**EPIDEMIOLOGY, COST, AND AIRCRAFT CHOICE
FOR AEROMEDICAL EVACUATION IN AFRICOM**

THESIS

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Abstract

A significant shortfall exists in the medical capability provided to US Service members deployed to the African Area of Responsibility because of unknown epidemiology, large distances, limited resources, and high patient movement cost. The first step in closing this gap is to understand the types, demographics, diagnoses, and distribution of the patients requiring aeromedical evacuation. This research examined the DoD's aeromedical evacuation missions from Africa between 2010 and 2014. Of the 274 patients and 170 missions identified from available data, a gap is evident in aeromedical evacuation capability with over 23% of Priority patients and almost 10% of Urgent patients picked-up beyond the critical 24-hour mark. A decision tree and web-based decision support tool are proposed that identified improper airlift choice in 46 of the 170 missions examined. These decisions cost the DoD $2.6M. Making better aeromedical movement decisions can enable the DoD to reallocate funds to reduce the existing medical gap in Africa.

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To my Wife and Daughter

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                     Daniel A. Griffith

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Table of Contents

List of Figures

List of Tables

EPIDEMIOLOGY, COST, AND AIRCRAFT CHOICE

FOR AEROMEDICAL EVACUATION IN AFRICOM

I.   Introduction

The Department of Defense lists Logistics and Force Support as two of their nine core competencies (Gates, 2009). One piece of these skill sets is ensuring adequate medical response in the form of aeromedical evacuation. As such, the DoD maintains personnel and equipment to facilitate global patient movement with the primary goal of supporting US military members involved in contingency operations (Department, 2012b). Since 2001, the DoD moved more than 150,000 patients in Iraq and Afghanistan (USTC, 2015). From the aircraft design and dispatch centers, to the alliances and partnerships with other nations and civilian corporations, the DoD has the capability to move large numbers of patients worldwide.

General Issue

Over the last 14 years, the DoD essentially automated patient movement from Iraq and Afghanistan. By building medical treatment facilities in both countries, the DoD created a network of medical support that provided surgical care and stabilization in theater. This infrastructure allowed the establishment of aeromedical evacuation channel missions that ensured patient movements occurred within the appropriate timeframes as specified by regulation (Routine-72 hours; Priority-24 hours; Urgent-ASAP) (Department, 2014).

Within AFRICOM, however, the current construct of patient movement does not appear to support the military to the same level experienced in CENTCOM. Africa is a large continent consisting of 11.7 million square miles and 54-58 countries (Wikipedia, 2015). Each of these

countries has various degrees of stability, economic prosperity, terrorist activities, and amenability toward the US. The US relies on multiple small-scale operations to pursue its interests in promoting a stabilized Africa. As a result, the DoD has a small number of troops spread over a very large area, each with limited access to medical or aeromedical evacuation support (Whitlock, 2012). The only base with a surgical medical capability in Africa is Camp Lemonnier, located in Djibouti (Schmidt, 2005).

In the current patient movement system, each Service Component provides its own patient movement from point of injury to initial stabilization (Department, 1996). The aeromedical evacuation system then moves "stabilized" patients from one medical treatment facility to another. In many countries, the DoD relies on the local medical systems for this support, but the majority of Africa lacks adequate medical infrastructure, requiring the DoD to provide its own support (Mullan, et al., 2011). However, given the sparse nature of troops, the complicated political environment, and the high cost to supply medical assets in theater, the DoD does not typically provide surgical level medical support to anyone outside the Camp Lemonnier catchment area. As a result, when members become ill or wounded, even small issues become unstable and generate a Priority or Urgent Patient Movement Request (PMR) due to the inability to treat patients onsite. At the same time, the Air Force does not man, train, or equip the aeromedical evacuation system to move unstable patients. Therefore, the inability to stabilize and hold patients within Africa places unwarranted pressure on the aeromedical evacuation system to move patients in an unsafe manner (Department, 2014). Further complicating the situation, the closest military aeromedical evacuation support is located at Ramstein Air Base, Germany. This distance makes it difficult to move a Priority patient within the 24-hour requirement, and in most cases, impossible to move an Urgent patient with military aeromedical

evacuation assets. The vast distances, coupled with the high cost to support few troops, and the poor state of the local medical infrastructure poses an obvious problem for the traditional construct of patient movement planning and execution. To compensate for this lack of medical and aeromedical evacuation support, the DoD relies on civilian air ambulance contracts to fill the gap in service. However, these contracts are expensive and have limited use during contingency operations. Compounding the issue, little analysis exists on the cost, incidence, distribution, causes, and requirements for aeromedical evacuation in Africa. This lack of awareness translates to a gap in preparation and planning that is necessary for executing adequate medical support in Africa.

Problem Statement

Due to the unknown epidemiology, the large distances, limited resources, and the high cost to support a sparse number of personnel, there is a significant gap in the medical capability provided to US Service Members deployed to the African Area of Responsibility (AOR) as compared to other AORs.

Research Objectives/Research Questions & Hypotheses

The goal of this research is fourfold. 1) Perform a descriptive epidemiological analysis of the types, demographics, and distribution of the diagnosis requiring aeromedical evacuation transport in Africa. 2) Calculate the current cost of performing aeromedical evacuation in Africa. 3) Develop a decision tool that shows the current gaps and helps planners determine the most cost effective aircraft for aeromedical evacuation in Africa. 4) Determine any cost savings available through aircraft choice. This study considers the four most common aircrafts for

aeromedical evacuation to include C-130s, C-21s, C-17s, and civilian air ambulances. It is the

hope of this research that identifying the epidemiology of aeromedical evacuation brings

awareness to the lack of medical coverage in Africa and helps planners identify the specific

medical capabilities and preventative factors necessary to reduce the incidence of aeromedical

evacuation. In addition, formalizing the trade-off between the most common aeromedical

evacuation platforms (C-130s, C-21s, C-17s, and civilian air ambulances) in terms of risk,

response time, and cost will result in better medical planning factors that can increase the

efficient allocation of assets and minimize the medical gap experienced by deployed personnel

on the African continent. This research addresses the following questions:

- What is the epidemiology of military aeromedical evacuation in Africa?

- What is the current cost of aeromedical evacuation in Africa?

- What is the most cost effective aircraft for aeromedical evacuation in a given
  situation?

- How much cost can the DoD avoid through proper aircraft choice?

- Where are the gaps in aeromedical evacuation coverage in Africa?

Methodology

The data required to perform the appropriate analysis includes the Patient Movement

Request records located in the TRANSCOM Regulating and Command and Control Evacuation

System (TRAC2ES) database controlled by the USTRANSCOM Surgeon General and

maintained by the Global Patient Movement Integration Center. This database captures every

Patient Movement Request made to USTRANSCOM since 2001. The data include indications

of the patients' locations, movement dates/times, precedencies (Routine, Priority, or Urgent),

diagnoses, and demographics. Additionally, this research requires data from the Global Decision Support System (GDSS), also controlled by USTRANSCOM. This system records data from all Mobility Air Force missions, to include aircraft type, take-off times, landing times, and ground times. Furthermore, this research requires access to the data from the Air Force Instruction 65-503, Table A4-1, Logistics Cost Factors Description (Air, 2015). This table is an Excel spreadsheet published by the USAF Financial Management office under the Financial Management functional area of the Air Force Portal. Accordingly, "This table calculates the logistic costs by flying hour and primary aircraft authorizations. It includes supplies, fuel, and organic/CLS (contract) maintenance and repair" (2015). Finally, this research requires access to the civilian air ambulance records held by the Theater Patient Movement Requirements Center-Europe. These records indicate the cost of each civilian air ambulance movement as quoted by the firm International SOS.

In order to conduct this research, I conduct an in-depth review and analysis of all the Patient Movement Requests from 2010-2014 within AFRICOM and cross-reference these requests with the actual mission data from GDSS. I then use the data from the Logistics Cost Factors Description and the Theater Patient Movement Requirements Center-Europe's records to determine the avoidable cost of the current aeromedical evacuation system for AFRICOM. Next, I analyze the factors that determine aircraft choice and develop a decision tree that minimizes the cost of aeromedical evacuation while maintaining regulated standards of care. Finally, I calculate the avoidable cost as if the DoD used the aircraft identified by my decision tree.

Assumptions/Limitations

This research assumes that the data reported in the TRAC2ES, GDSS, the Logistics Cost Factors Description, and the Theater Patient Movement Requirements Center-Europe databases are accurate, including the patient diagnoses and the precedence categorization. This study also assumes that the resources (work force, equipment, infrastructure, etc.) supplied by the DoD to support aeromedical evacuation are not subject to significant changes in the near future. The applicability of this study is limited to the aeromedical evacuation of US military forces deployed to Africa. As technology, medicine, and the African continent progresses, the factors identified in this research may prove insignificant.

Implications

This research can help DoD planners by providing a tool to compare various alternatives when seeking to allocate scarce resources to their most efficient use. In addition, this research identifies the current epidemiology of aeromedical evacuation in Africa, which can provide planners insight on trends and/or deficiencies with AFRICOM medical assets. Finally, the findings of this research can help inform commanders regarding the aeromedical evacuation costs and medical risks associated with extending the military's reach into more remote and austere environments.

In the next few chapters, I will review the pertinent literature regarding aeromedical evacuation in Africa. Then, I will discuss the methodologies used to research my proposed questions. Finally, I will provide the results and analysis of the research, followed by my conclusions and recommendations.

II.   Literature Review

This literature review establishes the foundation of my study. The chapter begins with an overview of the DoD's Concept of Operations for patient movement. After which, I review the current and future presence of US forces in Africa as well as the existing state of medical care and conditions on the continent. Additionally, this review describes the methods employed and the difficulties encountered by aeromedical evacuation operations in Africa. Next, this review looks at the medical literature to establish the importance of response time as a factor of survivability, after which, I look at the existing epidemiological studies concerning aeromedical evacuation. Finally, I examine the literature on costing as well as the development of decision tree models.

Patient Movement Concept of Operations

In order to provide worldwide patient movement coverage, the DoD divides patient movement into various steps, each step falling under the responsibility of different entities, but ultimately controlled by USTRANSCOM (Department, 2012b). USTRANSCOM monitors and controls "regulated" patient movement with four Joint control centers known as Patient Movement Requirements Centers (PMRCs) (Department, 1996). These centers, currently located in Hawaii, Illinois, Germany, and Qatar, provide 24-hour ability to approve, coordinate and track patient movement by coordinating organic aeromedical evacuation, civilian air ambulances, ground ambulances, commercial airline tickets, taxicab services, and other transportation functions. A "regulated" patient movement is any patient movement approved, monitored, and controlled by a Patient Movement Requirements Center (Department, 2006).

While these centers manage all types of patient movements, their focus is on aeromedical evacuation. Aeromedical evacuation is the movement of patients on fixed wing aircraft with a designated medical crew between medical treatment facilities (Department, 2014). The Air Force is responsible for all fixed-wing aeromedical evacuation and is only manned, trained, and equipped to move "stabilized" patients (Department, 2006). A stabilized patient is defined where the "patient condition may require emergency, but not surgical intervention, within the evacuation phase. Patient's condition is characterized by secure airway, control or absence of hemorrhage, shock adequately treated, and major fractures immobilized" (Department, 2006 p. A13). Numerous complications occur with patients during flight. Air pressure and temperature transients, increased vibrations and decreased oxygen levels are just a few of the many factors affecting patients (Parsons, 1982). Patients on aeromedical evacuation flights experience hypoxia and 35% expansion of gases due to a cabin pressure equivalent to 5,000-8,000 feet altitude (Essebag, et al., 2003), (Teichman, et al., 2007). The aeromedical evacuation crews and the staff at the Patient Movement Requirements Centers train in high-altitude medicine and have the ability to monitor, treat, and compensate for these effects. Without the experience and knowledge necessary, it may be more dangerous to move a patient via air, than to wait in place. The Patient Movement Requirements Centers operate 24 hours a day with a medical technician, flight doctor (known as the Validating Flight Surgeon (VFS)), flight nurse, and an administrator. Once the Patient Movement Requirements Center receives a Patient Movement Request, the team discusses the patient with the attending medical personnel to establish a valid need to move the patient, determine the best destination, proper manner of travel, and precedence required. AF regulation classifies patient movements into three categories of precedence. Routine is the least serious precedence and requires movement within 72 hours. Priority is the next level and

requires movement within 24 hours, while Urgent is the final category and is reserved for patients at risk to lose life, limb, or eyesight and requires movement immediately or as soon as possible. The Validating Flight Surgeon is the final authority on these determinations (Department, 2014).

The DoD differentiates aeromedical evacuation by inter-theater and intra-theater movements (Department, 2006). USTRANSCOM is responsible for inter-theater patient movements, while the COCOM commanders are responsible for intra-theater patient movements. The type of aircraft used by each command depicts this division. EUCOM, for instance, typically uses C-21s and C-130s for its primary aeromedical evacuation platform. In comparison, USTRANSCOM uses C-17s for aeromedical evacuation (2006). The AFRICOM AOR is an exception to this rule because it is supported by EUCOM aeromedical evacuation assets for both inter and intra-theater movements. Since EUCOM does not control any C-17 aircraft, they use C-21s and C-130s to support aeromedical evacuation in Africa. Requests for C-17s support must flow to USTRANSCOM for approval (Department, 1996).

There are several platforms used by the DoD for patient movement. For aeromedical evacuation in Africa, the C-17, C-130, and C-21aircraft are the most common platforms (Department, 1996). For ground, AMBUSs (school buses converted for carrying litters) or traditional orange and white ambulances move the majority of critical patients, while privately owned vehicles are the vehicle of choice for most well-patient movements. Army Blackhawks or civilian helicopters provide needed rotary-wing resources (Department, 1996). For staffing, the AF maintains 4 Active Duty, 18 Reserve, and 9 Guard Aeromedical Evacuation Squadrons (Affairs, 2014). Each squadron consists of several complements of aeromedical evacuation

crews. A basic aeromedical evacuation crew consists of two flight nurses and three flight

medical technicians (Department, 2014). The aeromedical evacuation crews are limited to the

same duty-day regulations as other aircrew members as shown in Table 1. A basic duty day is

14 hours for the C-21 and 16 hours for other aircraft. The time on the duty day begins one hour

after the alert. An augmented aeromedical evacuation crew adds an additional nurse and

technician. Augmentation allows them to extend their duty day as shown in Table 1. The AF

restricts C-21s to a 14-hour duty day because the small size of the aircraft prevents crew

augmentation.

Table 1. Crew Duty Day and Alert Times (Air, 2011), (Department, 2014)

	C-17	C-130	KC-135	C-21
Basic Flight Duty Period	16	16	16	14
Augmented Flight Duty Period	24	18	24	N/A
Crew Alert	3:45	3:15	4:15	3:00

Crews require a minimum of 12 hours of crew rest prior to their alert time and the

Aeromedical Evacuation Control Team (AECT) can alert crews up to six hours after their

scheduled alert time. En route, crews require a minimum ground time of 17 hours for a RON

(remain overnight). These 17-hours include crew rest and alert times (Department, 2014).

In addition to a standard aeromedical evacuation crew, the Patient Movement

Requirements Center can identify the requirement for a Critical Care Air Transport Team

(CCATT). A Critical Care Air Transport Team consists of a critical care doctor, a critical care

nurse, and a cardiopulmonary technician (Department, 2015). Together with the basic

aeromedical evacuation crew, a Critical Care Air Transport Team provides an intensive care unit

(ICU) capability to an aeromedical evacuation. With this capability, the DoD can move critically

ill or injured patients with "positive patient outcomes" and "fewer patient complications" (2015 p. 5). However, Critical Care Air Transport Teams still require local medical personnel to provide initial stabilization for patients (2015). Another manner in which the Air Force is attempting to bridge the African medical gap is through the Tactical Critical Care Evacuation Team Enhanced (TCCET-E) concept. The Tactical Critical Care Evacuation Team Enhanced was originally designed for Special Operation missions, but a new look at the concept may prove useful in Africa (Hatzfeld, 2014). The team consists of a surgeon, emergency medicine physician, two nurse anesthetists and an operating room technician (Svan, 2013). In essence, the Tactical Critical Care Evacuation Team Enhanced aims to create a flying operating room that is capable of transporting soldiers from their point of injury, and if necessary perform stabilization procedures on the ground and perhaps damage control surgery in the air. This concept has already shown some better results than the traditional approach although the time-distance factor remains a limitation (Apodaca, 2013).

The second division of patient movement, called tactical casualty evacuation (Tacevac, Medevac, or Casevac), is the movement of a patient from the point of injury to the point of stabilization. Technically, Casevac and Medevac are both forms of Tacevac, where Casevac is the ad hoc movement of patients from the point of injury to a point of stabilization and Medevac uses predetermined medical vehicles and personnel (Department, 2006). However, literature and personnel often use these terms interchangeably. By regulation, each branch of the DoD is responsible for providing its own tactical casualty evacuation services (Department, 1996). This construct lends itself to a disorganized, Service specific nature of tactical casualty evacuation, where each Service delegates responsibility down to individual units to devise a plan, resulting in

improvised solutions rather than a well-constructed systematic approach to patient movement (Cecchine, 2001).

US Military in Africa

Although Camp Lemonnier in Djibouti represents the US' only "enduring element" in Africa, there are numerous "expeditionary cooperative security locations and contingency locations" throughout the continent with a number of high threat posts (Figure 1) (Rodriguez, 2015 p. 6).
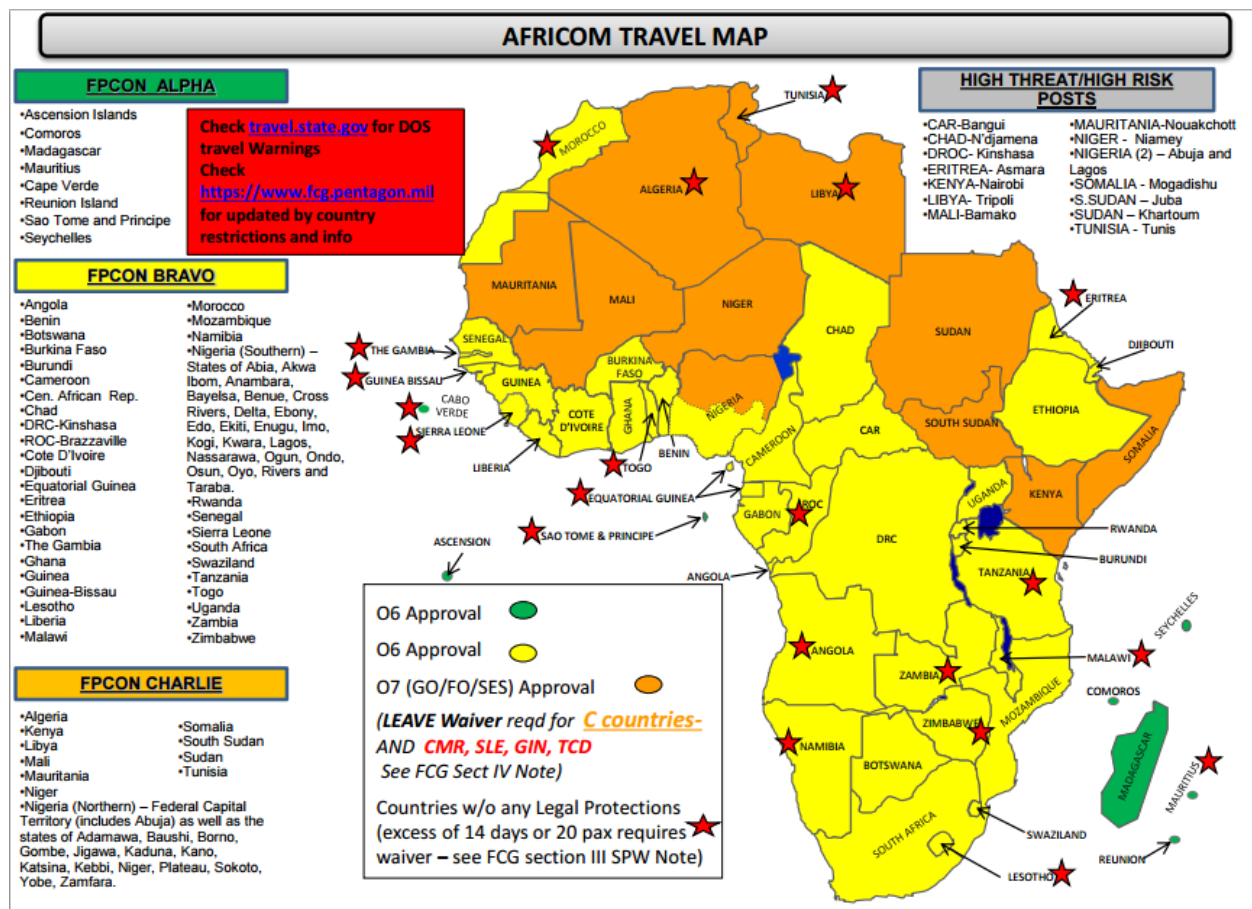
Figure 1. AFRICOM Travel Map (AFRICOM, 2015)

According to the AFRICOM commander General Rodriguez (2015), the US is increasing its presence throughout Africa. In 2014, the US "conducted 68 operations, 11 major Joint exercises, and 595 security cooperation activities," a 23% increase in activity from 2013 (Rodriguez, 2015 p. 2). General Rodriguez (2015) freely admits that requirements in Africa outpace the resources provided, leaving significant gaps in capability that require non-traditional mitigation. Figure 2 is an operations overview slide from an AFRICOM briefing that highlights five areas representing discernable threats to the US. These operations span much of the continent.
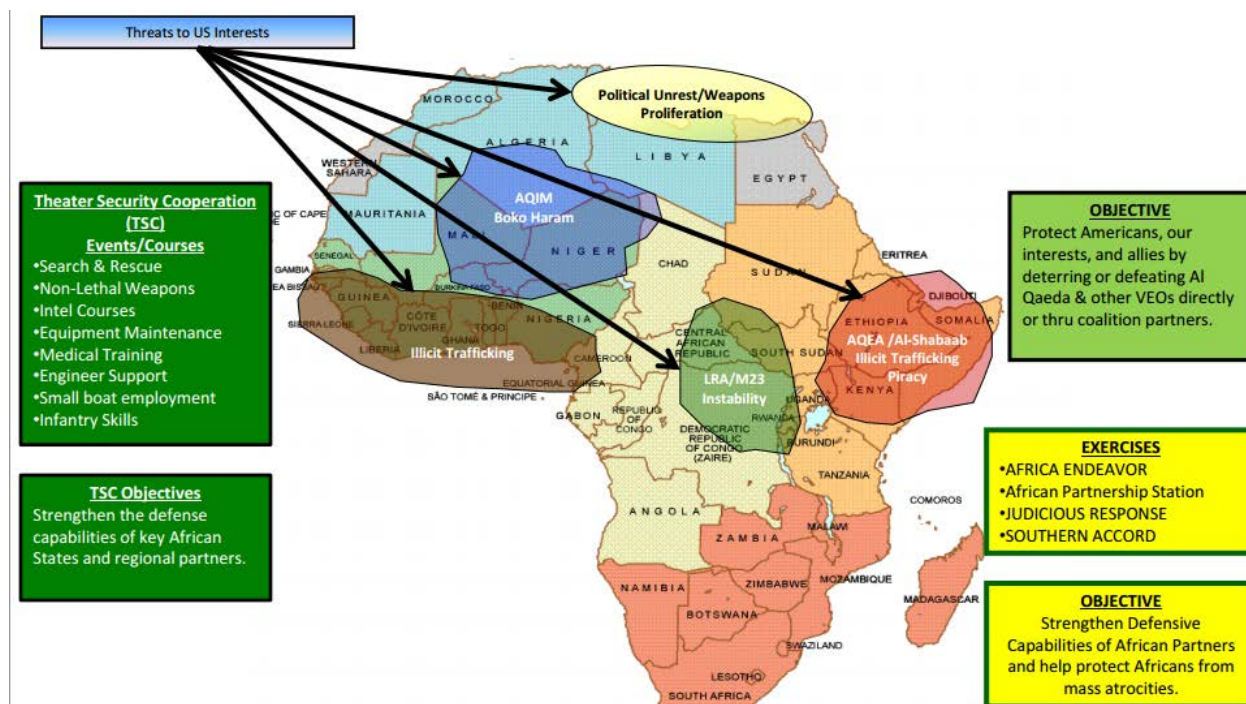
Figure 2. AFRICOM Operations Overview (AFRICOM, 2014)

The White House agrees that the Africa-US relationship will continue to grow. According to the US Strategy toward Sub-Sahara Africa, "Africa is more important than ever to

the security and prosperity of the international community, and to the United States in particular" (Obama, 2012 p. 0). While the rapid growth potential of Africa's population and economies makes Africa an asset for the US economy, the widespread political corruption and potential for failed states creates an ideal environment for terrorists groups to thrive (2012). Both reasons contribute to Africa's importance in the international community.

The number of AFRICOM deployments also shows the increasing US presence. An estimated 5,000 to 8,000 US military personnel are currently present in Africa. Major General Raymond Fox stated that from 2012 to 2014, the number of Marines in Africa increased from 150 to around 2,000 (McLeary, 2014). According to Gen Rodriguez, "Africa Command's capability gaps are likely to grow in the year ahead" (Rodriguez, 2015 p. 11). Among these capabilities is that of aeromedical evacuation. To mitigate these gaps, AFRICOM is looking to (2015 p. 11):

1. Increase collaboration and interoperability with multinational and interagency partners to better leverage and support allies and partners.
2. Refine our posture and presence in Africa and Europe to reduce risk in operations to protect U.S. personnel and facilities.

Given this guidance, the importance of this study is clear. A need exists to rethink how the DoD executes patient movement in order to provide the most efficient, comprehensive support to US personnel in Africa.

African Medical Capability

The continent of Africa has some of the poorest healthcare systems in the world (World Health Organization, 2006). Experts estimate that the country is short 2.4 million healthcare workers, resulting in only 2.3 medical personnel per 1000 individuals (Naicker, 2009). In comparison, the Americas have more than ten times that amount at 24.8 per 1000 (Table 2). Compounding this issue, western sanitary conditions are practically nonexistent on the continent (Figure 3) and Africa accounts for approximately 25% of the world's disease while having only 1.3% of the medical personnel (2009). In Africa, infectious diseases cause a startling 69% of death and chronic disease mortality rates are among the highest in the world (Aikins, 2010).

Table 2. Global Healthcare Workers

Region	Total Number (Millions)	Density per 1000 Population
Africa	1.64	2.3
Eastern Mediterranean	2.10	4.0
Southeast Asia	7.04	4.3
Western Pacific	10.07	5.8
Europe	16.63	18.9
Americas	21.74	24.8
World	59.22	9.3

Figure 3. Countries with Western Sanitary Standards (Duchateau, et al., 2009)

The problem is more dire for many countries, especially those in Sub-Sahara. As seen in Table 3, the majority of the healthcare workers are concentrated in northern African countries and South Africa, with many of the remaining countries having less than one doctor per 10,000 people.

Table 3. Doctors in Africa

Country	Total	Per 10,000
Egypt	179900	24
Seychelles	121	15
Liberia	7070	13
Togo	13330	13
Algeria	35368	11
Morocco	1303	11
South Africa	34829	8
Cape Verde	231	5
Mauritius	15991	5
Sao Tome and Principe	81	5
Botswana	715	4
Equatorial Guinea	153	3
Madagascar	5201	3
Namibia	598	3
Nigeria	34923	3
Sudan	11083	3
Cameroon	3124	2
Comoros	115	2
Congo	756	2
Djibouti	140	2
Ghana	3240	2
Swaziland	171	2
Zimbabwe	2086	2
Cote d'Ivoire	2081	1
Democratic Republic of the Congo	5827	1
Gambia	156	1
Guinea	987	1
Guinea-Bissau	188	1
Kenya	4506	1
Mauritania	313	1
Zambia	1264	1
Angola	1165	<1
Benin	311	<1
Burkina Faso	708	<1
Burundi	200	<1
Central African Republic	331	<1
Chad	345	<1
Eritrea	215	<1
Ethiopia	1936	<1
Lesotho	89	<1

These poor healthcare conditions create a need for aeromedical evacuation that would not exist in most other countries. The inability to locally hold and manage even simple patients forces normally Routine Patient Movement Requests into the Priority and Urgent categories. In fact, the results of one regression study found three factors which significantly predicted the need for immediate aeromedical evacuation; 1) The patient is less than 15 years old, 2) The patient

resided in a country without a "high standard structure" (Figure 4), and 3) The patient resided in

sub-Saharan Africa (Duchateau, et al., 2009). As seen, two of the three criteria are functions of

being in Africa, indicating a strong need for concern toward any US military patient in the

continent. As a result, "cases occurring in sub-Saharan Africa demand extreme caution"

(Duchateau, et al., 2009 p. 394).

Figure 4. Countries with a High Standard Structure (Duchateau, et al., 2009)

Current Patient Movement Operations in Africa

In most western countries, the DoD relies on local medical systems for support (Meza, et

al., 2006). In Afghanistan, the DoD and Coalition partners have deployed numerous medical

treatment facilities throughout the country to provide the needed medical coverage (Figure 5).

Each of these smaller facilities use Army rotary wing for Medevac transport to higher levels of

care. The larger facilities have access to fixed wing aeromedical evacuation assets to facilitate

patient movement to a definitive care facility at Landstuhl Regional Medical Center, Germany.

The density of troops and the relatively small landmass in Afghanistan, allows the DoD to

provide a viable "911" type system over the entire country, at a relatively low cost per troop (International Security Assistance Force Headquarters, 2011).
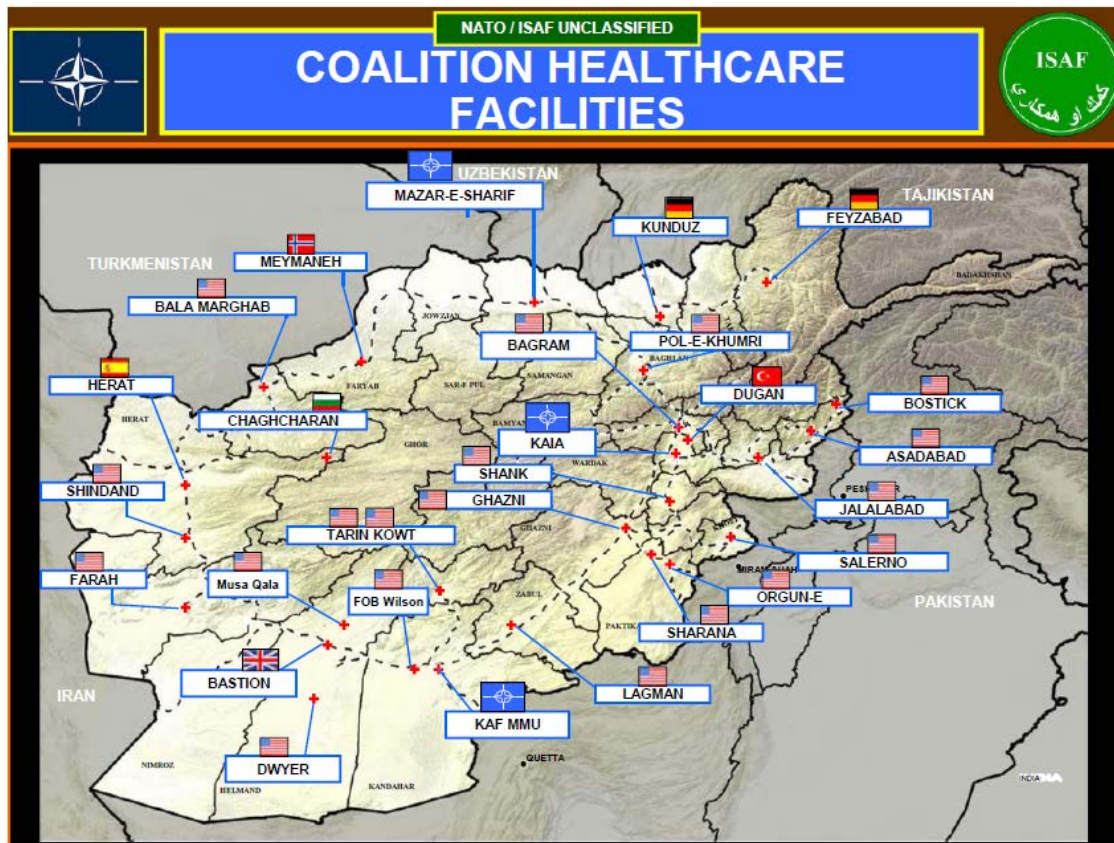
Figure 5. Medical Treatment Facilities in Afghanistan

Africa, however, lacks adequate medical infrastructure (Duchateau, et al., 2009) and due to the enormity of the country, deploying a comprehensive set of scarce medical resources for such a few number of troops is too costly (Bayles, 1990). Consequently, the DoD relies heavily upon the aeromedical evacuation system to bridge the gap in medical coverage. While the aeromedical evacuation system staffs, trains and equips personnel to move stabilized patients under well-defined and planned circumstances, the lack of medical capability in Africa places unwarranted pressure on the aeromedical evacuation system to move unstable patients that are deteriorating due to lack of resources or expertise (Department, 2003).

The Air Force currently supports Africa with aircraft and aeromedical evacuation teams based in Ramstein, Germany where there is always a C-21 and an aeromedical evacuation crew sitting on Bravo Alert (three-hour launch window). However, Africa is a very large continent, requiring long flight times to reach even the closest areas. Figure 6 displays the size of Africa relative to other countries.
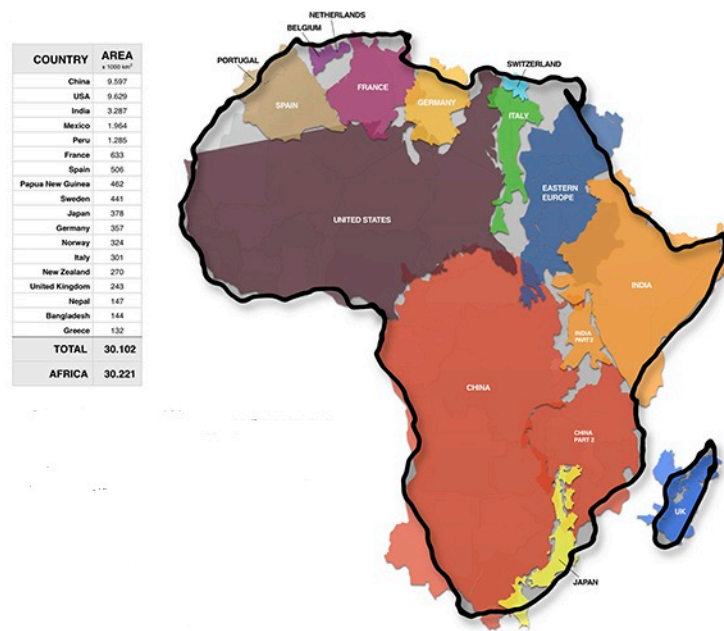
Figure 6. Relative size of Africa

Table 4 shows the flight times from Ramstein to Djibouti based on aeromedical evacuation mission data from 2010-2014. Out of these three platforms, only the C-17 can make this trip without stopping while the C-130 and C-21 typically require two stops en route. Not only do stops lengthen flight times, but they also require planners to consider contingency plans for each stop, in case the plane cannot take-off again and there is a patient onboard.

Table 4. Flight times, Ramstein to Djibouti

	Time (hrs)	Flight + Alert Time (hrs)	Round Trip w/1 hr ground time
C-17	7:06	10:51	18:57:00
C-21	10:27	13:27	24:54:00
C-130	11:47	15:02	27:49:00

Adding to this flight time is the initial alert response time. Since the only aircraft currently dedicated to aeromedical evacuation is the C-21, tasking a C-130 or C-17 can significantly lengthen the response time from the times listed in Table 4. For a C-130, the Patient Movement Requirements Center must send a request to the Aeromedical Evacuation Control Team in the 603rd Air Operations Center (AOC). The Aeromedical Evacuation Control Team then works with the C-130 planners to see what is available. Typically, an Urgent or Priority request takes precedent over other mission concerns and the aeromedical evacuation can "steal" a mission through the In-System Select (ISS) process. However, taking an active mission does not speed the response time because the aircraft must first fly to Ramstein; unload its current cargo and pick-up an aeromedical evacuation crew. Once the aeromedical evacuation crew responds, they must re-configure the aircraft to support an aeromedical evacuation mission before take-off. For a C-17, the issue becomes more critical because there are no C-17s belonging to Ramstein. Therefore, the Aeromedical Evacuation Control Team must request a C-17 from the Tanker Airlift Control Center (TACC) in Scott AFB, IL. If there is a C-17 available, it must go through the same process as a C-130.

According to Duchateau et al (2009), "Setting up an aeromedical evacuation has some unavoidable time intervals: team recruitment, checking aircraft availability, travel to the airport, travel time to the incident site, and the evacuation itself" (p. 394). Without any incident, the

quickest response time to a Patient Movement Request out of Djibouti is 10:51 hours. However, as seen in Table 4, only the C-17 can make the round trip flight within the duty day restrictions. The other aircraft must RON, adding an additional 17 hours to the mission time.

Adding to the delay, Africa consists of numerous small countries, each with various rules on how the DoD can operate. Some countries do not allow the US to flyover, causing increased delays; other countries require a Raven crew to provide ground security. If Ravens are required, there is another level of tasking and waiting. Additionally, the Diplomatic Clearances (DIPS) (country specific permission to land) are not always up to date, and depending on the runway, the TERPS (runway landing survey that provides the landing and take-off instructions) may not be current for the specified runway. In addition, refueling is a problem for most of the African countries. Not only is the quality of the fuel questionable, but the payment method lends itself to corruption. In many cases, airfields require cash payments and the prices vary, even at the same location, depending on who is managing operations at the time (Goldstein, 1999).

As seen, "Planning of aeromedical evacuation cases often represents a logistical challenge. Difficulties involving gathering adequate patient medical information, decisions on transport, route planning, different time zones, languages, and the variety of different health organizations in the country of transport origin should not be underestimated" (Sand, et al., 2010 p. 408). Each new level of complication creates another problem, while an injured troop is waiting in a possibly substandard medical facility.

Given the limited availability of medical care in Africa, the decision of where to move the patient is very limited. The number one choice is the Landstuhl Regional Medical Center (LRMC) in Ramstein, Germany. This facility is a top tier trauma center that offers definitive

surgical care in a US owned, western environment. However, given the time/distance factor, the

Landstuhl Regional Medical Center is not always a feasible choice. In some cases, heart attacks

for instance, it is better to move the patient to Johannesburg, South Africa or even Dubai, given

the criticality of the illness and location of the patient. The importance of good relations with

these countries is essential to bridge the gap in US medical coverage in Africa. The 1995 version

of JP 4-02, in reference to Special Operation Forces, describes a situation similar to the current

situation in Africa, "AE [Aeromedical Evacuation] for SOF is difficult because SOF frequently

operate at distant locations without any other assets in theater. Remote locations in immature

theaters not served by the strategic evacuation system requires close coordination between the

supporting Air Force Component Command and Joint medical planners to identify the details

and procedures for aeromedical evacuation" (pp. III-3). In the same manner, aeromedical

evacuation in Africa requires special consideration and detailed planning from all parties

involved.

International SOS

Due to the limitations of the military's current patient movement system, the DoD relies

on International SOS for aeromedical evacuation support in Africa. According to their website,

"ISOS provides integrated medical, clinical, security, and customer care solutions to

organizations with international operations," and they act as the TRICARE medical insurer for

all Active Duty Military overseas (International SOS, 2015a). In addition to providing

insurance, International SOS operates several 24/7 call centers, very similar to the Patient

Movement Requirements Centers. In fact, the International SOS call centers and the Patient

Movement Requirements Centers work closely on a daily basis to track and manage all patient

movements within their respective theaters. The London International SOS call center is the one
responsible for oversight of Africa. This call center has access to International SOS' extensive
medical facility database that describes the capabilities of most hospitals in the theater.
International SOS sends teams to survey these hospitals and grade them against a Western
standard of medicine. Based on this information, International SOS can recommend local
medical facilities; what treatments are advisable at these locations, how long the facilities are
capable of holding a patient, along with other medical and administrative recommendations. In
addition, International SOS has access to translator services and can communicate with the local
medical staff to determine the seriousness of the patient's situation. Furthermore, International
SOS is the insurer and can guarantee payment for services, to ensure the service member
receives the necessary care.

After receiving notice of an injured service member, the Patient Movement Requirements
Center contacts the medic on the ground, International SOS, and the Aeromedical Evacuation
Control Team. This four-way communication allows a synchronized effort between all parties.
The Validating Flight Surgeon then makes the decision of patient movement destination and
precedence level. If it is decided to move the patient via aeromedical evacuation, the
Aeromedical Evacuation Control Team looks for an aircraft to meet the necessary precedence
(i.e. Urgent=ASAP, Priority =24 hours, Routine=72 hours). Simultaneously, International SOS
looks to its civilian air ambulance sector to see if they can better meet the patient movement
requirements. International SOS has one Learjet 35A in Nurnberg, Germany; one Learjet 45 in
Lagos, Nigeria; one Learjet 35A in Abu Dhabi, UAE; and one Falcon 10 and two Learjet 35As
in Johannesburg, South Africa (International SOS, 2011). This infrastructure allows
International SOS to reach into Africa from all four corners of the continent, typically quicker

than the DoD. In addition, their aircraft are smaller and faster than most Air Force aeromedical evacuation platforms, and since they are not US flagged military planes, they typically have more over-flight and landing freedom than the military. Furthermore, International SOS civilian air ambulances are not restricted to the AF TERPS, but can use commonly published take-off and landing procedures for any airport. These factors make International SOS an extremely flexible and valuable partner in African aeromedical evacuation.

However, International SOS is not without limitations. International SOS supports a number of corporations and private individuals with this same capability, and the DoD must compete for International SOS' limited resources (International SOS, 2015a). Therefore, availability can be an issue. In addition, International SOS is a civilian company. As such, they will not operate in hostile environments. If there is a security risk for their aircraft or personnel, International SOS is not obligated to provide patient movement support. Therefore, International SOS is not a reliable planning factor for contingency response situations.

Limited Resources Trade-off

At the current level of operations in Africa, there is not enough incentive to build new medical treatment facilities on the continent. Instead, the DoD continues to use aeromedical evacuation supplemented with other deployable medical resources such as Forward Surgical Teams (FSTs). However, these resources are limited in their availability and the extent of their usefulness (Department, 2013b). While each Forward Surgical Team offers surgical capability, they are an expensive, limited resource that the DoD allocates to their best use. Additionally, a typical Forward Surgical Team requires logistical support, such as a Role 2 medical facility.

Therefore, what starts as a small Forward Surgical Team can quickly grow to a large operation (Department, 2013b).

In reality, limited resources force the DoD to make trade-offs between additional risk and additional cost. At equilibrium, the DoD has an unstated level of risk, which they place on the individual soldier, rather than spend money on additional medical resources. The DoD cannot afford to provide a personal physician for every soldier, so the question becomes, what is the equilibrium level of risk and cost? As the intensity of operations increase in Africa, the DoD will eventually cross the risk threshold, incentivizing additional medical expenditures. However, this level is not expected in the near future. In the meantime, the DoD requires a new way of thinking about the design and implementation of patient movement in order to bridge the medical gap with the currently supplied resources.

Golden-hour

The Golden-hour is the terminology given to a theory first hypothesized by Dr. R. Adams Cowley. In his time spent in the University of Maryland Trauma Center, Cowley noted a significant increase in mortality and morbidity rates if trauma patients did not reach surgical care within an hour. Boersma (1996) states, "There is conclusive evidence from clinical trials that reduction of mortality…is related to the time elapsing between onset of symptoms and commencement of treatment" (p. 771). Some studies even suggest that mortality triples with every passing 30 minutes (Cowley, et al., 1973). Other research presents evidence of the importance of elapsed time between injury and treatment as a critical factor in mortality and morbidity. According to Blow, et al.'s (1999) article, early intervention improves survival after trauma. Blow, et al. (1999) go on to state that "early rapid hemodynamic stabilization" and

"early correction of organ perfusion" are critical to prevent death in trauma patients (p. 964).
Furthermore, Blow et al. (1999) finds that "early identification and aggressive resuscitation...
improves survival and reduces complications in severely injured trauma patients" (p. 964).
While the one-hour mark is highly debated, it is widely accepted that elapsed time to definitive
surgery influences mortality and morbidity rates. Nonetheless, there is a period of elapsed time,
where depending upon the type and severity of the injury, the patient needs to have surgical
intervention in order to prevent death (Stroud, 2008). Given everything else is constant; it is true
that providing quicker transportation is better (American, 2005).

Epidemiology of Aeromedical Evacuation

Very few epidemiologic studies exist in regards to aeromedical evacuation transport
(Sand, et al., 2010). There are a range of issues that mandate aeromedical evacuation, however,
the lack of proper equipment, facilities, sanitation and expertise are usually involved (2010).
According to Sand, et al. (2010), "Epidemiological assessment of aeromedical evacuation cases
are needed to support efforts to optimize the logistic, medical, and economic aspects of this
specialized form of monitored air transport" (p. 405).

According to two studies, trauma, stroke, and myocardial infarction (MI) are the most
common diagnosis for aeromedical evacuation patients who require a litter (Table 5) (Chawla, et
al., 2001), (Sand, et al., 2010). Sand, et al.'s (2010) study consists of 504 aeromedical
evacuation cases performed by a German aeromedical evacuation company. As a result, the
cases originated primarily in Europe, Africa, and the Middle East (Table 6). Approximately 95%
of the patients were over the age of 18 with a range from one month to 96 years and a median of
66 years. Of the patients, 54% were male and 46% were female.

Table 5. Most frequent diagnoses of aeromedical

Diagnosis	n
Femoral neck fracture	74
Stroke	69
Myocardial infarction	39
Cerebrocranial trauma	38
Polytrauma	17
Pneumonia	16
Pelvic fracture	14
Lumbar spine fracture	14
Renal failure	13
Herniated intervertebral disk	11
Thorax trauma	11
Thoracic spine fracture	10
Chronic obstructive pulmonary disease	10
Cervical spine fracture	9
Ileus	8
Pulmonary edema	8
Fracture of the lower leg	8
Pulmonary embolism	7
Post-cardiopulmonary resuscitation, cause unknown	6
Cardiac insufficiency	5
Gastric carcinoma	5
Leg vein thrombosis	5
Pancreatitis	5
Psychoses	5

Table 6. Geographic data: regions of transport origin

Region	n	%
Europe	340	67.5
Africa	84	16.6
Middle East	62	12.3
North America	4	0.8
Southeast Asia	4	0.8
Asia (except Southeast and Central Asia)	3	0.6
Australia	2	0.4
Central Asia	2	0.4
South Pacific Ocean	2	0.4
Central America	1	0.2

Figure 7 shows Sand, et al.'s (2010) results with trauma and internal medicine being the top medical specialties required. According to Blow, et al. (1999), trauma is the leading cause of death for people under 40 and trauma victims suffer from organ failure, respiratory complications, and increased ICU stays. Given the poor state of African healthcare, a rapid

response to trauma is important. Figure 8 shows the distribution of medical specialties by age. Here, the older populations dominate certain medical specialties like internal medicine and neurology while psychiatry and gynecology are typically for the younger populations.
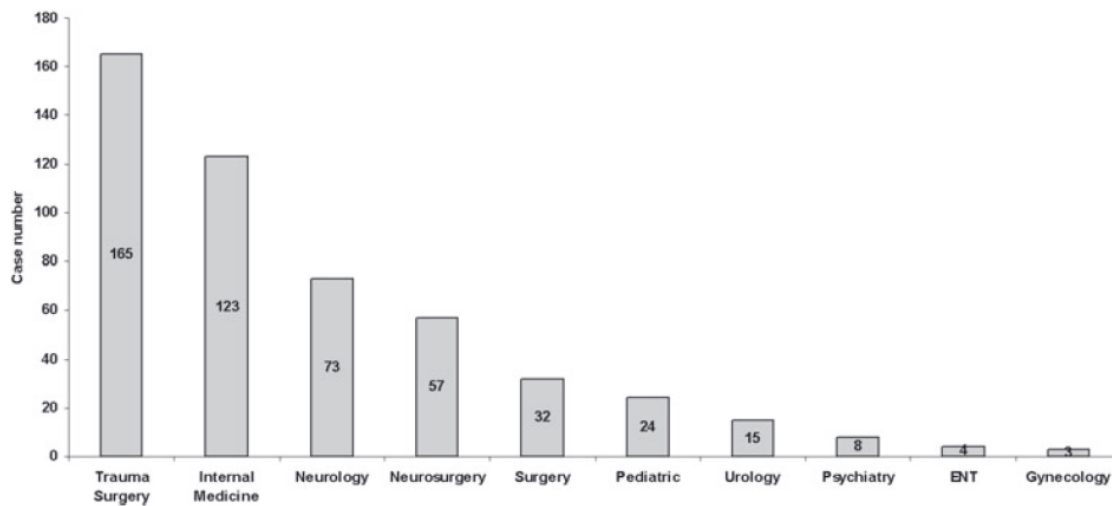

Figure 7. Number of different types of cases classified according to the specialty in charge of the patient prior to transportation
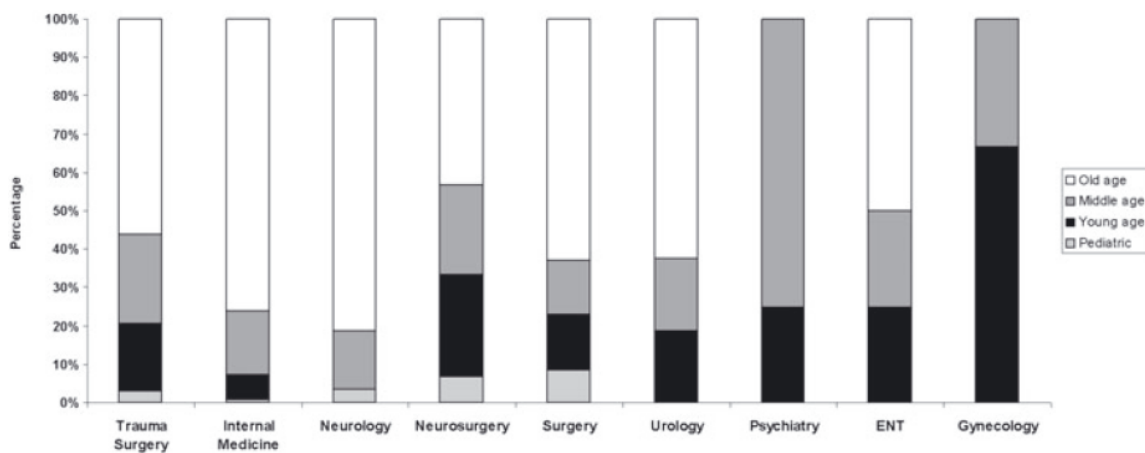

Figure 8. Age distribution relative to specialty (old age: >70 y, middle age: 41–70 y, young age: 18–40 y, and pediatric: 1–18 y)

Costing

According to Richmond (1992), "cost analysis is art, not science," and requires many assumptions. However, due to its high cost and predicted future growth as a means of providing medical care, "The economic aspects of aeromedical evacuation need to be critically evaluated" (Sand, et al., 2010 p. 408). One of the first steps to optimize these resources is to determine "the cost-effectiveness and selection of the appropriate form of air transportation, while assuring the right medical response" (2010 p. 405). "Cost effectiveness," includes the calculation of the cost to perform an aeromedical evacuation mission.

The absolute cost of flying one additional patient includes numerous resources by support activities such as personnel, finance, and CE (Kaplan, et al., 1998). However, in the short term, the decision to produce one additional flight does not affect these resources because they are already "committed". Kaplan and Cooper (1998) illustrate this concept in the equation:

$$\text{resources supplied} = \text{consumed} + \text{excess capacity}$$

When the DoD determines to "consume" an additional aeromedical evacuation mission, they do not need to increase the resources supplied by a full "mission's worth" as long as they have excess capacity that is already committed to the mission (Kaplan, et al., 1998). For instance, the pilots, aeromedical evacuation crews, aircraft, runways, and control towers are committed resources and will not change with an additional mission. Therefore, the only additional costs incurred are the truly variable costs such as fuel, maintenance, and supplies. In the same manner, flying one less mission does not save a full "mission's worth" of resources supplied, but merely shifts those resources from consumed back into excess capacity.

Aeromedical evacuation missions, like all services, cannot be inventoried and have no residual value (Rathmell, 1966). Therefore, any excess capacity is simply lost, along with the committed resources supplied. Since this study assumes the resources supplied for aeromedical evacuation missions are fixed in-spite of the aircraft type chosen and will not change even if 100% of flights were contracted to civilian agencies, it focuses on the truly avoidable costs rather than the absolute cost of flying an aeromedical evacuation mission (Malik, et al., 1995). According to Martin (1993), when the government wants to determine the potential savings due to contracting out a service, they should focus on avoidable costs. Using avoidable costs is the generally accepted method in a make-buy decision. Martin states the following three principles to determine which costs are avoidable (1993):

1. The ability of the public sector to reallocate resources efficiently.

2. The extent of the privatization effort.

3. The time period in which resource allocation is expected to occur.

In accordance with these principles, this study assumes that:

1. The DoD will not reallocate committed resources as a result of contracting aeromedical evacuation missions.

2. The DoD will not completely privatize aeromedical evacuation and will always maintain organic aeromedical evacuation capability.

3. This study focuses on short-run decisions and cannot affect committed resources.

Decision Tree Making

The current process for determining which aircraft to use is simple. The planners at the

Patient Movement Requirements Center look at the time requirement to move the patient, and

then they give MilAir the right of first refusal. If the Air Operations Center cannot support the

mission within the given timeframe, International SOS takes the mission. This simple decision

tree does not optimize the use of assets for training, cost, risk, or opportunity cost. Rather, this

tree is concerned with asset utilization rates. The DoD's use of fully allocated overhead costs

creates many wrong incentives and resulting actions. On one hand, the cost structure

incentivizes the overuse of assets in an effort to decrease the cost per mission. On the other

hand, like in a make-buy decision, the inflated costs make the DoD uncompetitive with the

market. Neither approach is optimal. A proper decision tree balances these incentives in an

effort to maximize the effectiveness of the entire system and allocate scarce resources in a

manner that ensures each service member receives the required care at the lowest possible cost to

the system.

According to Safavian and Landgrebe (1991), decision trees have three benefits:

1.   They allow the derivation of complex decisions through the combination of
       simple decisions.

2.   Not all decision points of the tree need testing in order to arrive at an optimal
       decision.

3.   Trees have a high degree of flexibility that improves performance.

However, Safavian and Landgrebe (1991) identify the following as possible drawbacks to

decision trees:

1.	Overlap: failure to eliminate an option at a decision point, resulting in the option appearing in multiple choices at the next layer, increases the complexity of trees.

2.	Errors accumulate from layer to layer.

3.	The performance of the tree depends on the design. Therefore, the design phase requires special attention.

Safavian and Landgrebe (1991) offer several guidelines for developing a decision tree.

1.	Make obvious decisions first.

2.	Keep the tree as small as possible.

3.	Ensure decisions remain sequential.

4.	Test the tree for its robustness and understand its limits.

In general, there are two types of tree designs. The first is a "perfect tree," built in a manner that correctly classifies every sample point used to construct the tree. The second is an "imperfect tree" and is the preferred method. The imperfect tree does not correctly classify every sample point, but rather provides the smallest possible error rate when testing its robustness against reality (Safavian, et al., 1991).

Summary

Africa is a very poor continent with high levels of disease, few medical personnel, and some of the worst healthcare systems in the world. In spite of this fact, the DoD continues to grow its presence on the continent without providing adequate additional medical treatment

facilities. Instead, the DoD relies on the aeromedical evacuation system to bridge this medical gap in ways it is not designed, manned, trained or equipped to perform. Further complicating this situation, the enormity of the continent makes it impossible for the DoD to meet its own patient movement standards in the Priority and Urgent categories over much of the continent. This lack of response places a level of risk on the military akin to that only experienced historically by Special Forces. To rectify this situation, the DoD relies on contracted aeromedical evacuation support as a replacement for organic capability. In an effort to better allocate the available resources to their highest benefit, this study seeks to develop a decision tree that determines the appropriate aircraft choice for aeromedical evacuation transport that will yield the required standard of care at the lowest cost to the DoD.

III. Methodology

Chapter Summary

Four phases comprise this research. First, I verify and analyze patient movement data to develop and present a clear picture of the epidemiology of aeromedical evacuation in Africa as related to the DoD. Second, I perform an economic evaluation to determine the avoidable cost of each mission, representing the actual cost savings had the missions not flown. Third, I analyze the epidemiological and cost data to determine which aircraft choice presents the lowest cost while still meeting the required level of patient care. This analysis then allows the development of a decision tree tool that provides an easy and robust method to determine the optimal aircraft choice for aeromedical evacuation.

Methodology for Epidemiology

I used Sand, et al.'s (2010), *Epidemiology of Aeromedical Evacuation*, as a general example of how to perform and present my study. The TRAC2ES database contains all the raw data for this analysis. I accessed TRAC2ES by request through the following email address: transcom.scott.tcj6.mbx.service-desk@mail.mil and received access to the Patient Movement and Ad-hoc Reporting tools. At the end of each calendar year, TRAC2ES archives its dataset into a Microsoft Excel format containing information on the Patient Movement Requests for that year to include origin, destination, mission ID and aircraft type (of the last mission boarded by the patient), as well as precedent, patient classification, diagnosis, and other pertinent information. These files reside in the Patient Movement module under the Tools tab and the Downloads sub tab. Although 2007 marked the first year of AFRICOM, the current

patient movement system did not exist until International SOS won the Tricare Overseas

Program contract in October 2009 (International SOS, 2015b). Therefore, for this study I use the

five Patient Movement Request data files that correspond with 2010 through 2014.

After downloading the data files, the first step was to combine each file into a single

Excel spreadsheet with 106,740 records. I then filtered by the preexisting headings and sorted to

show only the records with a "Current PMR State" of "Completed" and with an "Origin Theater"

of "AFRICOM," leaving 836 records. This data represented all completed Patient Movement

Requests that originated in the AFRICOM Theater to include those moving with commercial

airline tickets, privately owned vehicles, or as MEDPAX. MEDPAX is a type of patient

movement where the patient is well enough to travel without medical supervision and travels on

a military aircraft as a "space available" passenger. Since I am only interested in aeromedical

evacuation movements, I eliminated any record without a Mission ID as all aeromedical

evacuation missions have an ID number assigned. This filter left 344 records, but still contained

MEDPAX patients because they also have a Mission ID assigned. Next, I filtered out any record

with a "Movement Classification Code" of 9V. The 9V code is the designation for MEDPAX,

beginning in 2014. This filter resulted in 286 records. In order to identify and filter any previous

MEDPAX records; I looked at the Mission IDs. In a standard mission ID, aeromedical

evacuation missions have an L for the second character. In addition, it is the Theater Patient

Movement Requirements Center-Europe's convention to begin the mission ID of any civilian air

ambulance mission with "CAA." Moreover, only ambulatory outpatients (Movement

Classification Code of 5A) can fly as MEDPAX. Using this information, I identified 27

questionable records. Of those 27 records, three of the missions also had patients with a

Movement Classification Code that requires aeromedical evacuation transport. Filtering out

these codes left only 15 questionable records representing eight different missions. I then looked

up each of these records in the Patient Movement Request Archives section of TRAC2ES, where

I used the Movement Remarks section to determine if the patient traveled on an aeromedical

evacuation mission or as a MEDPAX.

To ensure I correctly identified all the AFRICOM aeromedical evacuation missions, I

requested access to GDSS through the Account Validation Manager and Functional

Representative located at HQ AMC/A6. Once granted, I accessed the GDSS website

at https://gdssams.maf.ustranscom.mil and ran the standard report called Aeromedical

Evacuation Billing, located under the report tab. This report allowed me to see the mission

information (including take-off times, landing times, origins, and destinations) for missions

billed as aeromedical evacuations from 2010 to 2014. I copied the data into Excel and sorted for

missions with a destination or origin ICAO code (International Civil Aviation Organization)

beginning with D, F, G, or H. ICAO codes are internationally recognized airport identification

codes. The letters D, F, G, and H represent airports in Africa. In this data, nine GDSS missions

did not appear in the TRAC2ES data. To reconcile this mismatch, I pulled a complete list of all

Mission IDs and Cite Numbers from the Ad-Hoc Reporting function in TRAC2ES. I then used

the mission IDs, flight times, dates, origins, and destinations to identify the missing missions.

Once identified, I looked up the corresponding information in TRAC2ES to determine if the

mission should be included. Of these nine missions, one originated from an island with an

African ICAO but under the jurisdiction of PACOM. One originated from the Sinai Peninsula,

which falls under CENTCOM. One mission had an aeromedical evacuation designation in

GDSS when it was actually a MEDPAX mission. One mission was in TRACE2ES with a

typographical error where someone typed the mission as 220B041 rather than 210B041. One

mission was in TRAC2ES under a different ID because a change in patient status required the use of a different aeromedical evacuation mission with a Critical Care Air Transport Team. One mission incorrectly listed the origin theater as EUCOM within TRAC2ES. One was due to the patient flying to CENTCOM prior to flying to EUCOM. This additional leg resulted in the Patient Movement Request showing the origin theater as CENTCOM. One was a case where a new aircraft replaced the original aircraft because it broke during a fuel stop. Finally, one mission was not in TRAC2ES presumably due to its classification level.

Next, I compared the TRAC2ES data to the GDSS data and found 20 mission IDs in TRAC2ES that were not in GDSS (not counting the civilian air ambulance missions because GDSS only tracks MilAir). To reconcile this data, I performed a Mission Search in GDSS using the date-time group and ICAO codes indicated for each of the mission IDs. If this did not help me locate the mission in GDSS, I searched for a partial mission ID match by using the first few letters of the ID. This process allowed me to identify missions that crossed multiple days, but were the same flight. The last three letters of a mission ID are the Julian date and the same mission can have multiple IDs if it crosses different days. Eight of the twenty missions were C-21 missions as indicated by a 2 in the first digit of the mission ID. All EUCOM C-21 missions receive funds through USAFE Operations and Maintenance and not through the Transportation Working Capital Fund (TWCF). Therefore, these missions do not show on the "AE Billing" report. One mission was an experimental mission with a contracted G-III that was not in AE-Billing. Four missions lacked the appropriate "L" indicator and therefore did not appear in the AE Billing report. One mission was a MEDPAX mission. The remaining missions did not appear in the AE Billing report because TRAC2ES lists the "last boarded" mission. In these cases, the patients traveled on other aeromedical evacuation flights, primarily back to the US,

causing new mission IDs to appear in TRAC2ES. I identified these occurrences by mission IDs beginning with J, A, or P. These letters indicate a C-17 mission, and most follow-on missions to the US are on C-17s. Once identified, I updated the data with the mission ID of the original aeromedical evacuation rather than the flight home.

Through process of elimination, record review, and cross-referencing between the two databases, I successfully reconciled 100% of the aeromedical evacuation missions listed in both GDSS and TRAC2ES. Once I reconciled a missing mission, I found the corresponding record in GDSS and TRAC2ES and either added or deleted the record from my initial file. The result was a total of 274 Patient Movement Requests and a corresponding 170 aeromedical evacuation missions originating from Africa between 2010 and 2014.

Once I had the correct records identified, I aligned the TRAC2ES data with the GDSS data within the same file. I then ensured that every category of data was correct by cross-referencing other categories. For instance, if the Personnel Service Code was A11 (Army Active Duty), then the "Service" block had to read "Army", the "Age" had to be above 18, and they had to have a rank. I clarified and corrected any mismatched or blank data by reading the remarks section of the Patient Movement Request. I corrected several of the "Personnel Status Names" and "Service Grade Names" to show the nature of the move as "humanitarian", "active duty", or a "dependent/DoD employee." This data needed correction because TRAC2ES' coding scheme changed between 2010 and 2014. As a result, K-codes became X-codes and some of the verbiage in the naming conventions changed. I also verified that all the mission times, dates, ICAOs, and aircraft matched in TRAC2ES and GDSS and that the times recorded were for the correct leg of the aeromedical evacuation mission. Although many patients had follow-on aeromedical evacuation missions to the US or other location, I focused on the initial movements.

Next, in a separate tab, I identified the missions that had multiple patients onboard and assigned to those missions the total number of litter patients, ambulatory patients, and the highest precedence classification of any patient on that flight. Since many of the Origin Facility names listed "Other AFRICOM", I identified all the origin and destination countries for each mission by looking at the ICAOs in GDSS or by the itinerary section of the Patient Movement Request in TRAC2ES.

Finally, I took the data and composed a series of charts, graphs, and maps to present a clear picture of the epidemiology of the DoD's aeromedical evacuation in Africa.

Methodology for Costing

Once I had clean data, I began the process of assigning avoidable costs to each mission. The Theater Patient Movement Requirements Center-Europe provided the civilian air ambulance cost data. This data originates from quotes presented by International SOS prior to performing each mission. An operations officer at the Theater Patient Movement Requirements Center-Europe signs each quote and retains a copy for their records. The Theater Patient Movement Requirements Center-Europe provided an Excel file that listed these costs for each civilian air ambulance move from 2011 to 2014, based on the country where the patients originated. They also provided a homegrown Microsoft Access database called the Intratheater Movement Tracker. This database had the dates, costs, and origins of civilian air ambulances for 2010-2012 with some data for 2013. Although these cost databases were not complete, together, they accounted for all but 13 of the 123 civilian air ambulance missions. I estimated the missing costs based on the average cost of civilian air ambulance missions with the same country of origin except for the Zimbabwe mission CAA3AF01A084A. This mission was the only one to

Zimbabwe, so I estimated its cost based on the average cost of $7K/flight hour and an average speed of 380mph as derived in the Methodology for Decision Tool section. Although Martin (1993) suggests considering contract administration costs in addition to the quoted price when calculating avoidable costs, as long as International SOS maintains the Tricare Overseas contract, of which aeromedical evacuation is only a small portion, we assume the administration costs are committed and do not change. As a result, the only avoidable cost is the quoted price.

In order to determine the avoidable cost of each military flight, I determined the length of time for each mission using the GDSS data. The calculation included the flight from the aircraft origin to the pick-up location and the flight from the pick-up to the final destination. In determining avoidable cost, I assumed the aircraft choice does not affect the number of planes, personnel, infrastructure, and support activities provided by the DoD to perform aeromedical evacuations. Therefore, the avoidable costs consisted of certain direct operating costs which, according to SH&E International Air Transport Consultancy, consist of four categories (Horder, 2003):

1. Flight Operations
2. Maintenance
3. Depreciation
4. User Charges

For Flight Operations, I included general crew expenses, fuel and oil. For Maintenance, I included labor (if contracted), repairs, and material. This data came from the AFI 65-503, Table A4-1, Logistics Cost Factors Description (Air, 2015). I used the cost data for each aircraft based on what year the mission was flown. For Depreciation, I did not include a value since the market values of aircraft depreciate primarily with time, and therefore, utilization is only a concern if it

is significantly different from an average aircraft (Conklin & deDecker, 2016). User Charges are the various fees charged by governments and airports for using their facilities or airspace (Horder, 2003). These fees include charges for landing, passengers, security, infrastructure, parking, environment, terminal usage, fly-over, and taxes (International Civil Aviation Organization, 2009). According to McLaren (2007), Sub-Sahara Africa is very expensive, citing a single flight from Europe to Nigeria costing over $10,000, with $4000 in handling, $3100 in navigation and $3036 in airport fees. This is confirmed from the Djibouti International Airport website stating landing fees alone are $7/ton (based on maximum take-off weight) plus $380 (Aéroport de Djibouti, 2015). Based on the C-17's 585,000-pound maximum take-off weight, this puts the cost of a landing at $2,427. In addition, there are other charges such as $84 per passenger, $65 for lighting, $0.50 per hectoliter fuel surcharge, $0.17 per ton per hour parking, and up to $2,500 each for cargo and passenger handling (2015). Although these costs are truly avoidable, I do not have the necessary information to determine what the DoD pays in user charges. Therefore, to remain conservative in my cost calculations, I did not include any user charges.

Next, I determined the number of personnel aboard each aircraft in order to calculate the cost of per diem and special pays. To determine the number of personnel, I used the base crews for each aircraft as outlined in 11-2C-21v3 (2010), 11-2C-17v3 (2011), 11-2C-130v3 (2012a), and AFI11-2AEv3 (2014). I then determined if the crew required augmentation based on the calculated total mission time. If the total mission time was more than the basic flight day, I considered it an augmented crew unless there was enough ground time for crew rest, in which case, I considered it a basic crew. Additionally, I added the appropriate medical crewmembers if the mission required a Critical Care Air Transport Team.

Depending on the origin of the patient, each member of the crew is eligible to receive certain special pays and allowances. To determine this expense, I identified eight different countries within my dataset from which the DoD flew an aeromedical evacuation mission with MilAir. I then cross-referenced my list with the special pay locations identified in DoD 7000.14-R. Of these locations, Djibouti is the only country designated for Combat Zone Tax Exclusion (CZTE). However, Egypt, Kenya, Liberia, Djibouti, and Libya qualified for Imminent Danger Pay of $7.5/day. To calculate the cost of Combat Zone Tax Exclusion, I assumed an average rank of Captain for officers and Staff Sergeant for enlisted. I then used the AFI 65-503, Table A19-2, Active Air Force Standard Composite Rates by Grade Description to determine the average base pay for each rank (SAF/FM, 2015). From there, I calculated the cost based on the 15% federal tax bracket. Combat Zone Tax Exclusion exempts each member from paying taxes on income for the month they were present in the zone.

In addition to special pay, the DoD compensates crewmembers for lodging, meals, and incidental expenses, collectively referred to as per diem. Using the Per Diem Rates Query Tool on defensetravel.dod.mil, I identified the per diem allowance for each location based on 2015 rates. If the crew did not RON, then I subtracted the lodging expense from the per diem rate. Once calculated, I summed the costs to determine the total avoidable costs for MilAir aeromedical evacuation missions.

On four of the C-130 missions to Djibouti, the initial legs of the flights did not match the scenario because the aeromedical crew flew to Djibouti on separate missions. Without this data, I could not calculate the appropriate flight hours. To compensate, I assigned a cost equivalent to the lowest costing C-130 mission to Djibouti. For the single G-III mission, I used the cost factor

of a C-20. For the one mission that switched from a C-130 to a C-21, I used the cost data of the

C-130 since it flew the majority of the mission.

Methodology for Decision Tools

Decision tools provide a quick and easy method to analyze multiple factors with limited

expertise. In this research, I develop a decision tree tool and a map tool. These tools identify the

aircraft that minimizes the cost of aeromedical evacuation missions while meeting the criteria

specified by the Validating Flight Surgeon and DoD regulations. Within these tools, I included

duty day, crew rest requirements, aircraft speed, aircraft size, aircraft origin, and cost per flying

hour as constraints. Other factors not considered were the amount of tasking time needed to task

an aircraft, if the mission requires a Raven crew, restrictions on over flight of US flagged

military aircraft, if TERPS are up to date, and diplomatic clearances. These factors are a

secondary consideration since they are outside the scope of these tools.

The decision tree tool walks the user through the necessary steps to identify the most

economical aircraft choice. The inputs considered in the development of this decision tree were

contingent environment, precedence category, distance from Ramstein Air base, number of

patients injured, necessary training requirements for the 86th Aeromedical Evacuation Squadron,

avoidable cost, and "no-stop" requirements. In developing this tool, the number one priority was

to meet the patient care standards as designated by Urgent, Priority, or Routine. The financial

implications were second to patient care; however, once I met the patient requirements, the

avoidable cost became the dominant discriminator. I designed the decision tool to eliminate

possibilities as quickly as possible in order to minimize the length of the tree. Broad categories

such as contingent/not contingent are early in the tree, in order to eliminate the most possibilities.

I designed the tool to work best for the Theater Patient Movement Requirements Center-Europe and the 603 Aeromedical Evacuation Control Team, however, military planners from all branches can use this tool to see the medical coverage available for forward deployed forces in Africa. A completed AF Form 3899, Patient Movement Record, provides the minimum information required to complete the tool. The tool asks about training requirements for the Aeromedical Evacuation Squadron, however, this is primarily for the Aeromedical Evacuation Control Team and the Theater Patient Movement Requirements Center-Europe since they work closely with the Aeromedical Evacuation Squadron on a daily basis. The Aeromedical Evacuation Squadron is limited to four hours of training on an operational mission. Therefore, I calculated any savings incurred by training during an operational mission at the C-130 rate of $5K per flight hour, resulting in a $20K savings per training mission (Department, 2013a). Additionally, I added a Decision Tree for Routine patient movements to help users identify the optimal aircraft for Routine aeromedical evacuations. This decision tree identifies the optimal aircraft choice for a "normal" movement. However, other factors affect aircraft choice such as aircraft availability, weather, political boundaries, and severity of patient condition. Therefore, this tool is only a guide and does not usurp the recommendation from experienced operators.

I began developing the map tool with Google's *My Map*. Using My Map, I created 10 map layers in which I plotted aircraft locations, ranges, areas of responsibilities, costs, and patient movement data. The first step was to plot the location of the aircraft and the corresponding AORs for the civilian air ambulances. I assumed that the civilian air ambulance closest to the patient's origin is the primary responder, unless that patient is returning to South Africa, in which case the civilian air ambulance from Johannesburg is the primary responder. I developed four layers, each representing the AOR of the four civilian air ambulance locations

(FALA: South Africa, DNMM: Nigeria, EDDN: Nurnberg, OMAA: Abu Dhabi). For MilAir, their AOR is all of Africa. The second step was to plot the ranges for each aircraft on a cost basis. This step required the calculation of the cost per flight hour for each MilAir aircraft, as well as each of the four civilian air ambulance locations. Using my mission data in Excel, I assigned each civilian air ambulance mission to a specific civilian air ambulance AOR based on my assumption that the closest civilian air ambulance would provide response, except for those with a destination of South Africa. This assignment allowed me to calculate the total miles flown on each mission. I then calculated the average speed of the aircraft according to the corresponding AOR. I filtered the data by AOR and calculated the actual speed based on the number of miles flown and the corresponding take-off and landing times. All distances came from the Great Circle Mapper at www.gcmap.com. I then averaged these speeds according to their AOR, resulting in a speed of 398 mph for Abu Dhabi, 380 mph for Nurnberg, 441 MPH for Nigeria, and 380 mph for South Africa. I also calculated the average speed of the MilAir planes based on their actual number of miles flown and the corresponding take-off and landing times. The result was 411mph for the C-17, 276 mph for the C-130, and 298 mph for the C-21. These numbers agree with the block-speeds listed in AFPAM 10-1403.

With the civilian air ambulance speeds calculated, I then calculated the number of flight hours from initial take-off to the patient location and then from the patient location to the final destination. This data already existed for the MilAir missions. Using these hours and the previously calculated avoidable costs, I calculated an avoidable cost per flight hour for each mission. I then took the average cost per flight hour for each MilAir aircraft type and civilian air ambulance AOR. The result was $13.4K/hour for Abu Dhabi, $4k/hour for Nurnberg, $15.3K/hour for Nigeria, $7K/hour for South Africa, $14K/hour for the C-17, $5K/hour for the

C-130, and $1.8K/hour for the C-21. With the average avoidable cost per flight-hour and the average aircraft speed, I then calculated the range that each civilian air ambulance location could support for different price intervals and plotted these ranges on the map.

For MilAir, I calculated the maximum ranges of each aircraft based on the average speed, the augmented duty day and the standard alert times shown in Table 1, and the average ground-time. The duty day does not begin until one hour after alert; however, the regulated time to respond to a patient begins once the Validating Flight Surgeon approves the Patient Movement Request. I calculated an average ground-time of 2.37 hours by averaging the ground-times of missions that did not go into crew-rest. I then valued each range at the average avoidable cost per flight hour calculation. For the C-21 and the C-130, the range is the same for an Urgent or Priority mission since the duty day is the limiting factor. Since the C-17 has a duty day of 24 hours, the limiting factor is the regulated response times. As such, the C-17 has a separate range for Urgent and Priority moves. I did not factor tasking time into the range calculations. However, the Urgent ranges for the C-130 and C-17 have no buffer for tasking time. Therefore, any additional time used to task these aircraft for an Urgent mission reduces their ranges by the same amount of time. I included a note in the map layers to remind the user of these tasking limitations.

Civilian air ambulances have a more lax enforcement of duty day limitations as compared with MilAir. Therefore, their primary limiting factor was the size of their AOR. I calculated the maximum possible flight distances for each civilian air ambulance's AOR. Given these distances, the aircraft speeds, and a 2.37-hour ground-time, I determined that the civilian air ambulances could move patients from any location within the prescribed Urgent/Priority timeframes and deliver the patients to their final destinations within an 18-hour duty day. It is

reasonable to assume that these civilian air ambulances fly 18-hour duty days since the FAA

rules allow 14 hours and any additional time needed to reach the closest acceptable destination in

order to accomplish emergency and government-sponsored operations (Federal Aviation

Administration, 2011). I did not consider alert time in range calculations for civilian air

ambulances since the civilian duty day begin when the pilot reports for duty (2011). In addition,

since International SOS has dedicated aeromedical evacuation aircraft, I considered the pre-flight

preparation time inconsequential.

In the final two layers, I plotted all the Urgent and Priority patient movements that

occurred over my study period. These layers allow the user to see actual data points, reinforcing

the accuracy of the tool.

Methodology for Comparing Decision Tree with Actual Cost

I ran the 170 missions through my decision tree tool in order to analyze the differences

between my proposed model for choosing an aircraft type and the actual choice made. I used the

following assumptions in the execution of my tool: all aircraft types are available, there are zero

"no-stop" requirements, there are zero training requirements, no space-A, and MilAir missions

originate from Ramstein.

Next, I analyzed the financial impact of using the decision tree versus the real-world

decision. Specifically, I evaluated the differences in avoidable costs of each mission in which

the decision tree recommended a different aircraft than that actually chosen. For this analysis, I

first determined the number of flight hours required to get the patient to the final destination with

the newly designated aircraft. For MilAir, I used Ramstein as the aircraft origin and final

destination. Great Circle Mapper provided the round-trip distances. Using the speeds calculated

earlier, I determined the number of flight hours and priced them using the logistics cost factor

per diem, Immanent Danger Pay, and Combat Zone Tax Exclusion just as I did during my initial

cost determinations. For civilian air ambulances, I used the aircraft origin closest to the patient

location. I assumed the final destination for patients in the South Africa AOR was South Africa.

I used Ramstein as the final destination for all other patients. Great Circle Mapper provided the

distances of the following legs: aircraft origin: patient origin and patient origin: patient

destination. Using the speeds as calculated earlier, I determined the total flight hours for each

mission. I then calculated the average cost per flight hour by year for each AOR using the

original data set. With this cost information, I priced each mission according to the AOR and

year flown. I then compared these costs to the actual costs incurred as calculated in the

Methodology for Costing section.

Summary

This chapter discussed the research methodologies used to develop the epidemiology of

aeromedical evacuation, calculate the avoidable costs, develop decision tools that identify the

most economical aircraft choice, and compare the decision tool outcome with real-world

decisions. The following chapter presents the analysis and results of this research.

IV. Analysis and Results

Chapter Overview

This chapter begins with the results of the epidemiological analysis of the 274 patients moved on the 170 aeromedical evacuation missions in Africa from 2010-2014. For ease of understanding, I present the information in graphical form and provide a brief interpretation and analysis of each graph. Following the epidemiology, I present the overall cost of aeromedical evacuation in Africa. Next, I present the decision map tool to show the gaps in aeromedical evacuation coverage. I conclude with an analysis of the results found using the decision tree tool, including the cost savings available through proper aircraft choice.

Epidemiology
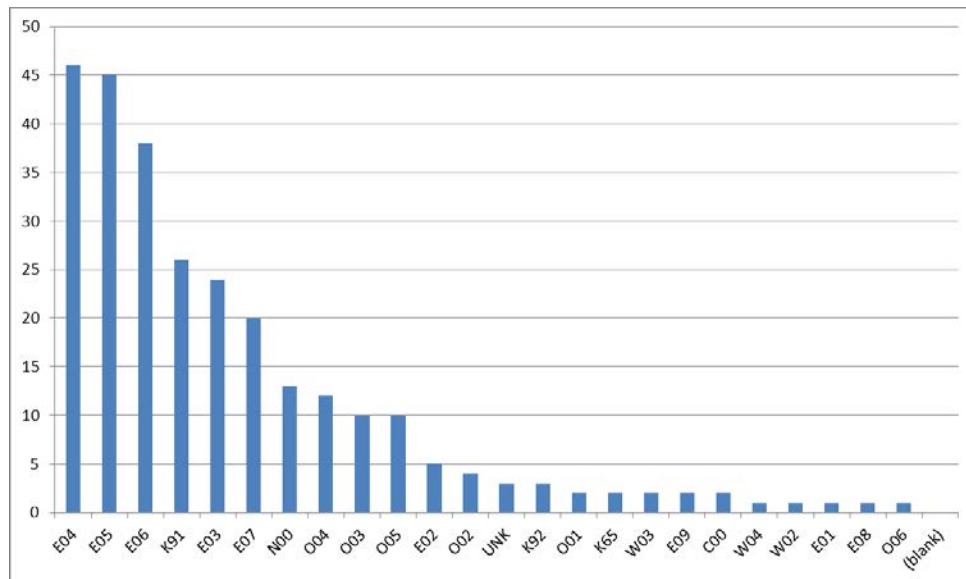
Figure 9. Patient Movement Requests by Patient Grade

Figure 9 shows the number of Patient Movement Requests by pay grade. As expected, I see the military's heavy dependence on E4s through E6s and O3s through O5s. The category,

K91, represents "Civilian-Disaster/Humanitarian/Refugee." The DoD moved these 26 patients

on the same day from Libya. The code N00 represents dependents and civilian federal

employees. Civilian employees represent a challenge because, while they are entitled to

aeromedical evacuation, they are not entitled to Tricare benefits. As a result, they are restricted

to the limited capability of MilAir, without the benefit of civilian air ambulances.
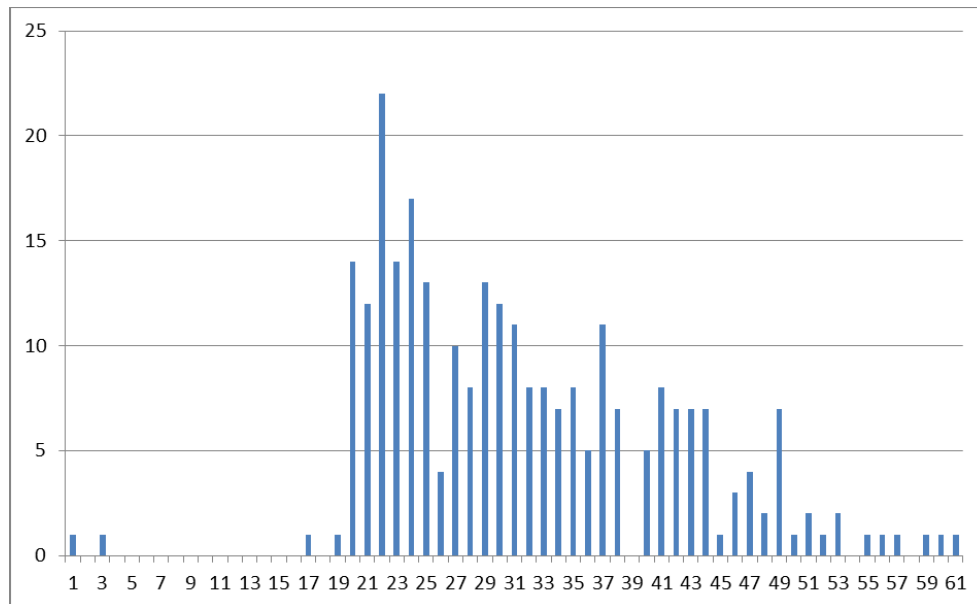
Figure 10. Patient Movement Requests by Patient Age

Figure 10 represents the number of aeromedical evacuations by age. This graph shows

that the DoD moves very few children in Africa, primarily due to the lack of dependent families

stationed on the continent. Instead, there is a peak at the age of 22 with a steady decline

afterwards. Of these 22 year old patients, all were enlisted E2s through E5s except for a single

civilian humanitarian move.
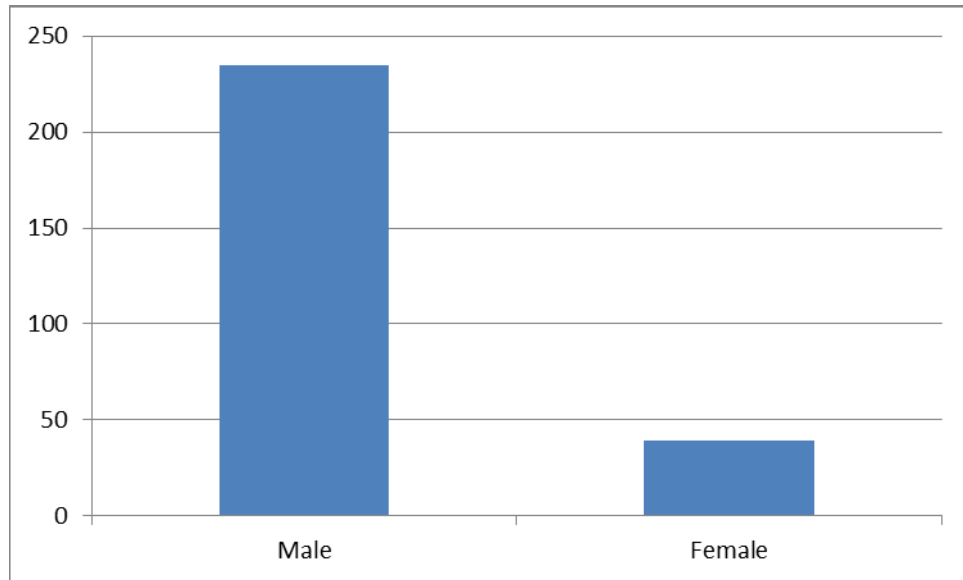
Figure 11 shows the breakdown of male and female aeromedical evacuations. Over the last five years, approximately 14.2 percent of aeromedical evacuations were for females. This number coincides with the overall number of females serving on active duty (CNN, 2013).
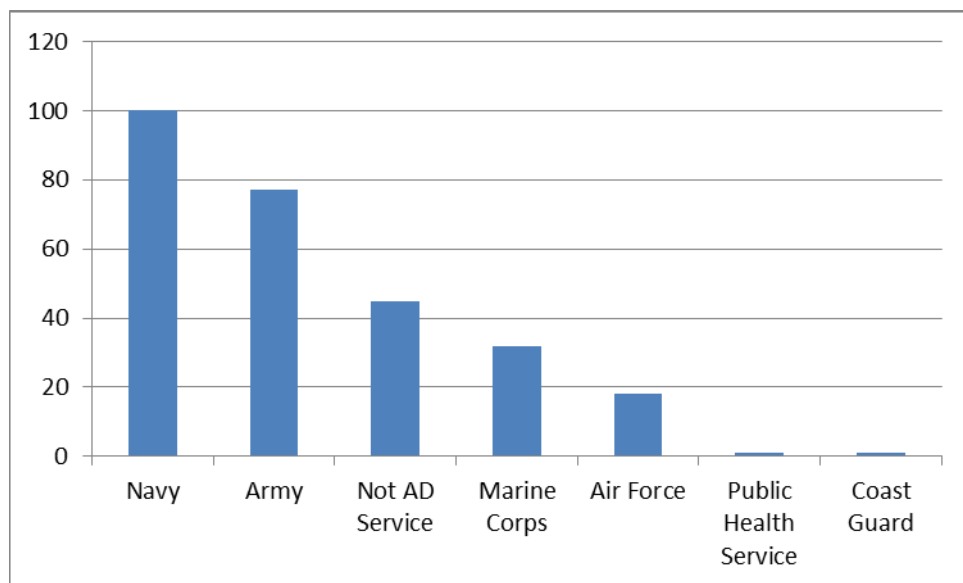
Figure 12 displays the number of aeromedical evacuations by patients' branch of service. The "Not AD Service" category represents all Guard, Reserve, civilians, and dependents. Over 16% of movements fall into this category. As expected, the Navy has the highest occurrence of patient moves in Africa since they maintain the only permanent base on the continent.
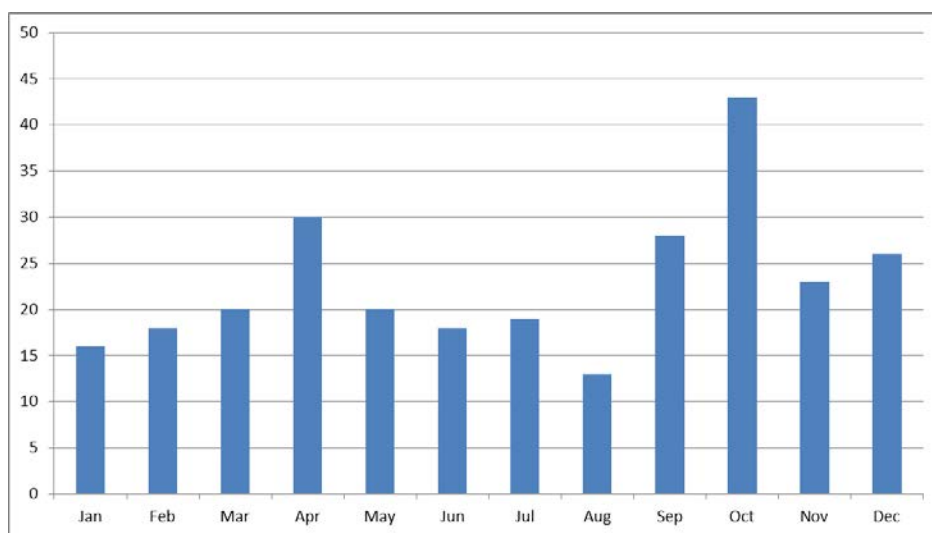
Figure 13. Patient Movement Requests by Month (five-year Total)

Figure 13 attempts to identify any cyclical nature of aeromedical evacuations in Africa. There is a clear peak in Patient Movement Requests in April and another in October; however, the outlier of 26 humanitarian moves skews the October peak as seen in Figure 17. Excluding these moves, the second peak occurs in September, with January and August representing the months with the fewest moves. Mission frequency, as shown in Figure 14, may provide a better understanding of aeromedical evacuation demand. This graph has the same peak in April, but the October peak subsides. On the average, the DoD flies 3 missions and 4.5 patients from Africa each month.
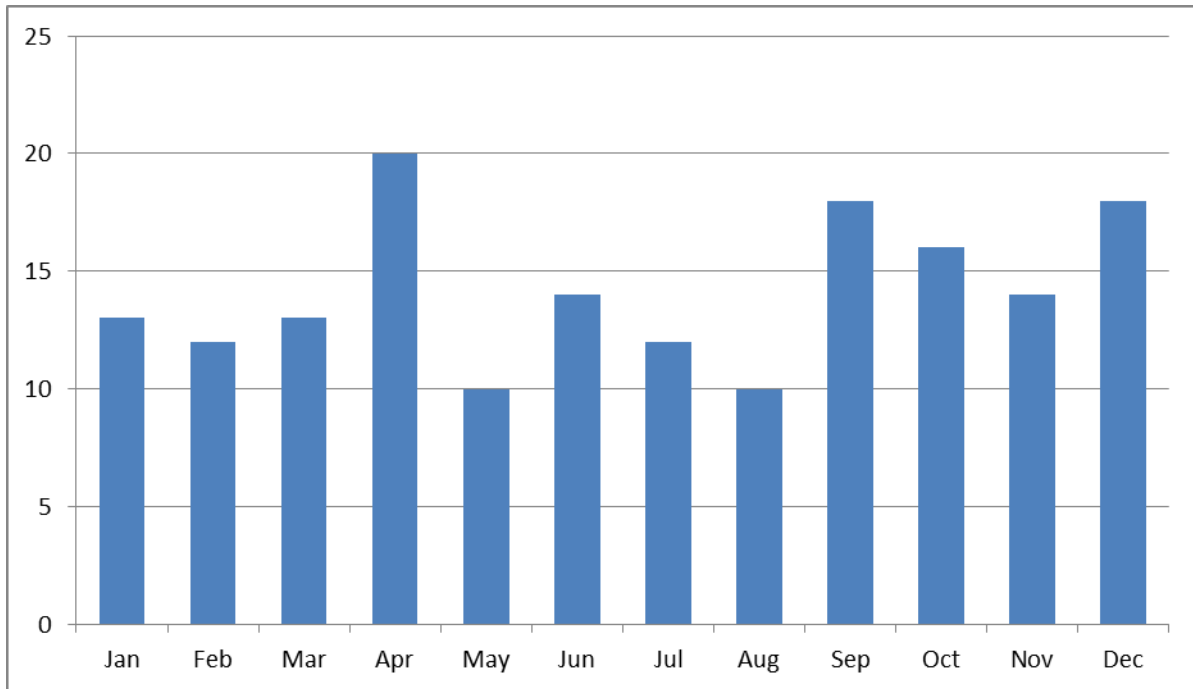
Figure 14. Missions by Month (five-year Total)
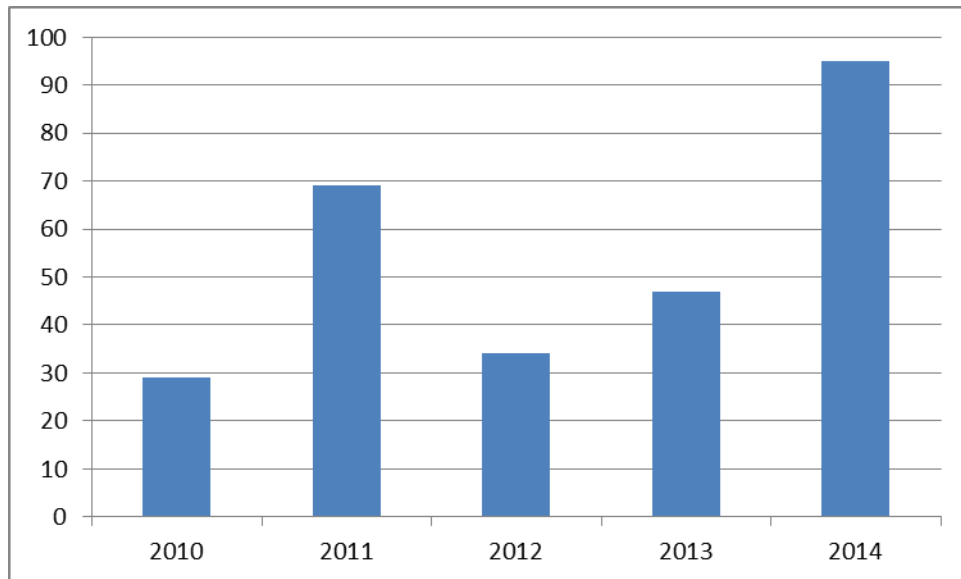
Figure 15. Patient Movement Requests by Year (five-year Total)

Figure 15 shows the trend of patient movements over time. There is a clear jump in 2011, partly due to the civilian movements that occurred during the Libyan conflicts. There is a growing trend in patient movements from 2012 through 2014. This increase is partly due to an

increasing number of Routine patients moved via aeromedical evacuation as seen in Figure 22. In addition, aeromedical evacuations resulting from deployments during the Liberian Ebola outbreak contributed to seven additional patient movement requests.
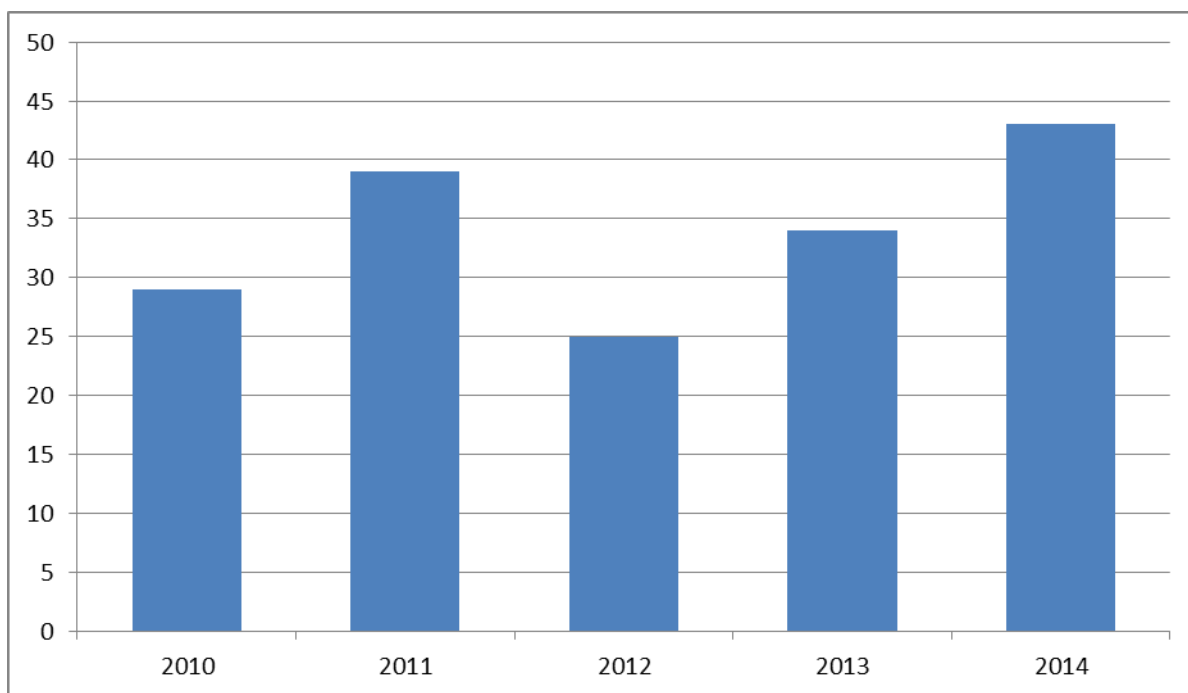
Figure 16. Missions by Year (five-Year Total)

The number of missions per year as seen in Figure 16 closely mimics the number of patients moved each year. The DoD moves an average of 55 patients on 34 aeromedical evacuation missions each year.
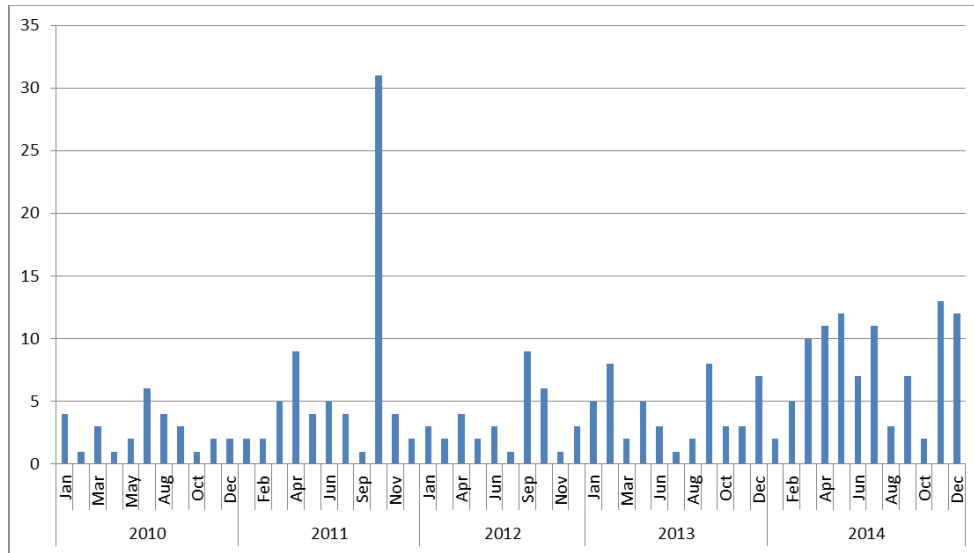
Figure 17. Patient Movement Requests Over Time

Figure 17 displays the number of aeromedical evacuations over time. As seen, the past five years do not show a clear seasonal pattern. However, there is a clear increase between March and July of 2014. Of the 51 patients moved in these months, 38 were Routine patients on nine MilAir missions departing from Djibouti. In comparison, only 11 Routine patients on five missions moved from Djibouti from 2010 through 2013. The cause of this increase is unknown, but may be due to planners choosing to group "well-patients" and fly them on Routine aeromedical evacuation missions rather than fly them on commercial airlines.
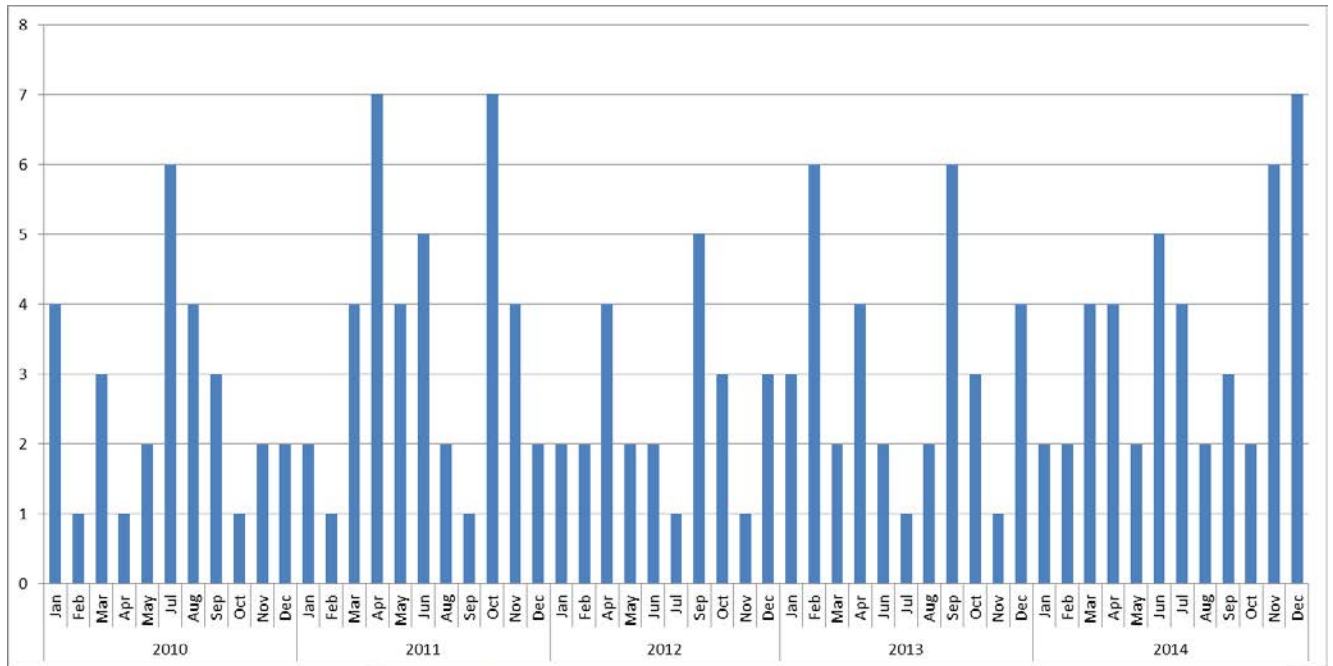
Just as the number of Patient Movement Requests vary each month, so do the number of missions. Figure 18 shows the number of missions each month, ranging from zero to seven.
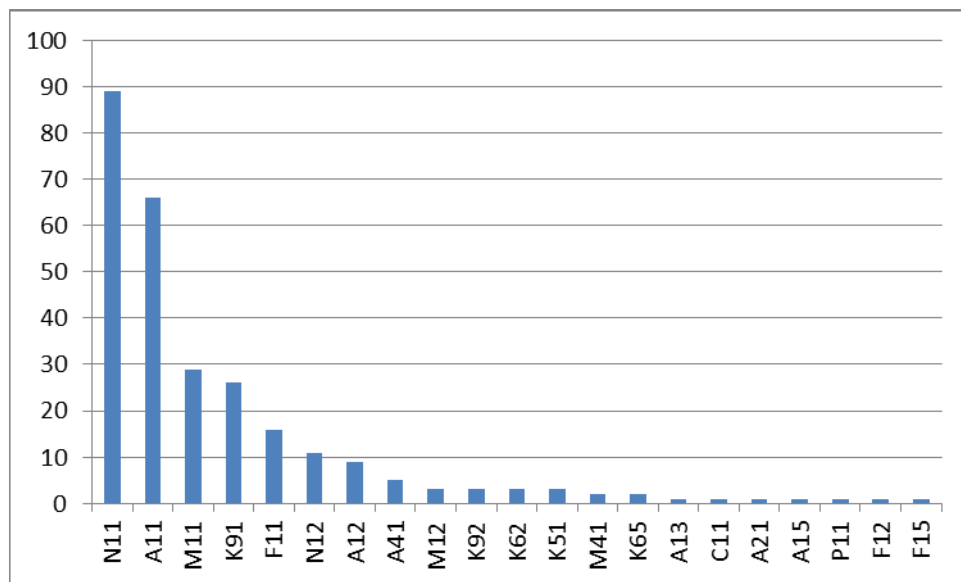
Figure 19. Patient Movement Requests by Patient Status Code

57

Figure 19 shows the number of aeromedical evacuations by patient status code. The Ns, As, Ms, Fs are Navy, Army, Marine, and Air Force. The 11s are active duty, 12s are Reservist, 15s are Guard, and 41s are dependents. The Ks represent other civilian categories, while C and P are Coast Guard and Public Health Service. Of the total patients moved, 56% are Active Duty Navy and Army.
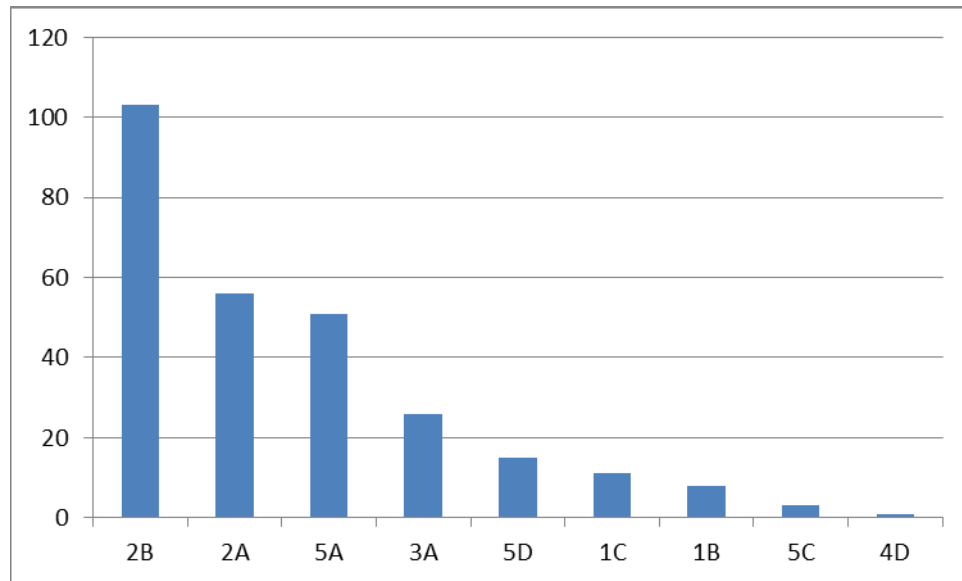
Figure 20. Patient Movement Requests by Patient Classification Code

Figure 20 shows patient moves by their classification. Codes beginning 1-4 represent inpatients and 5 represents outpatients. The most common classification is a mobile litter patient (2B) followed by an immobile litter patient (2A). Together, these classes comprise 58% of all movements. Psychiatric categories (1B, 1C, and 5C) represent 8% of movements as compared with 12% of global patient movements during the same period.
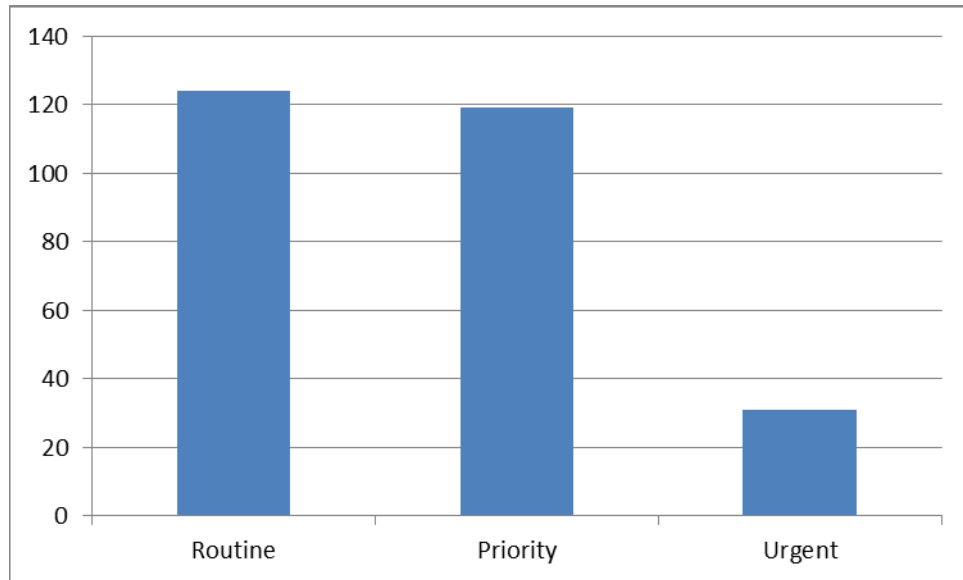
Figure 21. Patient Movement Requests by Patient Precedence Category

Figure 21 decomposes aeromedical evacuations by Precedence. The split between Routine and Priority is roughly equal around 45%. The 31 Urgent moves comprise 11% of all aeromedical evacuations. I further analyzed these categories in the following graphs.
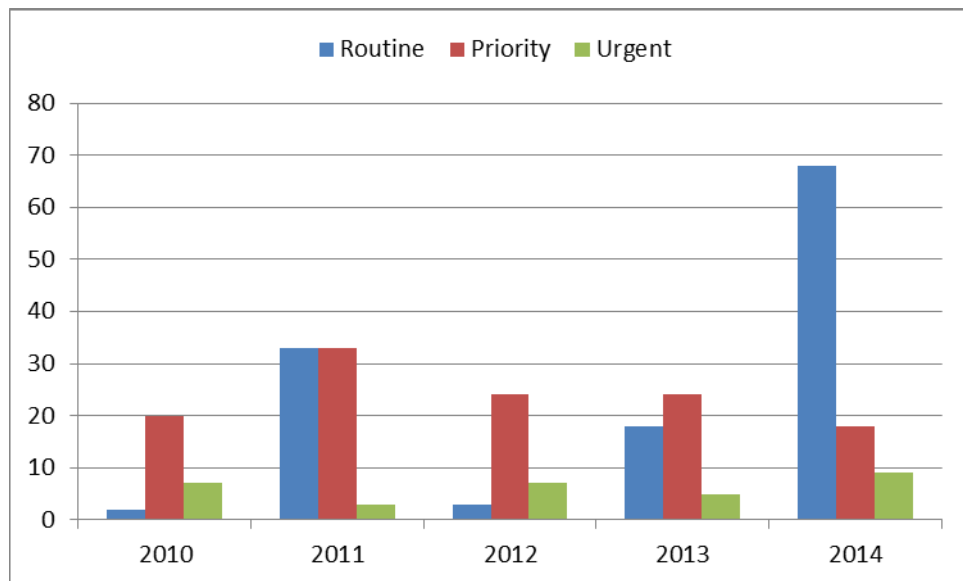

Figure 22. Patient Movement Requests by Precedence Over Time

Figure 22 shows the breakdown of precedence over time and shows the increase of Routine movements in 2014. As described in the Methodology section, these missions do not include the MedPax patient categories. The remaining precedence categories appear more stable over time.
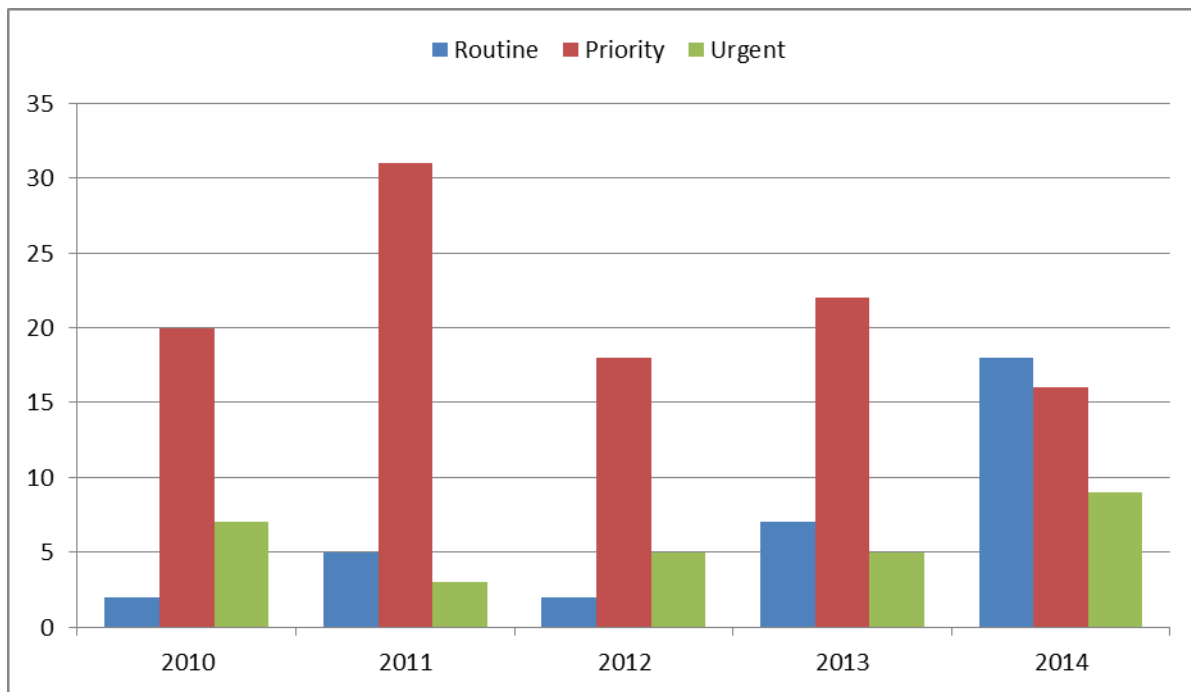
Figure 23. Missions by Precedence Over Time

Figure 23 shows the number of missions flown by precedence category. This graph indicates a rising trend in Routine and Urgent missions with little change to Priority missions.
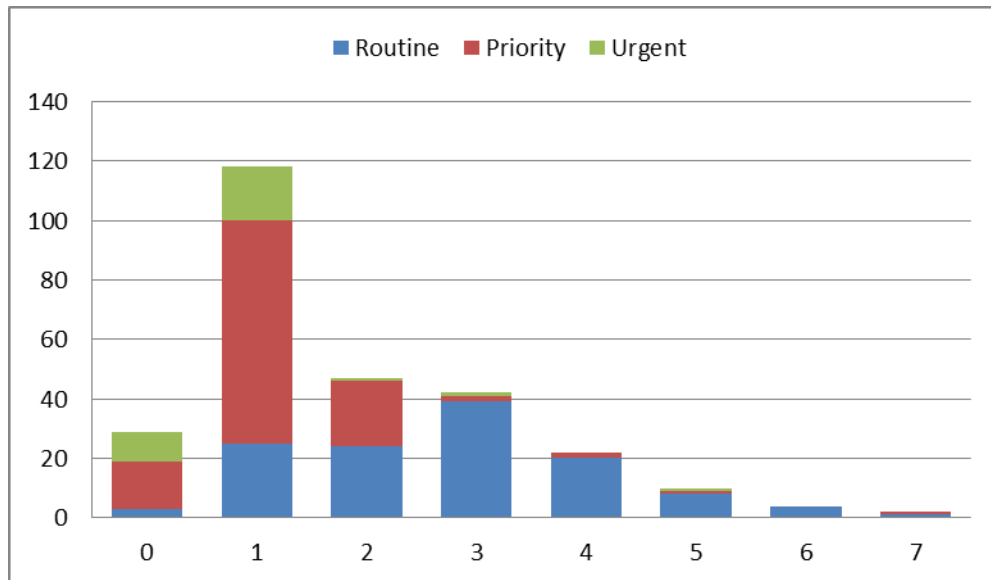
Figure 24 shows the number of days it took to move each patient by their precedence classification. To generate this chart, I compared the TRAC2ES cite number with the actual pick-up date. The cite number generates once a Patient Movement Request is submitted in TRAC2ES and consists of the five digit Julian Date (YYDDD), a three digit Patient Movement Requirements Center indicator (235 being the Theater Patient Movement Requirements Center-Europe), and a two digit number specifying the order in which that Patient Movement Request appeared that day. Given the standards (12 hours for Urgent, 24 hours for Priority, and 72 hours for Routine), no movement should take longer than three days, and no Urgent or Priority patient should take more than one day. However, 14% of all patients moved 72-hours or more after submitting the request. Furthermore, over 23% of the Priority patients and almost 10% of Urgent patients moved 24-hours or more after submitting the request. In the worst case, it took seven days to move a Priority patient and five days to move an Urgent patient. In all, over 23% of movements in Africa missed the regulated timelines. However, this data does not show the

61

time it took the Theater Patient Movement Requirements Center-Europe to validate the patient move as safe and necessary.
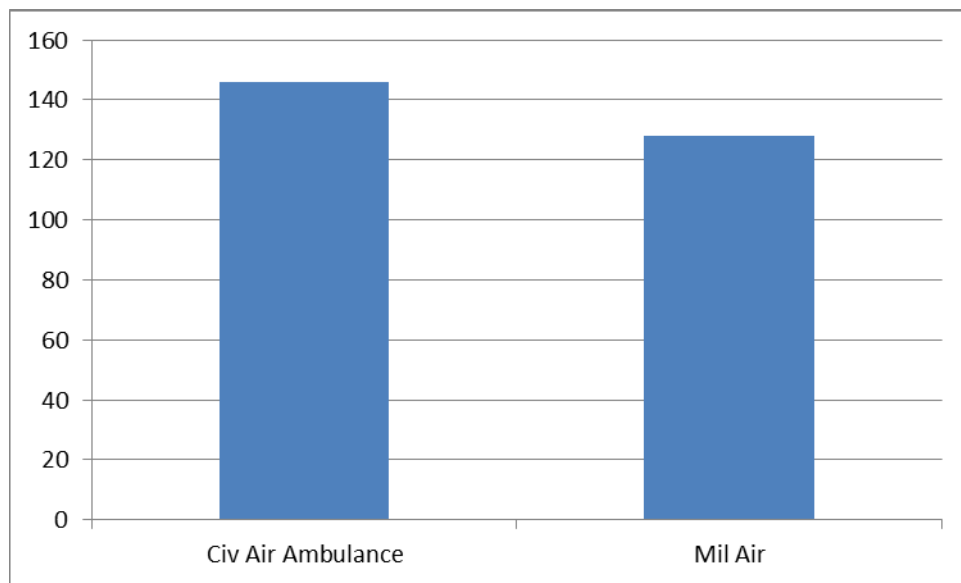

Figure 25. Patient Movement Requests by Aircraft Type

Figure 25 shows a similar number of patients split between civilian air ambulances and MilAir. However, as seen in Figure 36, civilian air ambulances fly many more missions. The difference is in the patient load. MilAir missions have more than one patient 51% of the time as compared with only 18% of civilian air ambulances. This difference is due to the small size of civilian air ambulances and to the fact that the 1998 version of DODi 6000.11restricted use of civilian air ambulances to Urgent and Priority patients. Although the 2012 version deleted this restriction, it is still a common practice. In the last five years, civilian air ambulances flew 17% of Routine missions compared with 83% of Urgent and Priority missions. Since Routine missions are more likely to have multiple patients (Figure 35), the overall number of patients moved by the two segments is comparable.
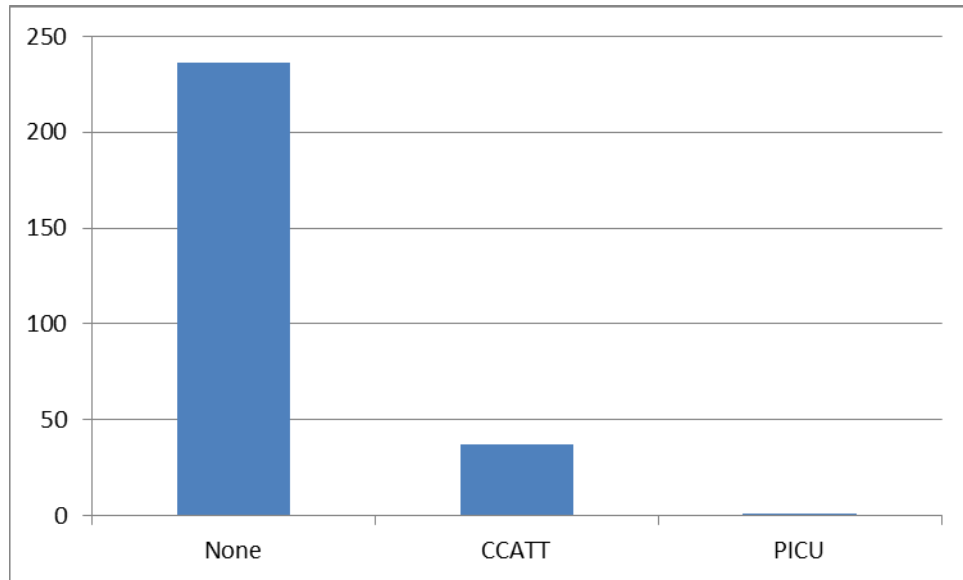
Figure 26 shows 14% of all patients required some sort of special care team. Both MilAir and civilian air ambulances have a Critical Care Air Transport Team capability. Table 7 shows the medical specialty and diagnosis of patients on missions requiring a special team.

Table 7. Diagnosis and Required Specialty for Aeromedical Evacuations with Special Teams

| Primary MEDSPEC Name	Primary Diagnosis Name
Burns	BURN NOS TRUNK-UNSPEC
Cardiology	MI,INF,UNSPEC EPISODE
Cardiology	TACHYCARDIA NOS
Cardiology	OLD MYOCARDIAL INFARCT
Cardiology	MI,SUBENDCARD,UNSPEC EPISODE
Cardiology	SINOATRIAL NODE DYSFUNCT
Cardiology	MI,SUBENDCARD,UNSPEC EPISODE
Cardiology	MI,ANT,UNSPEC EPISODE
Cardiology	MI,UNSPEC SITE,INIT EPISODE
Gastroenterology	GASTROINTEST HEMORR NOS
General Surgery	TRAUMATIC SHOCK
General Surgery	OTHER INJURY OF CHEST WALL
Infectious Disease	MALARIA NOS
Internal Medicine	CHEST PAIN, UNSPECIFIED
Internal Medicine	HEAT STROKE SUNSTROKE
Internal Medicine	VENOUS THROMBOSIS NOS
Internal Medicine	ANGINA PECTORIS NEC/NOS
Internal Medicine	POISON-MEDICINAL AGT NOS
Neurology	TB MENINGITIS-UNSPEC
Neurology	CEREBRAL EDEMA
Neurosurgery	ACUTE ILL-DEF CEREBROVASC
Neurosurgery	TRAUMATIC SUBDURAL HEM
Neurosurgery	INJ SUPERF NERV HEAD/NCK
Neurosurgery	INJURY TO NERVE NOS
Neurosurgery	SUBARACHNOID HEMORRHAGE
Neurosurgery	CEREBROVASCULAR ANOMALY
Orthopedic Surgery	FX FIBULA NOS-OPEN
Orthopedic Surgery	FX FEMUR NOS-OPEN
Orthopedic Surgery	FX RADIUS SHAFT-OPEN
Orthopedic Surgery	AMPUT ABOVE KNEE, UNILAT
Otorhinolaryngology	PERITONSILLAR ABSCESS
Peripheral Vascular Surgery	INJ INTERNL JUGULAR VEIN
Peripheral Vascular Surgery	INJ COMMON FEMORAL ARTER
Psychiatry (Male General Care)	SUIC,POIS,ANALG/ANTIPY/ANTIRHE
Pulmonary Disease	OTHER PULMON EMBOL & INFARCT
Pulmonary Disease	PNEUMONIA, ORGANISM NOS
Pulmonary Disease	FUM/VAPOR UP RESP INFLAM
Pulmonary Disease	ASTHMA, UNSPEC, W EXACERBATION
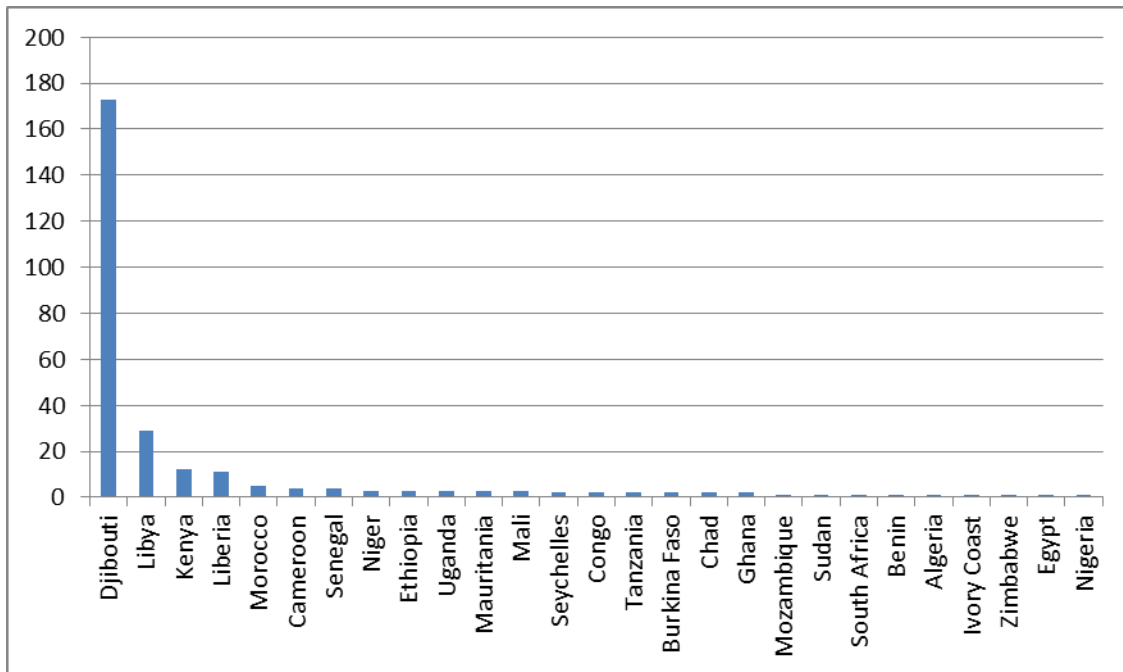
Figure 27. Patient Movement Requests by Country of Origin

Figure 27 shows the frequency of aeromedical evacuations by country. The DoD moved patients from 27 different countries, with Djibouti being the most prevalent.
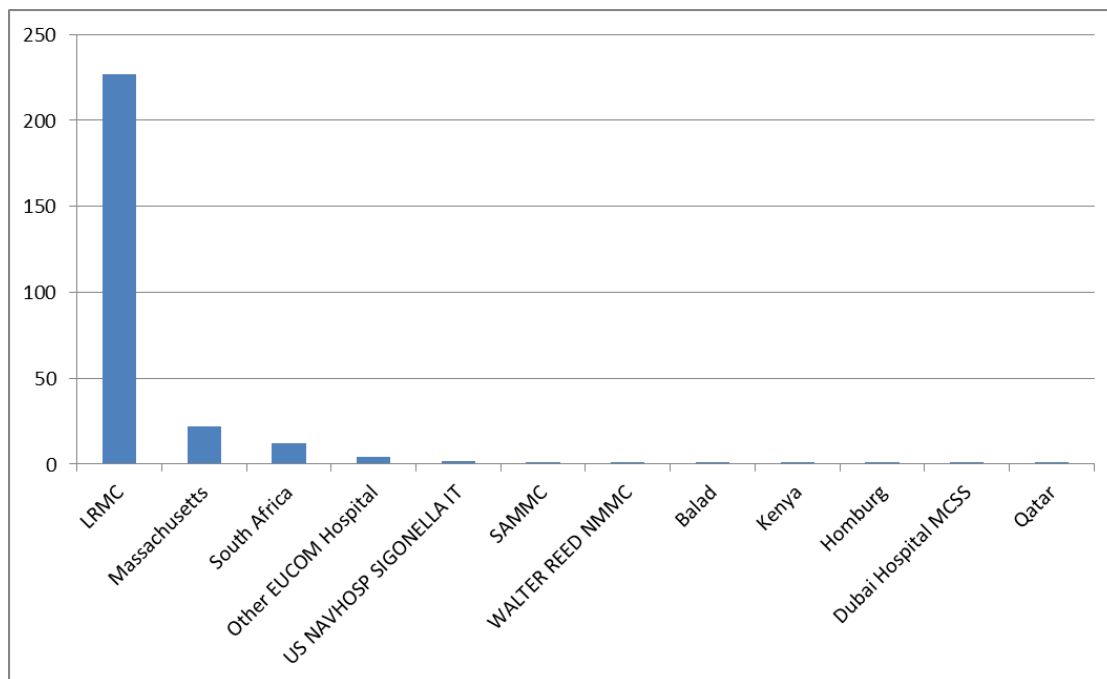

Figure 28. Patient Movement Requests by Destination

Figure 28 shows the patients' destination. The majority of patients return to the Landstuhl Regional Medical Center, however, the DoD retains the ability to send a patient to an alternate destination if required.
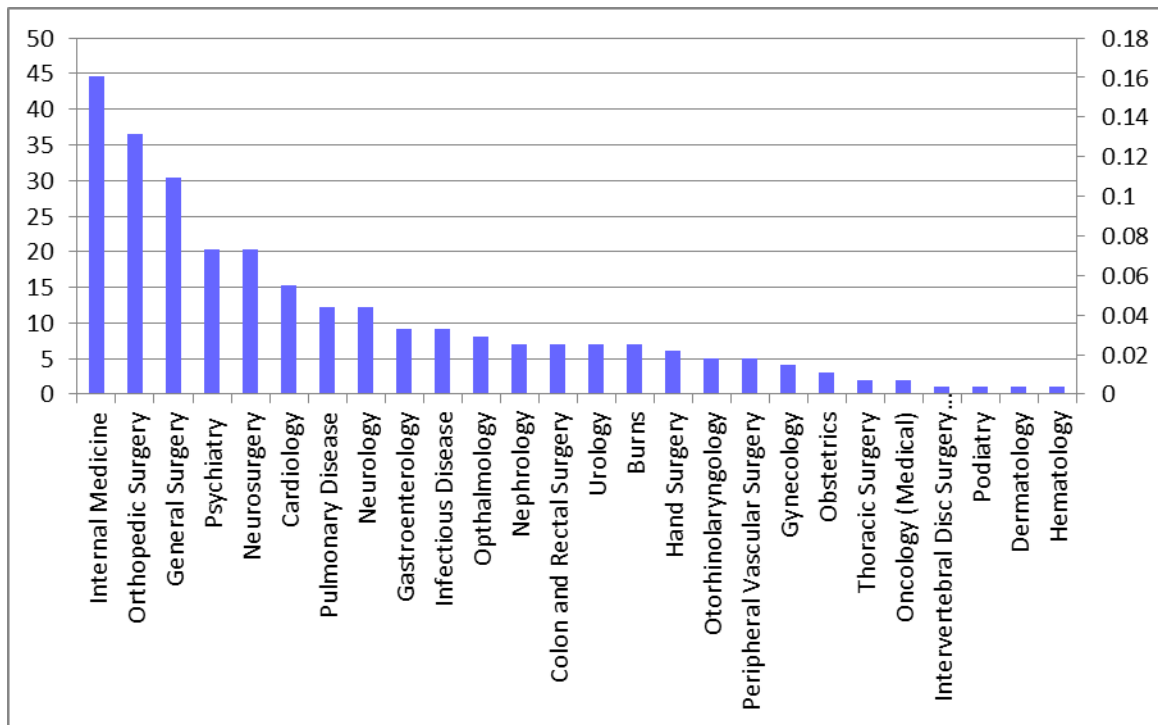

Figure 29. Number of Patient Movement Requests and Percent of Patient Movement Requests by Medical Specialty

Figure 29 shows the number of aeromedical evacuations by medical specialty. The most frequent specialties were Internal Medicine, Orthopedic Surgery, and General Surgery. In comparison, Sand, et al.'s (2010) study of civilian aeromedical evacuations found Internal Medicine, Surgery, and Neurology to be the top required specialties. Figure 30 and Figure 31 show the same information for Urgent and Priority patients. As seen, the top specialties shift slightly based on precedence.
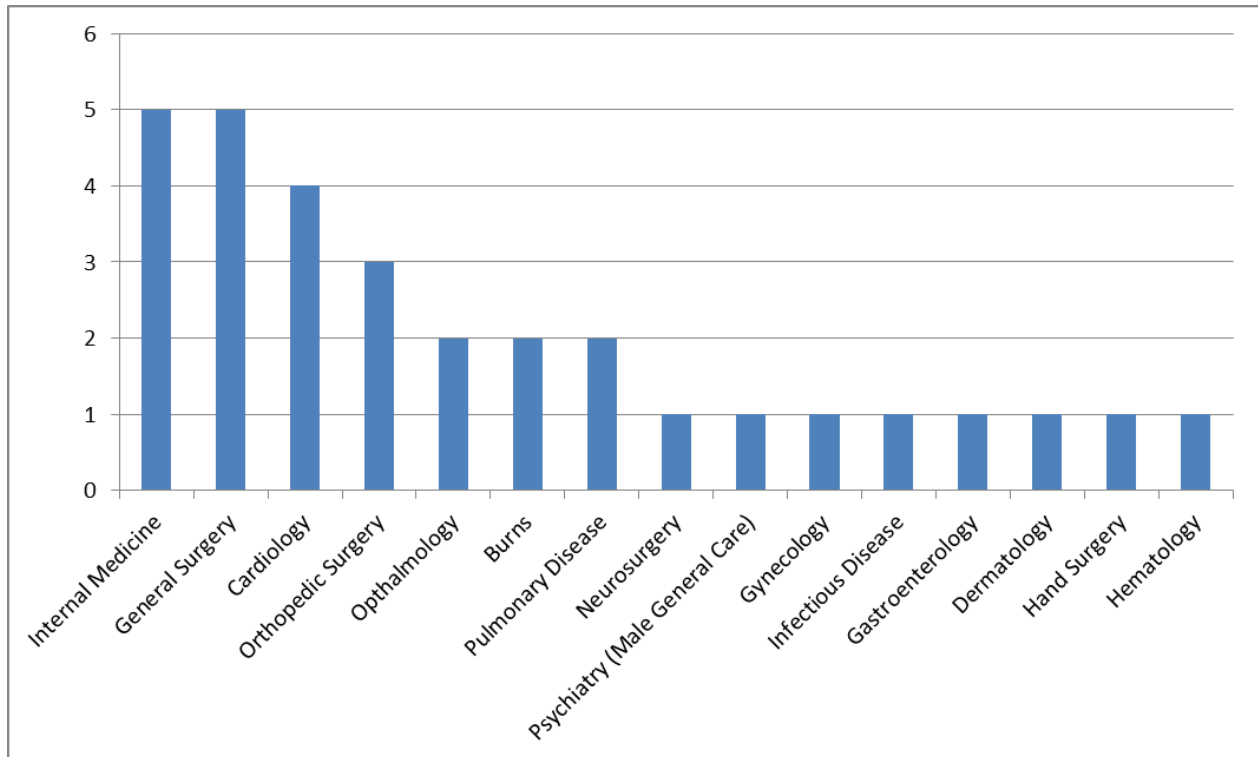
Figure 30. Number of Urgent Patient Movement Requests by Medical Specialty
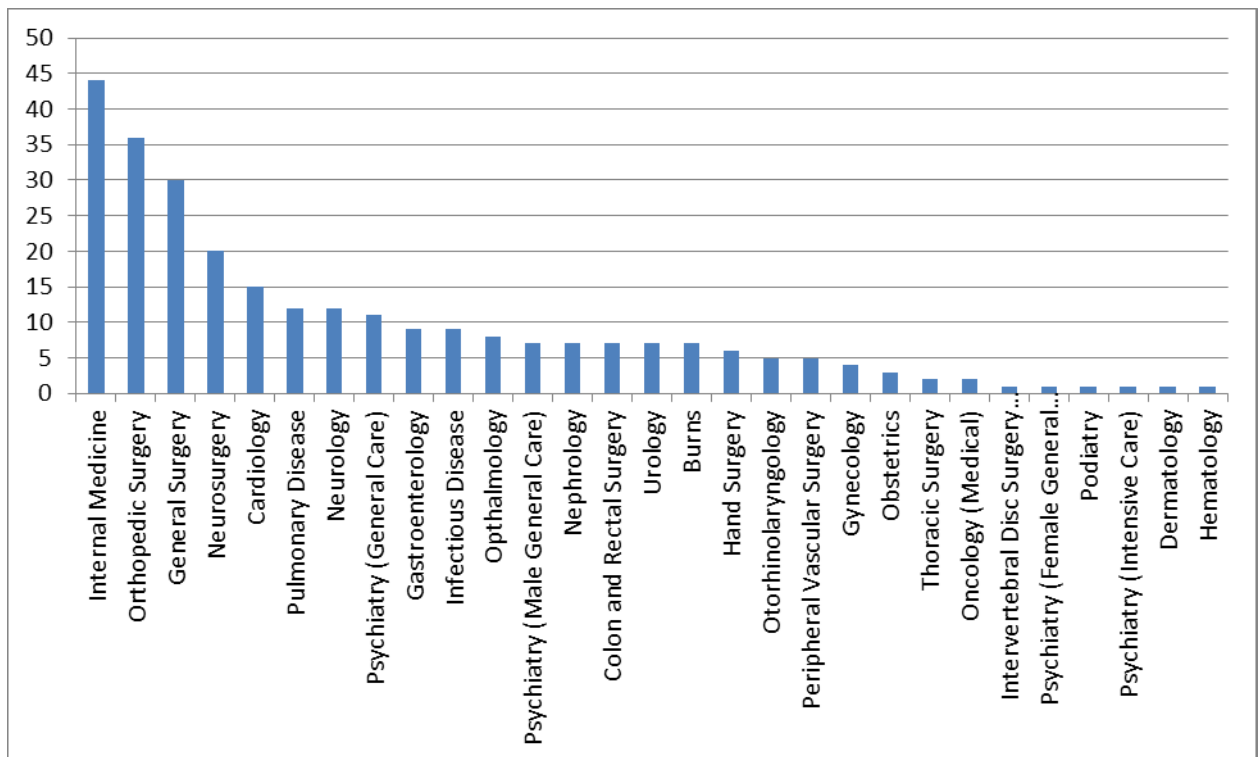

Figure 31. Number of Priority Patient Movement Requests by Medical Specialty

Figure 32 and Figure 33 show the breakdown of medical specialty required by country. These graphs show the disease profile evenly spread throughout Africa. There is, however, an increased need for General Surgery and Neurosurgery in Libya as well as an increased need for Psychiatry in Djibouti as compared to other countries.
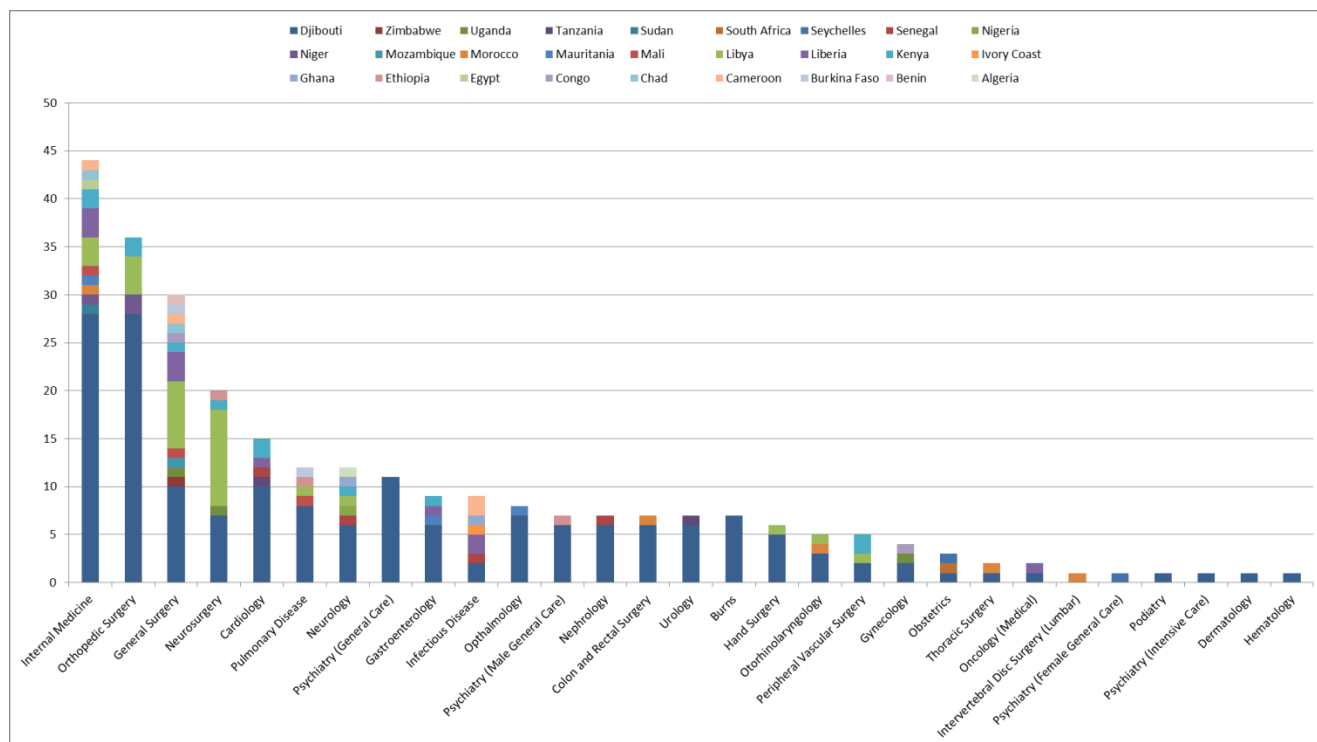

Figure 32. Patient Movement Requests by Medical Specialty by Country of Origin
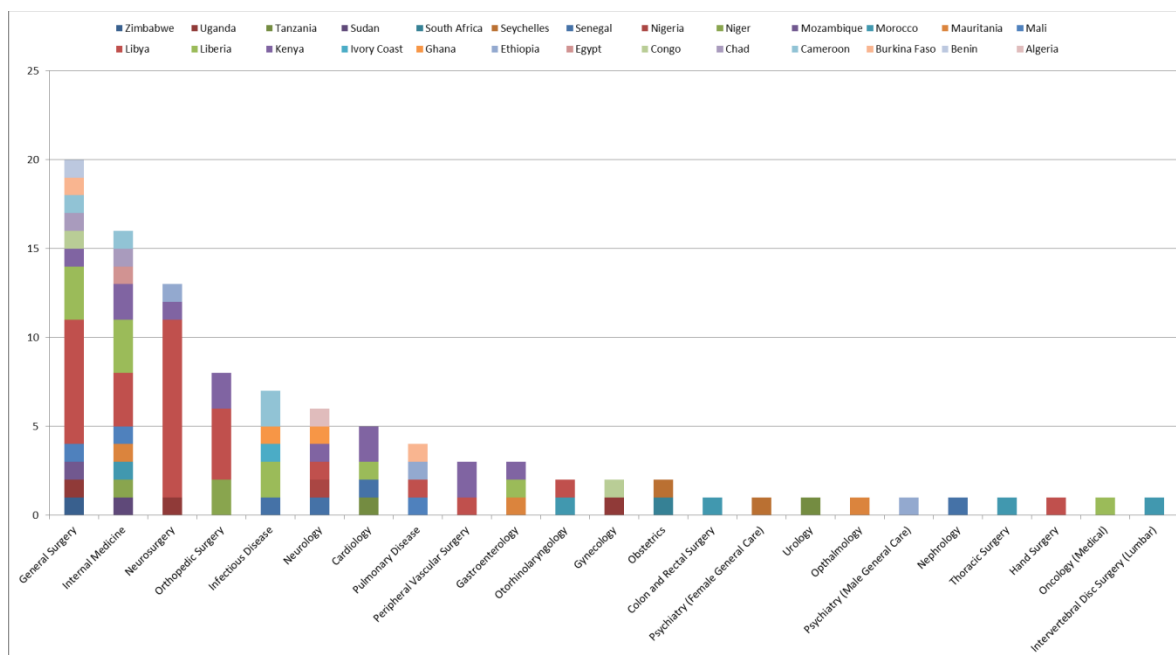
Figure 33. Patient Movement Requests by Medical Specialty by Country of Origin (Excluding Djibouti)

Table 8 provides a list of the most common diagnosis. This list is significantly different from that seen by Sand, et al.'s study (2010). Sand, et al. (2010) found Neck Fracture, Stroke, MI, Cerbrocranial trauma, and Polytrauma as the top five diagnoses. This difference may be in part to type of activities performed by patients as well as the age profile of the civilian and military populations. However, Table 8 does show four MIs and 13 Chest Pains. This fact suggests a commonality in cardiac problems between the two studies. To note, many of these diagnosis occurred in a field environment without a medical doctor present.

Table 8. Frequency of Diagnosis (n=274; only diagnosis occurring more than once are shown)

| Diagnosis	Count
CHEST PAIN, UNSPECIFIED	11
CALCULUS OF KIDNEY	6
ACUTE APPENDICITIS NOS	5
DVRTCULITIS OF COLON,WO HMRG	4
INJURY SCIATIC NERVE	4
MALARIA NOS	4
FX ANKLE NOS-CLOSED	3
OPEN WOUND OF HIP/THIGH	3
OTHER CONVULSIONS	3
DEPRESSIVE DISORDER NEC	3
GASTROINTEST HEMORR NOS	3
MI,OTHER SITE,UNSPEC EPISODE	2
VEN EMBL&THRMB,UNSPC DP VSL,LE	2
PNEUMONIA, ORGANISM NOS	2
ADJMT DISORD W DISTRBNCE,CNDCT	2
ABDOMINAL PAIN, GENERALIZ	2
AMPUTATION FINGER	2
PARTIAL EPIL,W IMP CON,WO INTR	2
CHEST PAIN NEC	2
SPONT TENS PNEUMOTHORAX	2
EPILEPSY NOS,WO INTR	2
INJ COMMON FEMORAL ARTER	2
ESOPHAGEAL DISORDER NOS	2
INJURY TO NERVE NOS	2
FEVER, UNSPECIFIED	2
MI,SUBENDCARD,UNSPEC EPISODE	2
FX LUMBAR VERTEBRA-CLOSE	2
PERITONSILLAR ABSCESS	2
FX NAVICULAR, WRIST-CLOS	2
PSYCH DISORDR W DELUSIONS, CCE	2
FX TIBIA NOS-CLOSED	2
SUICIDAL IDEATION	2
HAND INJURY NOS	2
HEAT STROKE SUNSTROKE	2
HYPHEMA	2
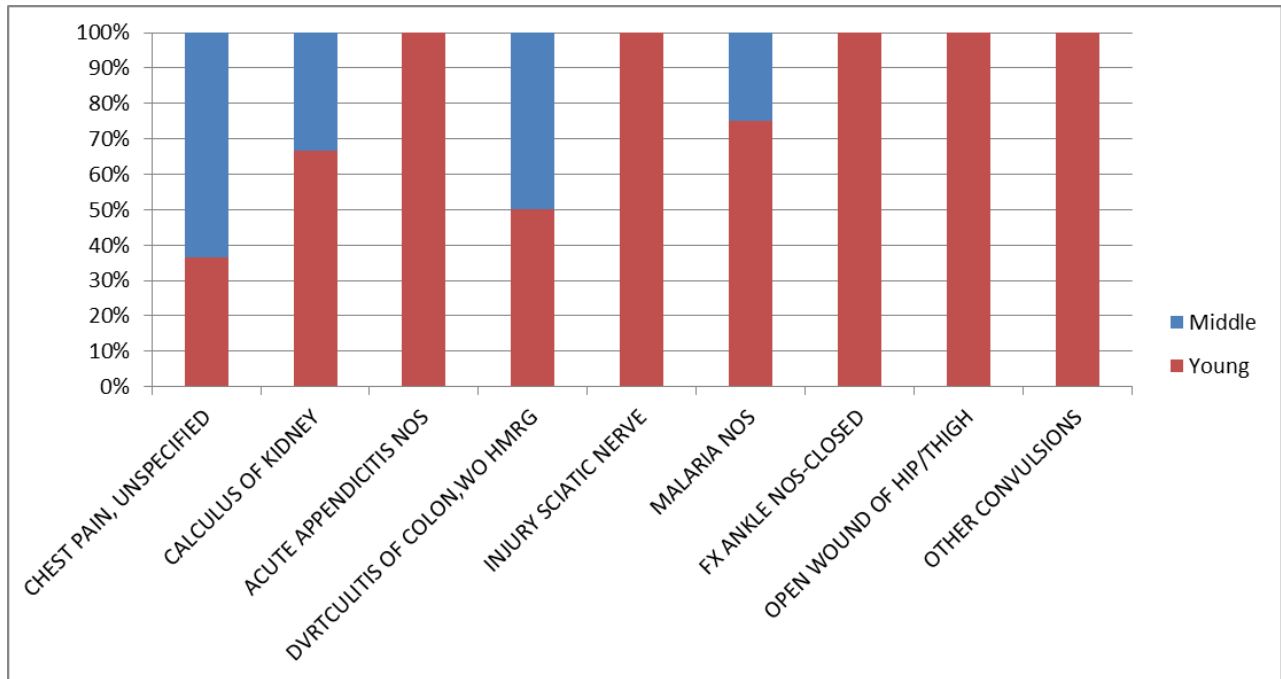
Figure 34. Age Distribution by Medical Specialty (Middle:41-70 y, Young: 17-40 y)

Figure 34 shows the age distribution of the top required medical specialties. Although only 21% of patients fall into the Middle age group, this category accounts for over 60% of Chest Pain and 50% of Diverticulitis of Colon diagnoses.
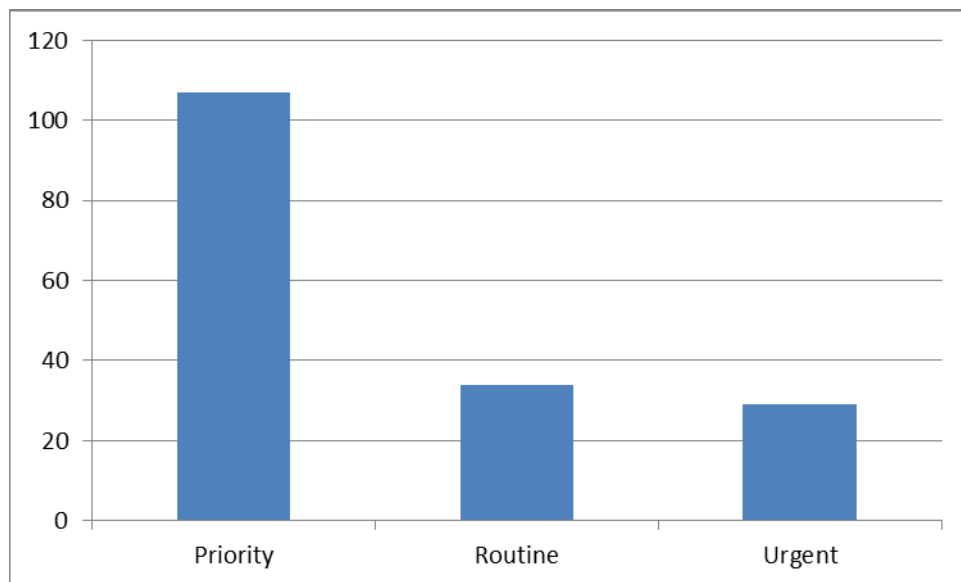

Figure 35. Missions by Precedence

71

Although Figure 21 shows the number of Urgent and Routine patients to be equivalent, Figure 35 shows the number of Priority missions to be three times greater than the number of Routine or Urgent missions. This difference is because only 19% of Priority and Urgent missions had more than one patient on board, where 58% of Routine missions had more than one patient. This difference is likely due to the use of Routine missions as "theater clearing" missions, where planners evacuate borderline patients as a precautionary measure.
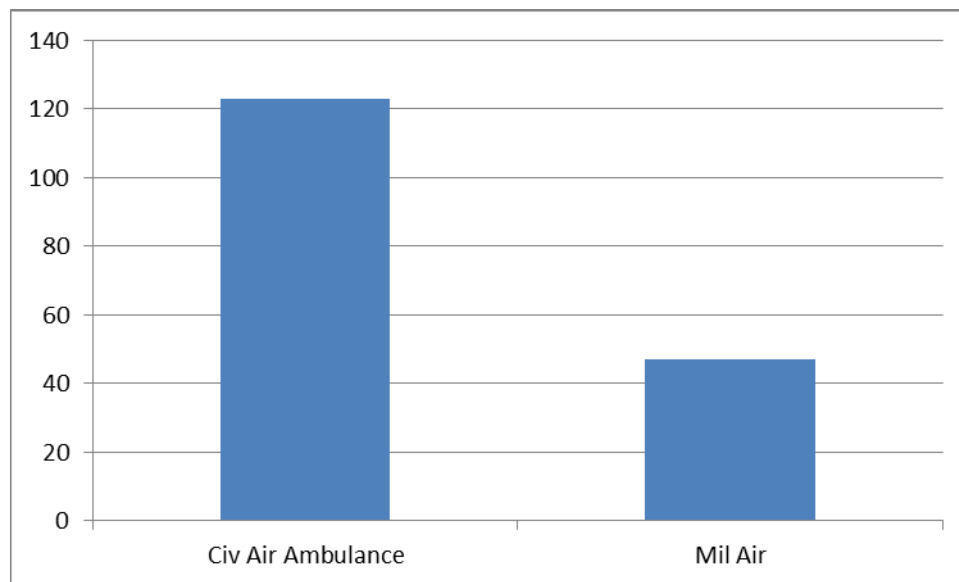

Figure 36. Missions by Aircraft Segment

Figure 36 shows the DoD's dependence on contracted civilian air ambulances for aeromedical evacuation in Africa. Although this reliance is a point of concern for many planners, the partnership is successful in expanding military capability and capacity in the region without long-term commitments. However, as seen in Figure 37, the recent trend is toward MilAir missions with fewer civilian air ambulances. Perhaps, this trend is due to the increase in Routine patients moved via aeromedical evacuation as shown in Figure 23, but highlights the importance of this study as determining aircraft type is an important factor in reducing overall cost.
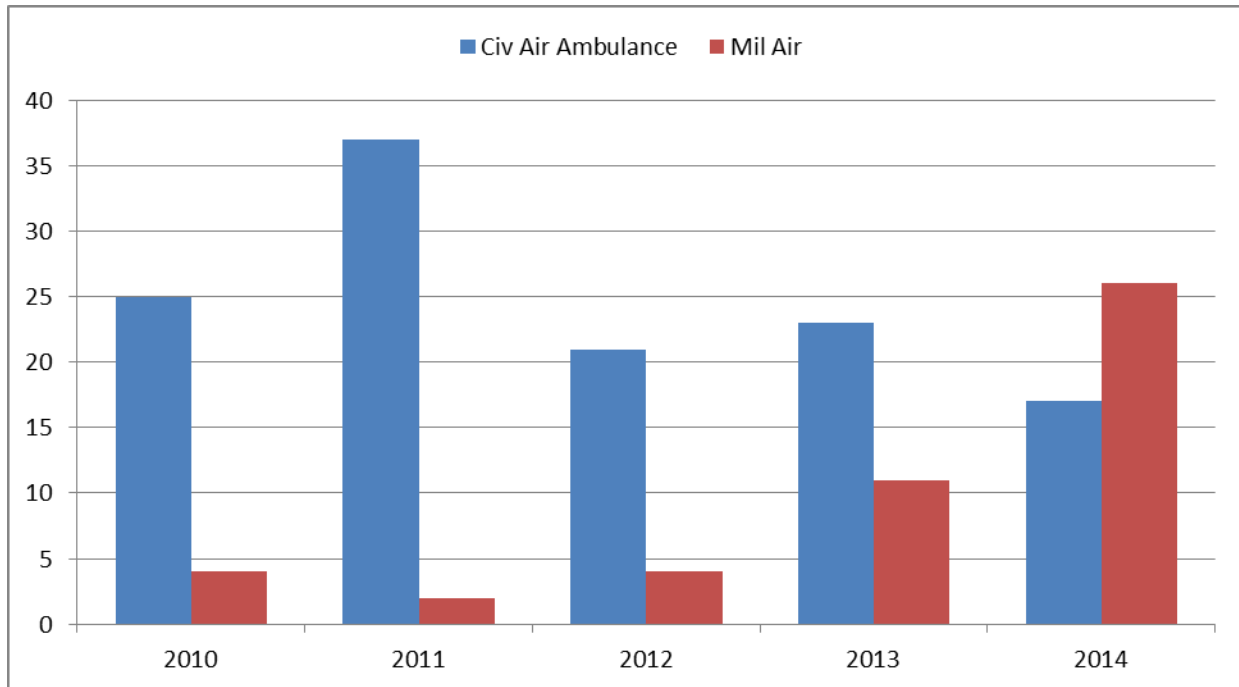
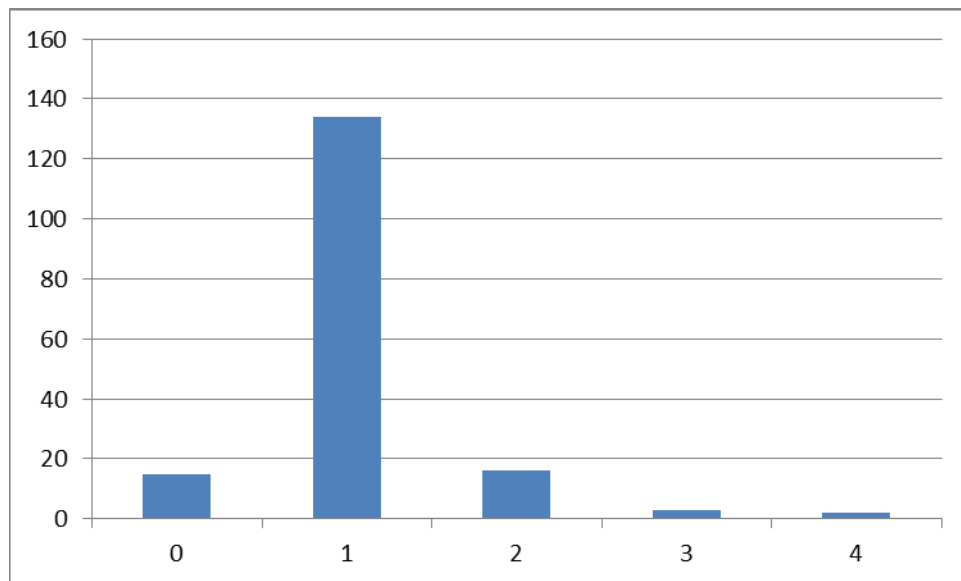Figure 37. Missions by Aircraft Segment Over Time

Figure 38. Missions by Litter Patient Count

Figure 38, Figure 39, and Figure 40 show the distribution of patient load by mission.

Comparing these figures shows the majority of missions are for a single litter patient. The

maximum load experienced was a single mission with 22 patients. These graphs demonstrate the

value of small aircraft like the C-21. Not only are they less expensive to operate, but also handle the majority of mission requirements.
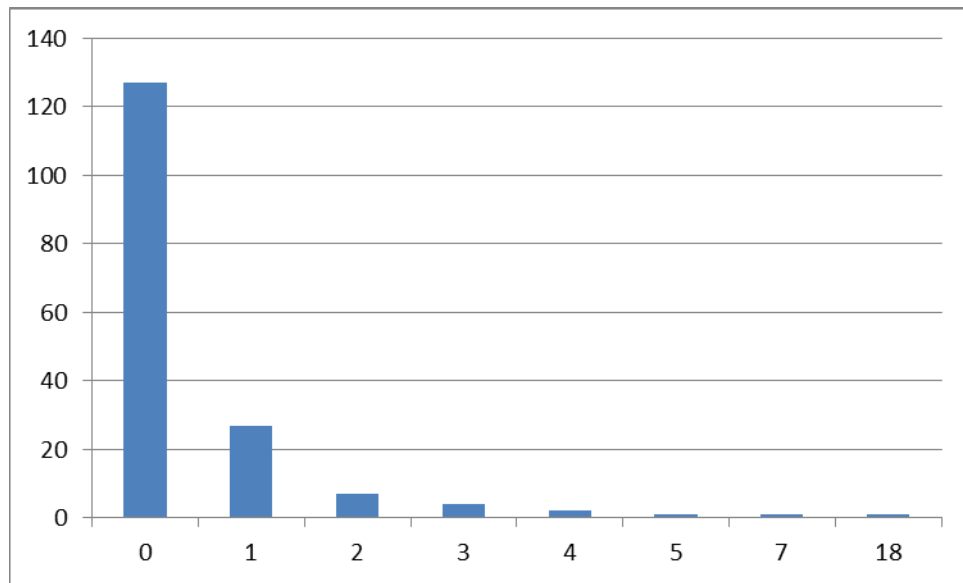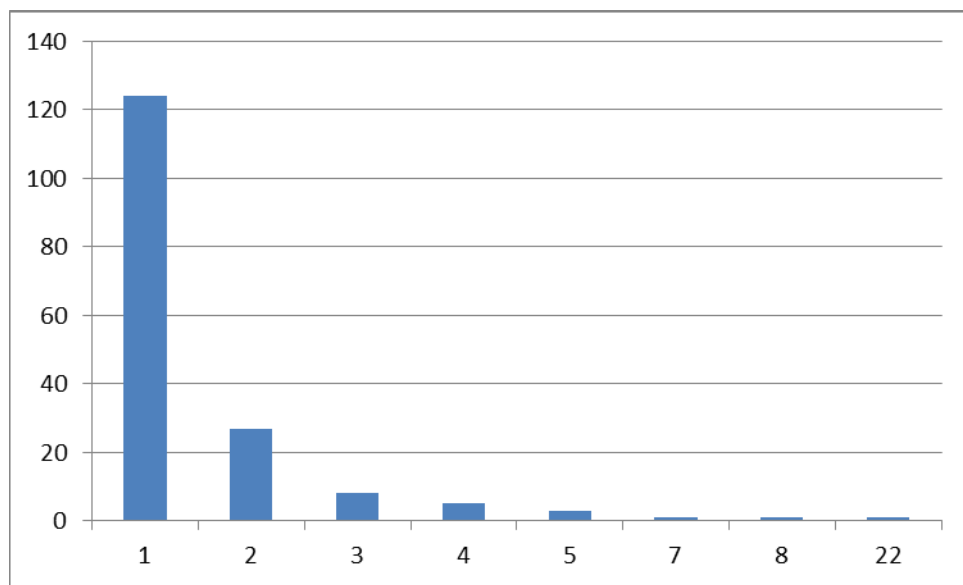

Figure 39. Missions by Ambulatory Patient Count

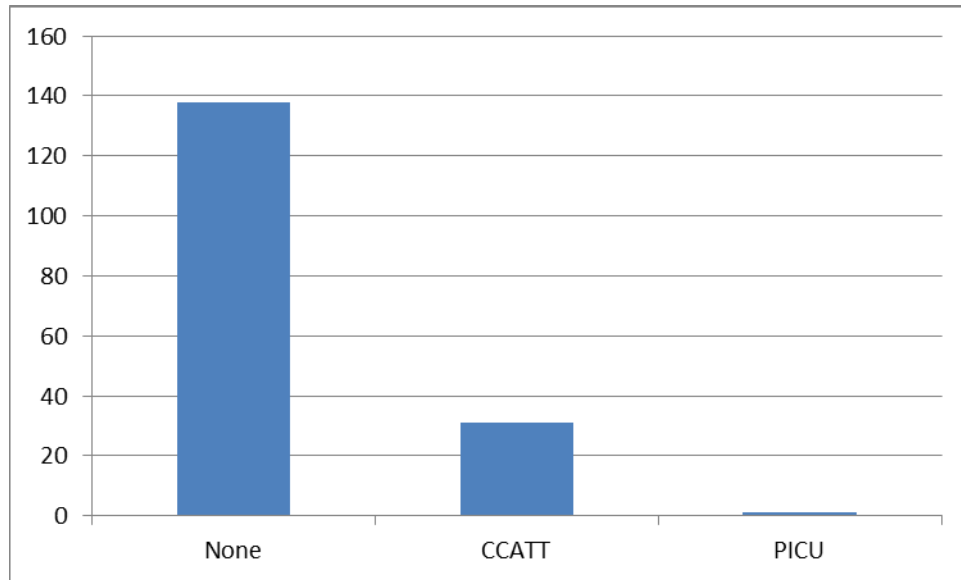

Figure 40. Missions by Patient Load

Figure 38 shows about 19% of missions require a Critical Care Air Transport Team. Together with Figure 26 and Table 7, they provide insight on the usefulness of a Tactical Critical Care Evacuation Team Enhanced capability for Africa. In the past five-years, only 32 missions required Critical Care Air Transport Teams. Of which, only a few would benefit from a Tactical Critical Care Evacuation Team Enhanced. Even if a Tactical Critical Care Evacuation Team Enhanced flew all 32 missions, maintaining their currency would require additional training and expenses. The Tactical Critical Care Evacuation Team Enhanced concept requires further analysis to justify this additional capability.
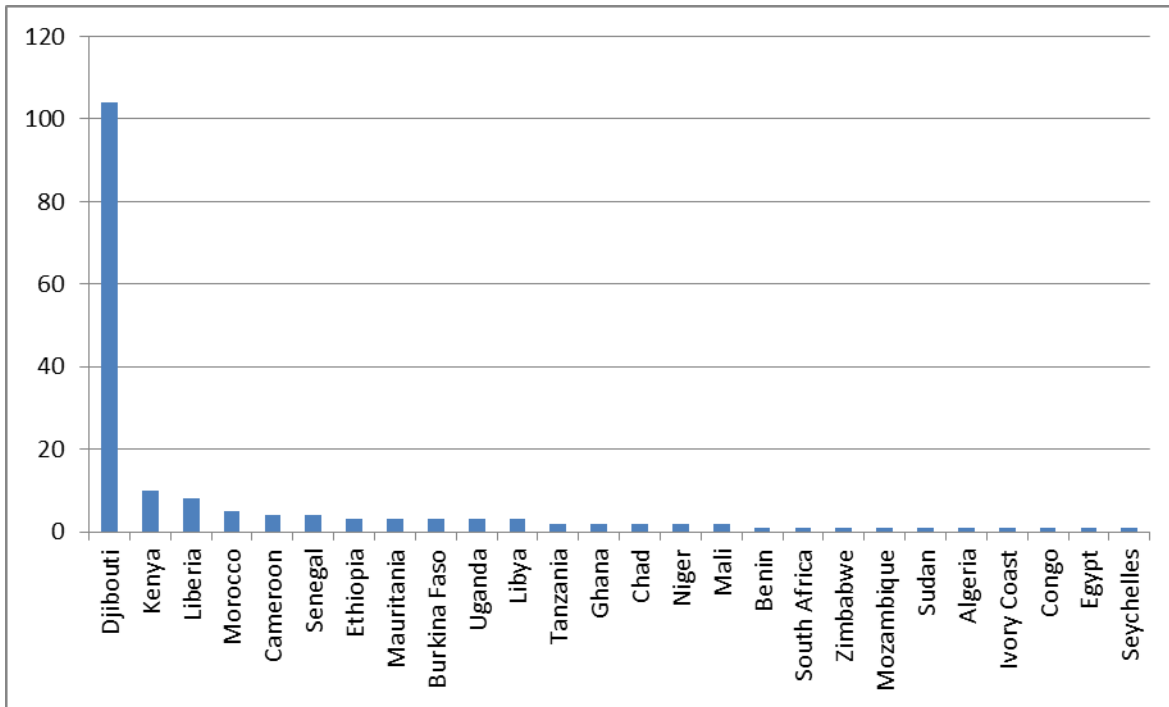
Figure 42. Missions by Country of Origin

While Figure 27 shows several patients came from Libya, Figure 42 shows most mission requirements generate from Sub-Saharan Africa. This fact is significant because of the range limitations of MilAir flights that originate from Germany.
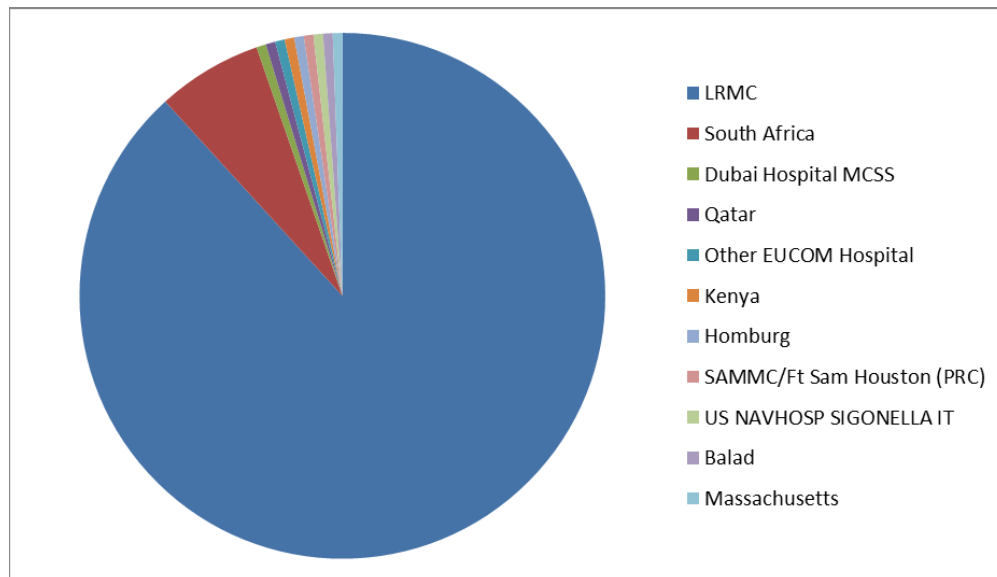

Figure 43. Missions by Destination

Figure 43 portrays a slightly different picture than Figure 28. While the majority of missions are destined for the Landstuhl Regional Medical Center, this chart shows a significant portion of missions destined to South Africa. This fact is understandable given the excellent medical care in South Africa and the large time differential between there and Germany.
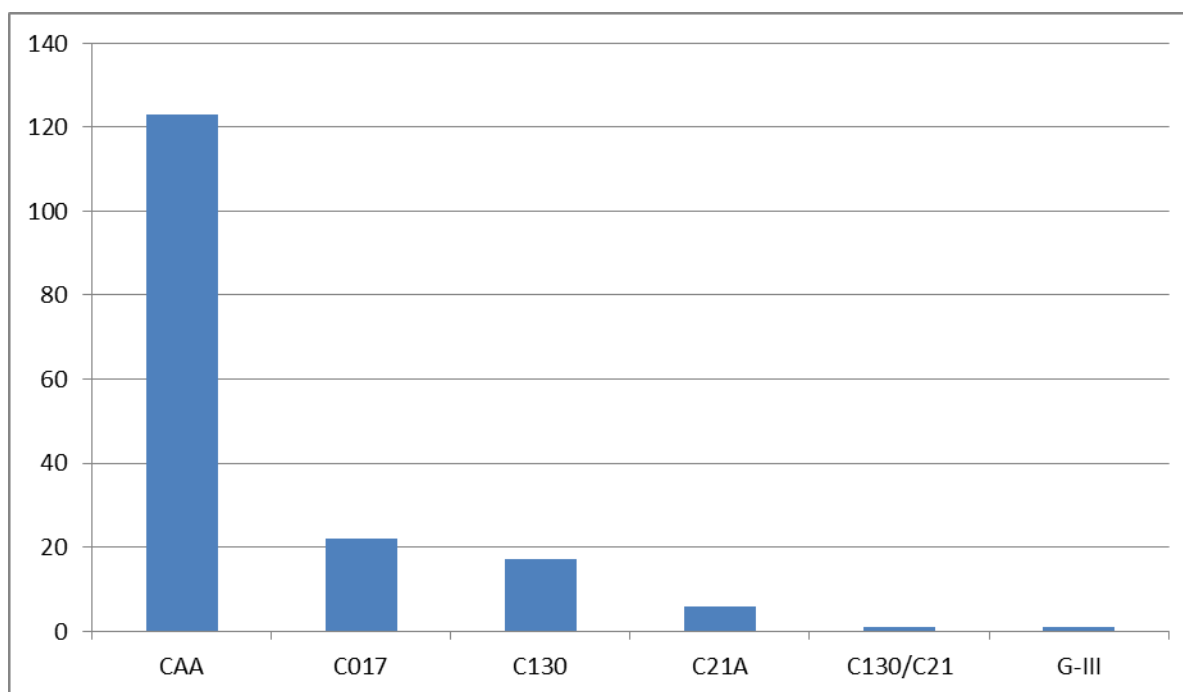
Figure 44. Missions by Aircraft Type

Figure 44 breaks down the number of missions flown by each aeromedical evacuation platform. While civilian air ambulances fly the majority of missions, C-17s fly more MilAir missions than C-130s or C-21s. This fact highlights the demand for range and speed over price. The "C130/C21" category is a single mission that switched platforms en route. The "G-III" category represents a single mission performed by an 86th aeromedical evacuation crew aboard a G-III aircraft that was on contract by AFRICOM HQ in Stuttgart.

Avoidable Costs

Figure 45 shows the frequency of the calculated avoidable cost per mission, broken into eight bins. The mode is $143K with a range from $7K to $269K. The mean is $133K with a standard deviation of $52K.
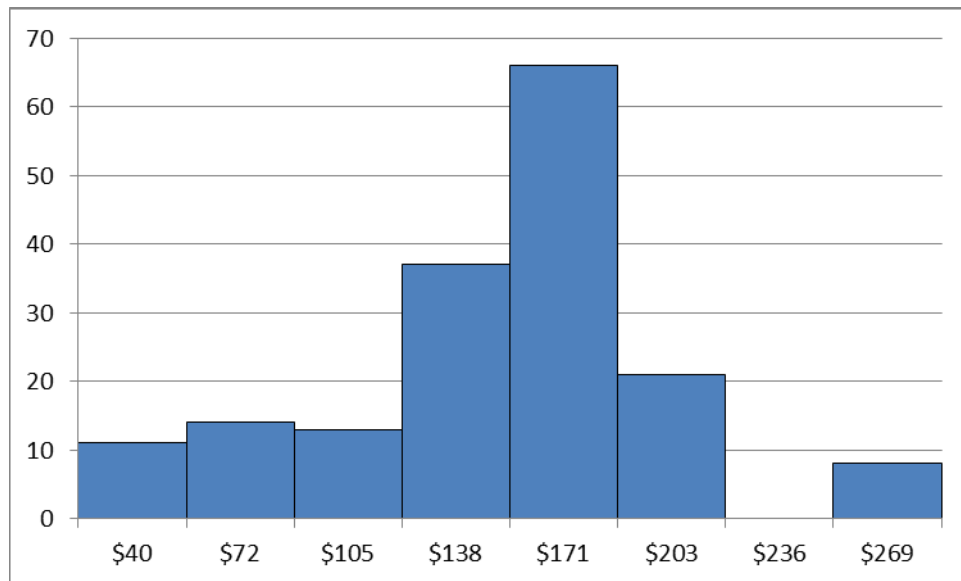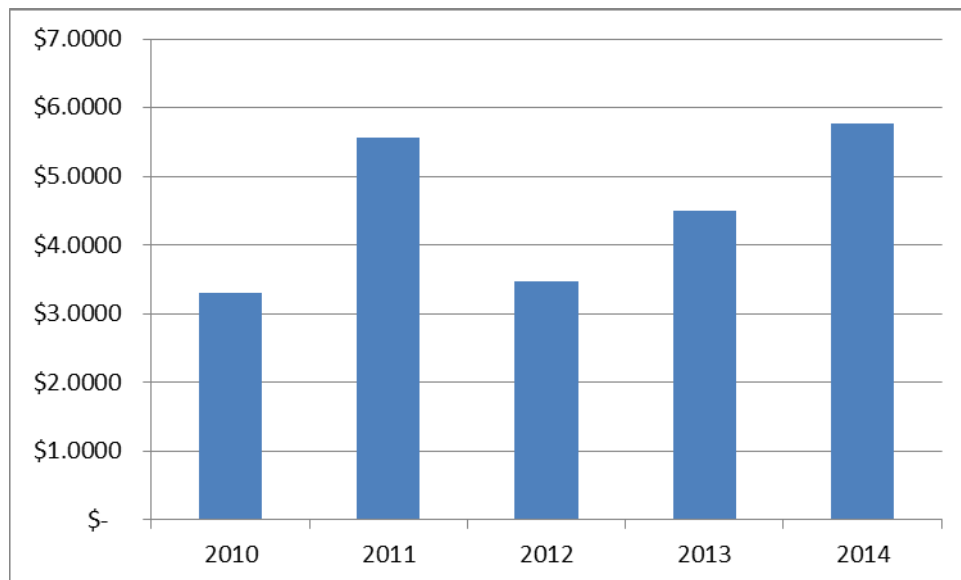
Figure 46 shows the avoidable costs by year. The total avoidable cost for aeromedical evacuation in Africa over the last five years was $22.6M or $4.5M per year. Understanding these costs helps planners identify the cost/benefit of adding medical capability on the continent. If adding an additional surgeon in Djibouti reduces aeromedical evacuations by 10%, then the DoD can spend up to $450K on that capability each year.
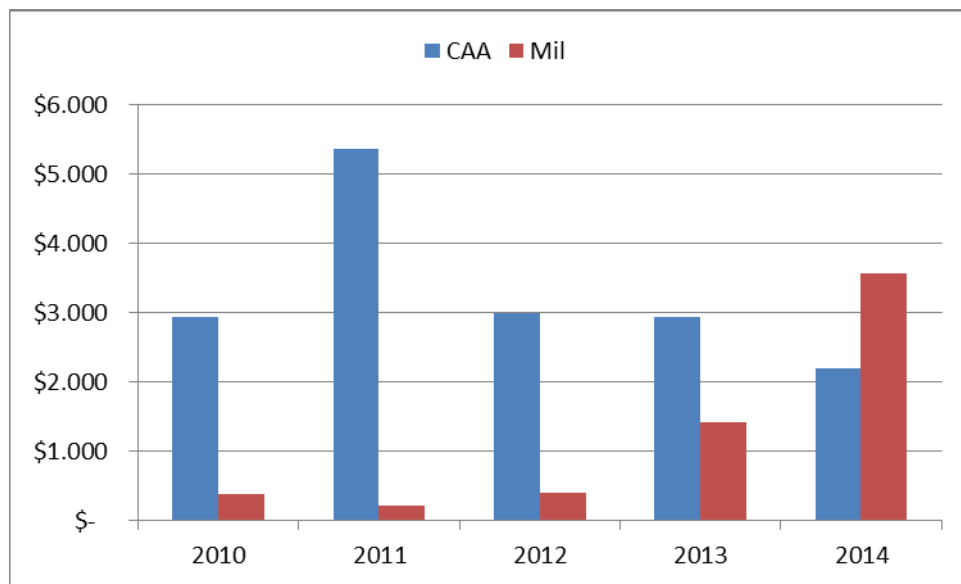
Figure 47. Avoidable Cost by Aircraft Segment per Year (Millions $)

Figure 47 separates the avoidable costs by civilian air ambulance versus MilAir. Since 2011, the cost of civilian air ambulances has declined while the cost of MilAir has increased. This raises the question of the appropriate mix of resource use. Under the current system, MilAir has the right of first refusal, regardless of cost. Figure 48 breaks down the MilAir portion by aircraft type. This chart shows the increase in MilAir is due to an increased use of all aircraft types.
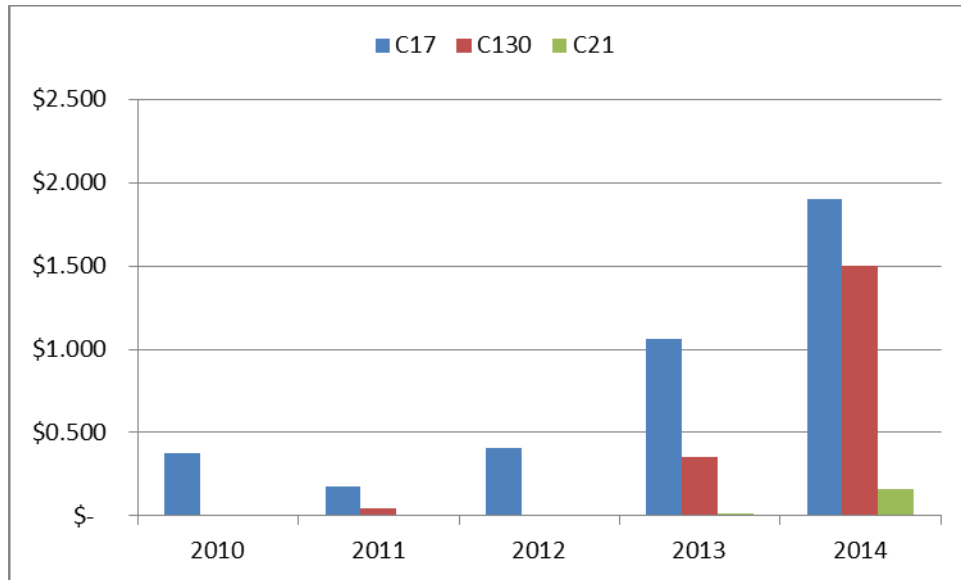
Figure 48. Avoidable Cost for MilAir by Aircraft Type per Year (Millions $)
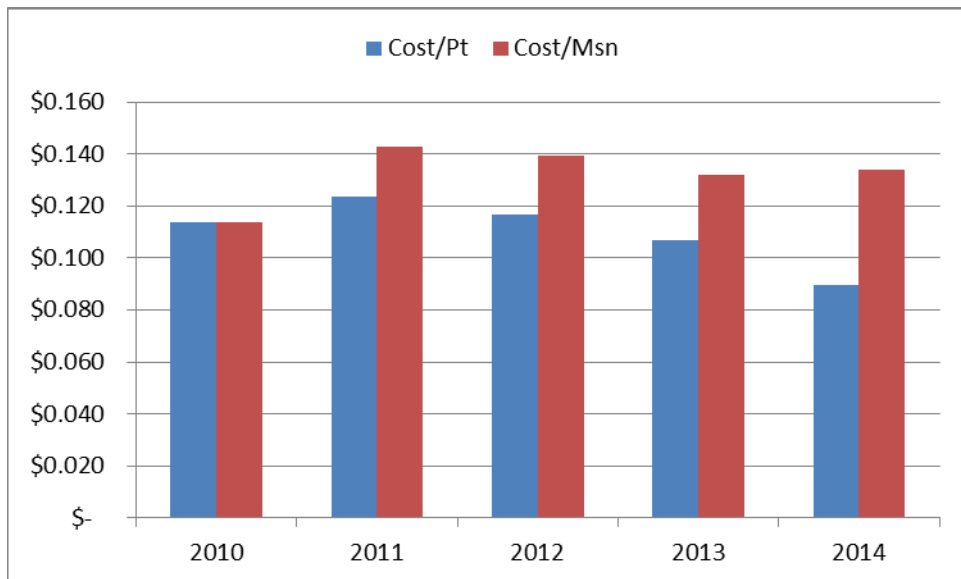
Figure 49. Avoidable Cost per Patient and per Mission each Year (Millions $)

Figure 49 shows the cost per patient and cost per mission each year. While the average cost per mission is $133K, the average cost to move a patient is $109K. The cost per mission increased from 2013 to 2014 while the cost per patient decreased.
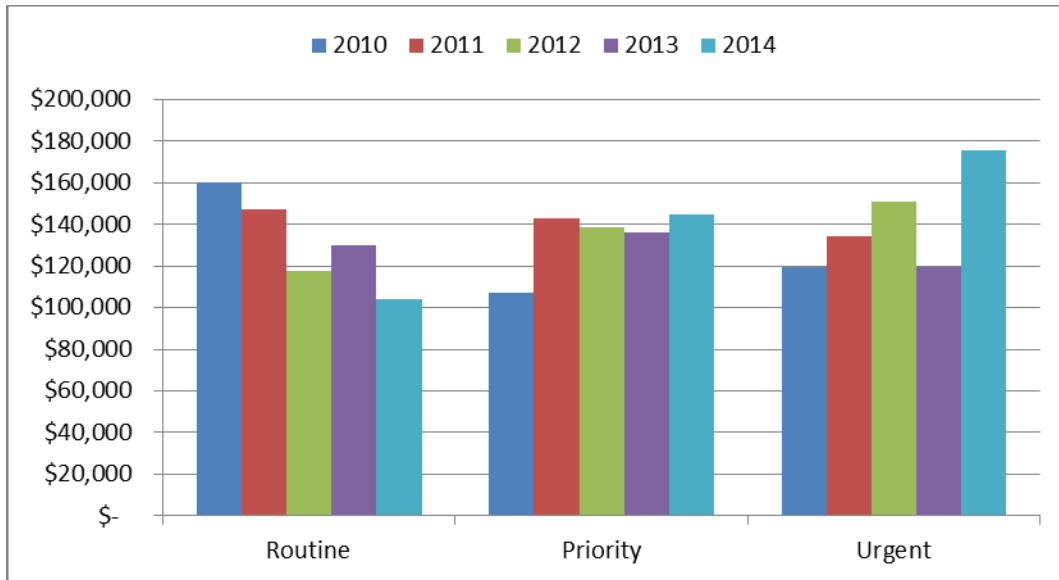
Figure 50. Average Avoidable Cost per Mission by Precedence Over Time

Figure 50 shows the average mission costs broken down by precedence over time. This figure shows an overall decreasing trend in the cost of Routine missions, a steady state for Priority missions, and an increase in the cost of Urgent Missions. The average cost of a Routine mission is $120K, a Priority mission is $134K, and an Urgent mission is $144K.
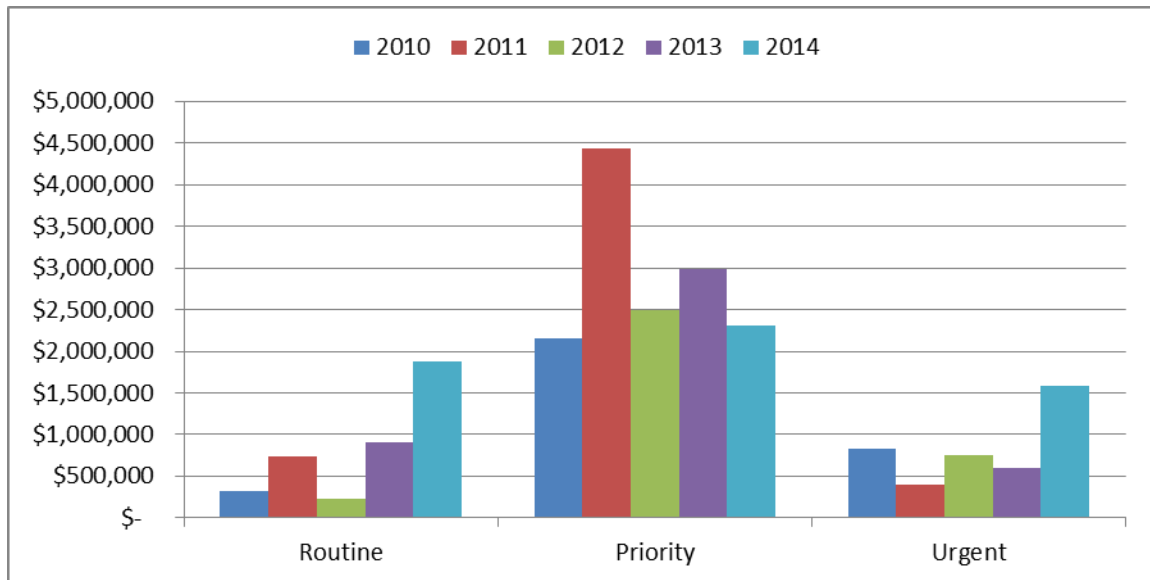
Figure 51. Total Avoidable Costs by Precedence Over Time

Figure 51 breaks down the total avoidable cost of aeromedical evacuation in Africa by precedence for each year. This graphic shows that Priority patients consume a bulk of the cost and that the cost of Routine and Urgent patients is on the rise. Over the five-year period, the DoD spent around $4M each on Routine and Urgent aeromedical evacuations and $14M on Priority aeromedical evacuations.

Decision Map

This section shows the various aspects of the map tool, analyzes some of the findings, and provides an example of how to use the tool. The visual aspect of the map tool revealed some unexpected analysis.

Figure 52 shows the Urgent ranges for MilAir aircraft and their avoidable cost at their maximum range. The costs represent the furthest each aircraft can fly and still move a patient within 12 hours. The $17K, $63K, and $188K lines represent the C-21, C-130, and C-17.
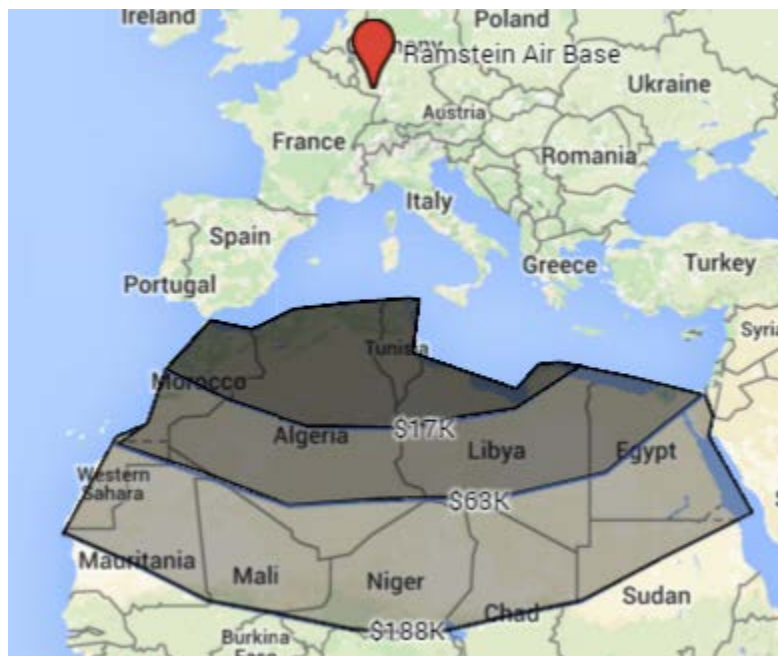
Figure 52. Urgent Range of C-21, C-130, and C-17 Respectively

Similarly, Figure 53 represents the Priority ranges of MilAir, and the ability to move patients within 24 hours. As seen, the C-21 and C-130 lines do not change because they are limited by their duty day. However, the C-17 range extends to the $265K line due to its 24-hour duty day.

Figure 53. Priority Range of C-21, C-130, and C-17 Respectively

Combined, these two figures show a significant gap in coverage and capability of MilAir to provide adequate support in Africa. The DoD does not have the organic ability to move an Urgent patient within the specified timeframe if they originate beyond the $188K line. In addition, the DoD cannot move a Priority patient within the specified timeframe if they originate beyond the $265K line. Figure 54 demonstrates the significance of this gap by overlaying the actual Urgent and Priority patient origins. All but one Urgent patient movement location falls

beyond the capability of the DoD. Furthermore, most of these Patient Movement Requests

originate beyond the $63K line. This line represents the range of a C-130, Ramstein's home-

based aircraft. Therefore, any movement beyond this line requires "borrowing" a C-17 from

Tanker Airlift Control Center, which may or may not be available for support. Without C-17

support, the DoD cannot support most of the Priority requests as well.

This analysis has several implications for planners. By definition, CONPLANS execute

in a contingent environment. As such, the DoD relies solely on MilAir for aeromedical

evacuation support. Without civilian air ambulance support, most of Africa lacks coverage for

Urgent patient movement requests. Therefore, forward deployment of aeromedical evacuation or

surgical capability is necessary to ensure proper medical support. The same logic stands for

Priority requests. Although C-17s cover most of the continent, planners must understand the

necessity of this aircraft for aeromedical evacuation when considering its capacity to perform

other functions.
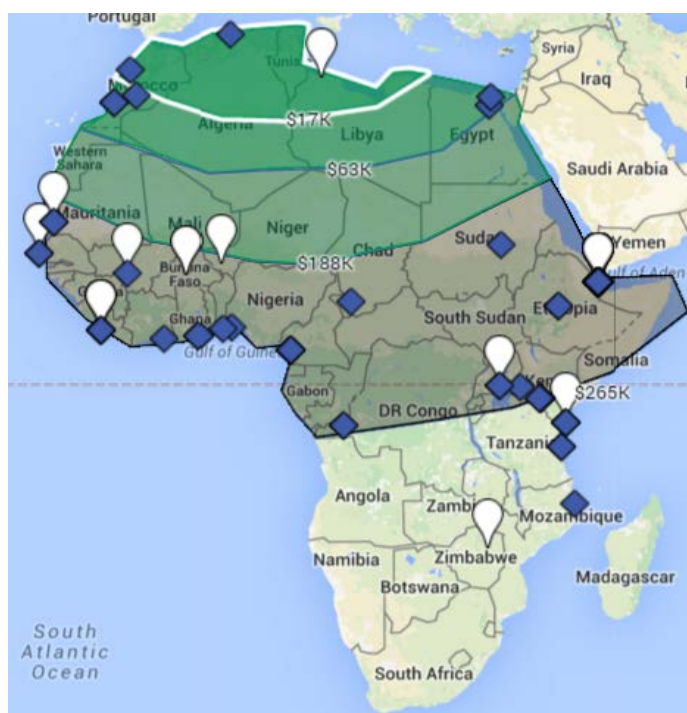
Figure 54. Urgent (White Tear) and Priority (Blue Diamond) Patient Locations

84

Furthermore, planners should be aware of the range limitations for "no-stop" requirements as dictated by the Validating Flight Surgeon. Figure 55 shows the maximum range of a C-130J. Djibouti, the location with the highest number of patient movements, lies outside that range. Therefore, a "no-stop" requirement forces the use of a C-17, even for Routine patients.

Figure 55. Empty Range of C-130J (2600nm)

In a peaceful environment, the DoD has a more robust patient movement system. As previously discussed, in order to fill the gaps in capability, the DoD uses civilian air ambulances. Figure 56 shows the four civilian air ambulance AORs. The teardrop markers represent their home bases and the lines with the corresponding colors represent the approximate cost of moving a patient from that AOR. These lines are similar to topographic lines, but with increasing costs rather than elevations. As mentioned, the cost lines assume that any patient falling in the southern AOR flies to South Africa, while patients in other AORs fly to Germany. This civilian air ambulance network can move patients from anywhere on the continent within the Urgent timeframe.
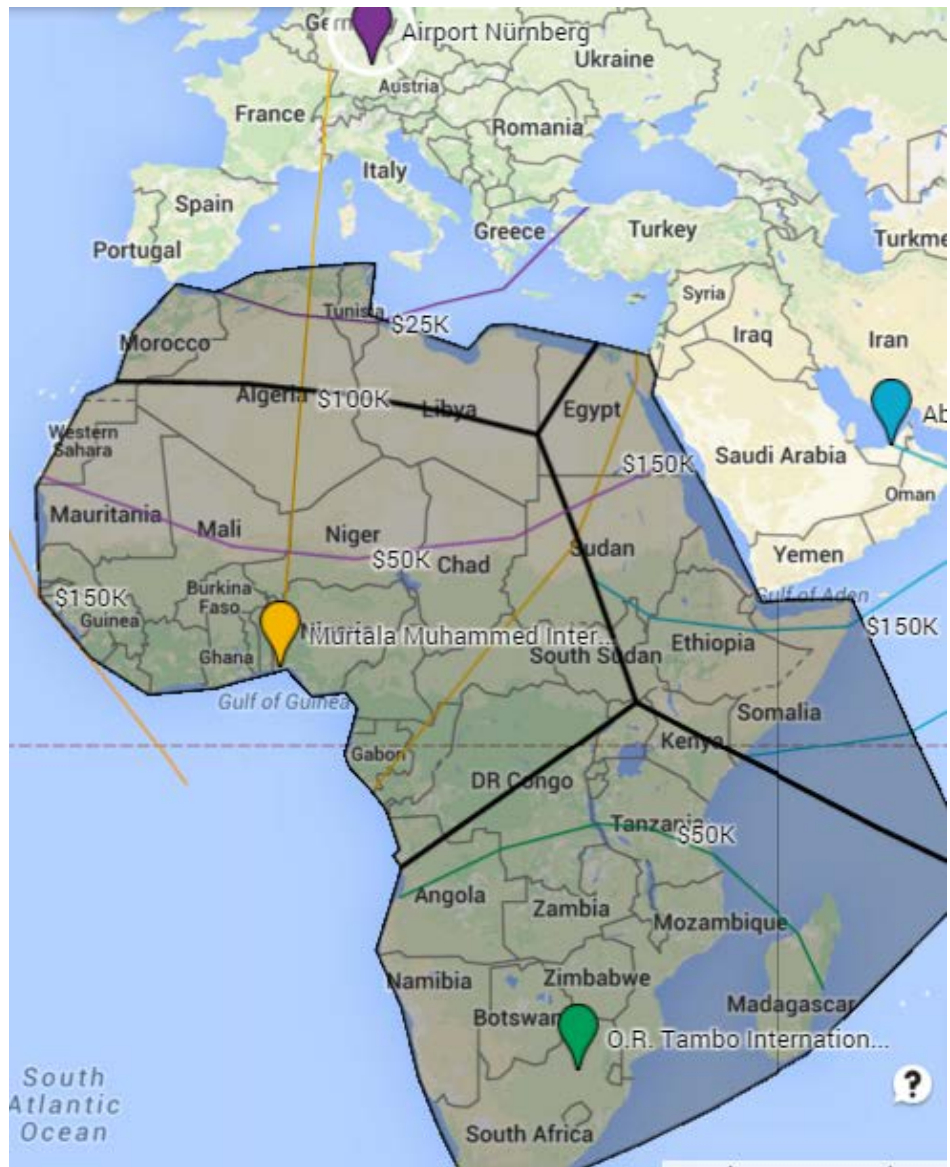
Figure 56. Civilian Air Ambulance AORs on Decision Map Tool
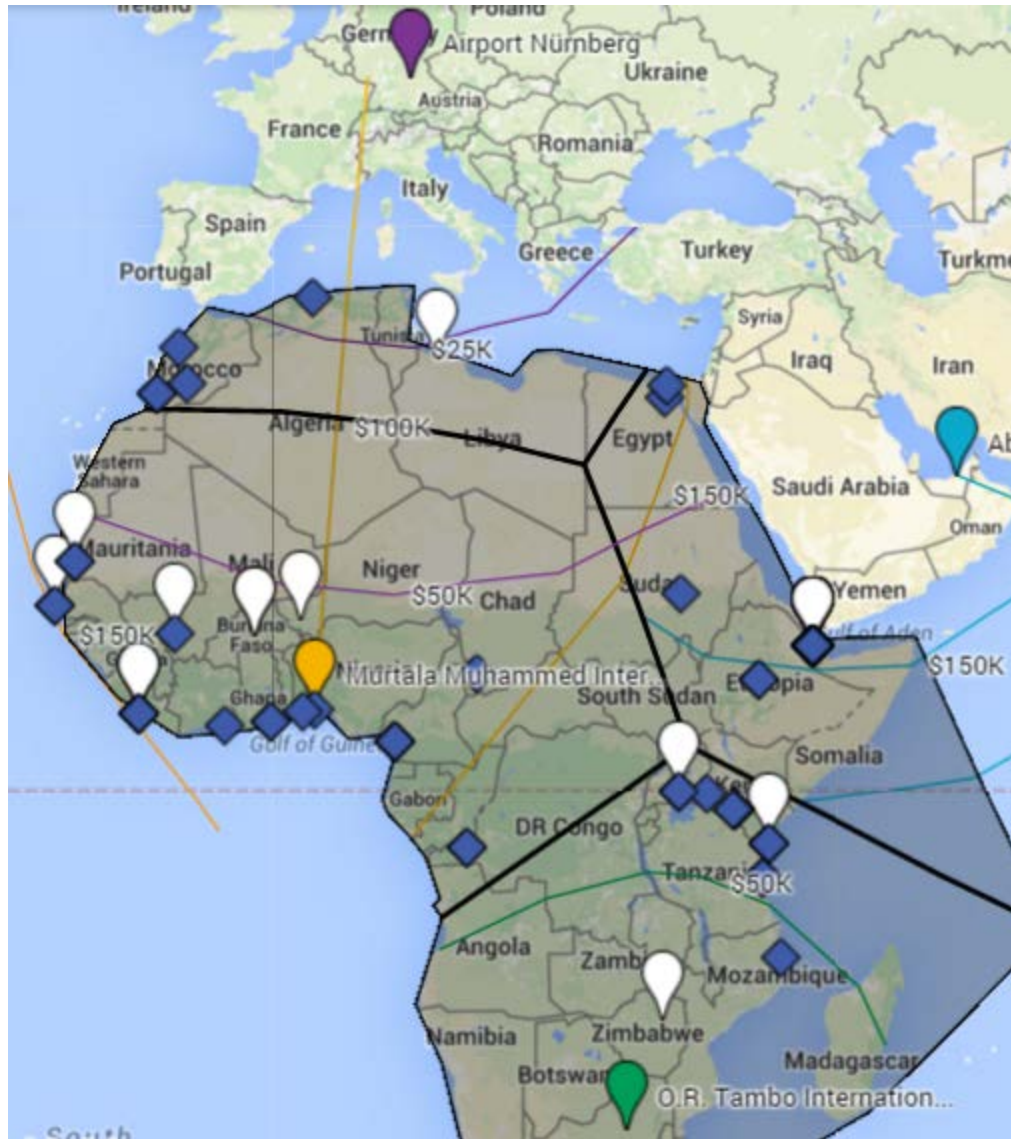
Figure 57. Civilian Air Ambulance AORs and Urgent (White Teardrop) and Priority (Blue Diamond) Patient Locations

As seen in Figure 57, civilian air ambulances are capable of reaching any patient within the prescribed timeline. With this tool, it is easy to see that the South Africa civilian air ambulance responds to an Urgent request out of Zimbabwe for $50k. At the same time, a MilAir flight to the same location cost over $265K and cannot meet the necessary timelines. If the civilian air ambulance capability is unavailable, it is impossible to meet the requirements with the current MilAir system.

Figure 58. No-Stop Range of Civilian Air Ambulances (2300mi)

Similar to the C-130, the civilian air ambulances have limited fuel ranges. Only if the patient falls within the ranges shown in Figure 58 can a civilian air ambulance handle a "no-stop" requirement. When compared to the patient locations in Figure 57, it is easy to see that many patient locations (to include Djibouti) fall outside these ranges. As a result, either patients must endure additional stressors that occur during take-off and landing, or the DoD must use a C-17, its most expensive form of patient movement. This fact stresses the limits of aeromedical evacuation capability in Africa, even with the civilian air ambulance capability.

Map Tool Example

Operationally, this tool provides a quick method of determining the lowest cost aircraft for aeromedical evacuation with a given set of criteria. Figure 59 is an image of the map tool with all layers activated. This figure shows that the cost of aeromedical evacuation varies widely

depending upon location and aircraft choice. For an example, I use the highlighted white tear-shaped marker, which represents an Urgent movement from Burkina Faso. Immediately, I see this patient is beyond the range of the C-130 and C-21 Urgent capability, very close to the C-17 boundary, and well within the Nigerian civilian air ambulance AOR.
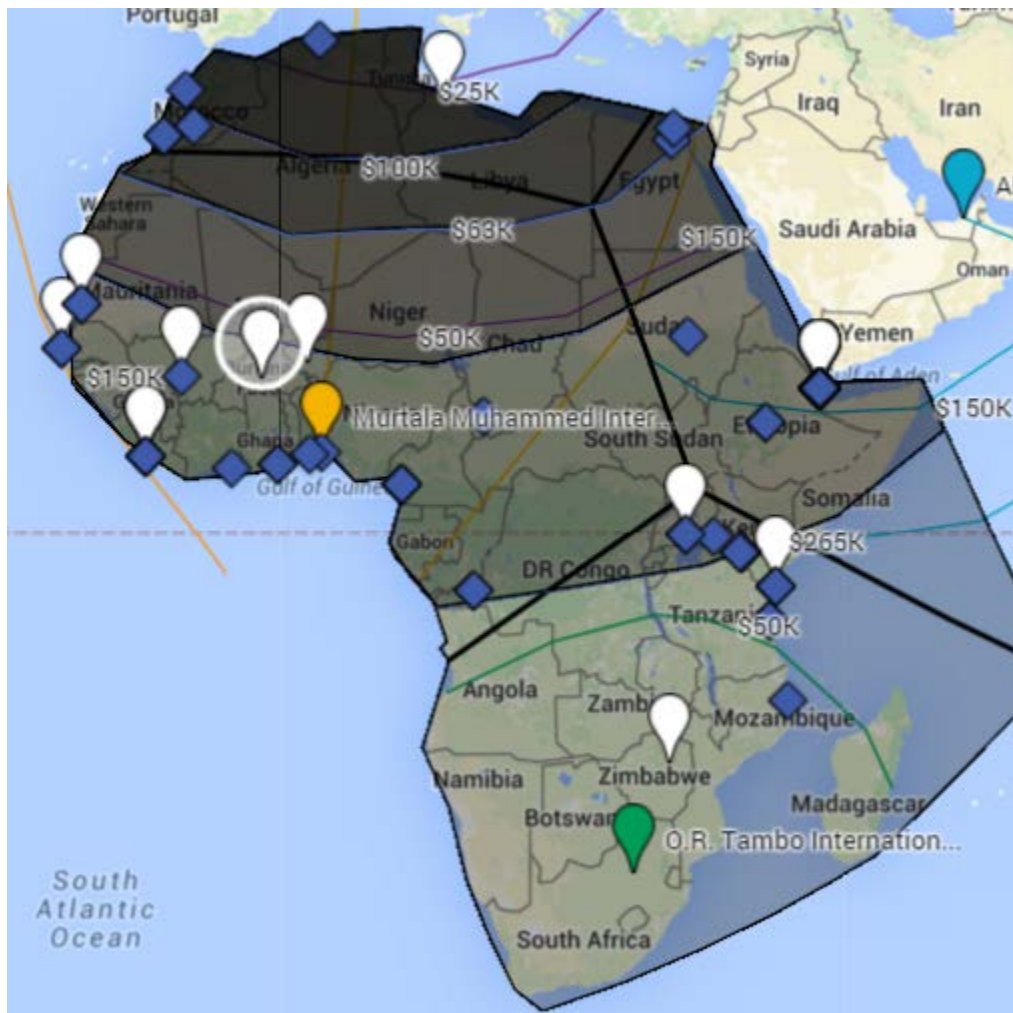
Figure 59. Aeromedical Evacuation Map Tool with All Layers Activated

Eliminating all other layers (Figure 60), I see the patient movement would cost over $188K with a C-17 and between $100K and $150K (yellow lines) for a civilian air ambulance. Given that this is a single patient and that the civilian air ambulance is more capable of moving the patient within the prescribed timeframe, this tool recommends the use of a civilian air

ambulance. However, this location is beyond the "non-stop" range of the civilian air

ambulance, so the plane requires a fuel stop en route. To choose the appropriate aircraft, the

decision maker must weigh this information against the quicker response time and lower cost of

the civilian air ambulances. Since each patient situation differs, the Map Tool defers to the

Validating Flight Surgeon and The Aeromedical Evacuation Control Team to make the final

decision.
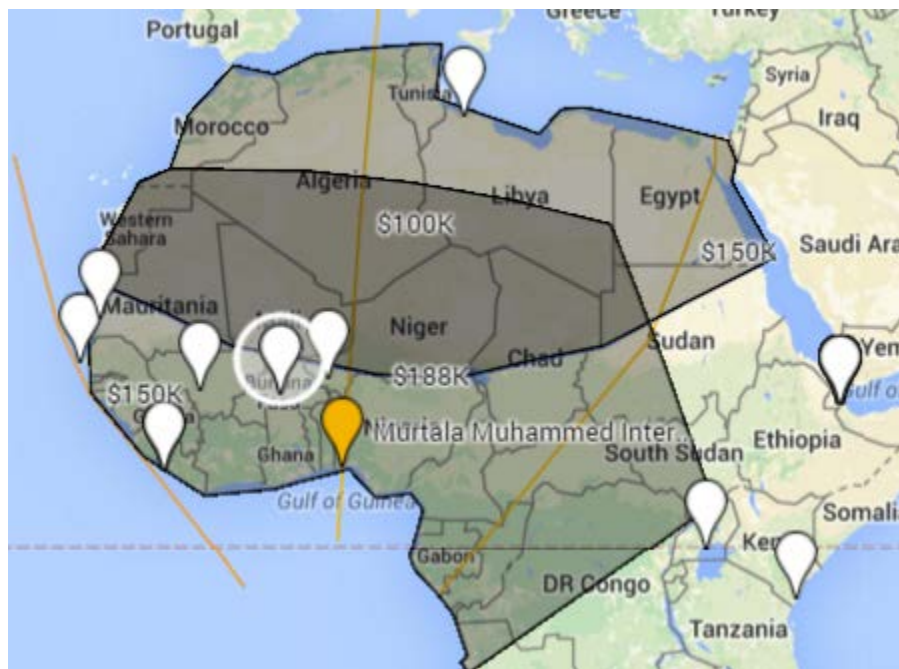
Figure 60. Western Civilian Air Ambulance AOR and Urgent C-17 Layers

The tool also provides information on past moves by selecting the corresponding marker.

Figure 61 shows that a civilian air ambulance moved this patient over a 12 hours period with a

destination of Landstuhl Regional Medical Center and a cost of $129K.
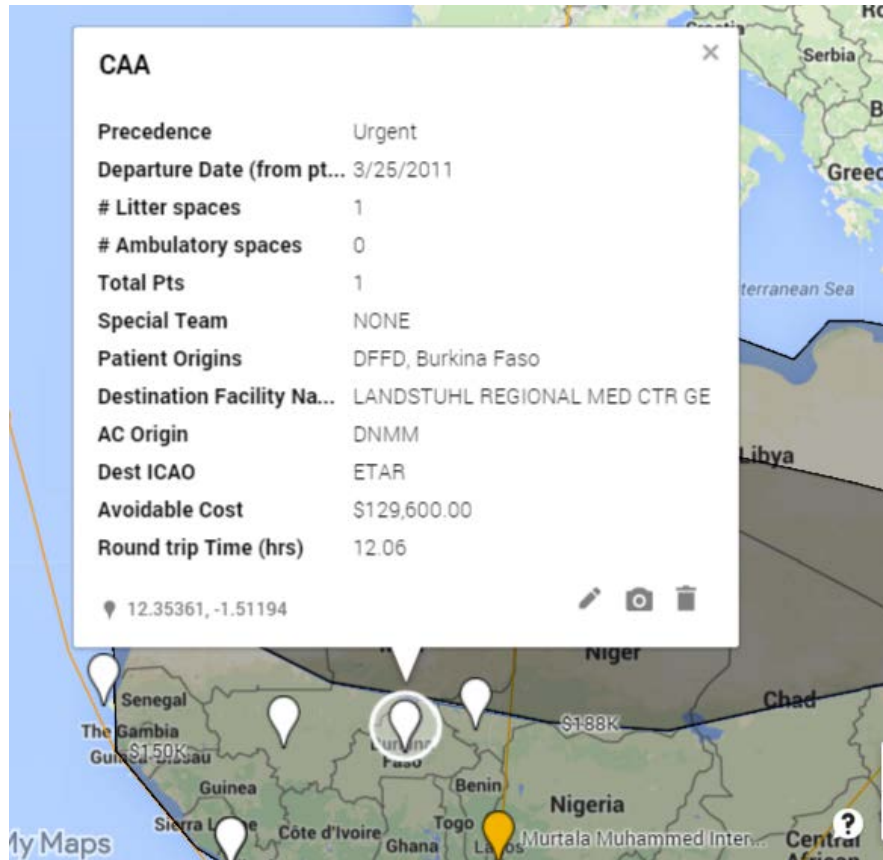
Figure 61. Patient Movement Information Example

Decision Tree

In addition to the map tool, this research developed the following two decision trees. The first tree is for Priority and Urgent patients. The second tree is for Routine patients. These tools identify the most cost efficient aircraft choice while abiding by Air Force and FAA regulations.

Priority/Urgent Decision Tree:

1. What is the Precedence of the Patient Movement Request?

    a. If Urgent or Priority→Go to step 2

    b. If Routine→Use the Routine Tree (found on the following pages)

2. Is the patient located in a contingent environment?

    a. If Yes→

        i. Is the patient less than 1850 miles from Ramstein Air Base (C-130 duty day range)?→ Go to step 3

        ii. Is the patient more than 1850 miles from Ramstein?→ Use a C-17 (note: while this is the optimal choice, in this scenario, the system is incapable of reaching Urgent patients located further than 2500 miles or Priority patients further than 3900 from Ramstein)

    b. If No→go to step 3

3. How far is the patient located from Ramstein Air Base?

    a. Less than 1450 miles (C-21 duty day range)?→ Go to step 4

    b. Between 1450 miles and 1850 miles?→Use a C-130

    c. More than 1850 miles?→ Go to step 6

4. Does the 86th Aeromedical Evacuation Squadron need to conduct training?

    a. If Yes→ Use a C-130

    b. If No/ Do Not Know→ Go to step 5

5. How many patients need moved?

    a. Less than or equal to one litter and two ambulatory patients→ Use a C-21

    b. More than one litter and two ambulatory patients→ Use a C-130

6. Did the Validating Flight Surgeon mandate a No-Stop requirement?

    a. If Yes→ Go to step 7

    b. If No→ Go to step 8

7. How far is the patient located from Ramstein Air Base?

    a. Less than 2300 miles (civilian air ambulance fuel range)?→ Go to step 8

    b. Between 2300 miles and 3900 miles?→ Use a C-17

       (note: while this is the optimal choice, in this scenario, the system is incapable

       of reaching Urgent patients located further than 2500 miles from Ramstein)

    c. More than 3900 miles?→ Go to step 8

       (note: civilian air ambulances go to South Africa if located more than 3900

       miles from Ramstein.)

8. How many patients need moved?

    a. Less than or equal to two litter and one Ambulatory patients?→ Use a Civilian

       Air Ambulance

    b. More than two litter and one Ambulatory patients?→ Use a C-17

Routine Decision Tree (use only for Routine Patient Movements):

1. Did the Validating Flight Surgeon mandate a No-Stop requirement?

    a. If Yes→ Go to step 2

    b. If No→ Go to step 3

2. How far is the patient located from Ramstein Air Base?

    a. Less than 2300 miles (C-21 fuel range)?→ Go to step 3

    b. Between 2300 miles and 2600 miles (C-130 fuel range)?→ Use a C-130

    c. Between 2600 miles and 3900 miles?→ Use a C-17

    d. More than 3900 miles?→ Go to step 6

3. How many patients need moved?

    a. Less than or equal to one litter and two Ambulatory patients?→ Go to step 4

    b. More than one litter and two Ambulatory patients→ Use a C-130

4. Is there space available on military aircraft already scheduled to move from Ramstein to the patient's location and back?

    a. If Yes→Use space-a

    b. If No→ Go to step 5

5. Does the 86th Aeromedical Evacuation Squadron need to conduct training?

    a. If Yes→ Use a C-130

    b. If No→ Use a C-21

6. Is the patient located in a contingent environment?

    a. If Yes→ use a C-17

    b. If No→ Go to step 7

7. How many patients need moved?

    a. Less than or equal to two litter and one Ambulatory patients→ Civilian air ambulance to South Africa

    b. More than two litter and one Ambulatory patients→ Use a C-17

Using these decision trees, I analyzed all 170 missions that occurred over the five-year period of the study. In the analysis, I found 46 of the 170 missions (27%) used a less than optimal aircraft choice. Only nine of which were due to the use of aircraft from CENTCOM (an option that was available in the past, but assumed to no longer be an option). Broken down by precedence, I found a less than optimal aircraft chosen 24% of the time for Urgent missions, 16% of the time for Priority missions, and 64% of the time for Routine missions. These results were

interesting since Routine missions have the longest planning horizon and should have the greatest ability to use the most appropriate aircraft. Further analysis revealed that 23% of Routine missions used a C-130 when a C-21 was more appropriate. In addition, 35% of Routine missions used civilian air ambulances when either a C-21 or C-130 was more appropriate. Of the Urgent missions, 17% of them flew with a C-17 although a civilian air ambulance was more appropriate.

In addition, my analysis found cost savings on 40 of the 46 missions identified as a sub-optimal aircraft choice. On the remaining six missions, my decision tree recommended a more expensive aircraft as the optimal choice. The total savings were $2.6M. This is a savings of $520K each year or about $15K per mission. Figure 62 shows the breakdown of these savings per year, revealing a significant rise in 2013 and 2014.
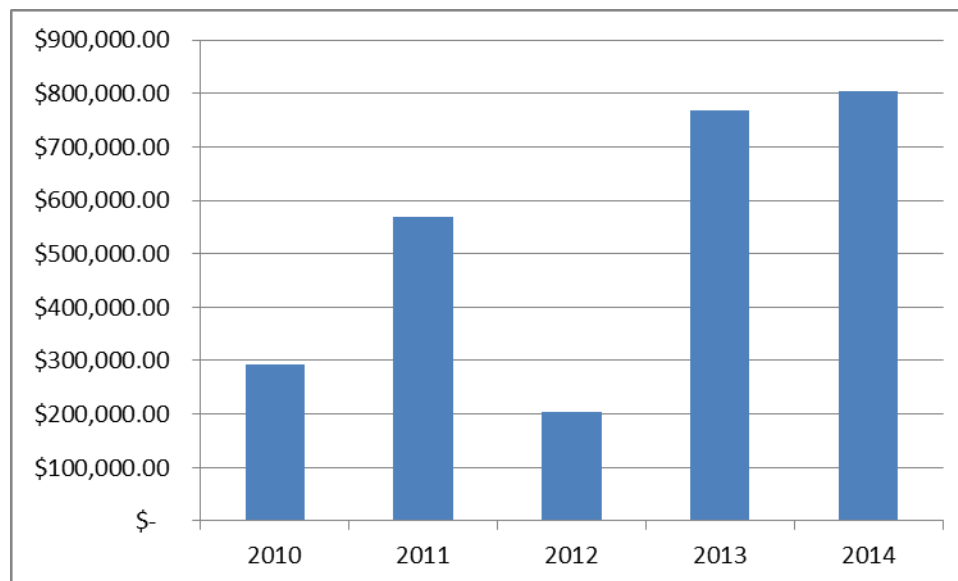

Figure 62. Avoidable Cost Savings Estimates by Decision Tree Aircraft Changes

Table 9 shows the list of differences in aircraft choice and cost between my model and the actual mission. Of the 46 missions, eight resulted in savings of $100K or more per flight. The largest saving was on a Routine civilian air ambulance mission that moved two ambulatory

95

patients from the Seychelles in 2011. This mission cost $267,105, but if flown by a C-21 would cost $53K. Of the six missions that resulted in additional costs, one was a Priority mission to Agadir, Morocco for a single litter patient in 2014. This location is on the border of the C-21 range as defined by the decision tree. The actual flight and ground time took 11:38. Adding two hours for alert time brings the total time to 13:38, leaving only 00:22 on the duty day. My model directs the use of a C-130. Although costlier, the duty day is longer on a C-130, allowing for more ground time and time for any other complications. Another mission that resulted in additional cost was an Urgent mission to Djibouti for two litter patients and two ambulatory patients. This mission used a C-130, resulting in a total flight and ground time of 41:46. From the time the plane took-off, over 30 hours elapsed before picking up the patient. This timeframe does not meet the requirements for a Priority patient, much less an Urgent. My model directed the use of a C-17. While a C-17 could likely not move the patient within a 12-hour window, it has the duty day to reach the patient and return without remaining overnight. In fact, of the six Urgent/Priority C-17 missions that flew from Ramstein to Djibouti, the average time to move the patient was around 13.5 hours, to include alert time, one leg of the flight, and ground time. However, as seen in Table 9, this additional capability comes at an estimated additional cost of $143K. The third mission was a Priority C-21 mission to Djibouti. This mission took over 40 hours to return to Ramstein. My tree recommended using a civilian air ambulance at an additional cost of $120K. The next mission was a Priority C-17 to Djibouti in 2010. The cost per flight hour for a C-17 was significantly lower in 2010, making this flight $3.7K cheaper than the civilian air ambulance suggested by my model. The final two missions were C-17s that originated from Al Udeid Air Base. My model does not consider using aeromedical evacuation teams from CENTCOM. Therefore, it recommends using civilian air ambulances.

Table 9. Estimated Savings from Decision Tree Analysis

Original Mode	Original Avoidable Costs	Decision Tree Mode	Decision Tree Avoidable Costs	Estimated Savings
C017	$ 268,976.77	CAA	$ 119,814.97	149,161.80
C017	$ 260,721.33	CAA	$ 158,617.61	102,103.72
C017	$ 256,083.97	CAA	$ 158,617.61	97,466.35
C017	$ 253,401.13	CAA	$ 158,617.61	94,783.52
C017	$ 249,532.67	CAA	$ 158,617.61	90,915.05
C017	$ 186,890.48	CAA	$ 158,617.61	28,272.87
C017	$ 175,713.70	C-130	$ 37,789.21	137,924.49
C017	$ 172,449.12	CAA	$ 158,786.08	13,663.04
C017	$ 169,350.20	CAA	$ 134,852.49	34,497.71
C017	$ 165,016.00	CAA	$ 134,852.49	30,163.51
C017	$ 164,534.90	CAA	$ 134,852.49	29,682.41
C017	$ 153,985.70	CAA	$ 103,864.22	50,121.48
C017	$ 152,668.38	CAA	$ 158,786.08	(6,117.70)
C017	$ 143,797.80	CAA	$ 55,902.86	87,894.94
C017	$ 129,129.23	CAA	$ 132,830.88	(3,701.65)
C017	$ 98,144.10	CAA	$ 132,830.88	(34,686.78)
C017	$ 97,153.87	CAA	$ 45,306.46	51,847.40
C017	$ 84,029.37	C-130	$ 40,986.75	43,042.62
C017	$ 52,694.60	C-130	$ 36,871.17	15,823.43
C130	$ 127,718.97	C-21	$ 43,670.94	84,048.02
C130	$ 126,895.60	C-21	$ 43,027.40	83,868.20
C130	$ 122,088.80	C-17	$ 265,371.12	(143,282.32)
C130	$ 119,252.00	C-21	$ 43,027.40	76,224.60
C130	$ 117,833.60	C-21	$ 43,027.40	74,806.20
C130	$ 116,178.80	C-21	$ 43,027.40	73,151.40
C130	$ 112,554.00	C-21	$ 43,670.94	68,883.06
C130	$ 97,917.60	C-21	$ 34,220.80	63,696.80
C130/C21	$ 127,483.27	C-21	$ 43,670.94	83,812.32
C21A	$ 37,828.30	CAA	$ 158,617.61	(120,789.31)
C21A	$ 26,980.32	C-130	$ 55,022.91	(28,042.60)
CAA	$ 267,105.00	C-21	$ 52,667.87	214,437.13
CAA	$ 184,620.00	C-21	$ 37,937.10	146,682.90
CAA	$ 153,762.00	C-130	$ 114,804.57	38,957.43
CAA	$ 153,762.00	C-21	$ 41,429.62	112,332.38
CAA	$ 143,600.00	C-21	$ 43,670.94	99,929.06
CAA	$ 143,600.00	C-21	$ 43,670.94	99,929.06
CAA	$ 143,600.00	C-21	$ 43,670.94	99,929.06
CAA	$ 139,529.00	C-21	$ 38,807.08	100,721.92
CAA	$ 136,160.00	C-21	$ 29,975.06	106,184.94
CAA	$ 128,108.00	C-21	$ 37,513.61	90,594.39
CAA	$ 122,982.00	C-21	$ 29,508.44	93,473.56
CAA	$ 100,740.00	C-130	$ 78,259.83	22,480.17
CAA	$ 42,600.00	C-130	$ 31,649.48	10,950.52
CAA	$ 39,307.00	C-21	$ 17,060.79	22,246.21
CAA	$ 21,070.00	C-21	$ 10,142.73	10,927.27
G-III	$ 81,528.15	C-21	$ 41,429.62	40,098.53
			Total	2,639,109.15

Summary

This chapter gave a descriptive analysis of the patients, diseases, aircraft, timelines, and costs of aeromedical evacuation in Africa. Of the 274 patients and 170 missions analyzed, there is a gap in aeromedical evacuation capability with over 23% of the Priority patients and almost 10% of Urgent patients picked-up beyond the 24-hour mark. In the worst case, it took seven days to move a Priority patient and five days to move an Urgent patient. The DoD averaged $4.5M in avoidable costs each year to support aeromedical evacuation in Africa. In spite of this expense, the map tool demonstrates large gaps in capability and the majority of patients falling within these gaps. As a result, this map tool highlights the need for plans and efforts to mitigate the risks associated with the lack of aeromedical coverage. Efficiently using the supplied current resources helps reduce this gap. Applying the decision tree tool shows that efficient aircraft choice reduces cost by an average of $520K per year, freeing these funds to improve medical capability in Africa.

V.   Conclusions and Recommendations

Chapter Overview

This chapter summarizes the study and highlights its most significant applications. The chapter begins with a description of the significance of this research followed by recommendations for action as well as future research. The chapter ends with a brief summary.

Research Conclusions

Africa is an extremely large continent with an increasing level of importance to the US. In the future, the DoD expects to perform more activities on this continent, without promise of additional medical capability. As a result, the DoD must ensure the efficient use of available resources. Identifying the epidemiology of aeromedical evacuation is a first step in understanding the best ways to minimize risk and meet requirements. This study breaks down the aeromedical evacuation data from 2010 through 2014 by patient demographics, disease profiles, avoidable cost and aircraft type. Implementing the proposed decision tree has the potential to reduce aeromedical evacuation costs in Africa by $520k each year.

Additionally, this study shows the DoD's reliance on civilian air ambulances to fill significant gaps in capability. All but one Urgent aeromedical evacuations fell outside the capability range of MilAir assets. This gap is of special significance for CONPLANs where civilian air ambulances are not contractually required to operate. Planners should understand and plan for these limitations in advance. The map tool is a powerful resource to visualize the disparity in aeromedical evacuation coverage.

Significance of Research

The decision tree and map tools have further implications as to facility location plans for CONPLANS, exercises, and long-term basing options. By showing planners where the majority of aeromedical evacuation requirements exist and the current capability of aeromedical evacuation assets, planners can analyze potential sites according to their ability to provide medical coverage. Additionally, planners can quickly see the need to task additional field medical/surgical and Medevac support.

This study highlights the gaps in aeromedical evacuation response time and shows the importance of each Branch's ability to provide initial response, surgical stabilization, and patient holding capabilities. The importance of properly trained personnel in self-aid and buddy care and the initial response time to surgical intervention cannot be overstated. One study shows that, "most battlefield casualties died of their injuries before ever reaching a surgeon" and that over 24% of battlefield deaths were potentially preventable (Eastridge, et al., 2012 p. S431). Planners must provide the needed support, rather than relying on aeromedical evacuation, especially in sub-Saharan Africa.

This study also highlights the cost of aeromedical evacuation and shows the true cost avoidance potential of minimizing the need for aeromedical evacuation. By showing these costs, the DoD has an idea of how much it can spend on additional screening, capabilities, and training in order to reduce the incidence of aeromedical evacuation. It also helps planners understand where to focus the majority of effort and resources in order to have the greatest impact. The DoD can spend $450K each year to reduce aeromedical evacuations by 10% and break even.

Recommendations for Action

This study recommends the implementation of the decision tools as a method of suggesting the most cost efficient aircraft for aeromedical evacuation. In addition, this study recommends Service Components provide the necessary surgical stabilization and holding capability for operations and exercises in Africa. As seen in this study, depending on aeromedical evacuation for medical coverage is not doctrinally correct or operationally feasible. Rather, each service must account for the gaps in aeromedical evacuation coverage and develop plans and resources that mitigate the risk. Perhaps the DoD should implement a base-line metric, such as the time it takes to get personnel to surgery for a given level of risk. Such a metric would drive medical funding, research, resources, training, and planning while maintaining equal risk across all Components of the DoD.

This study also highlights a policy gap regarding aeromedical evacuation of civilian Government employees. While deployed government employees are entitled to aeromedical evacuation, they do not have TRICARE, so there is no mechanism to provide civilian air ambulance support. As a result, the DoD uses MilAir, which often has a slower response time at an increased cost. The DoD would benefit from creating and funding a tool, such as a blanket purchase agreement with International SOS, that provides coverage to DoD civilians.

Recommendations for Future Research

This study highlights the need for further research into aeromedical evacuation precedence timeframes. While research suggests time is a critical factor in survivability, the DoD does not understand the points where mortality and morbidity curves change slope. The DoD should fund research to determine if moving a patient within 24 hours for a Priority or 72

hours for a Routine has significantly different outcomes as, for instance, 30 or 96 hours respectively. Identifying these points through research will enable military planners and policy-makers to allocate the limited supply of medical resources efficiently.

Further research on the reasons why patients require aeromedical evacuation is necessary to understand what preventative screening/training to perform prior to deployment. Preventing aeromedical evacuation not only minimizes financial impact, but also increases effectiveness of deployed units that need each member to be healthy and ready for duty.

Additional research into the potential costs and benefits of a dedicated long-range, high-speed aeromedical evacuation platform is necessary. Procuring such an aircraft may prove cost effective and improve the DoD's ability to provide aeromedical evacuation support in remote locations. Additionally, this capability has the potential to extend the DoD's strategic reach, power, and influence by allowing troops to deploy into remote locations with minimal risk and a small footprint.

Summary

This chapter provides a summary of the study's conclusions, significance, recommended actions, and recommended future research in regards to aeromedical evacuation in Africa. With its expansive territory, numerous political borders, limited local capabilities, and widespread operations, Africa represents a challenge to aeromedical evacuation. However, through evidence based research and planning, the DoD can reduce the overall risk to its personnel as it applies its available capabilities in the most effective and efficient manner.

Appendix A. Map Tool User Guide

The map tool is located at the following

link: https://www.google.com/maps/d/edit?mid=z5Hd3poIUmss.kXRPqs41Avsw&usp=sharing

and anyone with this link can access the tool for viewing and manipulation. However, only

Major Daniel Griffith has the ability to edit the information within the map.

Once you arrive at the website, you will see the screen as shown in Figure 63. From this

screen, you can check the layers on the left side to display the information in which you are
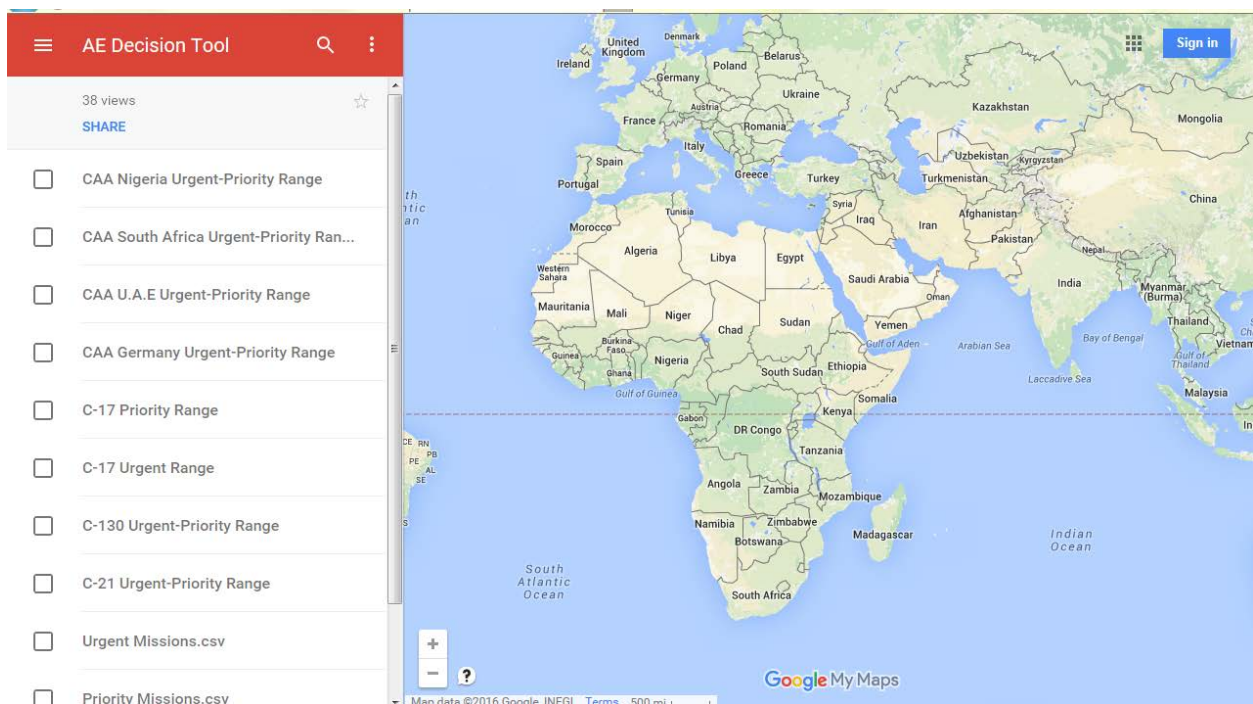
interested.

Figure 63. Map Tool Opening Page

.

Figure 64 provides an example using civilian air ambulances located in Nigeria. This figure shows the area for which the Nigerian civilian air ambulances have responsibility and the approximate costs to move patients within this AOR.
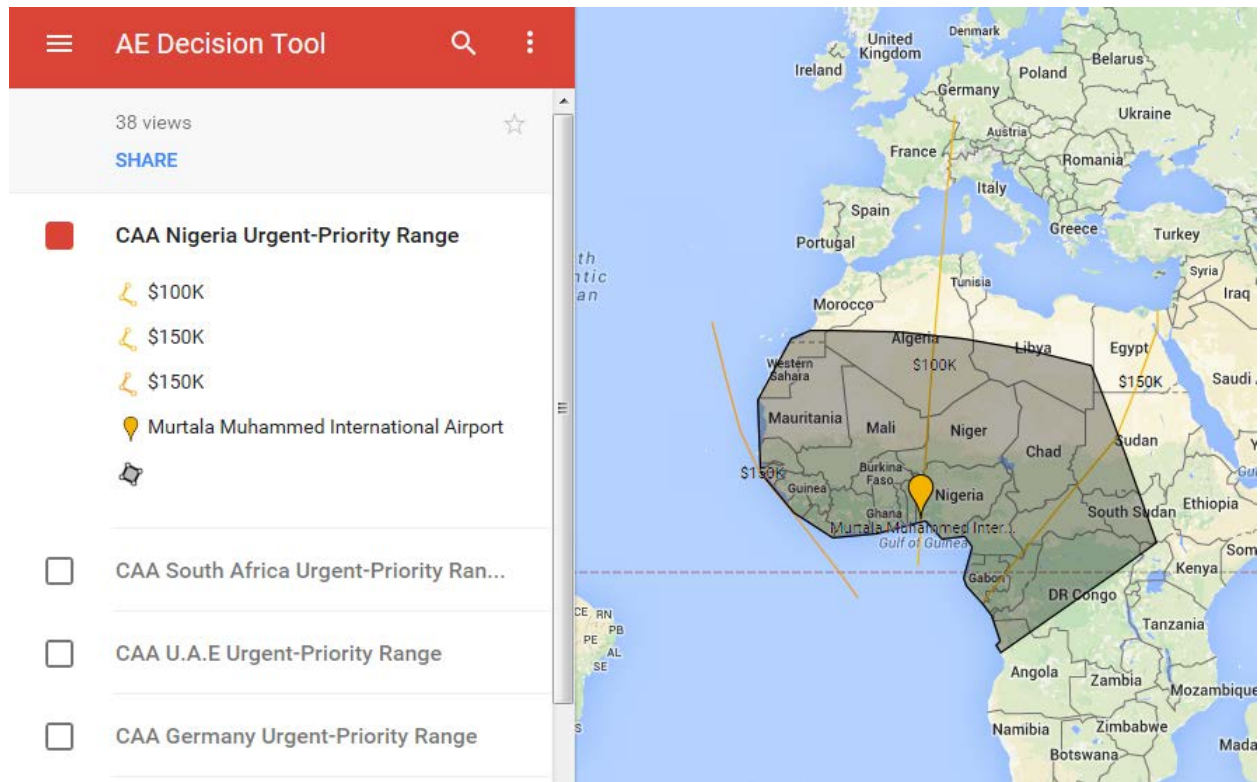

Figure 64. Map Tool Showing Nigerian AOR

Figure 65 displays the area a C-17 can cover and still move a patient within the designated 12-hour Urgent window. The map displays an avoidable cost of $188K for moving a patient at the frontier of this range.
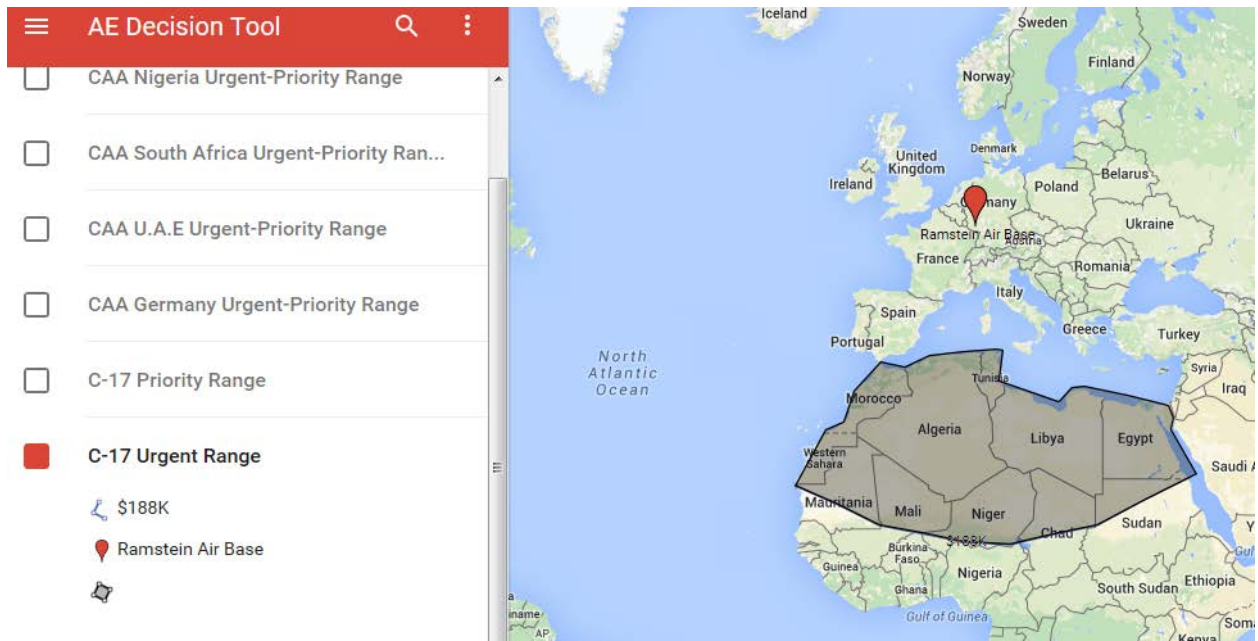
Figure 65. Map Tool Showing C-17 Urgent Range

Clicking a layer on the map allows the user to see notes left by the editor. For instance, Figure 66 displays a note that describes the highlighted AOR. The note specifies that in order to have this range with a C-17, there is no tasking time remaining.

Figure 66. Map Tool Note Example

Figure 67 displays the view shown by selecting the "Urgent Missions" layer. This layer identifies the location of all Urgent missions completed between 2010 and 2014. On the left, the tool shows a list of those missions by aircraft type. On the right, the tool shows the locations from which the patient originated.
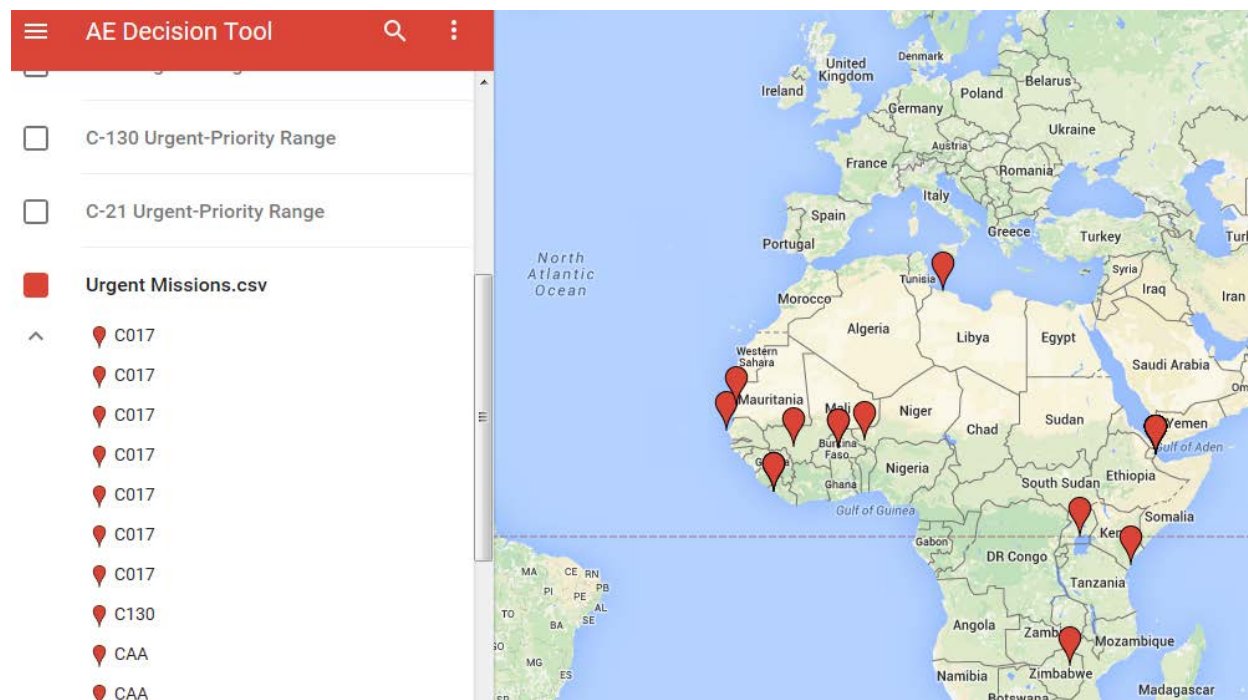

Figure 67. Map Tool Urgent Missions Example

Clicking on one of the markers on the left allows the user to see details of the mission. Figure 68 shows that the highlighted mission was for a single Critical Care patient from Djibouti, flown on a C-17. This mission took 23.92 hours, which includes flight time, alert time, and ground time. The mission incurred $256K in avoidable costs. For military flights, the flight and ground times are the actual times while the alert times are standard according to Table 1. For the civilian air ambulances, the flight times of the legs with the patients on board are the actual times. For the legs without patients, I estimated the times based on the calculated distance and

speed of each AOR. For ground times, I used the average ground time and the alert times are
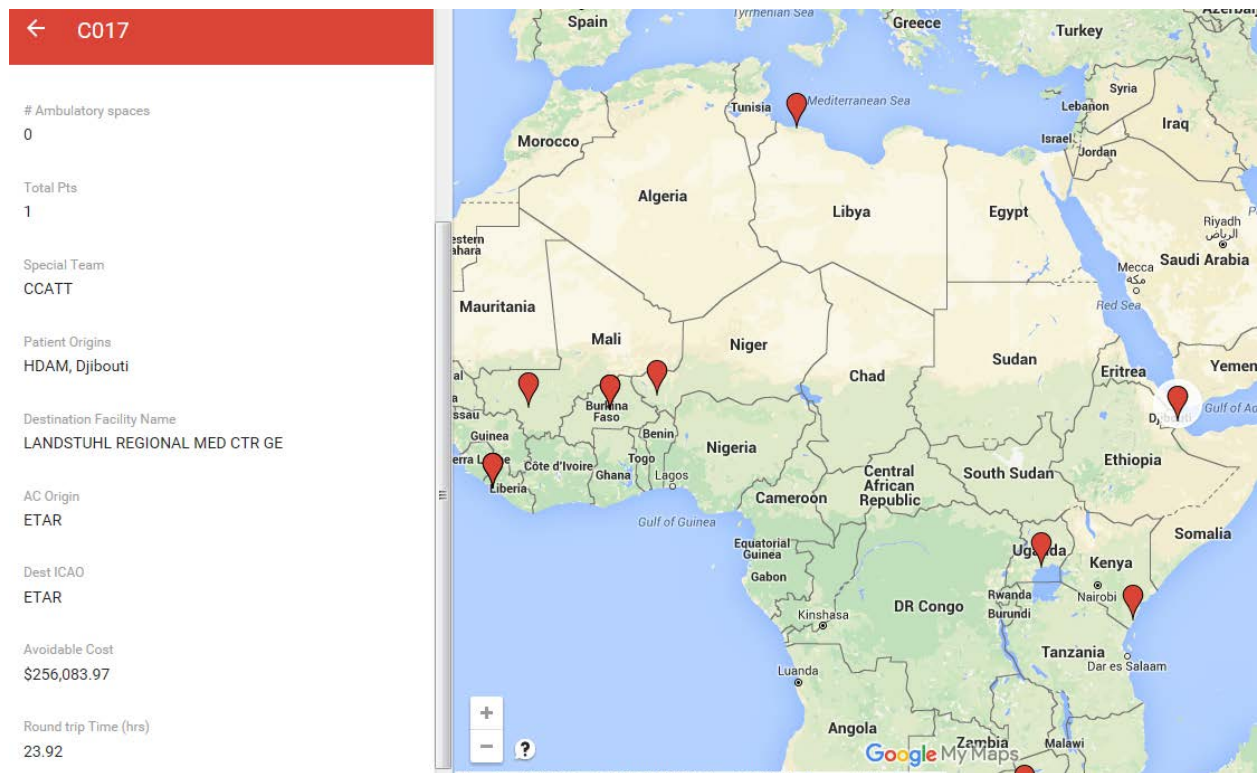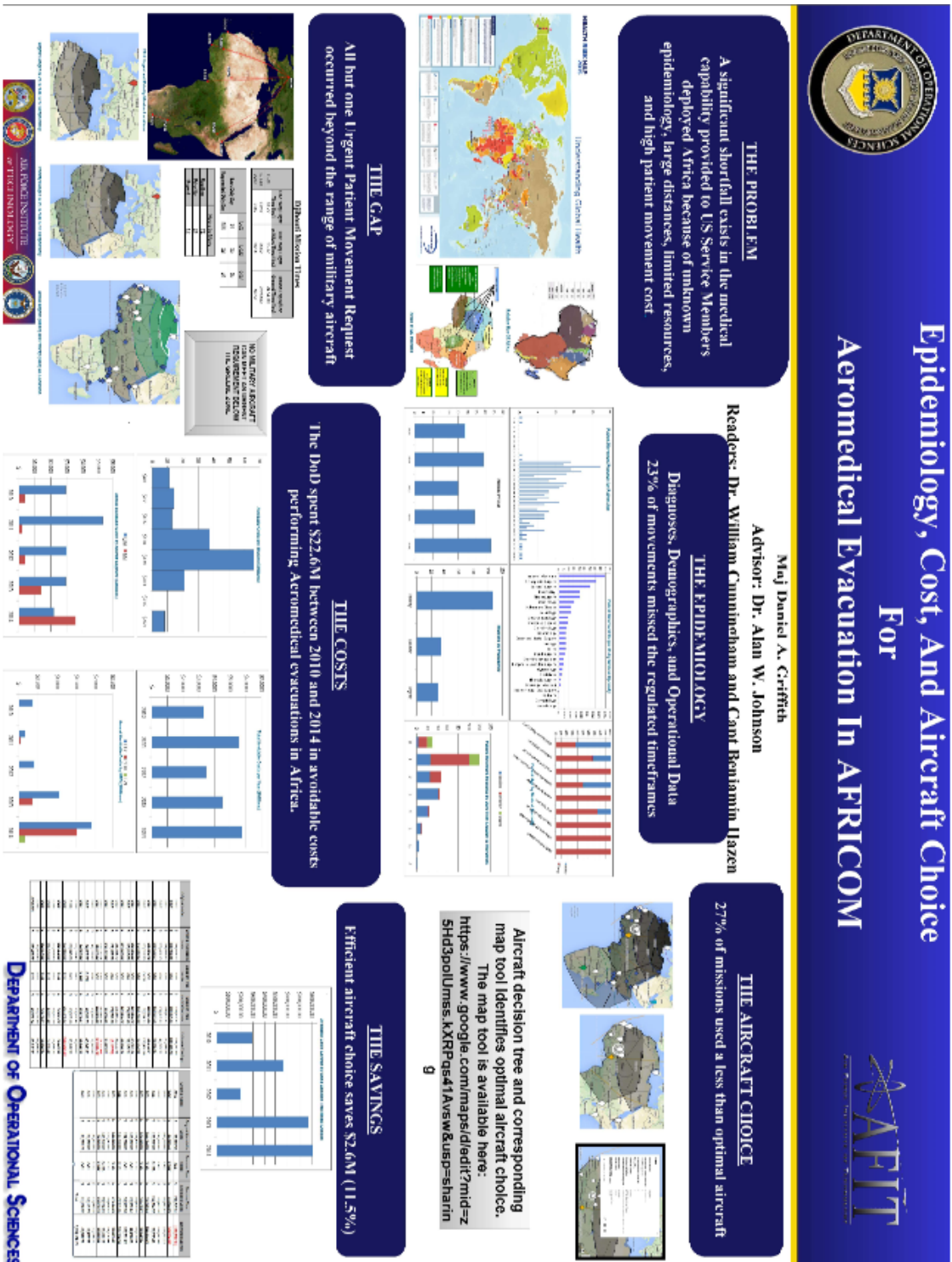
three hours.

Figure 68. Map Tool Mission Details

Appendix B. Storyboard

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14. ABSTRACT

A significant shortfall exists in the medical capability provided to US Service members deployed to the African Area of Responsibility because of unknown epidemiology, large distances, limited resources, and high patient movement cost. The first step in closing this gap is to understand the types, demographics, diagnoses, and distribution of the patients requiring aeromedical evacuation. This research examined the DoD's aeromedical evacuation missions from Africa between 2010 and 2014. Of the 274 patients and 170 missions identified from available data, a gap is evident in aeromedical evacuation capability with over 23% of Priority patients and almost 10% of Urgent patients picked-up beyond the critical 24-hour mark. A decision tree and web-based decision support tool are proposed that identified improper airlift choice in 46 of the 170 missions examined. These decisions cost the DoD $2.6M. Making better aeromedical movement decisions can enable the DoD to reallocate funds to reduce the existing medical gap in Africa.

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