE</td>
<td>Air Evacuation</td>
</tr>
<tr>
<td>AFB</td>
<td>Air Force Base</td>
</tr>
<tr>
<td>AFPAM</td>
<td>Air Force Pamphlet</td>
</tr>
<tr>
<td>AFTTP</td>
<td>Air Force Tactics, Techniques and Procedures</td>
</tr>
<tr>
<td>Air-Evac</td>
<td>Aeromedical Evacuation</td>
</tr>
<tr>
<td>AMC</td>
<td>Air Mobility Command</td>
</tr>
<tr>
<td>CAA</td>
<td>Civilian Air Ambulance</td>
</tr>
<tr>
<td>Case-Evac</td>
<td>Casualty Evacuation</td>
</tr>
<tr>
<td>CONUS</td>
<td>Continental United States</td>
</tr>
<tr>
<td>CP</td>
<td>Cruise Speed</td>
</tr>
<tr>
<td>CRAF</td>
<td>Civil Reserve Air Fleet</td>
</tr>
<tr>
<td>DES</td>
<td>Discrete Event Simulation</td>
</tr>
<tr>
<td>DOE</td>
<td>Design of Experiments</td>
</tr>
<tr>
<td>DOTMLPF</td>
<td>Doctrine, Organization, Training, Maintenance, Leadership, Personnel and Facilities</td>
</tr>
<tr>
<td>EHR</td>
<td>Electronic Medical Record</td>
</tr>
<tr>
<td>EPC</td>
<td>End Point of Care</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FM</td>
<td>Field Manual</td>
</tr>
<tr>
<td>GPMRC</td>
<td>Global Patient Movements Requirement Center</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphic User Interface</td>
</tr>
<tr>
<td>IP</td>
<td>Integer Programming</td>
</tr>
<tr>
<td>ITV</td>
<td>In-Transient Visibility</td>
</tr>
<tr>
<td>JDMS</td>
<td>Journal of Defense Modeling and Simulation</td>
</tr>
<tr>
<td>JOSAC</td>
<td>Joint Operational Support Airlift Center</td>
</tr>
<tr>
<td>KS</td>
<td>Kolmogorov-Smirnov</td>
</tr>
<tr>
<td>LCC</td>
<td>Life Cycle Cost</td>
</tr>
<tr>
<td>LF</td>
<td>Landing Factor</td>
</tr>
<tr>
<td>MAAF</td>
<td>Mobility Aircraft Availability Forecasting</td>
</tr>
<tr>
<td>MAC</td>
<td>Military Airlift Command</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>MATS</td>
<td>Military Air Transport Service</td>
</tr>
<tr>
<td>MC</td>
<td>Mission Capable</td>
</tr>
<tr>
<td>MCC</td>
<td>Mission Control Center</td>
</tr>
<tr>
<td>MCRT</td>
<td>Minimum Crew Rest Time</td>
</tr>
<tr>
<td>Medevac</td>
<td>Medical Evacuation</td>
</tr>
<tr>
<td>MILP</td>
<td>Mixed Integer Linear Program</td>
</tr>
<tr>
<td>MSE</td>
<td>Mean Square Error</td>
</tr>
<tr>
<td>MTF</td>
<td>Medical Treatment Facility</td>
</tr>
<tr>
<td>NPS</td>
<td>Naval Post-Graduate School</td>
</tr>
<tr>
<td>OEF</td>
<td>Operation Enduring Freedom</td>
</tr>
<tr>
<td>OIF</td>
<td>Operation Iraqi Freedom</td>
</tr>
<tr>
<td>OOT</td>
<td>Onload and Offload Time</td>
</tr>
<tr>
<td>PACAF</td>
<td>Pacific Command</td>
</tr>
<tr>
<td>PM</td>
<td>Patient Movement</td>
</tr>
<tr>
<td>PMCC</td>
<td>Patient Movement Clinical Coordinator</td>
</tr>
<tr>
<td>PMR</td>
<td>Patient Movement Request</td>
</tr>
<tr>
<td>PMRC</td>
<td>Patient Movements Requirement Center</td>
</tr>
<tr>
<td>POI</td>
<td>Point of Injury</td>
</tr>
<tr>
<td>QTS</td>
<td>Queueing Theory Software</td>
</tr>
<tr>
<td>SME</td>
<td>Subject Matter Expert</td>
</tr>
<tr>
<td>TACC</td>
<td>Tanker/Airlift Control Center</td>
</tr>
<tr>
<td>TAD</td>
<td>Total Average Distance</td>
</tr>
<tr>
<td>TF</td>
<td>Takeoff Factor</td>
</tr>
<tr>
<td>TRAC2ES</td>
<td>TRANSCOM Regulating and Command and Control Evacuation System</td>
</tr>
<tr>
<td>UAS</td>
<td>Unmanned Aerial System</td>
</tr>
<tr>
<td>USAFA</td>
<td>United States Air Force Academy</td>
</tr>
<tr>
<td>VFS</td>
<td>Validating Flight Surgeon</td>
</tr>
<tr>
<td>WMC</td>
<td>Weighted Mean Center</td>
</tr>
<tr>
<td>WPAFB</td>
<td>Wright-Patterson Air Force Base</td>
</tr>
</tbody>
</table>
MATLAB Code (example)

%initialize the environment
clear all; clc; format short;

%load the data file. 57 latitudes and longitudes of Major CONUS AFB's
load Latitude.mat;
load Longitude.mat;

latN = [29.34167,38.26278,38.81083]; % Brooks, Travis, Andrews latitude (N)
longW = [98.43518,121.9275,76.86694]; % Brooks, Travis, Andrews longitude (W)

for j = 1 : 3
for i = 1 : size(Lat)

% Earth radius in km
R = 6371;
% Coordinates of two points.
lat1 = latN(j);
long1 = longW(j);
lat2 = Lat(i,:);
long2 = Lon(i,:);

% Converts degrees into gradians
lat1 = lat1*2*pi/360;
lat2 = lat2.*2*pi/360;
long1 = long1*2*pi/360;
long2 = long2.*2*pi/360;
dlat = lat2-lat1;
dlong = long2-long1;
a = (sin(dlat/2))^2 + cos(lat1)*cos(lat2)*(sin(dlong/2))^2;
c = 2*atan2(sqrt(a), sqrt(1-a));
d = R*c*.6214;
x(i,j) = d;

end
end

AvgDist = mean(x);
MaxDist = max(x);
fprintf('The max distance is %3.4f \n',MaxDist)
fprintf('The average distance is %3.4f \n',AvgDist)

(Peyrad, 2011)
LINGO Code (2 region model)

model:

title Hub Allocation 2 ;

sets:
  Location : Population;
  Hub: ;
  Links(Location, Hub) : X , Distances;
endsets

data:
Location, Hub, Distances, Population = @ole('AELingoInput2.XLSX', 'Location', 'Hub', 'Distances', 'Population') ;
TotalPop = 249848;

@text() = ' to Travis AFB Area ';
@text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 2: 'Assign ', Location(i),
  @newline(1));

@text() = ' to Andrews AFB Area ';
@text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 3: 'Assign ', Location(i),
  @newline(1));
enddata

min = @sum(Links(i,j): X(i,j) * Distances(i,j)); ! Minimizes based off of distances from hubs ;

@for(Location(i): @sum(Hub(j): X(i,j)) = 1); ! ensures only one hub is assigned to a location ;

@for(Hub(i): @sum(Location(j): X(j,i)) >= 27); ! Lower number of location assignments to a hub ;

@for(Hub(i): @sum(Location(j): X(j,i)) <= 29); ! Upper number of location assignments to a hub ;

@for(Hub(i): @sum(Location(j): X(j,i)*Population(j))/TotalPop >= .32); ! Lower percentage of location assignments to a hub ;

@for(Hub(i): @sum(Location(j): X(j,i)*Population(j))/TotalPop <= .34); ! Upper percentage of location assignments to a hub ;

@for( Links: @BIN( X));
end
LINGO Code (3 region model)

model:

title Hub Allocation;

sets:
    Location : Population;
    Hub: ;
    Links(Location, Hub) : X , Distances;
endsets

data:
    Location, Hub, Distances, Population = @ole('AELing0Input3edit.XLSX',
    'Location', 'Hub', 'Distances', 'Population') ;
    TotalPop = 249848;

    @text() = ' to Brooks AFB Area ';
    @text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 1:
        'Assign ', Location(i),
        @newline(1));

    @text() = ' to Travis AFB Area ';
    @text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 2:
        'Assign ', Location(i),
        @newline(1));

    @text() = ' to Andrews AFB Area ';
    @text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 3:
        'Assign ', Location(i),
        @newline(1));
enddata

min = @sum(Links(i,j): X(i,j) * Distances(i,j)); ! Minimizes based off of distances from hubs ;

@for(Location(i): @sum(Hub(j): X(i,j)) = 1); ! ensures only one hub is assigned to a location ;

@for(Hub(i): @sum(Location(j): X(j,i)) >= 18); ! Lower number of location assignments to a hub ;

@for(Hub(i): @sum(Location(j): X(j,i)) <= 19); ! Upper number of location assignments to a hub ;

@for(Hub(i): @sum(Location(j): X(j,i)*Population(j))/TotalPop >= .32); ! Lower percentage of location assignments to a hub ;

@for(Hub(i): @sum(Location(j): X(j,i)*Population(j))/TotalPop <= .34); ! Upper percentage of location assignments to a hub ;

@for( Links: @BIN( X));
End
LINGO Code (4 region model)

model:

title Hub Allocation 4;

sets:
  Location : Population;
  Hub: ;
  Links(Location, Hub) : X , Distances;
endsets

data:
  Location, Hub, Distances, Population = @ole('AELingoInput4.XLSX', 'Location', 'Hub', 'Distances', 'Population');

  TotalPop = 240032;

  @text() = ' to Brooks AFB Area ';
  @text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 1:
     'Assign ', Location(i),
     @newline(1));

  @text() = ' to Travis AFB Area ';
  @text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 2:
     'Assign ', Location(i),
     @newline(1));

  @text() = ' to Andrews AFB Area ';
  @text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 3:
     'Assign ', Location(i),
     @newline(1));

  @text() = ' to USAFA Area ';
  @text() = @writefor(Links(i,j) | X(i,j) #gt# 0 #AND# j #eq# 4:
     'Assign ', Location(i),
     @newline(1));
enddata

min = @sum(Links(i,j): X(i,j) * Distances(i,j)); ! Minimizes based off of distances from hubs ;

@for(Location(i): @sum(Hub(j): X(i,j)) = 1); ! ensures only one hub is assigned to a location ;

@for(Hub(i): @sum(Location(j): X(j,i)) = 13); ! Lower number of location assignments to a hub ;

@for(Hub(i): @sum(Location(j): X(j,i)*Population(j))/TotalPop >= .24); ! Lower percentage of location assignments to a hub ;

@for(Hub(i): @sum(Location(j): X(j,i)*Population(j))/TotalPop <= .26); ! Upper percentage of location assignments to a hub ;
@for( Links: @BIN(X)); !ensures and integer solution;
End

LINGO Output *condensed (2 region model)

Global optimal solution found.
Objective value: 43390.96
Objective bound: 43390.96
Infeasibilities: 0.000000
Extended solver steps: 2
Total solver iterations: 75

to Travis AFB Area
Assign BEALE_AIR_FORCE_BASE
Assign BUCKLEY_AIR_FORCE_BASE
Assign CANNON_AIR_FORCE_BASE
Assign DAVIS_MONTHAN_AIR_FORCE_BASE
Assign DYESS_AIR_FORCE_BASE
Assign EDWARDS_AIR_FORCE_BASE
Assign ELLSWORTH_AIR_FORCE_BASE
Assign FAIRCHILD_AIR_FORCE_BASE
Assign FRANCIS_E_WARREN_AIR_FORCE_BASE
Assign GRAND_FORKS_AIR_FORCE_BASE
Assign HILL_AIR_FORCE_BASE
Assign HOLLoman_AIR_FORCE_BASE
Assign KIRTLAND_AIR_FORCE_BASE
Assign LOS_ANGELES_AIR_FORCE_BASE
Assign LUKE_AIR_FORCE_BASE
Assign Malmstrom_AIR_FORCE_BASE
Assign MCCORD_AIR_FORCE_BASE
Assign MCCONNELL_AIR_FORCE_BASE
Assign MINOT_AIR_FORCE_BASE
Assign MOUNTAIN_HOME_AIR_FORCE_BASE
Assign NELLIS_AIR_FORCE_BASE
Assign OFFUTT_AIR_FORCE_BASE
Assign PETERSON_AIR_FORCE_BASE
Assign SCHRIEVER_AIR_FORCE_BASE
Assign SHEPPARD_AIR_FORCE_BASE
Assign TINKER_AIR_FORCE_BASE
Assign UNITED_STATES_AIR_FORCE_Academy
Assign VANDENBERG_AIR_FORCE_BASE

to Andrews AFB Area
Assign ALTUS_AIR_FORCE_BASE
Assign ARNOLD_AIR_FORCE_BASE
Assign BARKSDALE_AIR_FORCE_BASE
Assign CHARLESTON_AIR_FORCE_BASE
Assign COLUMBUS_AIR_FORCE_BASE
Assign DOVER_AIR_FORCE_BASE
Assign EGLIN_AIR_FORCE_BASE
Assign GOODFELLOW_AIR_FORCE_BASE
Assign HANSCOM_AIR_FORCE_BASE
Assign HURLBURT_FIELD
Assign KEESLER_AIR_FORCE_BASE
Assign LANGLEY_AIR_FORCE_BASE
Assign LAUGHLIN_AIR_FORCE_BASE
Assign LITTLE_ROCK_AIR_FORCE_BASE
Assign MACDILL_AIR_FORCE_BASE
Assign MAXWELL_AIR_FORCE_BASE
Assign MCGUIRE_AIR_FORCE_BASE
Assign MOODY_AIR_FORCE_BASE
Assign PATRICK_AIR_FORCE_BASE
Assign POPE_ARMY_AIRFIELD
Assign ROBINS_AIR_FORCE_BASE
Assign SCOTT_AIR_FORCE_BASE
Assign SEYMOUR_JOHNSON_AIR_FORCE_BASE
Assign SHAW_AIR_FORCE_BASE
Assign TYNDALL_AIR_FORCE_BASE
Assign VANCE_AIR_FORCE_BASE
Assign WHITEMAN_AIR_FORCE_BASE
Assign WRIGHT_PATTERSON_AIR_FORCE_BASE

Model Title: Hub Allocation 2

LINGO Output *condensed (3 region model)

Global optimal solution found.  
Objective value: 32100.87  
Objective bound: 32100.87  
Infeasibilities: 0.000000  
Extended solver steps: 2  
Total solver iterations: 867

to Brooks AFB Area
Assign ALTUS_AIR_FORCE_BASE
Assign BARKSDALE_AIR_FORCE_BASE
Assign BUCKLEY_AIR_FORCE_BASE
Assign CANNON_AIR_FORCE_BASE
Assign DYESS_AIR_FORCE_BASE
Assign EGLIN_AIR_FORCE_BASE
Assign GOODFELLOW_AIR_FORCE_BASE
Assign HOLLOMAN_AIR_FORCE_BASE
Assign HURLBURT_FIELD
Assign KEESLER_AIR_FORCE_BASE
Assign LAUGHLIN_AIR_FORCE_BASE
Assign LITTLE_ROCK_AIRFORCE_BASE
Assign MCCONNELL_AIR_FORCE_BASE
Assign SCHRIEVER_AIR_FORCE_BASE
Assign SHEPPARD_AIR_FORCE_BASE
Assign TINKER_AIR_FORCE_BASE
Assign TYNDALL_AIR_FORCE_BASE
Assign VANCE_AIR_FORCE_BASE
Assign WHITEMAN_AIR_FORCE_BASE

to Travis AFB Area

61
Assign BEALE_AIR_FORCE_BASE
Assign DAVIS_MONTHAN_AIR_FORCE_BASE
Assign EDWARDS_AIR_FORCE_BASE
Assign ELLSWORTH_AIR_FORCE_BASE
Assign FAIRCHILD_AIR_FORCE_BASE
Assign FRANCIS_E__WARREN_AIR_FORCE_BASE
Assign HILL_AIR_FORCE_BASE
Assign KIRTLAND_AIR_FORCE_BASE
Assign LOS_ANGELES_AIR_FORCE_BASE
Assign LUKE_AIR_FORCE_BASE
Assign MALMSTROM_AIR_FORCE_BASE
Assign MCCHORD_AIR_FORCE_BASE
Assign MINOT_AIR_FORCE_BASE
Assign MOUNTAIN_HOME_AIR_FORCE_BASE
Assign NELLIS_AIR_FORCE_BASE
Assign OFFUTT_AIR_FORCE_BASE
Assign PETERSON_AIR_FORCE_BASE
Assign UNITED_STATES_AIR_FORCE_ACADEMY
Assign VANDENBERG_AIR_FORCE_BASE
Assign ARNOLD_AIR_FORCE_BASE
Assign BARKSDALE_AIR_FORCE_BASE
Assign ARNOLD_AIR_FORCE_BASE
Assign CHARLESTON_AIR_FORCE_BASE
Assign COLUMBUS_AIR_FORCE_BASE
Assign DOVER_AIR_FORCE_BASE
Assign GRAND_FORKS_AIR_FORCE_BASE
Assign HANSCOM_AIR_FORCE_BASE
Assign LANGLEY_AIR_FORCE_BASE
Assign MCDADE_AIR_FORCE_BASE
Assign MAXWELL_AIR_FORCE_BASE
Assign MCGUIRE_AIR_FORCE_BASE
Assign MOODY_AIR_FORCE_BASE
Assign PATRICK_AIR_FORCE_BASE
Assign POPE_ARMY_AIRFIELD
Assign ROBINS_AIR_FORCE_BASE
Assign SCOTT_AIR_FORCE_BASE
Assign SEYMOUR_JOHNSON_AIR_FORCE_BASE
Assign SHAW_AIR_FORCE_BASE
Assign WRIGHT_PATTERSON_AIR_FORCE_BASE

Model Title: Hub Allocation

**LINGO Output *condensed (4 region model)**

Global optimal solution found.
Objective value: 25779.83
Objective bound: 25779.83
Infeasibilities: 0.000000
Extended solver steps: 0
Total solver iterations: 795

Assign ARNOLD_AIR_FORCE_BASE
Assign BARKSDALE_AIR_FORCE_BASE

62
Assign COLUMBUS_AIR_FORCE_BASE
Assign DYESS_AIR_FORCE_BASE
Assign EGLIN_AIR_FORCE_BASE
Assign GOODFELLOW_AIR_FORCE_BASE
Assign HURLBURT_FIELD
Assign KEESLER_AIR_FORCE_BASE
Assign LAUGHLIN_AIR_FORCE_BASE
Assign LITTLE_ROCK_AIR_FORCE_BASE
Assign MAXWELL_AIR_FORCE_BASE
Assign TYNDALL_AIR_FORCE_BASE
Assign VANCE_AIR_FORCE_BASE
    to Travis AFB Area
Assign BEALE_AIR_FORCE_BASE
Assign DAVIS_MONTHAN_AIR_FORCE_BASE
Assign EDWARDS_AIR_FORCE_BASE
Assign FAIRCHILD_AIR_FORCE_BASE
Assign HILL_AIR_FORCE_BASE
Assign LOS_ANGELES_AIR_FORCE_BASE
Assign LUKE_AIR_FORCE_BASE
Assign MALMSTROM_AIR_FORCE_BASE
Assign MCCORD_AIR_FORCE_BASE
Assign MOUNTAIN_HOME_AIR_FORCE_BASE
Assign NELLIS_AIR_FORCE_BASE
Assign TINKER_AIR_FORCE_BASE
Assign VANDENBERG_AIR_FORCE_BASE
    to Andrews AFB Area
Assign CHARLESTON_AIR_FORCE_BASE
Assign DOVER_AIR_FORCE_BASE
Assign HANSCOM_AIR_FORCE_BASE
Assign LANGLEY_AIR_FORCE_BASE
Assign MACDILL_AIR_FORCE_BASE
Assign MCGUIRE_AIR_FORCE_BASE
Assign MOODY_AIR_FORCE_BASE
Assign PATRICK_AIR_FORCE_BASE
Assign POPE_ARMY_AIRFIELD
Assign ROBINS_AIR_FORCE_BASE
Assign SEYMOUR_JOHNSON_AIR_FORCE_BASE
Assign SHAW_AIR_FORCE_BASE
Assign WRIGHT_PATTERSON_AIR_FORCE_BASE
    to USAFA Area
Assign ALTUS_AIR_FORCE_BASE
Assign CANNON_AIR_FORCE_BASE
Assign ELLSWORTH_AIR_FORCE_BASE
Assign FRANCIS_E_WARREN_AIR_FORCE_BASE
Assign GRAND_FORKS_AIR_FORCE_BASE
Assign HOLLOMAN_AIR_FORCE_BASE
Assign KIRTLAND_AIR_FORCE_BASE
Assign MCCONNEL_AIR_FORCE_BASE
Assign MINOT_AIR_FORCE_BASE
Assign OFFUTT_AIR_FORCE_BASE
Assign SCOTT_AIR_FORCE_BASE
Assign SHEPPARD_AIR_FORCE_BASE
Assign WHITEMAN_AIR_FORCE_BASE

Model Title: Hub Allocation 4
**URGENT AEROMEDICAL EVACUATION NETWORK CAPACITY PLANNING**

**RESEARCH QUESTION**
- Is it desirable for AMC to have dedicated aircraft (either owned or contracted) that could be tasked first before using current non-specialized ACs?

**RESEARCH OBJECTIVES**
- Develop idea of new hybrid dedicated asset system
- Find best locations for AE assets
- Determine number of AE assets at different locations
- Use simulation to determine costs and utilization of hybrid system

**RESEARCH SPONSOR**
Air Mobility Command, Scott AFB, IL

**RESULTS**
- C-37B performs best from a cost perspective
- Contracted QSSO comparable to lowest current aircraft however also includes crew, fuel and maintenance costs (requires further study)
- C-40C performs best on Quality of Care factors

**CONCLUSION**
- **C-37B** performs best from a cost perspective
- Contracted QSSO comparable to lowest current aircraft however also includes crew, fuel and maintenance costs (requires further study)
- **C-40C** performs best on Quality of Care factors

**RECOMMENDATION**
Explore acquisition of C-40C aircraft due to low flying hour costs and potential to provide same or greater capacity than current aircraft.
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Urgent Aeromedical Evacuation Network Capacity Planning

Aeromedical Evacuation (AE) has been steadily utilized during Operation Iraqi Freedom and Operation Enduring Freedom. AE is a global enterprise. The current structure of AE is facing changes as forces scale down from operations in Iraq and Afghanistan. AE will, however, continue to be important in its domestic use in the continental USA (CONUS). Current practice is to pull aircraft (e.g. C-17, C-130 or KC-135) from their normal operations to meet Urgent and Priority patient needs when local alternatives are infeasible. An alternative to the current system would be having a centralized “bed-down” location for AE operations that would house dedicated aircraft as well as AE personnel. In this thesis, a hybrid queuing and discrete-event simulation approach is used to determine how many aircraft are needed for a given level of AE patient care and an integer programming model is used to locate aircraft within the provider network. The high costs associated with operating current aircraft drive this research to look for solutions that better represent the future of Urgent and Priority patient movement operations whether CONUS or global.

15. SUBJECT TERMS
Aeromedical Evacuation, Dedicated, Urgent, Priority, Queueing, Discrete-Event Simulation

16. SECURITY CLASSIFICATION OF:
 a. REPORT U
 b. ABSTRACT U
 c. THIS PAGE U

17. LIMITATION OF ABSTRACT
UU

18. NUMBER OF PAGES 81

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