



**APPLICATION OF A NON-LINEAR  
PROGRAM TO THE ESTABLISHMENT OF A  
HUB AND SPOKE SYSTEM IN AFRICA**

GRADUATE RESEARCH PAPER

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AFIT/IMO/ENS/10-04

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HUB AND SPOKE SYSTEM IN AFRICA

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### **Abstract**

Due to the increasing threat of terrorism, particularly from the Sahara region of Africa, as well as a result of the growing strategic importance of Africa to the United States, the United States established Africa Command (AFRICOM). The mission of the Department of Defense's newest combatant command is to aid African development and promote regional security. However, this may not be an easy task, especially due to the lack of an effective and efficient transportation network on the continent. In order for AFRICOM to succeed, it will need to be able to effectively and efficiently transport personnel and goods across the continent. The lack of transportation infrastructure may make this a daunting and expensive task. But, there exists a solution to the problem. The Canadian Operational Support Command (CANOSCOM) developed a mixed integer non-linear programming model based on the *Foreign Policy* Index of Failed and Failing States that minimizes cost and resources to support their global operations. By applying this model to Africa, AFRICOM planners can determine the optimal number and location of hubs to support operations on the continent. The Failed and Failing states index provides a realistic baseline for where AFRICOM may be involved in future operations. The models' capabilities and limitations are explored, and recommendations are made to assist AFRICOM in the use of the program to aid AFRICOM planners.

## **Acknowledgements**

I would like to thank this study's sponsor, Colonel John Parker, HQ USAFE, A8Z, for providing me with guidance for this research. While working for Colonel Parker at USAFE, I developed the inspiration for this project. I was assisting members of CANOSCOM in the establishment of the first of their global support hubs at Spangdahlem AB, Germany. My dealings with CANOSCOM representatives, in particular, Captain Vicki Ryan, MWO Pete Taylor, and Lt Col Roy Bacot, convinced me that this might be a valuable area of study. All three individuals provided immeasurable support and without their assistance, I could not have completed this project.

Air Force Expeditionary Center Librarian Pam Bennett Bardot helped in the initial research and past research on Africa, and the previous GRPs by Majors Jim Nichols and Tom Ulmer also assisted in paving the way.

My advisor, Dr James Moore was always available when I needed help, and he was especially helpful in assisting me with the LINGO programming code. His modeling expertise was invaluable and I could not have cracked the code on LINGO without his help.

Finally, my fiancée gave up countless hours of time together (as well as did the majority of the wedding planning!) so that I could do this research and she was also my editor. I owe her thanks for that and so much more. Here is to the end of “stolen time...” and the beginning of our future together.

# Table of Contents

	Page
Abstract.....	iv
Acknowledgements.....	v
Table of Contents.....	vi
List of Figures.....	viii
List of Tables.....	ix
<b>I. Introduction.....</b>	<b>1</b>
Background, Motivation, & Problem Statement.....	1
Research Focus.....	5
Research Objectives and Research Questions.....	6
Theoretical Lens.....	6
Methodology.....	7
Assumptions/Limitations.....	7
Implications.....	9
GRP Overview.....	9
<b>II. Literature Review.....</b>	<b>10</b>
The Growing Strategic Importance of Africa.....	11
African Transportation Infrastructure and Network.....	19
The Hub and Spoke Network.....	24
AFRICOM.....	26
Operating Locations and the Hub and Spoke Network.....	33
Literature Review Summary.....	35
<b>III. Methodology.....</b>	<b>36</b>
Description of the model.....	36
Research Design.....	38
Data Sources.....	42
Data Format.....	43
Assumptions.....	43
<b>IV. Results.....</b>	<b>53</b>

<b>V. Recommendations and Conclusion.....</b>	<b>59</b>
Recommendations.....	59
Limitations of this Study.....	60
Areas for Further Study.....	62
Conclusion.....	63
Glossary.....	65
Bibliography.....	67
Appendices.....	71

## **List of Figures**

Figure 1: Failed States Index 2009.....	2
Figure 2: The New Front in the War on Terror.....	16
Figure 3: Hub and Spoke Employment Concepts.....	25
Figure 4: How Big is Africa.....	27
Figure 5: Diagram of Hub Based Approach in CF Model.....	41
Figure 6: Updated Map for Proposed Hubs.....	56

## **List of Tables**

Table 1: Excerpt from Failed/Failing States 2009 Index.....	18
Table 2: List of Equation Symbols.....	48
Table 3: Model Results.....	54
Table 4: CANOSCOM Study Results.....	57

# APPLICATION OF A NON-LINEAR PROGRAM TO THE ESTABLISHMENT OF A HUB AND SPOKE SYSTEM IN AFRICA

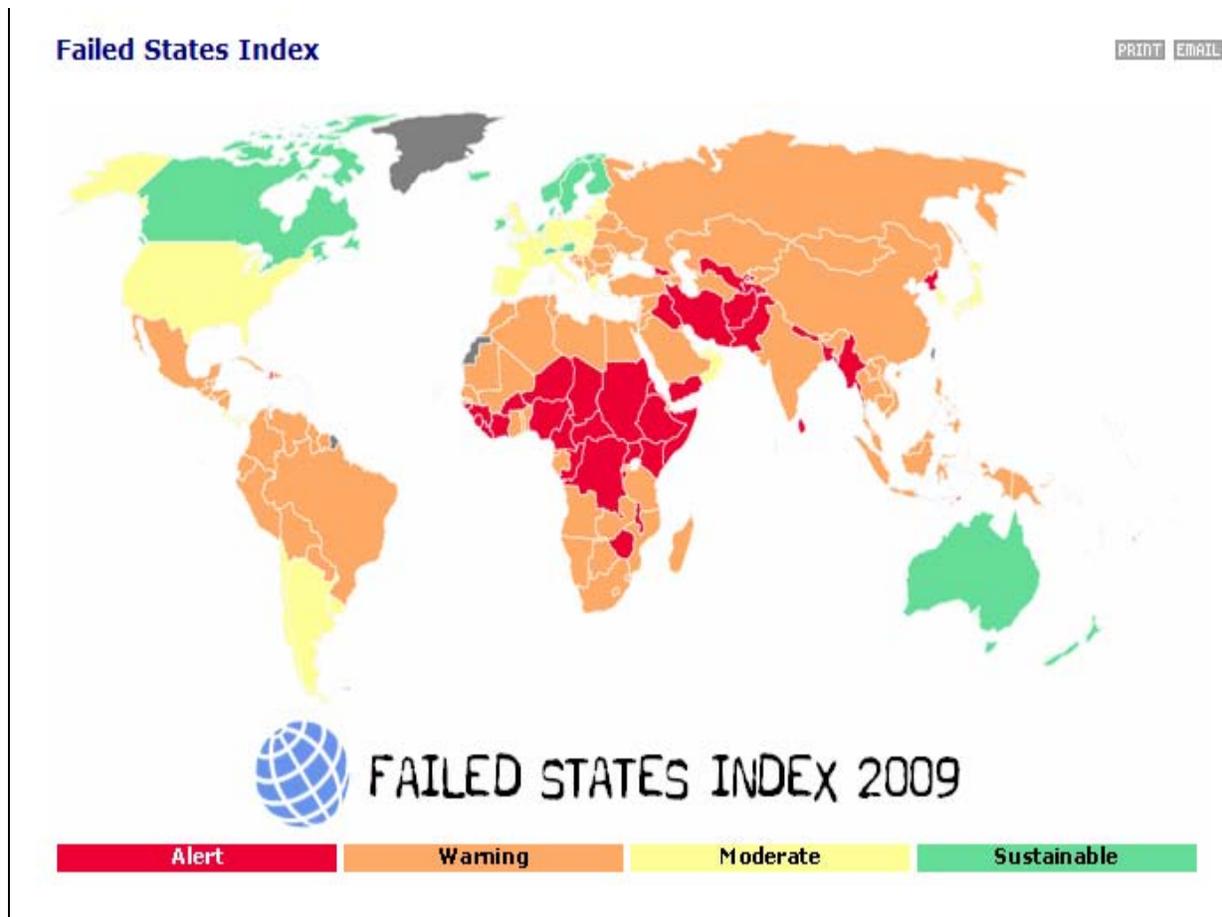
## I. Introduction

### Background, Motivation, and Problem Statement

Since the fall of the Berlin Wall and ultimately the end of the Cold War, the threats facing the United States (US) and its forces have increased exponentially. No longer is there a sole enemy of the state. These new threats and the dangers they pose have caused the US to alter its way of thinking in the execution of our foreign policy and the conduct of military operations. In addition, these threats have caused the US to deploy various military packages around the world in short time in order to defend our personnel and our interests. The majority of these new and emerging threats are associated with failing states. The number of failing states globally is increasing rapidly. The journal *Foreign Policy* conducts a yearly ranking of the failing states based on rating 12 social, economic, political, and military indicators. There are 177 states included in the 2009 index, the same number of states that was assessed in 2007 and 2008. The *Foreign Policy* rating examines the vulnerability of the state to fail and the perceived risk of violence in that state. The rank order of the states is based on the total score of the 12 indicators. The ratings are on a scale of 0 to 10, with zero being the lowest intensity (most stable/least likely to fail) and 10 being the highest intensity (least stable/most likely to fail). The total score is the sum of the 12 indicators on a scale of 0-120. A score in the range of 90-120 puts a state in the alert zone, indicating it has a greater propensity for failing. However, just because a country's score is in the alert zone, it does not guarantee that the state will fail. The state may actually be exhibiting positive signs of recovery or

be decaying at a slower rate than a state that is in the warning range (a combined score of 60-90) (*Foreign Policy* 2009). Basically, a critical state in the warning range may fail before a state in the alert zone. Of the 37 states world-wide in the alert range, 21 (or approximately 57%) are in Africa. The graphic in Figure 1 best demonstrates the severity of the situation:

Figure 1: Failed States Index 2009 (*Foreign Policy*)



Africa has grown in strategic importance due to its resources and perhaps more importantly its role in the War on Terror. In fact, one region in particular, the Sahara, has become an extremely useful base of operations for Muslim terrorists. The Sahara covers

an area of approximately 3.3 million square miles, and Al Qaeda and its allies are establishing operations and taking advantage of the area's lawlessness. If left unchecked, this area may serve as a launching point for future Al Qaeda operations (Powell, 2004). As a result of this increasing threat and under the direction of President Bush, on 1 October 2007, US Africa Command (AFRICOM) established its initial operating capability and became one of six Department of Defense (DoD) regional military headquarters (Fact Sheet, 2009). The US cannot afford to stand idly by and let African countries fail. Instability in the African states only increases overall global instability whether it be economically, politically, or militarily. Africa presents a world of opportunity for the United States to execute its foreign policy and assist one of the poorest regions in the world. But, none of this can be accomplished without overcoming some serious challenges. Perhaps the biggest of these challenges is the African transportation infrastructure. Although there were highly developed transport networks in many parts of Africa in pre-colonial times, during the colonial era that followed, these networks became fragmented. Transportation links between African countries were thinly developed, and artificial national frontiers began to develop between the different colonial powers. Unfortunately, when African countries gained their independence, they were left with maintaining the colonial transportation infrastructure. Without a significant economic infrastructure, this was difficult to do. Ultimately, this lack of solid economic infrastructure led to the decay and degradation of the transportation infrastructure. Specifically, due to the fact that different colonial powers ruled over different countries on the continent, railways with different gauges of track were built and were operated with different braking and coupling systems. This aided the fragmentation

of the African transportation network. There is a slim chance of developing a comprehensive network of new rail lines across the continent, but the construction of new lines or the modernization of existing infrastructure where it is deemed economically feasible could eventually be expanded into something more wide ranging (Njoh, 2008).

Rail is not the only form of inefficient transportation in Africa. Africa's lack of an effective and efficient road network is primarily the result of three circumstances. The first circumstance is the continent's relatively poor economic and political performance. Consistent political instability in the region as well as a general lack of funding had made it nearly impossible to build and maintain a comprehensive road network. The second reason for the continent's lack of effective road network is due to difficult geographic conditions (overall large size of the continent, as well as many mountains, rivers, and valleys). The third and final reason for the poor road network has to do with administrative ineptitude. African leaders have failed to recognize and prioritize the social and economic needs as well as utilize the scarce resources of their countries (Keller, 2007). This could almost be considered a corollary to the previous statement regarding the continent's poor political performance. Too many leaders are more concerned about their own wealth and well being than that of their people. Currently, Africa's inventory of roads is at 6.84 km/100 sq km, compared to Latin America's 12 km/100 sq. km, and Asia's 18 km/100 sq km (Amoako, 1997). Even though Africa's inventory of roads is minimal, in the absence of comprehensive rail connections across the continent, the majority of the haulage is mainly carried by trucks on roads. As stated previously, these roads are characterized by challenging geography to include loose soil, steep hills, and deep valleys. However, there is a potential solution to the transport

system in Africa. One plan might be to explore airlift initiatives on the continent. Airlift can overcome some of the geographic barriers that have impeded the establishment of an effective and efficient infrastructure. Unfortunately, due to the lack of resources and infrastructure to support this endeavor, this may be a difficult undertaking. The concept of doing more with less is not new to the US nor for that matter our allies. Specifically, our Canadian neighbors to the North under the direction of the Canadian Operational Support Command (CANOSCOM) have developed a model that is being used to establish a “hub and spoke” system globally to support Canadian Forces (CF) operations in response to failed or failing states. They look to establish 8 hubs worldwide, and the model they are using to establish their network can be applied to the US efforts in Africa to establish a “hub and spoke” system due to the similarities in conducting operations where there are limited resources, limited infrastructure, and a high number of failed or failing states. The model the Canadians developed provides insight as to the optimal location as well as the optimal number of hubs (Ghanmi, 2008). This model developed by CANOSCOM and Dr. Ghanmi may be able to assist AFRICOM in planning airlift operations to support missions as well as establishing a “hub and spoke” network in Africa. Ultimately, this will aid in the execution of US foreign policy in Africa.

### **Research Focus**

The focus of this research is applying the model developed by CANOSCOM and Dr. Ghanmi to proposed operating locations in Africa for the development of an optimized “hub and spoke” network. This model is applied to seven potential operating locations previously identified by Major James Nichol in his Graduate Research Paper *Analysis of AFRICOM Theater Airlift Distribution Network* (2008). These seven

operating locations have also been confirmed as valid possibilities by Major Andy Venne on the AFRICOM staff (Venne, 2009). As AFRICOM grows and other potential operating locations are established, this model may be applied to determine the optimal mix of airlift capabilities.

### **Research Objectives/Research Questions & Hypotheses**

The main goal of this research is to determine the optimal hub locations and optimal number of locations required to support airlift operations in Africa. The basic research requires two questions to be answered. The first question to be answered is: What is the optimal number of locations to operate out of in Africa? The second question to be answered is: Where are they located? The optimal locations are determined by using cost avoidance metrics (Ghanmi, 2008).

### **Theoretical Lens**

The approach that Dr. Ghanmi's model and consequently the one to be used in this analysis for AFRICOM is based on optimizing the use of available resources in the system while minimizing cost. His model is based on the pre-positioning of supplies for sustainment operations and he has developed mathematical models to determine the optimal relative cost of utilizing these resources. The optimization of these variables is what allows one to determine the optimal number of hubs and their location (Ghanmi, 2008). His model is a non-linear programming model utilizing Mixed Integer Nonlinear Programming (MINLP). The use of a non-linear model is more complex than the use of a linear model, but it allows for greater variation in modeling. The non-linear model may have multiple solutions and may be required to be solved multiple times to achieve the optimal global solution (Ragsdale, 2007).

## **Methodology**

The data required to conduct this research includes all the data needed by the Mixed Integer Nonlinear Programming Model (MINLP) for the AFRICOM scenario. The off the shelf computer program LINGO<sup>®</sup> is used to develop this model. The program determines the least cost locations as well as the least number of locations necessary to provide an optimized “hub and spoke” network. In order to accomplish this task, the number of hubs, locations, resources available, and the number of failing states is evaluated.

## **Assumptions / Limitations**

In the development of this model, several key assumptions were made. Most of these assumptions derive from the work and analysis of Dr. Ghamni. The following list summarizes the list of assumptions for the “hub and spoke” model:

1. Failed and failing states are used to determine future operations.
2. One mission is considered during the scenario. Multiple missions can be examined by varying the operational demand.
3. A continuous sustainment flow and constant operational demand are assumed.
4. A standard airlift pallet is used for a unit of measure for operational demand. Hub operating costs and the transportation costs are also expressed per pallet.
5. One month is used as a time scale for the sustainment frequency. Demand and logistics costs are calculated on a monthly basis.

6. The study is restricted to the strategic lift of supplies during the sustainment phase. The costs of deploying forces, personnel rotations, and local transportation supplies are excluded.
7. Transportation is conducted by airlift and a great circle distance is used to estimate airlift time, neglecting over flight issues and weather conditions.
8. Each hub has unlimited capacity for material storage.
9. The operational demand and the logistics distribution costs (airlift operating and hub operating costs) are known.
10. The hub locations and the deployment destinations are static and do not change over the scenario time horizon.

(Ghanmi, 2008)

These several assumptions make it possible to provide an excellent model on such a grand scale. For the purposes of applying this model to Africa, in addition to the assumptions stated above, the following limitations apply:

1. Since only failed and failing states are considered, this model does not allow for any country not in the alert zone to be considered (31 other countries).
2. There are no limitations on the flow of goods or fluctuations on demand (Ghanmi, 2008).
3. There are no limitations on hub material storage (Ghanmi, 2008).
4. This is purely a cost effectiveness model, as time responsiveness is not considered (Ghanmi, 2008).
5. This study only considers intra-theater movement in the AFRICOM Area of Responsibility (AOR).

6. More operating locations may be added at a later date.

### **Implications**

The implication of this study is to provide AFRICOM planners additional insight into the development of a “hub and spoke” system to support operations in Africa. This study provides AFRICOM planners with optimal locations as well as the optimal number of locations required to support this network.

### **Overview**

The remainder of the GRP lays the foundation for the establishment of a “hub and spoke” network in Africa. Chapter II covers an overview of the model and the growing strategic importance of Africa as well as the transportation infrastructure on the continent. Chapter III outlines the design, data sources, and the various methods of analysis used in applying the CANOSCOM model in Africa to support AFRICOM operations. Chapter IV contains a summary of the results of the model runs. Finally, Chapter V presents recommendations, conclusions, and areas for future study.

## **II. Literature Review**

This chapter begins by examining the growing strategic importance of Africa to the DoD due to its rich natural resources and potential links to the growing threat of terrorism. A brief overview of the transportation infrastructure in Africa is presented. The lack of an effective and efficient transportation infrastructure is impeding DoD's and AFRICOM's quest to conduct formal operations on the continent. Persistent political instability in the region as well as a general lack of funding had made it nearly impossible to build and maintain a comprehensive transportation network. In addition, the continent's lack of an effective transportation network is due to difficult geographic conditions (overall large size of the continent, as well as many mountains, rivers, and valleys). Finally, the existence of a poor transportation network has to do with administrative ineptitude. Africa is full of vast resources, but African leaders have failed to recognize and prioritize the social and economic needs as well as utilize these resources (Keller, 2007). This lack of an effective and efficient transportation network sets the stage for the development of an airlift "hub and spoke" network as airlift has the unique capability to overcome these limitations. The chapter then continues to discuss the creation of AFRICOM, the DoD's sixth geographic Combatant Command (COCOM). Under the direction of President Bush, on 1 October 2007, US Africa Command established its initial operating capability and became one of six Defense Department regional military headquarters (Fact Sheet, 2009). According to the fact sheet released by AFRICOM, the mission of AFRICOM in conjunction with other US government agencies and international partners is to conduct theater security engagement operations through either military-to-military programs, military-sponsored activities, or other

military operations. The purpose of these operations is to promote stability and to secure the operations of African governments in support of US foreign policy (Fact Sheet 2009). AFRICOM currently operates out of limited locations and the next and final part of the chapter examines the seven potential operating locations previously identified by Major James Nichol in his Graduate Research Paper *Analysis of AFRICOM Theater Airlift Distribution Network* (2008). Since Egypt is not traditionally considered part of AFRICOM, Cairo, Egypt, an eighth option presented in Major Nichol's paper, was not examined. The operating locations examined include Dakar, Senegal; Accra, Ghana; Libreville, Gabon; Gaborone, Botswana; Mombasa, Kenya; Djibouti, Djibouti; and Tunis, Tunisia (Nichol 2008). A brief overview of each of these locations and their suitability is provided.

### **The Growing Strategic Importance of Africa**

The history of Africa begins long before the history of the United States. Africa's written history started with the rise of the Egyptians in the 4th millennium BC (Britannica, 2009). The history of United States involvement in Africa is not one without turmoil or strife. The United States' first organized interaction with Africa occurred during the Tripolitan War of 1801-1805 (King, 1994). This was the first sustained and coordinated use of American military power outside the Western Hemisphere (King, 1994). This war would also shape many of the American experiences with Mideastern countries to include cultural barriers, religious fanaticism, and hostage taking (King, 1994). Perhaps the greatest impact on the history of Africa and its relations with the United States was a result of the slave trade. From the 16<sup>th</sup> to the 19<sup>th</sup> century, an estimated 10,000,000 people were transported to the New World (Britannica, 2009). This

incredible loss of people, coupled with the resultant devastating warfare and raiding associated with it, was a major cause of the subsequent weakness and decline of African societies (Britannica, 2009). The slave trade between the US and Africa provided a temporary boost to the African economy, but this was not to last. The abolishment of slavery in the US resulted in drastically reduced trade between the African continent and the United States for almost the next 100 years as well as a reduction in the strategic importance of Africa. However, the US lack of involvement would not be permanent. During the height of the Cold War, US aid to Africa reached its peak. When the fall of the Berlin Wall occurred in 1989 and as the Cold War eased, assistance to Africa dropped. During the 104<sup>th</sup> Congress in 1995, the importance of Africa to the US in a Post Cold War arena was addressed again. Congress acknowledged the growing importance of Africa and the US increased interest in growing US humanitarian, economic, and other interests in Africa (Copson, 2005).

The majority of the operations that the US has conducted in Africa have been humanitarian operations. However, humanitarian missions have increased in number and complexity since the end of the Cold War (Drilmeyer, 2003). The DoD conducts more than 200 humanitarian aid projects yearly at a cost of approximately \$27 million dollars (fiscal 2001 dollars) (Drilmeyer, 2003). Several factors have contributed to the increase in the DoD participation in humanitarian assistance missions, to include the evolving national security interests as a result of the end of the Cold War as well as climate change, population growth, emergence of new diseases, and the changing missions of the military (Drilmeyer, 2003). Although the US military has gained experience in working with public and private relief operations, humanitarian operations have been a matter of

course and the US military still has a lot to learn (Archer, 2003). Dr. Archer also states that an effective coordinated effort between civilian agencies and military agencies is essential with the military's primary responsibility being to establish and maintain a safe operating environment (Archer, 2003). General John M. Shalikashvili, former Chairman of the US Joint Chiefs of Staff, recognized the importance of the relationship between the civilian agencies and the military agencies when he stated that "If you are successful, they are successful; and if they are successful, you are successful. We need each other." (Archer, 2003). These operations are vital to the geographic unified combatant commands' theater engagement plans (Drilmeyer, 2003). The US supports and provides assistance to Africa through a variety of non-governmental organizations (NGOs), private and voluntary organizations (PVOs), and contractors. These organizations include but are not limited to the US Agency for International Development (USAID), the Peace Corps (with approximately 3000 volunteers participating), and the Trade for African Development and Enterprise (TRADE) (Copson, 2005). When President Bush took office, recognizing the increasing role of Africa in the Post Cold War world, he further increased aid to Africa. In a June 26, 2003 speech, he described a partnership with Africa to include support for security and development (Copson, 2005). In addition, his administration announced initiatives on access to potable water, clean energy, reducing hunger, and conservation (Copson, 2005). Perhaps the biggest initiative undertaken by President Bush was the Global HIV/AIDS Initiative (GHAI). GHAI is the primary component of the President's Emergency Plan for AIDS Relief (PEPFAR) and was initiated in 2004 (Copson, 2005). Support for GHAI was estimated at \$264 million in FY2004 and \$781 million in FY2005, and was estimated to be \$1.2 Billion under the

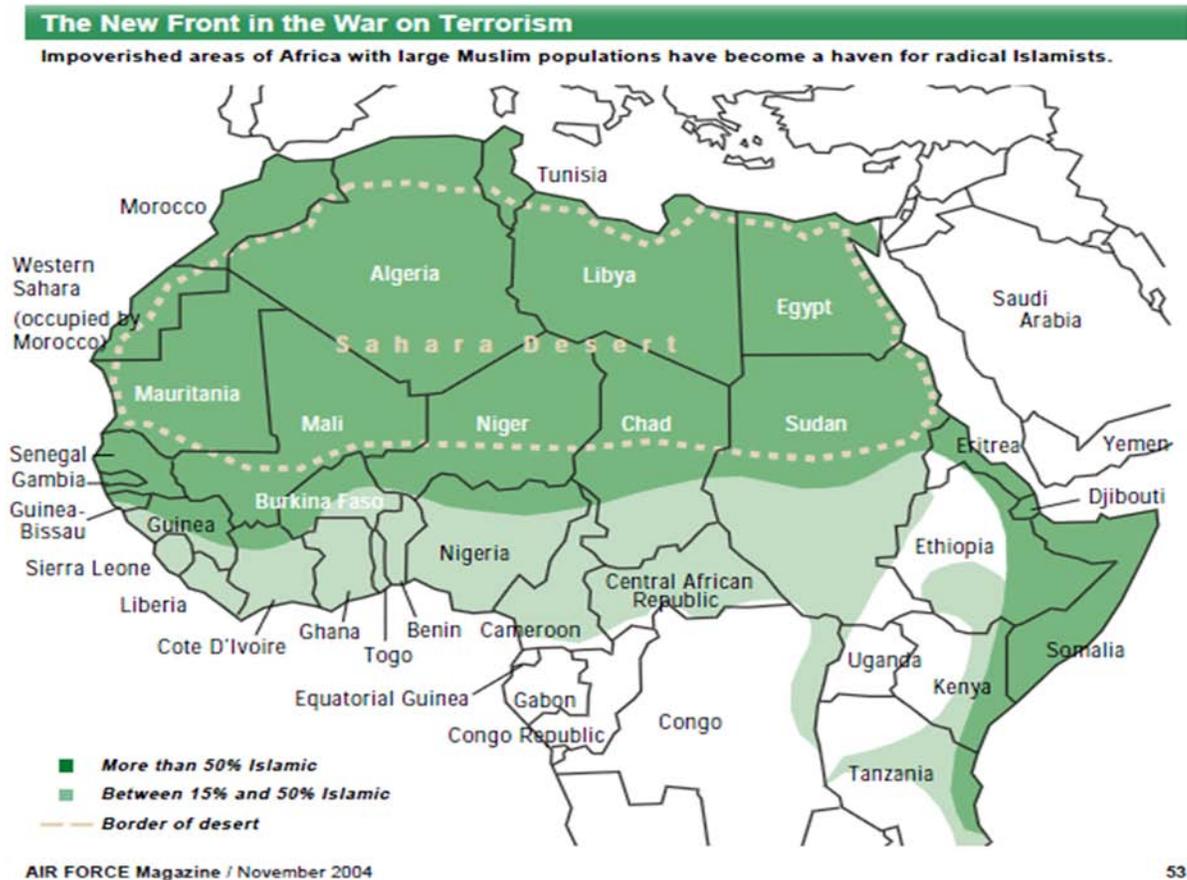
FY2006 request (Copson, 2005). In 2009, the World Health Organization reported that an estimated 23 million people were infected with HIV and another 1.6 million people died from AIDS in Africa (WHO, 2009).

As international and economic investment increased, so did the US military presence. After initially taking a step-back and remaining isolated from Africa as a result of the death of 18 and wounding of 75 US servicemen in Mogadishu, Somalia in October 1993, US' military involvement in Africa experienced a renaissance after 9/11 (Whitsitt, 2007). However, Africa has remained geographically important due to its central location relative to Europe and the Middle East (Whitsitt, 2007). In addition, Africa's known mineral wealth places it among the world's richest continents (Britannica, 2009). Africa has a very large share of the world's mineral resources to include coal, petroleum, natural gas, iron ores, copper, lead, gold, platinum, and diamonds (Britannica, 2009). Unfortunately, the US is not the only country that is interested in Africa. The results of an independent task force chaired by Anthony Lake and Christine Whitman speak of China and other countries involvement in obtaining access to African resources as well as providing influence in this region (Lake, 2006). Obviously, China's involvement in Africa is of particular interest to the US. China has started to acquire control of Africa's vast natural resources through outbidding Western contractors (Lake, 2006). In addition, China has been providing soft loans and other incentives to bolster its competitive advantage (Lake, 2006). China's Exim Bank, the country's official export credit agency, has approved at least \$6.5 billion in loans for Africa (Bosshard, 2007). China's imports from Africa primarily consist of oil and minerals while their exports to the continent include a wide variety of investment and consumer goods (Bosshard, 2007). China is

now the world's second largest oil importer with almost 28 percent of its oil coming from Africa, primarily from Angola, Sudan, and Congo (Lake, 2006). Overall the amount of trade between China and Africa increased tenfold between 1999 and 2006, and reached \$56 billion at the end of this period (Bosshard, 2007). Additionally, there are an estimated 700-800 Chinese companies operating in Africa (Bosshard, 2007). China presents a particularly important challenge to US interests and values as China does not share US concerns for issues of governance, human rights, or economic policy (Lake, 2006). China's influence is growing in Africa, and China has not been afraid to use its influence to protect the government of Sudan from United Nations sanctions for the ongoing attacks in Darfur (Lake, 2006). China is showing African countries that China can be a strong and valuable ally (Lake, 2006). If the US wants to maintain its presence on the continent of Africa, it will have to match some of China's efforts or be forced to deal with the consequences.

China is not the only threat facing the US on the continent of Africa. Perhaps more important is Africa's growing role in the War on Terror. In fact, one region in particular, the Sahara, has become an extremely useful base of operations for Muslim terrorists. The Sahara covers an area of approximately 3.3 million square miles and Al Qaeda and its allies are establishing operations and taking advantage of the area's lawlessness. If left unchecked, this area, nicknamed the Swamp of Terrors (see picture below), may serve as a launching point for future Al Qaeda operations (Powell, 2004).

Figure 2: The New Front in the War on Terrorism



53

President Bush's National Security Strategy of 2002 reflected a need for a more focused strategic approach toward the African continent (Ploch, 2009). Ploch (2009) continues to say that this strategy focuses on our core value in the US of preserving human dignity and our strategic priority of combating global terror. In addition, the revised National Security Strategy of 2006 refined its focus and said that the focus of this strategy will depend on partnering with Africans to strengthen fragile and failing states and bring ungoverned areas under control of effective democracies (Ploch, 2009). The

White House national security strategy released under President Bush's administration continued to say:

Regional conflicts can arise from a wide variety of causes, including poor governance, external aggression, competing claims, internal revolt, tribal rivalries, and ethnic or religious hatreds. If left unaddressed, however, these different causes lead to the same ends: failed states, humanitarian disasters, and ungoverned areas that can become safe havens for terrorists (The White House, 2002)

Terrorist attacks on the US embassies in 1998, and again on targets in 2002, have led one US official to remark that "Africa has been, is now, and will be into the foreseeable future ripe for terrorists and acts of terrorism." (Ploch, 2009). Furthermore, US officials have also warned that recruitment and support networks are operating in Africa, facilitating the activities of foreign fighters in Iraq, Afghanistan, and Pakistan (Ploch, 2009). DoD officials have recognized the need to work with African governments to counteract this emerging threat, as policy makers are concerned with the possible lack of challenge posed by "ungoverned spaces," defined as "physical or non-physical area(s) where there is an absence of state capacity or political will to exercise control" (Ploch, 2009). This lawless area has been previously described as the Swamp of Terror, an approximately 3.3 million square mile area of the Sahara desert, where lawless bands are reigning and terrorism abounds (Powell, 2004). This area is ripe for the taking, and Islamic terrorists are already in the area. Recently, al Qaeda has sent terrorist from Saharan hideouts to join the anti-US jihad in Iraq (Powell, 2004). In addition, Islamic militants from Algeria's Sahara region used \$6 million of kidnap ransoms to recruit more jihadists and to buy more weapons and high tech equipment (Powell, 2004). But, the US is fighting back. Through the Pan Sahel Initiative launched by the Bush Administration,

the US is providing \$7.75 million for US military training for the armed forces of Mali, Niger, Mauritania, and Chad, while the Pentagon also sought \$125 million to train anti-terrorist forces in Morocco, Tunisia, and Algeria (Powell, 2004). Currently, the number one nation listed on the *Foreign Policy* failed and failing states index for propensity to fail is Somalia (*Foreign Policy*, 2009). Somalia is not alone, and as Table 1 shows, the top five failed and failing states are located in Africa:

Table 1: Excerpt from the 2009 Failed / Failing States Index

Country	Rank	Total	Demographic Pressures	Refugees and IDPs	Group Grievance	Human Flight	Uneven Economic Development	Economic Decline	Delegitimization of the State	Public Services	Human Rights	Security Apparatus	Factionalized Elites	External Intervention
Somalia	1	114.7	98	9.5	9.7	3.5	7.7	9.5	10.0	9.9	9.9	10.0	10.0	9.8
Zimbabwe	2	114.0	98	9.1	9.1	10.0	9.7	10.0	9.8	9.8	9.9	9.7	9.5	7.6
Sudan	3	112.4	90	9.8	9.9	9.0	9.6	7.0	9.8	9.5	9.8	9.7	9.5	9.8
Chad	4	112.2	93	9.4	9.8	7.8	9.3	8.3	9.8	9.5	9.5	9.9	9.8	9.7
Dem. Rep. of the Congo	5	106.7	97	9.6	9.9	3.1	9.3	8.3	8.6	9.2	9.0	9.7	8.7	9.6

Somalia perhaps provides the most recent and best example of what can happen if these states are allowed to continue to fail. Somalia has been in the news lately for its

links to piracy as there have been 83 attacks on ships off Somalia's coast this year while a total of 33 ships were hijacked and 200 crew were taken captive (TimesonLine, 2008). More than 1200 Somalis are estimated to be involved, and the US is facing increasing danger as the piracy gives terrorists linked to al Qaeda a robust income and a deadly way to fight against the US (TimesonLine, 2008). It will take all instruments of national power: diplomatic, informational, military and economic to affect peace and stability on the continent. However, as former Secretary of State Powell stated in his address to the Corporate Council in June 2003, "Africa's boundless potential could not be realized unless the continent moved against corruption" (Copson, 2005). The potential is there, but the US needs to act and stand firm in its efforts to support African governments. This will not be easy without the establishment of a solid transportation infrastructure.

### **African Transportation Infrastructure and Network**

Fifty three countries and more than 800 million people, yet there is not one network to link them all. Not one network to link this entire continent so that it may operate as a single market. Rather, the marketplace and the network are fragmented and disjointed. In terms of quantity, quality, cost, and access, Africa lags behind the rest of the world in all aspects of infrastructure development (Mutume, 2002). In Africa, like many other countries, roads are the primary means of transportation, and in 1997 Africa (excluding South Africa) had only 171,000 kilometers of paved roads. This is approximately 18 percent less than Poland which is comparable in size to Zimbabwe (Mutume, 2002). There is also the additional problem of road travel safety. The roads are poorly maintained, traversed by old vehicles, unregulated, and unenforced by law enforcement. In African countries, the average death rate is 339 per 10,000 motor

vehicles, while in the world's most highly motorized countries, the average death rate is 2.3 per 10,000 motor vehicles. (Mutume, 2002). The African transportation network is in a state of misery, and it must be repaired in order to aid in Africa's growth. Cletus E. Olebunne, the Executive Director of Nigerian Entrepreneurial Leadership, perhaps summed it up best when he stated the following:

Transportation Infrastructures (roads, rail, airports and seaports) are the arteries for the free flow of people, goods and information; three things necessary in a manufacturing and export economy.  
(Olebunne, 2006)

Hans Voordijk, a professor at Tilburg University in the Netherlands agrees with Mr. Olebunne's assessment through his statement that an efficient and well developed transportation network is crucial for providing organized flow of goods (Voordijk, 1999). Voordijk (1999) continues on to state that without efficient transport, economic growth would be impeded. Furthermore, in the world of business, it is impossible to carry out any enterprise without taking into account the logistics involved (Versi, 2007). The more efficient the logistics, the greater the volume of trade, while the converse is also true (Versi, 2007). In this case, it is assumed logistics is referring to the method and means of transporting goods. The government can assist in the development of this well organized effective infrastructure by eliminating regulatory and legal obstacles that constrain enterprises from investing in the country yet while still strengthening its role in the national economy by increasing investments in the transport infrastructures (Voordijk, 1999). Olebunne agrees and states that the government cannot possibly do all these without the involvement of private entrepreneurs in the building of transportation infrastructures (Olebunne, 2006). Obviously, transportation is vital to Africa and its growth.

Even though Africa's inventory of roads is minimal, in the absence of comprehensive rail connections across the continent, the majority of the haulage is mainly carried out by trucks on roads. As stated previously, these roads are characterized by challenging geography to include loose soil, steep hills, and deep valleys. To fix this infrastructure will cost billions of dollars in investment and it will also require a master plan that all countries can agree to; however, the resulting reward could be a new continent (Versi, 2007). Jeffrey Shane, Under Secretary for Policy for the US Department of Transportation stated in an address to the US – Africa Infrastructure Conference in September, 2006 that “an adequate, well maintained infrastructure is nothing less than a prerequisite to Africa's successful participation in the global economy. It is essential to Africa's long term economic growth, development, and prosperity” (Shane, 2006). In years past, national leaders in Africa viewed upgrades in transportation infrastructure as a second tier investment priority (Shane, 2006). Social improvement programs were the priority and in the face of pressure, upgrades to the transportation infrastructure, let alone the establishment of a new infrastructure, were postponed if not forgone (Shane, 2006). Clearly, improvements in the African transportation network are required and it will take a cooperative effort between the governments and outside agencies.

The improvements in the African transportation infrastructure present a daunting task not only because they will require a cooperative effort but also because although there was once highly developed transport networks in many parts of Africa in pre-colonial times, during the colonial era that followed these networks became fragmented. The colonial authorities believed that investments in transport infrastructure invariably

led to economic development but they assigned more weight to cost saving than to regional integration. This was further proof that the colonial powers were more interested in exploiting rather than developing, the colonial territories (Njoh, 2008). Conscious efforts were made to discourage interaction among the colonies and this was especially true when the two colonial territories were under the rule of different colonial powers (Njoh, 2008). Unfortunately, when African countries gained their independence, they were left with maintaining the colonial transportation infrastructure. Major seaports and railways were developed, but not maintained. Unfortunately, the largest cost associated with the railroad industry is the operation, maintenance, and ownership of tracks themselves (Coyle, 2006). Transportation costs remain high, with the poor infrastructure accounting for 40% of the predicted transport cost for coastal countries and up to 60% of the cost for landlocked countries (Njoh, 2008). The neglect of rail and waterways for decades has contributed to the nation's dependence on food importation, as agricultural produce from one part of the country cannot be transported cheaply to other parts (Olebunne, 2006). In addition, the lack of a cheap means of transportation has discouraged many farmers whose harvests perished because they could not access the market (Olebunne, 2006). This is only one example of the economic failure that only hampered African progress. Without a significant economic infrastructure, it is even more difficult to maintain the transportation infrastructure of Africa. From the end of Africa's colonial rule, Africa has been trying to overcome the shortcomings in the country's transportation infrastructure. Currently, the African continent invests only approximately \$5 billion annually while it is estimated that it will cost \$18-25 billion per year to provide an adequate transportation infrastructure (Mutume, 2002). Progress is

being made but more can be done. During the 1960s, new independent African governments came to power and recognized the value of solid transportation networks as a means to develop agriculture, embark on industrialization, and allow for cheaper transport rates (Britannica, 2009). Unfortunately, there remained a serious shortage of qualified labor to plan and manage transport systems and to keep up with the rapid development of transport technology (Britannica, 2009). But, the introduction of private contractors and public enterprises is starting to make a difference. Joint ventures between the private sector and some states are being introduced to raise capital (Mutume, 2002). For example, in South Africa, the BOT (build, operate, transfer) and FROM (finance, rehabilitate, operate and maintain) systems rely on private finance to design, construct and maintain roads. Once the roads are built, private operators charge tolls to recover costs and realize a reasonable return on investments before transferring ownership to the state (Mutume, 2002). Any effort to solve Africa's transportation infrastructure problems will require institutional reform and greater financial commitments by both the governments and the private sectors (Jerome, 2008). In addition, careful attention will have to be paid to product design, procurement practices, and identifying risks (Jerome, 2008). Limao and others summed it best when they stated the following in their article

*Infrastructure, geographical disadvantage, transport costs, and trade:*

The real costs of trade—the transport and other costs of doing business internationally—are important determinants of a country's ability to participate fully in the world economy. Remoteness and poor transport and communications infrastructure isolate countries, inhibiting their participation in global networks. (Limao, Nuno & Anthony J. Venables, 2001)

In order for Africa to succeed on a global scale, its transportation networks need to be reformed. It is possible, but it will be costly.

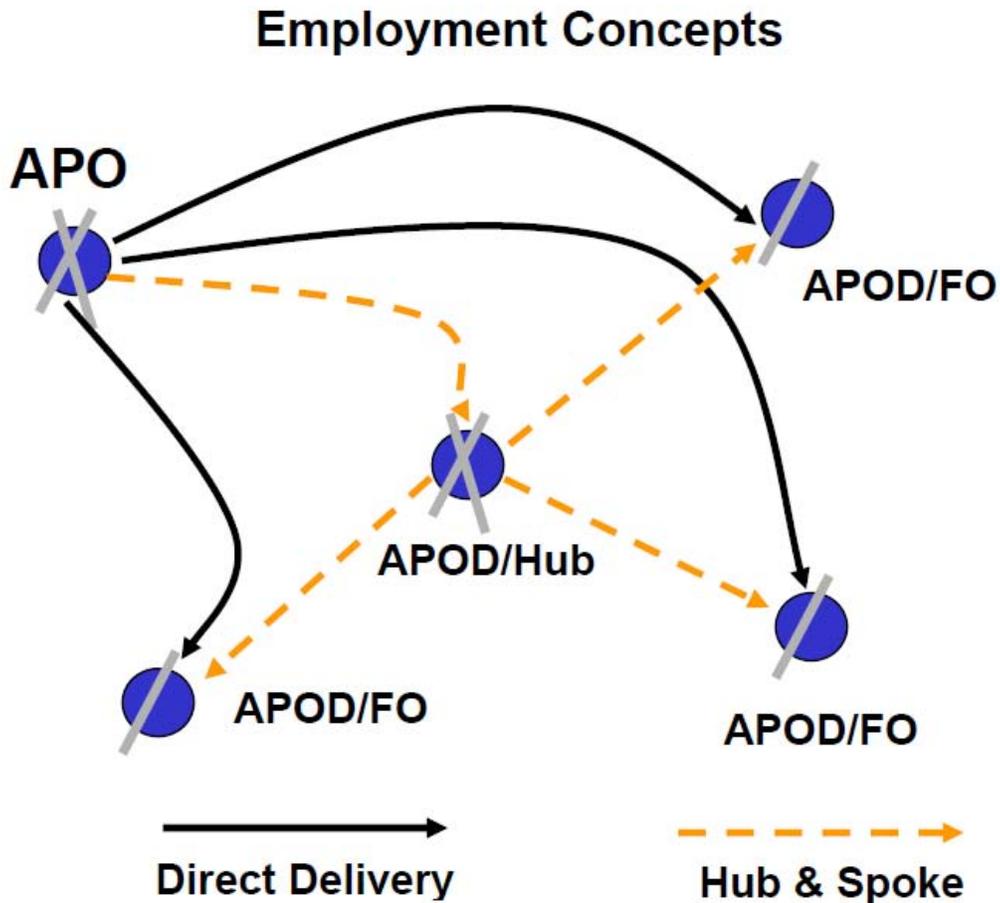
## **The Hub and Spoke Network**

Perhaps one solution to the African transportation problem is the development of an aerial “hub and spoke” network. The development of the “hub and spoke” system has been lauded as one of the most important inventions of the airline industry (Aykin, 1995). The centralization and broader scope of operations that this type of network provides allows the system to take advantage of economies of scale (Aykin, 1995). In a “hub and spoke” system, several points of departure are fed through a single airport (the “hub”) from which passengers and cargo can be transported to their various destinations (the “spoke”) (Wensveen, 2008). The small number of routes is considered more efficient, while more complex operations such as accounting and servicing can be carried out at the hub (Wensveen, 2008). The use of a centralized management system will allow for greater visibility of resources thus decreasing cost and response time, as well as increasing flexibility, and allowing for better control of the material (Ghanmi and others, 2008). Air Force Doctrine Document (AFDD) 2-6 *Air Mobility Operations* has the following to say about hub and spoke operations:

Hub and spoke operations integrate both inter-theater and intra-theater airlift operations. Starting from APOEs, the movement of cargo and personnel progresses through one or more en route staging bases to arrive at a main operations base (the hub) or APOD within a theater. The hub is the focal point for follow-on intra-theater airlift missions. Cargo and personnel are processed and readied for transshipment by intra-theater assets to FOBs—the spokes, throughout the theater. Hub and spoke optimizes air mobility operations when supporting multiple operational commanders and operations (AFDD 2-6, 2006: 43).

Figure 3 depicts a standard “hub and spoke” system.

Figure 3: Hub and Spoke Employment Concept



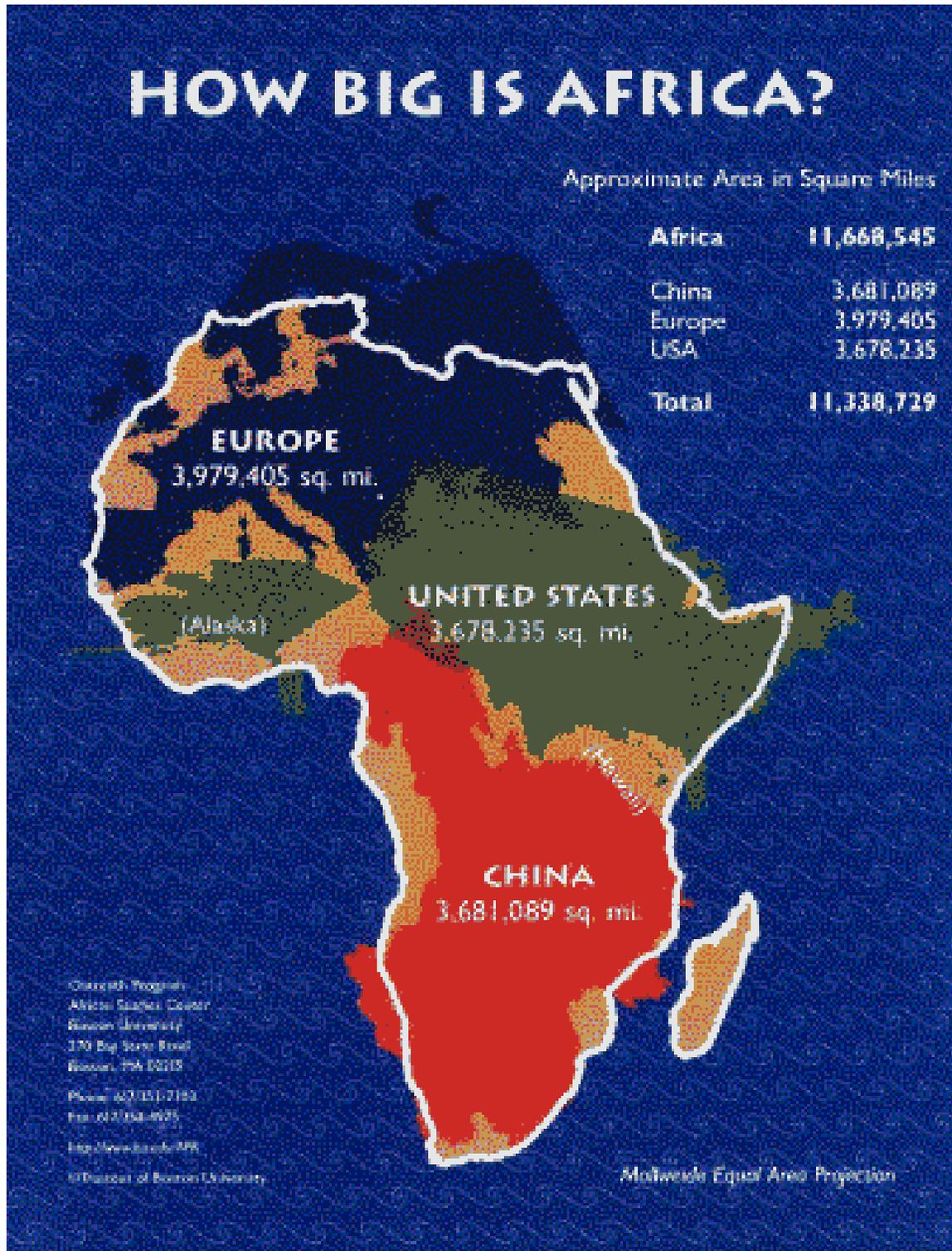
Airlift has the inherent ability to overcome some of the geographic limitations in Africa mentioned previously and the establishment of a “hub and spoke” system in Africa to support US operations there may be the answer. The cost of intra-theater airlift is usually the most expensive to operate but the economy of force achieved through centralizing airlift operations would maximize airlift availability, reduce overall operating costs, and provide greater flexibility for operations (Ghanmi and others, 2008). The cost optimization model developed by CANOSCOM for the establishment of their worldwide

“hub and spoke” system may provide insight for AFRICOM into the establishment of a hub and spoke network to support operations in Africa.

## **AFRICOM**

To say that Africa is unique and the challenges it presents to AFRICOM and the US are unique would be an understatement. Africa is the only continent to straddle both the Northern and Southern hemisphere while encompassing some nearly 12 million square miles. From the coast of Gabon in the East to the coast of Somalia in the West is a distance of 4,655 miles (in comparison, the distance from Los Angeles to New York is 2,462 miles), while from the furthest point in the North to the South in Africa is 4,989 miles. Africa encompasses an area more than three times the size of the United States and actually encompasses an area greater than Europe, the United States and China combined (Beaupre and others, 2007). Figure 4 demonstrates the comparison.

Figure 4: How Big is Africa?



The history of relations between the US and Africa is a long one. Morocco was actually the first country to recognize the US as a sovereign nation (United States Africa Command, 2008). Several years later, the US got involved in military operations in Africa. In 1801, Yusef Caramanli, the ruler of Tripoli, declared war on the US. He expected the US to pay tribute in exchange for protection from Tripolitan pirates. Shortly after Thomas Jefferson was inaugurated president, he dispatched a naval squadron to the Mediterranean Sea to combat these pirates. This marked the first use of American military power outside the Western Hemisphere (King, 1994). In 1941, President Roosevelt and British Prime Minister Winston Churchill signed the Atlantic Charter which called for the freedom of all nations. Africans would use this charter as the basis for calling for an end to colonialism (United States Africa Command, 2008). During World War II as part of Operation Torch, forces under the command of General Eisenhower invaded Morocco, Algeria, and eventually Tunisia and drove Axis forces out of Africa (United States Africa Command, 2008). In 1943, President Roosevelt became the first sitting US president to visit Africa as part of the Casablanca Conference (United States Africa Command, 2008).

During the Cold War, most of the US efforts were focused on subverting Soviet influence as the US perceived little if any strategic interest in the region (Lawson, 2007). Despite conducting more than 20 military operations in Africa during the 1990s, including the loss of life of US servicemen in Somalia, Department of Defense planners still maintained that they had very little strategic interest in Africa (Berschinski, 2007). In fact, in 1995 many questioned the rationale for assisting Africa as there appeared to be minimal accomplishments in terms of growth and democratization or promoting of US

interests, so Congress restructured and significantly reduced foreign assistance programs (Lawson, 2007). This feeling of lack of growth and democratization was reinforced in August 1998 when an al Qaeda affiliated group bombed the US embassies in Kenya and Tanzania killing 224 people and injuring an additional 5,000 (Berschinski, 2007). However, these attacks would not deter President Clinton from establishing the African Growth and Opportunity Act (AGOA) in 1999 which called for the creation of new economic opportunities by increasing African exports to the US (United States Africa Command, 2008). Since 2001, Africa has steadily grown in strategic importance due to the perceived security threats emanating from the continent (Berschinski, 2007). The threat of terrorism and terrorist activities on the continent steadily rose after 2001 as well. In 2003, al Qaeda once again struck in Kenya, this time killing 16 people. In addition, this same group came close to downing an Israeli airliner with a shoulder-fired surface-to-air missile (Berschinski, 2007). These attacks indicate the presence of local, regional, and worldwide actors comprising the global insurgency (Berschinski, 2007). The US would not remain out of Africa for too long. In 2005, the US returned to Africa in a peacekeeping role while supporting the United Nations Mission in Liberia and achieving its goal of establishing a cease-fire (Lawson, 2007).

With the growing instability on the continent and the increasing threat of terrorist activities, in 2007 the DoD announced the creation of AFRICOM. AFRICOM has three distinct goals: 1) promote US military and security interests throughout the continent 2) promote security partnerships in the region 3) support humanitarian aid efforts (United States Africa Command, 2008).

Douglas Lovelace, Jr, director of the Strategic Studies Institute, states that AFRICOM is pioneering a bold new method of military engagement focused on war prevention, interagency cooperation, and development rather than on traditional war fighting (Berschinski, 2007). Proponents of AFRICOM state that the new command is an accurate reflection of the US foreign policy of finding African solutions for African problems (Berschinski, 2007). Critics fear that AFRICOM is nothing more than an extension of a militarized foreign policy of the US and charge that the new command is an attempt by the US to secure Africa's energy supply, counter Chinese influence, and fight terrorism (Berschinski, 2007). China's influence in the region is definitely growing. The Chinese government has canceled more than \$10 billion in debt and provided more than \$5.5 billion in developmental aid for more than 31 African countries since 2000 (Harman, 2007). In addition, Beijing has surpassed the World Bank in lending to Africa, with China's Exim Bank lending \$12.5 billion in 2006, while in 2005 China committed \$8 billion to Nigeria, Angola, and Mozambique alone. The \$8 billion donated by China in 2005 was more than three times the amount donated by the World Bank in all of Africa (Harman, 2007). According to former European Command (EUCOM) commander General Bantz J. Craddock, Beijing clearly understands the importance of building relationships to help shape the future landscape of the continent (Craddock, 2007).

During his address to the House Armed Services Committee in March of 2007, General Craddock stressed the importance of US involvement in Africa. He described the continent of Africa as being full of vast potential and that this potential makes African stability a near term strategic imperative (Craddock, 2007). He continued with the following statement:

It is in our national interest to help Africa achieve broad-based and sustainable economic, security, political and social development. The DoD, in collaboration with other US agencies, is seeking more effective ways to mitigate or respond to humanitarian crises, sustain African unity and stability, and improve cooperation on such transnational issues as terrorism and HIV/AIDS. There is little doubt that Africa will occupy an increasingly larger amount of our national attention in the years ahead.  
(Craddock, 2007)

The mission facing AFRICOM is a difficult one. Africa is rich in resources, but it is even richer in instability. Very often, conflicts in one nation result in the destabilization of neighboring states and the amount of damage that can be done by the individual states or the groups in these states is unprecedented (Craddock, 2007). The potential for conflict in Africa is high and it has historically struggled with internal strife, economic problems, and unstable governments (Craddock, 2007). African states have not had much of a chance to recover. Many of them remain fragile. General Craddock lists a variety of factors as contributors to this fragility. These include but are not limited to corruption, health problems, historical ethnic animosities, and endemic poverty (Craddock, 2007). With AFRICOM, the US will establish a unified command focused on the African continent. Together with the help of our partners, allied nations, and African regional organizations, the US will work to advance common interests and values (Craddock, 2007). The future success of AFRICOM will depend on an effective collaboration of multiple agencies such as the State Department, USAID, Department of Commerce, Department of Energy, Department of Transportation, international organizations (IOs) and non-governmental organizations (NGOs) (Whitsitt, 2007). President Obama continues in the tradition of increasing the US role in Africa. He outlined his four priorities for Africa as the following:

1. Strong and sustainable democratic governments

2. Supporting development that provides opportunity
  3. Strengthening public health
  4. Peace and security necessary for progress
- (United States Africa Command, 2010)

The vision of a peaceful, plentiful Africa can be implemented by the US through AFRICOM (Berschinski, 2007). However, in order to succeed and silence critics, AFRICOM must demonstrate a commitment to programs that are mutually beneficial to both Africans and Americans (Berschinski, 2007). Something that would be beneficial to both Africans and Americans would be improving the dilapidated transportation network. This will neither be an easy nor an inexpensive undertaking. As mentioned previously, the establishment of an airlift network may assist in rebuilding this dilapidated transportation network. In addition, this network may provide stability as it will provide a means of rapid response to the failed and failing states in Africa. Berschinski points out that the success of AFRICOM will depend on its responsiveness to security issues (2007). The network being proposed uses a weighted average for the failed and failing states based on their ranking in the index to provide an optimized solution for the location and number of airlift hubs to support AFRICOM operations. A flexible, responsive, airlift network may be just the thing to assist AFRICOM in implementing the US national security strategy. The proposed operating locations include Dakar, Senegal; Accra, Ghana; Libreville, Gabon; Gaborone, Botswana; Mombasa, Kenya; Djibouti, Djibouti; and Tunis, Tunisia (Nichol 2008). Major Andy Venne, 17<sup>th</sup> Air Force/A3O, confirmed these as valid unclassified operating locations for the purposes of this study.

## **Operating Locations and the Hub and Spoke System**

The locations considered for this study as potential hub locations all were analyzed by Major James Nichol in his graduate research project *Analysis of AFRICOM Theater Airlift Distribution Network*. He conducted a thorough analysis of all the fields and examined the strategic relationships between the fields and their locations with respect to the five Regional Economic Communities (RECs) in Africa. Five of the seven locations selected have African Fuel Initiative (AFI) or Into-Plane (IP) contracts for fuel services (Nichol, 2008). Only Tunis, Tunisia and Gaborone, Botswana do not have AFI or IP contracts (Nichol, 2008). Major Nichol does not see a potential issue with either operating location. As he discovered in his study, Tunis was 15<sup>th</sup> in airlift throughput and has historical Foreign Military Sales (FMS) relationships while Gaborone is in close proximity to Molepolole-Thebephatshwa Air Base (Nichol, 2008). Each hub has the capability to handle C-130, C-17, C-5, and B-747 aircraft (Nichol, 2008). For the purposes of this study, only C-130 aircraft are considered. AFRICOM currently has two C-130 aircraft assigned to them to support operations (Venne, 2009). All of the potential locations considered are located in close proximity to the coast, so potential fuel or supply resupply issues are minimized. In addition, according to the Airfield Suitability and Restrictions Report (ASRR), all of the airfields considered have either a DoD approved approach and departure procedure or a Jeppesen approved approach (Air Mobility Command, 2009). The use of a Jeppesen approach or departure procedure requires Major Command (MAJCOM) approval, and in this case, United States Air Force in Europe (USAFE) approval (Air Mobility Command, 2009). Of note, Kenya is ranked 14<sup>th</sup> in the critical zone according to the failed and failing states index. From

2006 to 2009, Kenya's overall point score on the *Foreign Policy* index has increased from 88.6 to 101.4 (implying that the situation is deteriorating); however, US investment in Kenya is already substantial (United States Department of State, 2009). Currently, there are more than 9,000 US citizens that are registered with the US Embassy as residents of Kenya with almost two-thirds of these residents being American missionaries and their families (United States Department of State, 2009). Approximately 100,000 Americans visit Kenya each year (United States Department of State, 2009). The US invests almost \$285 million annually, primarily in the areas of commerce, light manufacturing, and the tourism industry (United States Department of State, 2009). Generally speaking, Kenya maintains a moderate profile in Third World politics and has also assisted in the ongoing conflict in Sudan (United States Department of State, 2009). Since the bombing of the US Embassy in Nairobi in 1998, the Kenyan and US government have intensified cooperation to address all forms of insecurity in Kenya, including terrorism (United States Department of State, 2009). The US government provides equipment and training to both Kenyan civilian and military security forces, as well as promoting broad-based economic development as the basis for continued progress in political, social, and related areas of national life (United States Department of State, 2009). There is a risk in establishing a hub in Kenya, but recent US involvement in supporting the government of Kenya and the geographic location of the airfield for a hub make its selection palatable for the purposes of this study.

The use of a "hub and spoke" system in Africa will not only provide the basis for a transportation infrastructure on the continent, but may also provide some stability to a country like Kenya. The opportunity exists for more frequent service, increased

flexibility, and more efficient use of the resources available (Ghanmi and others, 2008). The spoke design can be adapted easily for the addition or subtraction of new hubs. The flexibility provided by the hub and spoke design will allow AFRICOM to establish an optimal network for supporting operations in Africa as well as supporting the failed and failing states. The CANOSCOM model proposed for AFRICOM takes advantage of the resources available while minimizing cost. It uses the failed and failing states index and distance from each potential hub location to the failed and failing state as input for the model while providing the hub locations and optimal number of hubs as output. The goal of the model is to maximize cost avoidance, thereby saving money and resources. A more technical description of the model can be found in Chapter 3.

### **Literature Review Summary**

Over the past several years, Africa has grown in strategic importance and will continue to do so. President Bush recognized this and called for the creation of AFRICOM. The transportation infrastructure in Africa is poor at best, but there is hope. The development of an airlift network to support AFRICOM operations may be the solution to the problem. An airlift network may be able to provide the necessary resources and aid to assist in the development of future networks in Africa. The remainder of this research focuses on the application of the CANOSCOM model to the application of an airlift network in Africa based on limited resources and availability.

The following methodology section presents the capabilities of the CANOSCOM model. It discusses data sources and formats used by the model. Key modeling assumptions are also introduced.

### III. Methodology

This section outlines a description of the model, the design, data sources, and the various methods of analysis used in applying the CANOSCOM model for the establishment of a “hub and spoke” system in Africa to support AFRICOM operations.

#### Description of the Model

The model developed by Dr. Ghanmi is a version of a constraint problem that was applied to an operational support network. The use of the *Foreign Policy* failed and failing states index provides the backbone for the models and assists in determining where potential CF deployment destinations would be. In the same manner, the index will be used to determine future AFRICOM operating locations.

The main performance measures for this model are the cost effectiveness and the time responsiveness of the logistics distribution. The optimal use of resources in the system refers to the overall cost effectiveness of the system while the time responsiveness refers to the speed of the logistics distribution across the network. Due to the complexity of modeling time responsiveness for a hub-based support system, the study developed by the CF which is also applied to the proposal for AFRICOM is the cost effectiveness model.

The model is developed as a discrete facility location problem and is implemented through mixed integer nonlinear programming. Unlike a classic facility location problem, the hub-based support problem allows for a mission to be supported through multiple hubs. In addition, the hub-based support problem combines two types of problems: the facility location (i.e., optimal hub location) and resource allocation (i.e., optimal number of supplies at each hub). The two main aspects to this model are cost

avoidance and relative cost avoidance. These are two separate, distinct models that rely on the use of metrics and optimization techniques to determine the optimal number of hubs and their locations (Ghanmi, 2008). As stated previously, this model focuses on the cost avoidance metric. In this study, cost avoidance refers to the logistic distribution cost that could be potentially avoided if supplies are pre-positioned at different locations. The pre-positioning of supplies at the hubs is limited to sustainment supplies and does not include such assets as heavy equipment.

As part of the cost avoidance metric, the logistics distribution cost must be determined. The logistics distribution cost depends on such parameters as the type of aircraft providing the lift as well as constraints such as slot times at airports. This logistic distribution cost is used to help determine the average cost avoidance metric. The average logistics distribution cost, weighted by the probability of occurrence of failed and failing states ( $w_j$ ), is used to determine the overall cost avoidance that could potentially be avoided with the hub-based support approach. In a similar manner, the average relative cost avoidance metric is used to assess the average percentage of logistics distribution cost, weighted by the probability of failed and failing states, that could potentially be avoided with the hub-based support approach. The two different metrics are used to assess the logistics distribution cost avoidance as part of an optimization model objective function to determine the optimal hub locations. Depending on whether the objective is to maximize the average cost avoidance or the average relative cost avoidance, the optimal hub locations could be different. The combination of these two metrics will be used to maximize the savings over all destinations. The cost avoidance model tends to select locations that are close to failed and failing states with higher probability of

occurrence whereas the relative cost avoidance model tends to select locations that maximize the average relative cost avoidance over all failed and failing states (Ghanmi, 2008). The formulation and application of the formulas used in this model can be found in the Assumptions section of the Methodology

## **Research Design**

The Canadian Military was looking for a solution to the increasing cost of supporting their global operations as well as a means of determining future potential operating locations. They had limited funds and resources and needed a solution to fit their global reach needs in order to deploy and sustain their forces overseas. The Canadian Forces (CF) have acquired C-17 aircraft to provide their global reach, but they needed an approach to optimize their use. Canadian officials decided that a global “hub and spoke” system would be the best approach. They could optimize their locations as well as minimize their presence. Dr. Ahmed Ghanmi developed a model to minimize the cost and resources allocated in an effort to determine where the global hubs would be located. The model he proposed would improve the CF logistic distribution system and enhance effectiveness (Ghanmi, 2008). In addition, this would eliminate the ad hoc nature of support to the CF operations and provide a national military support capability (NMSC) (Beatty, 2007). The CF officers believe that this will improve the CF’s ability to deploy and sustain operations as well as allow for the capability to expand (Beatty, 2007). In that endeavor, the CF, under the direction of Dr. Ghanmi, developed a mixed integer nonlinear program (MINLP) model to model their distribution efforts and determine the location of their hubs. The CF based the development of their model on a three year deployment scenario that represented recent deployments and historical data

(Ghanmi, 2008). For most countries, the shift in foreign policy in a post-Cold War conflict requires a fairly dramatic and fresh approach for handling future contingencies. The nature of their military force and their employment must be closely examined and reshaped to meet future threats. Canada is certainly among those nations needing to do so (Boomer, 2006). The development of the global hub concept was Canada's answer to combating future threats. Dr. Ghanmi (2008) stated that the potential for improving responsiveness and effectiveness of Canada's logistics distribution was a key factor in consideration of the establishment of a network of operational support hubs. In the development of their model, CF determined optimal hub locations based on cost avoidance metrics and optimization techniques (Ghanmi, 2008). Creating the optimal system for deployment and sustainment of CF units and formations would require complete knowledge of where the CF will operate over the coming years and what the nature of those operations will be (Boomer, 2006). CANOSCOM officials determined a series of requirements for the model. These characteristics are outlined below:

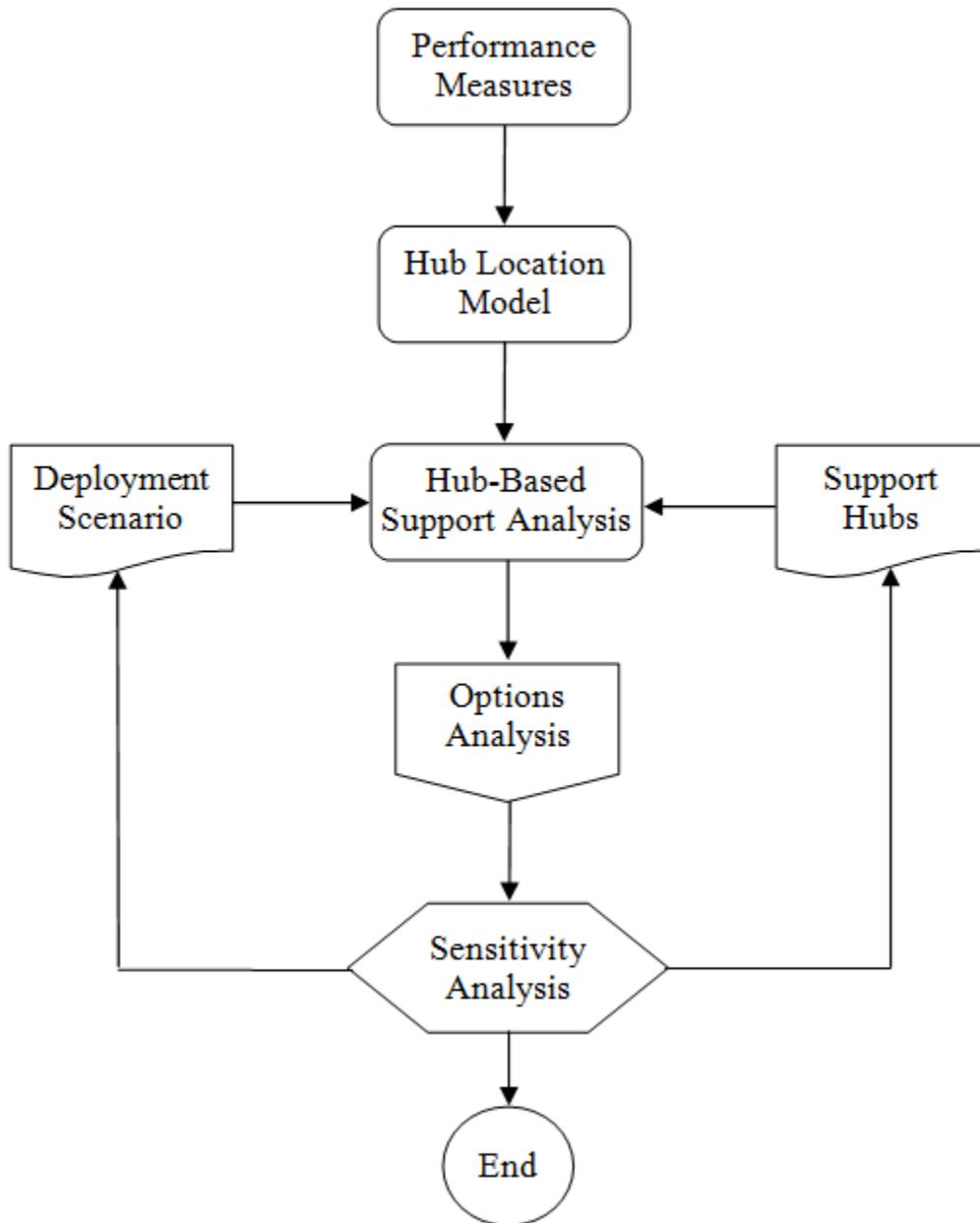
a. General:

- (1) Geography: the Hub would be close to the mission areas to reduce the cost and time for the move between the Hub and deployment areas;
- (2) Commercial LOCs: the Hub would already be a regional hub for commercial distribution and movements, connecting major off-continent air and seaports to the regional sea, air and land routes. Similarly, the Hub would have good commercial connections into the regional Public Telephone and Telegraph (PTT) infrastructure permitting maximum use of these existing facilities to support the communications needs of the CF in this region;
- (3) Climate: the Hub would be climatically similar to the deployment areas so that arriving troops could adapt before moving into the deployment areas;

- (4) Commercial Facilities: the Hub would possess commercial and/or military vehicle and equipment repair facilities that could be used to maintain CF materiel in theatre. The Hub would also possess good hotel and entertainment venues for troops exercising short R&R trips out of the deployment area;
- (5) Political. The Hub would be in a country whose population and government were favorably disposed to Canada and Canadian Forces members. Municipal and federal governmental officials should be relatively free of corruption, police and customs efficient and operating under a rule of law, and the country stable enough that it is unlikely to be severely affected by the regional problems that force the deployment of CF assets;  
(Boomer, 2006)

Through research, the CF determined that 80% of the lift costs to support a mission occur during the sustainment phase. They also determined that the Operational Support Hubs should be able to pay for themselves by avoiding unnecessary lift costs. In an effort to reduce hub operating cost, the CF planned the consolidation of loads to reduce unused cargo capacity. In addition, CF planned on the procurement of some material to reduce overall costs. Finally, the proposed model avoids backhaul costs to Canada for material that can be repaired at the Hub (Boomer, 2006). A graphical wiring diagram of the hub based approach in the CF model is displayed in Figure 5.

Figure 5: Diagram of the hub based approach in the CF model



The CF initially identified 6 potential world-wide hubs. These potential hub locations were: Mombasa, Kenya; Dubai, United Arab Emirates; Dakar, Senegal; Ramstein, Germany; Singapore, Singapore; and Panama, Panama (Ghanmi, 2008). CF

officials plan on using the hubs for cross-loading between modes of transportation, pre-positioning of non-perishable supplies, refueling stops, and as a staging base during troop rotations, etc (Ghanmi, 2008). Items that would be stored at hubs include subsistence items (food, water, etc), fuel, spare parts, some medical supplies, and construction material. Specific supplies like ammunition and weapons would be delivered directly from Canada and not stored at the hubs (Ghanmi, 2008). Also, based on the CF's intended purchases for strategic projection airlift and sealift, the establishment of repair and transit hubs will provide the foundation for optimizing the movement of both cargo and personnel into future theaters of operations (Boomer, 2006). The focus of this paper is on the application of the MINLP hub optimization model developed by CANOSCOM in support of their global operations and adapting this model to the development of a "hub and spoke" model of support operations in AFRICOM.

For the model being proposed for AFRICOM, the supplies would be delivered directly from Ramstein, Germany if not procured locally. For Canada, the creation of the global hubs represents a low risk, potential high return option for increasing their global reach. The same statement can be said for AFRICOM. AFRICOM can only gain in a similar manner through the application of the CF model in order to establish hubs in Africa. The creation of the hubs for AFRICOM would be a low risk undertaking that has the potential to support operations and help establish a transportation infrastructure.

### **Data Sources**

Computer modeling is described by Ragsdale (2007) as "a set of mathematical relationships and logical assumptions implemented in a computer as a representation of some real world decision problem or phenomenon." The computer model presented in

this study represents how a “hub and spoke” system could facilitate AFRICOM operations while minimizing resource requirements and cost. The data for this project is primarily obtained from the *Foreign Policy* index of failed and failing states. This data is input into a modified version of Dr. Ghanmi’s non-linear programming code in the LINGO<sup>®</sup> software program. The program is run a total of seven times each for the relative cost avoidance and the cost avoidance model. The results of the runs provide the data for the project.

### **Data Format**

The data is saved in a spreadsheet that is read directly into the non-linear programming model. The data populates a matrix that the computer program uses to get the results. The programming code for both the cost avoidance model, the relative cost avoidance model as well as the failed and failing states index, weighted averages for the countries, and the distance calculations matrix can be found in Appendix A: LINGO Input Summary.

### **Assumptions**

As previously stated in the introduction found in Chapter I, the following are the assumptions for the “hub and spoke” model:

1. Failed and failing states are used to determine future operations.
2. One mission is considered during the scenario. Multiple missions can be examined by varying the operational demand.
3. A continuous sustainment flow and constant operational demand are assumed (i.e. demand is constant).
4. A standard airlift pallet is used for a unit of measure for operational demand. Hub operating costs and the transportation costs are also expressed per pallet on a per month basis.
5. One month is used as a time scale for the sustainment frequency. Demand and logistics costs are calculated on a monthly basis.

6. The study is restricted to the strategic lift of supplies during the sustainment phase. The costs of deploying forces, personnel rotations, and local transportation supplies are excluded.
  7. Transportation is conducted by airlift and a great circle distance is used to estimate airlift time, neglecting over flight issues and weather conditions.
  8. Each hub has unlimited capacity for material storage.
  9. The operational demand and the logistics distribution costs (airlift operating and hub operating costs) are known.
  10. The hub locations and the deployment destinations are static and do not change over the scenario time horizon.
- (Ghanmi, 2008)

In addition, one further assumption is made for this study. All distances are calculated to be great circle distances and it is assumed that there will be no over flight restrictions, i.e. it will be possible to fly directly from one location to another. The distance matrix can be found in Appendix A. The assumptions presented here are not without their limitations. When the model is applied to Africa, the following limitations apply:

1. Only failed and failing states are considered. This model does not allow for any country not on the list to be considered.
2. There are no limitations on the flow of goods or fluctuations on demand.
3. There are no limitations on hub material storage.
4. This is purely a cost effectiveness model, as time responsiveness is not considered.
5. This study will only consider inter-theater movement in the AFRICOM AOR.
6. More operating locations may be added at a later date.

A critical part of the model and the assumptions made involve the airlift formulas employed in the model. For the purposes of this study, a C-130 is considered for its worldwide and austere operating conditions deployment capability. In addition, AFRICOM currently has 2 C-130 aircraft at its disposal to support operations. Before the costs for this model are examined, the constants in the implementation of the model must be examined. First, there are some fixed costs as part of the hub operating costs. These

fixed costs include a monthly maintenance cost per pallet, a monthly fixed warehousing cost, as well as a monthly fixed personnel support cost for each hub location. Basically, the fixed cost represents the sum of the warehousing cost and the personnel deployment allowances fees. The monthly warehousing cost was determined by averaging the cost for building a warehouse in a selection of African countries (the ones that data could be found on). This cost was then converted to US dollars and divided by twelve to determine the average monthly cost. Building a warehouse was considered to be the worst case scenario and the most expensive option and therefore was deemed to provide a more realistic value for the purposes of the study. In addition to the warehouse costs, there is also a deployment allowance fee for the personnel who must support and maintain operations at the warehouse and hubs. On average, these costs figure to be approximately \$5000 per month per person, based on current average per diem rates and temporary duty (TDY) rate calculations. Therefore, the value determined for the monthly overall fixed cost of operating a hub was approximated to be 21,400 US dollars. The average cost for warehousing pallets in a container was also determined through the same type of empirical research. This fixed cost was determined to be \$100 per month. For the purposes of this study, the average warehousing costs were obtained from the internet and the average personnel deployment fees were based on TDY rates to the continent.

Another critical factor in use in the model is the airlift ratio. It is obtained from the following formula:

$$\rho = \frac{r}{pv} \quad (1)$$

where  $\rho$  is the cost per nautical mile, where  $r$  is the aircraft chartering rate (\$/hr),  $p$  is the aircraft maximum payload (in pallets), and  $v$  is the aircraft maximum cruising speed, per Air Force Pamphlet (AFPAM) 10-1403. One of the core airlifters for AFRICOM is the C-130 and therefore for the purposes of this study, the airlift ratio was calculated for a USAF C-130. Per AFPAM 10-1403, aircraft cruising speed,  $v$ , is 272 knots, based on a 2500 nm range. The aircraft maximum payload,  $p$ , is 6 pallets. The aircraft chartering rate,  $r$ , is \$6000 / hr.

Therefore, the airlift ratio is:

$$\rho = \frac{r}{pv}, \quad \text{or } \$6000 / (272*6). \text{ Or } 6000 / 1632. \text{ Or } 3.6764$$

In addition to this, the model proposed assumes that AFRICOM and the US will be able to procure 50% of the required items on the local economy. This assumption may seem high, but it plays an invaluable role in helping to stimulate and reestablish the local economies through the use of local products. This ratio is designated by  $\alpha$  in the formulas and is calculated on a scale of 0 to 1, where the value of 1 represents procuring all goods on the economy. Again, this may seem like an outlandish assumption, but these efforts will be part of what makes AFRICOM successful in their efforts to nation build as well as carry out sustained operations on the continent. In an effort to normalize the data, each failed and failing state was also given a weight corresponding to its propensity for failure as well as its overall score on the index. The author calculated a normalized Z-score for each African country in the process of determining the weighted score. Each

individual country and normalized score can be found in Appendix B: Standard Weights and Scores.

Finally, there are three final fixed costs that must be considered by this study in the formulation of the models. These costs are the maintenance cost, warehousing cost, and deployment allowance fees. The basis for these definitions is taken from Dr.

Ghanmi's 2008 study, but they have been revised to support revised cost estimates and AFRICOM's needs. Their respective definitions are found below as they relate to this study:

- *Maintenance Cost*: This is the cost required to maintain supplies at hubs. There is a monthly cost for maintaining one sea container. Per the study conducted by the CF, one sea container can contain 3 pallets. The CF determined this cost to be between \$250 and \$350 in 2007. For the purposes of this study, a monthly maintenance cost, ( $c_i$ ), of \$100/pallet is used in the analysis.
- *Warehousing Cost*: The warehousing cost depends on different parameters such as the warehouse size, property insurance, location area, host nation agreements, etc. For the AFRICOM hubs, the cost for warehousing about 200 pallets (constant demand) is determined from online sources to be approximately \$6400 per month. Since there exists the potential for limited warehousing capability in some African nations, this value is based on what the average cost is to build a new warehouse in an African nation divided into a 12 month period to obtain the monthly cost.
- *Deployment Allowances Fees*: The third fee consists of the allowances fees for the personnel deployed to operate the support hubs. It is estimated from online per diem tables to be approximately \$5000 per month. In the CF study, they determined that a minimum of three personnel would be required to support the hubs. As a minimum, it is suggested AFRICOM do the same. Therefore, the average estimated cost for supporting three personnel per month is determined to be \$15000.

Using the revised cost estimates, the total hub operating cost per month is estimated to be:

$$c_{0i} = \$6400 + \$15000 = \$21400$$

In this study, there are two types of models that are analyzed and they are as follows: an average cost avoidance model and an average relative cost avoidance model. Table 2

below summarizes all of the symbols used in the model's equations and the computer programming code.

Table 2: List of Equation Symbols

<u>SYMBOL</u>	<u>DEFINITION</u>
$\alpha$	Supply pre-positioning ration, the percent of the amount of items procured locally versus the amount brought in
	Average cost avoidance
$C_i$	Monthly maintenance cost per pallet at each hub $i$
$C_i q_i$	Monthly maintenance cost at each hub $i$ times the number of pallets pre-positioned at hub $i$
$C_{0i}$	Total operating cost per month of hub $i$
$D$	Demand at each hub
$d_{ij}$	Distance from hub $i$ to destination state $j$
$d_{0j}$	Distance from Ramstein to the failed or failing state $j$
$H$	Maximum number of hubs to locate
$K_n$	Total monthly operating costs at $n$ hubs, includes transportation costs and hub operating cost
$m$	Number of failed or failing states
$n$	Number of hubs in operation
$P$	Maximum number of payload pallets that can be carried
$\rho$	Airlift ratio
$q_{ij}$	Quantity of supplies to deliver from hub $i$ to state $j$
$r$	Aircraft chartering rate (\$/hr)
	Relative Cost Avoidance
$T_{nj}$	Airlift cost round trip from the $n$ hubs or Ramstein to the failed or failing state $j$

$T_{0j}$	The total logistics distribution cost for state $j$
$v$	Aircraft maximum cruise airspeed, in knots
$x_i$	Decision variable for optimal hub locations ( $x_i=1$ if hub $i$ is selected, otherwise 0)
$x_{ij}$	Hub assignment variable ( $x_{ij}=1$ if hub $i$ is used to support state $j$ , otherwise 0)
$w_j$	Weighted average of failed / failing state $j$
$R$	Airlift ratio, for a C-130
$D$	Demand, constant
$H$	Number of hubs, 1 to 7
$A$	Pre-positioning ratio, same as alpha
$Q$	Amount of demand at hub
$X$	Decision variable, 1= yes, 0= no
$Co$	Hub fixed operating cost
$C$	Maintenance cost per pallet
$I$	Specific hub location
$J$	Specific failed or failing state

For the purposes of this study, the average cost avoidance metric is used to evaluate the average logistics distribution cost weighted by the probability of occurrence of failed and failing states and this model is determined as follows:

$$\overline{CA} = \sum_{j=1}^m w_j (T_{0j} - K_n - T_{nj}) \quad (2)$$

In order to implement this equation in the model and to facilitate the calculations and use of the equation, it was rewritten into the following form representing the objective function for the cost avoidance model:

$$\text{Maximize } \overline{CA} = \sum_{j=1}^m w_j \left[ 2\rho D d_{0j} - \sum_{i=1}^n x_i (c_{0i} + c_i q_i) - 2\rho \sum_{i=0}^n x_{ij} q_{ij} d_{ij} \right] \quad (3)$$

The constraints and restrictions are:

1.  $\sum_{i=0}^n x_{ij} q_{ij} \geq D \quad ; \quad \forall j$  (Demand)
2.  $\sum_{i=1}^n x_i = H$  (Number of hubs)
3.  $\sum_{i=1}^n x_{ij} q_{ij} \leq \alpha D \quad ; \quad \forall j$  (Pre-positioning)
4.  $x_i \geq x_{ij} \quad ; \quad \forall i, j$  (Hub assignment)
5.  $q_i \geq q_{ij} \quad ; \quad \forall i, j$  (Resource allocation)
6.  $q_i, q_{ij}$ , non-negative integer;  $x_i, x_{ij}$  binary (Variable domains)

(Ghanmi, 2008)

Granted, the pre-positioning ratio could be different for each hub. However, for the purposes of this study it is assumed constant.

In the preceding equations, the demand constraint ensures that the total quantity of supplies to deliver satisfies the operational demand. Meanwhile, the hub constraint specifies the maximum number of hubs to locate and their optimal locations while the resource allocation constraint specifies the minimum quantity of supplies that should be allocated to each hub. There are two more constraints that are required to bound the model and they are found below. Constraint (7) implies that if hub  $i$  has not been selected (i.e.,  $x_i = 0$ ), then there are no supplies at hub  $i$  (i.e.,  $q_i = 0$ ). Similarly, constraint (8) implies that if a hub  $i$  is not used for a given state  $j$ , (i.e.,  $x_{ij} = 0$ ), then it should not be assigned supplies to deliver (i.e.,  $q_{ij} = 0$ ). For the purposes of this study, these constraints can be enforced if  $M$  is a large number ( $M \gg D$ ).

7.  $q_i \leq M x_i \quad ; \quad \forall i$   
 8.  $q_{ij} \leq M x_{ij} \quad ; \quad \forall i, j$   
 (Ghanmi, 2008)

Once simplified to a single maximum cost avoidance equation, the Mixed Integer Nonlinear Programming (MINLP) is implemented in the commercial programming code LINGO<sup>®</sup> and is used to determine the hub locations. MINLP is a mathematical program where some of the variables are integer and some of the constraints or the objective function is nonlinear. The converted LINGO<sup>®</sup> programming code excerpt is provided in Appendix A.

In a similar manner, the Average Relative Cost Avoidance ( $\overline{RCA}$ ) model is developed. It is used to assess the average percentage of logistics distribution cost, weighted by the probability of failed and failing states, that could potentially be avoided with the hub-based support approach. The formula follows:

$$\overline{RCA} = \sum_{j=1}^m w_j \left( 1 - \frac{K_n + T_{nj}}{T_{0j}} \right) \quad (4)$$

Again,  $w_j$ ,  $K_n$ ,  $T_{nj}$ , and  $T_{0j}$  are the same as stated previously.

For the average relative cost avoidance sub-model, the simplified objective function can be formulated as follows, with the same constraints and variable definitions as the cost avoidance sub-model:

$$\text{Maximize } \overline{RCA} = \sum_{j=1}^m w_j \left[ 1 - \frac{\sum_{i=1}^n x_i (c_{0i} + c_i q_i) + 2\rho \sum_{i=0}^n x_{ij} q_{ij} d_{ij}}{2\rho D d_{0j}} \right] \quad (5)$$

**The relative cost avoidance programming code can be found in Appendix A.**

The two different metrics – average cost avoidance and the relative cost avoidance – are used to determine the optimal hub locations. Depending on whether the objective is to maximize the average cost avoidance or the average relative cost avoidance, the optimal hub locations could be different. However, a happy medium involving the two models is possible as will be seen in the results section of this study and maximum savings can be achieved over all possible AFRICOM hub locations.

#### **IV. Results**

The assumptions stated previously were applied to Dr. Ghanmi's model for the application to AFRICOM. A comprehensive list of the results for all the runs can be found in Appendices B and C. Appendix B contains the Cost Avoidance results while Appendix C contains the Relative Cost Avoidance results. A summary of the results in tabular form is presented in Table 2.

Table 3: Model Results

# of Hubs	Cost Avoidance Sub-model		Relative Cost Avoidance Sub-model	
	Hub Location	Cost Avoidance (\$M)	Hub Location	Relative Cost Avoidance (%)
1	Libreville	0.157039	Tunis	*
2	Dakar	*	Accra	*
	Gaborone		Libreville	
3	Dakar	0.054682	Libreville	.0655
	Accra		Mombasa	
	Djibouti		Tunis	
4	Dakar	0.123419	Accra	5.7
	Accra		Libreville	
	Gaborone		Djibouti	
	Mombasa		Tunis	
5	Dakar	0.273586	Dakar	*
	Accra		Accra	
	Libreville		Libreville	
	Gaborone		Gaborone	
	Tunis		Mombasa	
6	Dakar	0.253467	Dakar	5.2
	Accra		Accra	
	Libreville		Libreville	
	Gaborone		Gaborone	
	Mombasa		Mombasa	
	Tunis		Djibouti	
7	Dakar	0.012122	Dakar	*
	Accra		Accra	
	Libreville		Libreville	
	Gaborone		Gaborone	
	Djibouti		Djibouti	
	Mombasa		Mombasa	
	Tunis		Tunis	

Notes:

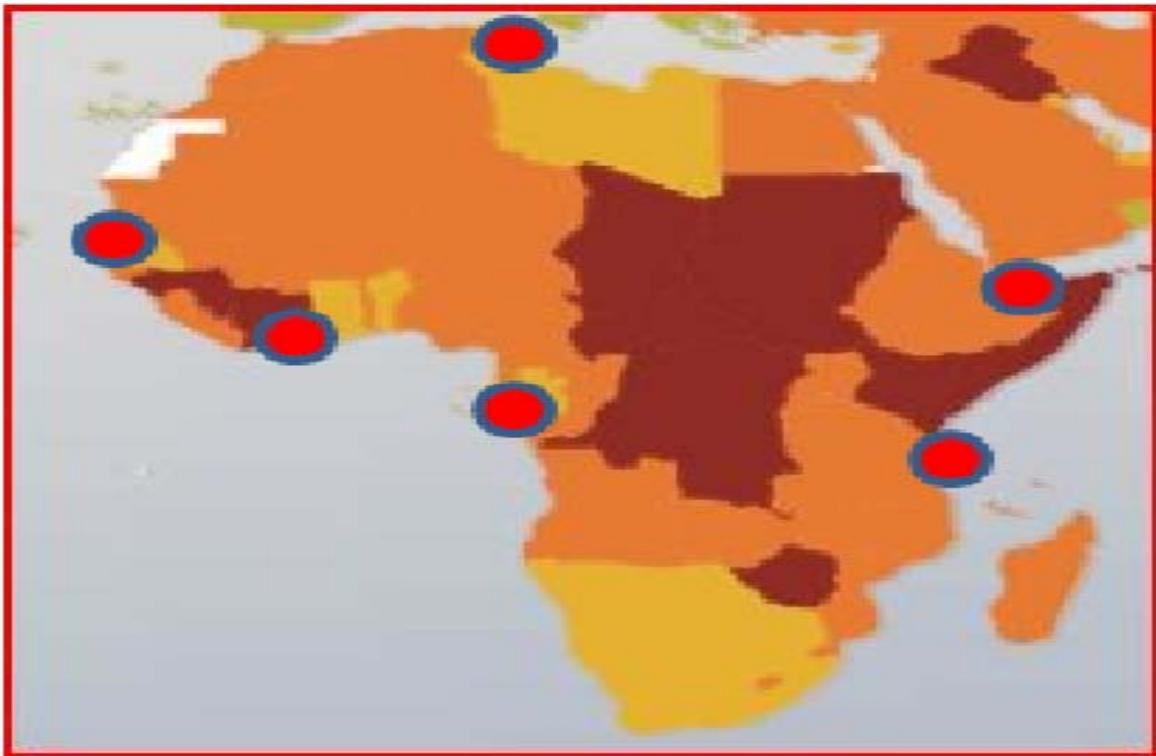
\*: No feasible solution found. Approximately zero savings on a per month basis.

Ideally, AFRICOM is looking for a solution that does its best to maximize the relative cost avoidance and the cost avoidance. The cost avoidance model tends to select locations that are close to the failed and failing states with a higher probability of failure. The relative cost avoidance model tends to select locations that maximize the average relative cost avoidance over all of the failed and failing states (Ghanmi, 2008). In a perfect world, these two solutions would converge to the same hub locations. In addition, keep in mind that these results depict per month savings and if the savings are extrapolated over a year, a significant overall savings can be achieved. However, there are some solutions that provide no apparent cost avoidance (savings). These instances are denoted by the symbol “\*” in Table 2. The existence of these situations can best be explained by the fact that in the case of the cost avoidance model, two hubs were not enough to support all of the failed and failing states. It would be cost prohibitive to make this selection. One could argue then that the same should apply for a single hub solution. However, a possible cost avoidance solution exists for the single hub scenario based on the fact that the proposed solution (Tunis) is the location physically closest to the resupply point (Ramstein). Overall, it may be more expensive to operate on the continent with only one hub, but the physical closeness of this hub to Ramstein provides some, even if minimal, cost avoidance. As for the relative cost avoidance solutions, the same logic can be applied as an explanation for why there are not any significant relative cost avoidance savings until three or more hubs are utilized. The average relative cost avoidance over all of the failed and failing states is minimal in this instance. Based on the results above, the solution which maximizes both the relative cost avoidance as well as the cost avoidance would be a six hub solution utilizing hub locations at Dakar, Accra,

Libreville, Gaborone, Mombasa, and either Tunis or Djibouti. An analysis of the physical locations of the failed and failing states reveals how either Tunis or Djibouti would serve as a viable location due to their proximities to failed and failing states. The optimal six hub solution yields savings of approximately \$254,000 per month (3.04M per year). As indicated in Table 2, an increase in the number of hubs to seven has a drastic decrease in the overall cost avoidance and the relative cost avoidance. Meanwhile, a decrease in the number of hubs to five may provide an increase in the average cost avoidance, but results in a drastic reduction in the relative cost avoidance over all of the failed and failing states.

The graph in Figure 6 depicts the new hub locations relative to the failed and failing states:

Figure 6: Updated Map depicting proposed hub locations relative to failed/failing states



Note: Red Dotes depict proposed hub locations

From the revised graphical depiction above, one can see that the proposed hub locations will more than adequately provide coverage for the support of the failed and failing states and AFRICOM operations. So how do the predicted savings for AFRICOM compare to those in the initial study predicted for CANOSCOM? The following table depicts the CANOSCOM results:

Table 4: CANOSCOM Study Results

# of Hubs	Cost Avoidance Sub-model		Relative Cost Avoidance Sub-model	
	Hub Location	Cost Avoidance (\$M)	Hub Location	Relative Cost Avoidance (%)
1	Mombasa/ Dubai	0.980	Mombasa/ Dubai	23.50
2	Mombasa	1.141	Dubai	29.43
	Dubai		Dakar	
3	Mombasa	1.252	Dubai	32.03
	Dubai		Dakar	
	Dakar		Panama	
4	Mombasa	1.261	Mombasa	34.00
	Dubai		Dubai	
	Dakar		Dakar	
	Panama		Panama	
5	Mombasa	1.265	Mombasa	33.92
	Dubai		Dubai	
	Dakar		Dakar	
	Panama		Panama	
	Singapore		Singapore	
6	All	1.267	All	33.66

Clearly, the CANOSCOM model depicts greater overall savings than the proposed AFRICOM model. This can easily be attributed to the mere scope of the two models. The CANOSCOM model is designed to determine worldwide operations while

using Trenton (Canada) as a point of support (the greater the distance from the failed and failing states, the greater the cost). The proposed AFRICOM model is designed to support operations on a smaller scale while being supported by Ramstein AB, Germany; a location much closer to the African continent.

Cost avoidance is not the only factor that should be considered in the selection of operating hubs for AFRICOM. Several other potential factors could affect the decision for the selection of a hub location. These factors include operational issues (such as operating hours of the airfield), political infrastructure (such as the presence of host nation agreements), and commercial issues (such as ground support capability and the presence of offload equipment). Historical data can assist in determining some of these factors, but prior to embarking on a new operating hub, these factors should be carefully reviewed.

## V. Recommendations and Conclusion

### Recommendations

The following two recommendations are based on the results of this study.

**Recommendation One.** While this study analyzed six potential airports and operating locations, they were not necessarily the “definitive” AFRICOM operating locations. Major Venne (17<sup>th</sup> AF) did agree that the locations used in this study were valid potential operating locations; however, he could not assure that they would be definitive hub locations where they would consistently operate. In order to maximize the benefits of this model and a study like this, AFRICOM needs to determine the locations where they might operate in theater. Understandably, there are some locations that AFRICOM operates out of that are classified and they will not be considered in an unclassified study similar to this one. However, if AFRICOM wishes to ensure success on the African continent in its future operations, it must develop a corps group of operating locations and capabilities at each location.

In addition, in determining which fields they will operate out of, AFRICOM also needs to consider what type of aircraft they will primarily employ. AFRICOM currently has two C-130 aircraft dedicated to supporting its operations. While the requirements for an operating location for a C-130 aircraft are minimal (as compared to say a C-5), AFRICOM needs to determine if whatever fields they deem to operate out of have the capability for expansion or the inherent capability to support larger aircraft and operations. AFRICOM needs to develop a strategy on how they want to support this massive AOR. Furthermore, AFRICOM planners need to determine the type of support infrastructure that will be required at each hub. AFRICOM may ultimately determine that

air support is not the right answer for how they wish to support future operations, but air makes the most sense at least initially to overcome inherent geographical limitations on the continent. Other means are possible, such as sea lift and haulage on roads, but the lack of an efficient and effective infrastructure at this time may limit the feasibility of either one of these methods. Airlift can provide the initial backbone of the support operations until these two other alternate methods become more established.

**Recommendation Two.** The second recommendation presented for AFRICOM's consideration is to develop a combined index utilizing the failed and failing states index as well as an index representing AFRICOM's prioritized goals, missions, and areas of support. This will provide a comprehensive and combined list that can then be appropriately weighted and implemented into the computer program to determine the optimal number of hubs and their locations. While the failed and failing states index is a good basis for the model and determining potential operating and support locations, it is not necessarily all that Africa needs. The model does not take into account what AFRICOM's specific goals and objectives may be on the continent, and as the model does not account for all of the countries in Africa, only the ones in the alert zone on the failed and failing states index. The development of a combined index may assist AFRICOM in pursuit of the first recommendation presented here (that of determining in theater operating locations) as the combined index will help AFRICOM set priorities for the continent.

### **Limitations of this Study**

Perhaps the biggest limitation of this model is the fact that it is based heavily on the use of the *Foreign Policy* failed and failing states index. If a country does not fall in

the alert zone on the index, it is not considered in this study. Even though there are 22 nations in Africa that meet this requirement, there are 31 others that do not. The failed and failing states index provides a great baseline for the development of this model, but it is by no means perfect.

A second limitation of this model involves the vast number of assumptions used in the development of the model. These assumptions include constant demand at the hubs, constant hub costs and maintenance fees, and unlimited capacity for material storage at the hub. Constant demand at the hubs is probably not a realistic assumption due to the fact that demand varies based on location and circumstances at each location as well. There are also several possible mission types. A humanitarian aid mission may not have the same demand requirements as a peacekeeping mission. As far as the cost is concerned, the presence of constant costs at each hub (to include maintenance fees) is probably also not realistic. The changing dynamics of each country and their respective economies will drive the cost of support at each hub and this will more than likely not be constant across the AOR. Finally, unlimited storage capacity at each hub is also probably unrealistic as “unlimited” capacity for storage at each hub would definitely be cost prohibitive. However, all of these assumptions were made to simplify the model and to provide an opportunity for a cost avoidance solution.

A third limitation of the study is the complexity of the LINGO<sup>®</sup> program itself. The program presented is a MINLP, and by its very nature, it is not an easy program to use or understand.

Finally, this study only examined the possibility of supporting AFRICOM operating locations and movement of cargo by air. In reality, while air may provide the

predominant mode of support and transportation, it more than likely will not be the sole provider. Sea lift, rail, and roads will also more than likely be used to support operations. However, a robust airlift network can provide the backbone for the establishment of a diverse transportation network, especially on a continent where there is a lack of an effective and comprehensive transportation infrastructure.

### **Areas for Further Study**

Several of the areas for further study relate to the previously mentioned limitations. The first area for further study could look at a comprehensive model that takes into account both the failed and failing states index as well as AFRICOM's priorities for operations. This model would determine the optimal method to support operations on the continent for all countries, not just the ones listed in the alert zone in the failed and failing states index. A second area for further study might consider the use of afloat pre-positioning to support the hubs. This may reduce the overall costs as the reliance on the economy to procure goods would be reduced along with the cost of warehousing and maintaining goods. In addition, this would virtually guarantee the availability of goods. A third area for consideration would be to conduct further sensitivity analysis involving different types of aircraft (airlift ratios), pre-positioning variables, as well as variable support costs. This would perhaps provide the best and most realistic model for the locations of the operational hubs for the "hub and spoke" network. The final area for further study would be to consider conducting a similar analysis for modeling seaports and railheads. The combination of these three studies and models (airfields, seaports, and railheads) may perhaps provide the most realistic, most

cost effective, and overall best model for determining the operational hub locations for supporting operations on the continent.

## **Conclusion**

This paper's intent was to focus on the establishment of an airlift "hub and spoke" network to support AFRICOM operations in Africa. However, the establishment of a "hub and spoke" network to support operations in Africa will not be a simple task. Africa's poor transportation infrastructure is a major roadblock to success on the continent. In addition, Africa's growing strategic importance is of great concern to the US and its newest COCOM, AFRICOM. The first part of the paper focused on the historical background of Africa and its transportation infrastructure as well as the basis and background for the model proposed. The remainder of the paper focused on how AFRICOM could use the proposed model to support their operations on the continent and develop a "hub and spoke" network to support these operations. The model has limitations, but overall provides a realistic look at the potential savings that could be achieved through the implementation of this model. While there are many operational, economic and political factors that should be considered in the selection of appropriate support hubs, this study focused only on the cost avoidance aspect. Personnel movement, delivery time requirements, support services availability, and political agreements were not considered in this study. While cost avoidance is crucial, particularly in today's economy, there are other factors that must be taken into consideration. However, the establishment of a "hub and spoke" network in Africa to support AFRICOM operations on the continent is a vital cog in the success of AFRICOM on the continent. This model provides AFRICOM an estimation of the potential cost savings as well as the optimal

locations for operational hubs on the continent. The hubs provide a low cost solution as well as potential cost avoidance for the strategic positioning of supplies for future operations as well as provide a staging base for personnel deployment, troop rotations and redeployment. The availability and reliability of locally procured goods is vital to the implementation of this model. Valid inputs are vital to the success and accuracy of this model. Overall, the model may not be perfect, but it does provide a realistic solution for the establishment of a “hub and spoke” network, especially if one recognizes the limitations of the model and how these limitations relate to the AFRICOM AOR.

## **Glossary**

AFDD – Air Force Doctrine Document

AFI – African Fuel Initiative

AFPAM – Air Force Pamphlet

AFRICOM – African Command

AGOA – African Growth and Opportunity Act

AIDS – Acquired Immune Deficiency Syndrome

AMC – Air Mobility Command

AOR – Area of Responsibility

ASAM – Advanced Study of Air Mobility

ASRR – Airfield Suitability and Restrictions Report

BOT – Build, Operate, Transfer

BC – Before Christ

CA – Cost Avoidance

CANOSCOM – Canadian Operational Support Command

COCOM – Unified Combatant Command

CF – Canadian Forces

DoD – Department of Defense

EUCOM – United States European Command

FMS – Foreign Military Sales

FROM – Finance, Rehabilitate, Operate, and Maintain

GHAI – Global HIV / AIDS Initiative

GRP – Graduate Research Project

HIV – Human Immuno Virus

IO – International Organization

IP – Into-Plane

MAJCOM – Major Command

MINLP – Mixed Integer Non-Linear Program

NGO – Non-Governmental Organization

NMSC – National Military Support Capability

PEFPAR – Presidential Emergency Plan for AIDS Relief

PTT – Public Telephone and Telegraph

R&R – Rest and Relaxation

RCA – Relative Cost Avoidance

REC – Regional Economic Communities

TDY – Temporary Duty

TRADE – Treaty for Africa Development and Enterprise

TRANSCOM – Transportation Command

US – United States

USAFE – United States Air Forces Europe

USAID – United States Agency for International Development

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## **Appendix A. LINGO Input Summary**

## COST AVOIDANCE MODEL (PROGRAM)

### Model:

! Support hub location optimization Problem. Given n hubs and m failed and failing states, the model determines the optimal hub locations and resource allocation in order to maximize the average cost avoidance.

```
*****
!
!
!           Application of Dr. Ahmed Ghanmi's model, CANOSCOM
!           to US operations in Africa. Used with permission.
!           November 2009
!
!
!*****;
```

### SETS:

```
State /1..22/: Weight;
Hub / RG DS AG LG GB MK DD TT /: Q, X, C0, C;
Hub_State (Hub, State): Distance, Quantity, Y;
```

### ENDSETS

### ! Objective Function;

```
[OBJ] Max = @SUM(State(J): Weight (J)*(2*R*D*Distance(1,J)-
@SUM(Hub (I) | I #NE# 1:X(I) *(C0(I) + C(I) * Q(I)))-
@SUM(Hub(I): 2 * Y(I,J)*R*Distance(I,J)*Quantity(I,J)));
```

### ! CONSTRAINTS;

#### ! Demand;

```
@FOR (State (J) : @SUM(Hub(I): Y(I,J)*Quantity(I,J))>= D);
```

#### ! Number of Hubs;

```
@SUM(Hub(I) | I #NE# 1: X(I)) = H;
@FOR(Hub(I) | I #NE# 1: X(I) <= Q(I));
```

#### ! Pre-positioning;

```
@FOR (State(J): @SUM(Hub(I) | I #NE# 1:Y(I,J)*Quantity(I,J))
<=A*D);
```

#### ! Hub Assignment;

```
@FOR(Hub_State(I,J) | I #NE# 1: X(I) >= Y(I,J));
```

#### ! Resource Allocation;

```
@FOR(Hub_State(I,J) | I #NE# 1: Q(I) >= Quantity(I,J));
```

#### ! Variable Domains;

```
@FOR( Hub : @BIN(X));
@FOR( Hub_State : @BIN(Y));
@FOR( Hub : @GIN(Q));
@FOR( Hub_State: @GIN(Quantity));
```

#### !Logical Constraints;

```
@FOR(Hub(I): Q(I) <= 20000*X(I));
@FOR(Hub_State(I,J) : Quantity(I,J) <=20000*Y(I,J));
```

```

! Model Parameters;
  DATA:
    R = 3.67;
    H = 8;
    A = 0.5;
    D = 200;

! State;
!Distance = @OLE('Distance.XLSX');
!Weight = @OLE('Weight.XLSX');
Weight = 0.965335 0.958014 0.936561 0.933366 0.855528 0.740452 0.706767
0.610041 0.556009 0.475801 0.430906 0.335051 0.316896 0.281911 0.265146
0.244925 0.207102 0.182813 0.151348 0.142657 0.128934 0.104302;
Distance = 2710 3245 2480 3435 2660 2230 2745 4220 2615 3350 2700 3610
3225 2890 2750 2570 2555 2425 2530 4030 3250 2270
      1045 2305 3045 3655 545 2000 695 3565 480 3045 2305 3435
3175 3415 1895 1495 3395 1220 282 3480 2350 960
      305 1175 2135 3045 830 1305 655 2480 870 1960 1220 2350
2090 2400 740 525 2700 565 1045 2350 1175 525
      870 525 1700 2260 1480 830 1350 1740 1525 1305 655 1695
1435 1870 260 610 2045 960 1655 1740 525 960
      2525 1440 2525 2090 3130 2305 2870 565 3200 1395 1830 1610
1610 2260 2000 2350 2565 2740 3305 785 1395 2525
      2525 1480 1350 525 3305 1830 3130 1045 3350 655 1460 305 1435 830
1740 2220 1305 2525 3435 700 1480 2695
      2960 1970 830 700 3480 1830 3305 1920 3695 1220 1740 785 870 565
2220 2480 740 2740 3695 1700 2045 2785
      2175 2525 960 3045 2260 1565 2350 3565 2260 2740 2090 2870 2595
2395 2785 1740 2175 1525 2175 3395 2480 1655;

!Hub;
C0 = 0, 21400, 21400, 21400, 21400, 21400, 21400, 21400;
C = 0, 100, 100, 100, 100, 100, 100, 100;
!Distance = @OLE('Distance.XLSX');

ENDDATA
end

```

**RELATIVE COST AVOIDANCE MODEL / PROGRAM**

Model:

! Support hub location optimization Problem. Given n hubs and m failed and failing states, the model determines the optimal hub locations and resource allocation in order to maximize the average cost avoidance.

```
*****
!
!
!           Application of Dr. Ahmed Ghanmi's model, CANOSCOM
!           to US operations in Africa. Used with permission.
!           November 2009
!
!
!*****;
```

SETS:

```
State / 1..22/: Weight;
Hub / RG, DS, AG, LG, GB, MK, DD, TT/: Q, X, C0, C;
Hub_State (Hub, State): Distance, Quantity, Y;
```

ENDSETS

! Objective Function;

```
[OBJ] Max = @SUM(State(J): Weight (J)*(1-
(@SUM(Hub (I) | I #NE# 1:X(I) *(C0(I) + C(I) * Q(I)))+
@SUM(Hub(I): 2 * Y(I,J)*R*Distance(I,J)*Quantity(I,J)))/
(2*R*D*Distance(1,J))));
```

! CONSTRAINTS;

! Demand;

```
@FOR (State (J) : @SUM(Hub(I): Y(I,J)*Quantity(I,J))>= D);
```

! Number of Hubs;

```
@SUM(Hub(I) | I #NE# 1: X(I)) = H;
@FOR(Hub(I) | I #NE# 1: X(I) <= Q(I));
```

! Pre-positioning;

```
@FOR (State(J): @SUM(Hub(I) | I #NE# 1:Y(I,J)*Quantity(I,J))
<=A*D);
```

! Hub Assignment;

```
@FOR(Hub_State(I,J) | I #NE# 1: X(I) >= Y(I,J));
```

! Resource Allocation;

```
@FOR(Hub_State(I,J) | I #NE# 1: Q(I) >= Quantity(I,J));
```

! Variable Domains;

```
@FOR( Hub : @BIN(X));
@FOR( Hub_State : @BIN(Y));
@FOR( Hub : @GIN(Q));
@FOR( Hub_State: @GIN(Quantity));
```

!Logical Constraints;

```
@FOR(Hub(I): Q(I) <= 20000*X(I));
@FOR(Hub_State(I,J) : Quantity(I,J) <=20000*Y(I,J));
```

```

! Model Parameters;
  DATA:
    R = 3.67;
    H = 8;
    A = 0.5;
    D = 200;

! State;
!Weight = @OLE('Weight.XLS');
Weight = 0.965335 0.958014 0.936561 0.933366 0.855528 0.740452 0.706767
0.610041 0.556009 0.475801 0.430906 0.335051 0.316896 0.281911 0.265146
0.244925 0.207102 0.182813 0.151348 0.142657 0.128934 0.104302;

! Hub;
Distance = 2710 3245 2480 3435 2660 2230 2745 4220 2615 3350 2700 3610
3225 2890 2750 2570 2555 2425 2530 4030 3250 2270
      1045 2305 3045 3655 545 2000 695 3565 480 3045 2305 3435
3175 3415 1895 1495 3395 1220 282 3480 2350 960
      305 1175 2135 3045 830 1305 655 2480 870 1960 1220 2350
2090 2400 740 525 2700 565 1045 2350 1175 525
      870 525 1700 2260 1480 830 1350 1740 1525 1305 655 1695
1435 1870 260 610 2045 960 1655 1740 525 960
      2525 1440 2525 2090 3130 2305 2870 565 3200 1395 1830 1610
1610 2260 2000 2350 2565 2740 3305 785 1395 2525
      2525 1480 1350 525 3305 1830 3130 1045 3350 655 1460 305 1435 830
1740 2220 1305 2525 3435 700 1480 2695
      2960 1970 830 700 3480 1830 3305 1920 3695 1220 1740 785 870 565
2220 2480 740 2740 3695 1700 2045 2785
      2175 2525 960 3045 2260 1565 2350 3565 2260 2740 2090 2870 2595
2395 2785 1740 2175 1525 2175 3395 2480 1655;

C0 = 0, 21400, 21400, 21400, 21400, 21400, 21400, 21400;
C = 0, 100, 100, 100, 100, 100, 100, 100;
!Distance = @OLE('Distance.XLS');

ENDDATA
end

```

## Failed and Failing States Index

Country	Rank	Total	Demographic Pressures	Refugees and IDPs	Group Grievance	Human Flight	Uneven Economic Development	Economic Decline	Delegitimization of the State	Public Services	Human Rights	Security Apparatus	Factionalized Elites	External Intervention
Somalia	1	114.7	9.9	9.9	9.7	8.5	7.7	9.5	10.6	9.9	9.9	10.0	10.0	9.8
Zimbabwe	2	114.0	9.8	9.1	9.1	10.0	9.7	10.0	9.8	9.8	9.9	9.7	9.5	7.6
Sudan	3	112.4	9.0	9.8	9.9	9.0	9.6	7.0	9.8	9.5	9.8	9.7	9.5	9.8
Chad	4	112.2	9.3	9.4	9.8	7.8	9.3	8.3	9.8	9.6	9.5	9.9	9.8	9.7
Dem. Rep. of the Congo	5	108.7	9.7	9.6	8.9	8.1	9.3	8.3	8.6	9.2	9.0	9.7	8.7	9.6
Iraq	6	108.6	8.7	8.9	9.7	9.1	8.6	7.6	9.0	8.4	9.3	9.7	9.6	10.0
Afghanistan	7	108.2	9.3	8.9	9.6	7.2	8.4	8.3	9.8	8.9	8.8	9.9	9.1	10.0
Central African Republic	8	105.4	8.9	9.0	8.6	5.7	9.1	8.4	9.3	9.3	8.9	9.6	9.5	9.1
Guinea	9	104.6	8.5	7.1	8.2	8.6	8.9	8.7	9.8	9.2	9.0	9.4	9.2	8.0
Pakistan	10	104.1	8.3	8.6	9.6	8.3	8.8	6.4	9.1	7.5	8.9	9.5	9.6	9.5
Ivory Coast	11	102.5	8.6	7.8	9.0	8.4	8.1	8.3	9.1	8.0	8.5	8.5	8.5	9.7
Haiti	12	101.8	9.3	5.8	7.3	8.6	8.2	8.9	9.2	9.5	8.5	8.4	8.3	9.8
Burma	13	101.5	9.0	8.8	8.9	6.0	9.5	8.2	9.5	9.0	9.0	8.4	8.7	6.5
Kenya	14	101.4	9.0	9.0	8.6	8.3	8.8	7.5	9.0	8.0	8.2	8.0	8.8	8.2
Nigeria	15	99.8	8.5	5.3	9.7	8.3	9.5	6.6	9.2	9.0	8.6	9.4	9.6	6.1
Ethiopia	16	98.9	9.4	8.0	8.2	7.7	8.8	8.3	7.9	8.2	8.5	7.5	8.8	7.6
North Korea	17	98.3	8.5	6.0	7.2	5.0	8.8	9.6	9.8	9.6	9.5	8.3	7.8	8.2
Bangladesh	18	98.1	8.9	6.9	9.4	8.4	9.0	8.0	8.5	8.0	7.6	8.0	8.9	6.5
Yemen	19	98.1	8.8	7.9	7.7	7.4	8.9	8.2	8.3	8.5	7.7	8.4	9.0	7.3
East Timor	20	97.2	8.4	9.0	7.3	5.7	6.8	8.4	9.4	8.4	7.0	9.0	8.8	9.0
Uganda	21	96.9	8.7	9.3	8.0	6.5	8.7	7.6	8.0	8.0	7.7	8.2	8.2	8.0
Sri Lanka	22	96.7	7.5	9.3	9.8	6.9	8.5	6.1	9.0	6.6	8.5	9.2	9.2	6.1
Niger	23	96.5	9.5	6.4	8.5	6.3	7.6	9.2	8.7	9.5	8.2	7.4	7.1	8.1
Burundi	24	95.7	9.2	8.1	7.5	6.5	8.4	8.0	7.5	9.0	7.6	7.3	7.7	8.9
Nepal	25	95.4	8.3	6.8	8.7	6.0	9.3	8.5	8.0	7.4	8.7	8.1	8.4	7.2
Cameroon	26	95.3	8.0	7.5	7.2	8.0	8.9	6.9	9.2	8.0	8.0	7.8	8.7	7.1
Guinea-Bissau	27	94.8	8.6	6.5	5.8	7.0	8.5	8.5	8.6	8.7	8.0	8.5	8.0	8.1
Malawi	28	93.8	9.3	6.3	5.9	8.3	8.5	9.1	8.3	8.8	7.5	5.6	7.8	8.4
Lebanon	29	93.5	7.0	9.0	9.2	7.2	7.4	6.3	7.8	6.2	6.9	9.1	9.1	8.3
Republic of Congo	30	93.1	8.9	7.8	6.5	6.1	8.0	8.0	8.6	8.8	7.9	7.8	7.1	7.6
Uzbekistan	31	92.8	7.9	5.3	7.4	7.0	8.7	7.2	9.0	6.6	9.2	9.0	9.0	6.5
Sierra Leone	32	92.1	8.9	6.9	6.6	8.5	8.4	8.6	7.4	8.7	7.0	6.1	7.7	7.3
Georgia	33	91.8	6.4	8.3	8.5	6.0	7.5	6.0	9.0	6.3	7.5	7.9	8.9	9.5
Liberia	34	91.8	8.6	8.0	6.1	6.8	8.5	8.2	7.0	8.5	6.7	6.9	7.9	8.6
Burkina Faso	35	91.3	9.0	6.0	6.1	6.5	9.0	8.2	7.9	9.0	6.5	7.5	7.6	8.0
Eritrea	36	90.3	8.6	7.0	5.8	6.5	6.0	8.6	8.6	8.6	7.9	7.4	7.7	7.6
Tajikistan	37	90.3	8.2	6.4	6.9	6.5	7.3	7.5	8.9	7.6	8.6	7.5	8.4	6.5
Iran	38	90.0	6.5	8.5	7.6	6.8	7.4	5.5	8.3	6.0	8.9	8.6	9.1	6.8
Syria	39	89.8	6.1	9.2	8.2	6.8	8.0	6.8	8.8	5.7	8.6	7.8	7.8	6.0
Solomon Islands	40	89.6	8.0	5.0	7.5	5.0	8.0	8.3	8.3	8.4	7.0	7.2	8.0	8.9
Colombia	41	89.2	6.9	9.2	7.2	8.5	8.5	4.3	7.9	6.0	7.2	7.5	8.0	8.0
Kirgizstan	42	89.1	8.0	5.3	7.2	7.5	8.3	7.6	8.3	6.5	7.6	7.7	7.3	7.8
Egypt	43	89.0	7.6	6.9	8.0	6.2	7.6	7.0	8.6	6.4	8.4	6.2	8.1	8.0
Laos	44	89.0	8.2	5.9	7.0	6.6	6.0	7.5	8.2	8.0	8.5	7.6	8.3	7.2
Rwanda	45	89.0	9.3	6.9	8.7	7.2	7.3	7.5	7.9	7.3	7.3	4.6	8.0	7.0
Mauritania	46	88.7	8.7	6.2	8.2	5.0	7.0	7.8	7.0	8.5	7.1	7.9	8.0	7.3
Equatorial Guinea	47	88.3	8.3	2.0	6.8	7.4	9.0	4.4	9.4	8.6	9.2	8.6	8.6	6.0
Bhutan	48	87.3	6.5	7.5	7.9	6.8	8.7	7.5	7.4	7.2	8.4	5.5	7.7	6.2
Cambodia	49	87.3	7.9	5.2	7.0	8.0	7.2	7.5	8.5	7.9	7.4	6.5	7.5	6.7
Togo	50	87.2	7.9	6.0	5.8	6.9	7.5	8.2	7.5	8.3	7.6	7.4	7.3	6.8
Bolivia	51	86.3	7.8	4.9	7.5	6.9	8.7	7.0	7.6	7.7	6.8	6.4	8.2	6.8
Comoros	52	86.3	7.4	3.7	5.5	6.0	6.3	7.8	8.7	8.7	7.0	7.5	7.9	9.8
Philippines	53	85.8	7.2	6.3	7.5	7.2	7.6	6.0	8.5	6.1	7.0	7.7	7.9	6.8
Moldova	54	85.1	6.6	4.2	7.1	8.0	7.0	6.8	8.1	6.7	7.0	8.0	8.0	7.6
Angola	55	85.0	8.6	7.0	6.1	5.5	9.4	4.5	8.0	8.0	7.2	6.2	7.3	7.2
Azerbaijan	56	84.6	6.4	8.2	7.9	5.7	7.4	6.1	8.2	5.5	7.0	7.3	7.9	7.0
China	57	84.6	9.0	6.8	7.9	6.1	9.2	4.5	8.5	7.2	8.9	6.0	7.2	3.3
Israel/West Bank	58	84.6	7.2	8.0	9.3	4.0	7.5	4.1	7.5	7.0	8.0	6.0	8.0	8.0
Turkmenistan	59	84.3	7.0	4.8	6.5	5.6	7.6	6.9	8.5	7.2	8.9	7.6	7.7	6.0
Zambia	60	84.2	9.0	7.1	5.3	7.0	7.1	8.5	7.8	8.4	5.6	5.2	5.7	7.5
Indonesia	61	84.1	7.3	6.7	6.3	7.2	8.1	6.9	6.7	6.7	6.7	7.3	7.3	6.9
Papua New Guinea	62	84.1	7.5	4.0	7.3	7.6	8.9	6.8	7.7	8.1	6.5	6.7	7.1	5.9
Bosnia	63	83.3	5.5	7.2	8.2	5.8	7.3	5.5	8.2	5.6	5.4	7.4	8.7	8.5
Nicaragua	64	82.6	7.4	5.2	6.3	6.9	8.1	7.7	7.1	7.8	5.8	6.5	7.2	6.6
Swaziland	65	82.4	9.2	4.0	4.0	6.0	6.0	8.0	8.8	7.8	7.5	6.8	6.9	7.4
Belarus	66	82.3	7.2	4.1	6.9	5.0	7.2	6.6	8.9	6.6	8.0	6.6	8.1	7.1
Lesotho	67	81.8	9.4	4.7	5.2	6.5	5.6	8.4	7.4	8.7	6.5	5.5	6.9	7.0
Madagascar	68	81.6	8.9	5.0	5.6	5.0	7.6	7.4	6.6	8.8	5.9	5.9	7.1	7.8
Ecuador	69	81.2	6.5	6.3	6.3	7.3	8.0	6.4	7.0	6.8	6.0	6.8	7.8	6.0
Tanzania	70	81.1	8.0	7.1	6.6	6.0	6.9	7.5	6.7	8.0	5.8	5.4	6.3	6.8
Russia	71	80.8	7.0	5.9	7.5	6.2	8.1	4.6	8.0	5.7	8.3	6.9	8.0	4.6
Mozambique	72	80.7	8.7	3.2	4.8	7.6	7.4	8.0	7.3	8.9	7.2	6.0	5.6	6.0
Algeria	73	80.6	6.7	6.7	7.7	6.2	7.3	4.6	7.7	6.7	7.6	7.0	6.7	5.7
Cuba	74	80.6	6.9	5.9	5.5	7.2	6.8	6.3	7.5	5.0	7.4	7.5	7.1	7.5
Djibouti	75	80.6	8.0	6.4	5.7	5.2	6.3	6.6	7.4	7.5	6.2	6.2	6.9	8.2
Guatemala	76	80.6	7.0	5.8	6.7	6.7	8.2	6.6	7.1	6.6	7.0	7.1	6.3	5.5
Venezuela	77	79.5	6.8	5.0	7.0	6.9	8.0	5.3	7.2	5.9	7.3	6.9	7.7	5.5
Serbia	78	79.2	5.8	7.3	7.9	5.5	7.4	5.9	7.3	5.2	5.8	6.3	7.9	6.9
Thailand	79	79.2	6.9	6.5	8.0	4.5	7.7	3.8	8.2	5.4	6.9	7.5	8.0	5.8
Gambia	80	79.0	7.2	5.7	4.4	6.4	7.0	7.4	7.8	7.1	6.9	6.0	6.2	6.9
Fiji	81	78.8	6.1	4.3	7.3	6.5	7.7	6.3	8.6	5.0	6.1	6.7	8.2	6.0
Maldives	82	78.8	6.5	6.5	5.2	7.0	5.2	6.7	7.2	7.3	7.5	6.3	7.4	6.0
Mali	83	78.7	8.7	4.6	6.5	7.4	6.9	8.3	5.3	8.4	5.2	6.5	4.0	6.9
Cape Verde	84	78.5	7.9	4.0	4.4	8.2	6.2	7.2	7.4	7.6	6.2	5.7	6.1	7.6
Turkey	85	78.2	6.8	6.6	7.7	5.0	8.0	5.3	6.5	5.3	6.0	7.0	7.8	6.2
Jordan	86	77.9	6.7	7.9	6.8	5.0	7.4	6.5	6.0	5.4	6.9	6.0	6.5	6.8
India	87	77.8	8.3	4.9	7.3	6.7	8.9	5.0	5.5	7.0	6.0	7.1	6.0	5.1
Dominican Republic	88	77.7	6.7	5.3	6.0	8.5	8.0	5.6	5.8	6.7	6.7	5.8	6.8	5.8
Saudi Arabia	89	77.5	6.5	6.0	8.0	3.4	7.0	2.7	8.4	4.3	8.9	8.0	7.8	6.5
El Salvador	90	77.2	7.6	5.7	6.2	6.9	7.8	6.3	7.0	6.6	6.9	6.4	4.5	5.3
Honduras	91	77.2	7.8	4.0	5.0	6.3	8.5	7.2	7.0	7.1	6.3	6.0	6.1	5.9
Morocco	92	77.1	7.0	6.7	6.8	6.2	7.8	6.5	7.4	6.5	6.7	5.1	6.2	4.2
Peru	93	77.1	6.6	4.5	6.4	7.3	8.2	5.6	6.9	6.3	5.5	7.2	6.9	5.7

Vietnam	94	76.9	6.8	5.3	5.5	6.0	6.5	6.7	7.3	6.3	7.2	6.2	7.1	6.0
Sao Tome	95	76.7	8.0	4.0	5.0	7.3	6.1	7.9	7.3	7.5	5.3	5.6	6.3	6.4
Namibia	96	75.6	7.7	5.5	5.8	7.7	9.1	6.1	5.0	7.1	6.0	5.8	3.6	6.2
Benin	97	75.5	7.5	6.2	4.1	7.0	7.4	6.9	6.6	8.0	5.6	5.2	4.3	6.7
Mexico	98	75.4	7.0	4.3	5.9	7.0	8.2	6.1	6.8	6.0	5.5	7.0	5.0	6.6
Gabon	99	74.4	7.2	5.7	3.0	6.0	7.8	5.5	7.3	6.8	6.3	5.9	7.2	5.7
Macedonia	100	74.4	5.0	4.6	7.5	6.9	7.3	6.3	7.4	4.8	5.3	5.8	6.7	6.8
Armenia	101	74.3	5.9	7.2	6.0	6.7	6.5	5.3	7.1	5.4	6.1	5.3	6.9	5.9
Senegal	102	74.2	7.4	6.0	6.3	5.6	7.5	6.5	6.0	7.3	6.0	5.9	4.0	5.7
Suriname	103	73.2	6.2	3.9	6.2	6.9	7.9	6.3	6.7	5.0	6.0	6.2	5.8	6.1
Guyana	104	73.0	6.3	3.5	6.1	7.9	7.9	6.6	6.7	5.5	5.4	6.8	5.1	5.2
Kazakhstan	105	72.5	6.0	3.9	5.5	4.0	6.4	6.4	7.7	5.3	6.8	6.5	7.6	6.4
Paraguay	106	72.0	6.4	1.3	6.5	6.0	7.9	5.9	7.9	6.0	6.9	5.3	7.5	4.4
Micronesia	107	71.9	7.2	3.1	4.5	8.3	7.0	6.6	6.6	6.8	3.0	5.3	5.5	8.0
Samoa	108	71.4	6.5	3.0	5.2	8.2	6.8	5.8	6.6	5.0	4.7	6.0	5.5	8.1
Albania	109	70.0	6.4	2.6	5.4	7.2	5.9	6.5	7.3	5.8	5.8	5.5	5.9	5.7
Ukraine	110	69.7	6.1	3.0	6.9	7.1	6.4	5.5	7.2	4.2	5.5	3.3	7.9	6.6
Belize	111	69.5	7.0	5.0	4.9	6.9	7.3	6.0	6.2	5.7	4.0	5.9	4.6	6.0
Libya	112	69.4	5.9	4.2	5.8	4.0	7.1	5.5	7.1	4.2	8.1	5.4	7.1	5.0
Brazil	113	69.1	6.4	3.9	6.4	5.0	8.9	4.1	6.4	6.0	5.6	6.9	5.1	4.4
Cyprus	114	68.9	5.0	4.5	7.5	5.2	7.8	4.0	5.4	3.6	3.8	5.2	7.9	9.0
Malaysia	115	68.9	6.5	5.2	6.2	3.8	6.9	4.7	6.1	5.2	6.5	6.1	6.1	5.6
Botswana	116	68.8	9.2	6.7	4.3	6.0	7.2	5.6	5.8	6.4	5.0	4.0	2.8	5.8
Jamaica	117	68.6	6.4	2.7	4.5	6.3	6.7	6.6	7.0	6.4	5.7	6.0	4.0	6.3
Brunei Darussalam	118	68.1	5.4	4.4	6.6	4.0	7.8	3.4	7.9	3.6	6.8	6.1	7.4	4.7
Grenada	119	67.9	5.9	2.9	4.5	7.8	6.9	5.9	6.3	4.1	4.7	5.5	5.8	7.6
Seychelles	120	67.7	6.3	4.4	5.0	4.7	6.8	4.8	7.1	4.6	5.9	5.6	6.0	6.5
Tunisia	121	67.6	5.9	3.2	5.4	5.3	7.2	4.9	6.6	6.1	7.4	6.2	6.0	3.4
South Africa	122	67.4	8.4	7.4	5.3	4.3	8.5	4.6	5.5	5.7	4.5	4.3	5.9	3.0
Trinidad	123	66.7	5.8	3.1	4.9	7.1	7.6	4.5	6.1	5.4	5.6	5.7	5.6	5.3
Ghana	124	66.2	7.0	5.1	5.4	8.1	6.6	5.5	5.3	7.2	4.7	2.4	4.2	4.7
Kuwait	125	63.4	5.7	4.2	5.1	4.3	6.1	3.5	6.5	3.5	6.9	5.1	7.2	5.3
Antigua and Barbuda	126	62.8	4.7	3.6	4.3	7.8	6.5	4.8	5.8	5.0	5.0	5.0	4.4	5.9
Mongolia	127	61.9	5.8	1.2	4.3	2.3	5.8	5.9	6.7	5.5	6.6	5.0	5.7	7.1
Bulgaria	128	61.5	4.7	3.8	4.4	6.0	6.3	5.0	6.0	5.0	4.8	5.3	4.6	5.6
Romania	129	61.3	5.6	3.4	5.5	5.1	5.8	5.3	6.2	5.0	4.5	4.3	5.1	5.5
Bahamas	130	60.9	6.7	3.7	5.0	5.7	6.9	4.4	5.5	4.6	3.0	5.3	4.8	5.3
Croatia	131	60.1	4.9	6.1	5.4	4.8	5.5	5.9	4.5	3.9	4.7	4.3	4.3	5.8
Panama	132	59.7	6.6	3.4	4.6	5.0	7.3	5.6	4.7	5.5	4.7	5.1	3.0	4.2
Bahrain	133	59.0	5.0	3.1	6.4	3.7	5.9	3.5	6.9	3.1	5.0	4.4	6.1	5.9
Montenegro	134	58.0	5.1	4.1	6.4	2.5	4.6	4.6	4.7	4.0	5.5	4.7	6.0	5.8
Barbados	135	57.2	4.1	3.3	5.3	7.0	7.1	5.2	4.5	2.8	3.0	5.0	4.5	5.4
Latvia	136	54.6	4.5	4.5	4.5	5.0	6.2	5.5	5.1	4.4	3.7	2.9	4.3	4.0
Costa Rica	137	52.5	5.7	4.5	4.1	4.7	6.7	5.0	4.1	4.0	3.5	2.2	3.2	4.8
Qatar	138	51.9	4.7	3.2	5.2	3.3	5.3	4.4	6.5	2.6	4.5	2.5	5.0	4.7
United Arab Emirates	139	51.8	4.6	3.4	4.7	3.3	5.7	3.2	6.7	3.6	5.8	2.3	4.0	4.5
Estonia	140	51.2	4.7	4.4	4.9	4.0	5.4	4.4	4.7	3.5	3.5	2.5	5.5	3.7
Hungary	141	50.7	3.5	3.0	3.4	5.0	6.1	5.0	5.5	3.8	3.5	2.1	5.0	4.8
Poland	142	49.6	4.9	3.0	3.2	6.1	4.9	4.8	4.4	3.9	4.0	2.3	3.7	4.4
Malta	143	48.8	3.9	6.0	4.0	4.3	4.6	3.9	4.3	3.5	3.6	4.0	1.7	5.0
Slovakia	144	48.6	4.3	2.0	4.3	5.4	5.8	4.6	3.9	4.0	4.0	2.0	3.9	4.4
Lithuania	145	48.0	4.5	2.8	4.2	5.2	6.2	4.7	4.1	3.4	3.5	2.1	3.0	4.3
Oman	146	47.2	4.5	1.0	3.0	1.3	2.3	4.4	6.0	4.5	6.4	5.0	6.6	2.2
Greece	147	46.1	4.5	2.7	4.4	4.7	4.8	4.0	4.5	3.9	3.6	3.5	2.0	3.5
Argentina	148	44.7	4.1	2.0	4.5	4.0	5.5	4.8	3.4	4.2	4.0	2.1	3.1	3.0
Mauritius	149	44.7	3.9	1.0	3.5	2.4	5.9	4.3	5.3	4.4	3.9	3.6	3.3	3.2
Italy	150	43.9	3.8	3.7	4.5	3.0	4.7	4.4	4.3	2.8	2.6	4.0	3.7	2.4
Spain	151	43.3	3.9	2.6	6.2	1.7	5.2	4.0	1.3	2.6	2.7	5.2	5.7	2.2
Czech Republic	152	42.6	3.5	2.7	3.6	4.5	4.3	4.1	3.6	3.8	3.5	2.0	3.3	3.7
South Korea	153	41.6	4.0	3.5	4.1	5.0	2.4	2.1	4.1	2.2	2.7	1.4	3.6	6.5
Uruguay	154	41.2	4.7	1.0	2.0	5.8	5.2	4.1	2.8	3.6	2.5	3.3	2.5	3.7
Chile	155	37.5	4.0	2.5	3.6	2.1	4.4	4.3	2.0	4.2	3.6	2.0	1.5	3.3
Slovenia	156	36.3	3.6	1.3	3.4	3.5	5.2	3.6	3.0	3.2	3.2	2.7	1.3	2.3
Germany	157	36.2	3.5	3.9	4.9	2.8	4.9	3.2	2.3	1.9	2.5	2.1	1.8	2.4
France	158	35.3	3.9	3.0	5.8	2.0	5.5	3.3	1.8	1.5	2.9	1.2	2.0	2.4
United States	159	34.0	3.1	3.7	3.3	1.0	5.3	2.9	3.0	2.3	4.0	1.4	2.5	1.5
Singapore	160	33.8	3.0	1.1	3.1	2.7	3.0	3.2	4.0	1.5	4.3	1.0	4.1	2.8
United Kingdom	161	33.6	3.2	2.8	4.3	1.9	4.7	2.5	1.8	2.2	2.3	2.6	2.9	2.4
Belgium	162	33.5	2.8	1.7	4.9	1.3	4.9	3.2	2.8	2.0	1.7	1.7	3.5	3.0
Portugal	163	32.7	3.9	1.4	2.6	2.3	3.9	4.2	1.6	3.8	3.7	1.1	1.2	3.0
Japan	164	31.2	4.2	1.1	3.8	2.0	2.5	3.1	2.0	1.2	3.4	2.0	2.0	3.9
Iceland	165	29.0	1.0	0.9	1.0	3.2	2.5	6.7	2.2	1.4	2.1	1.0	2.0	5.0
Canada	166	27.7	3.3	2.4	3.0	2.1	4.7	2.0	1.7	1.2	2.1	1.1	2.4	1.7
Austria	167	27.6	2.9	2.2	3.6	1.1	4.9	2.3	1.6	1.4	1.6	1.0	2.4	2.6
Luxembourg	168	27.6	2.1	1.5	3.2	1.2	2.5	2.2	2.9	2.4	1.5	2.0	3.6	2.5
Netherlands	169	27.0	2.9	3.1	4.7	2.1	3.3	2.5	1.4	1.4	1.2	1.0	1.4	2.0
Australia	170	25.9	3.1	2.2	3.4	1.1	4.4	2.8	1.4	1.4	2.5	1.0	1.5	1.1
New Zealand	171	23.3	1.3	1.2	3.2	2.3	4.2	3.6	1.1	1.4	1.7	1.0	1.2	1.1
Denmark	172	23.2	3.0	1.6	3.0	2.0	2.2	2.7	1.3	1.5	1.5	1.3	1.0	2.1
Ireland	173	21.6	1.9	1.5	1.0	2.0	3.0	2.7	1.8	2.3	1.5	1.1	1.3	1.5
Switzerland	174	21.2	2.6	1.3	2.9	2.0	2.6	2.1	1.2	1.6	1.7	1.0	1.0	1.2
Sweden	175	20.6	2.8	2.6	1.3	2.0	2.3	1.6	1.0	1.2	1.6	1.1	1.3	1.8
Finland	176	19.2	2.5	1.6	1.2	2.1	1.9	2.4	0.9	1.1	1.7	0.9	0.9	2.0
Norway	177	18.3	1.9	1.6	1.3	1.1	2.2	2.3	1.0	1.3	1.5	1.1	1.1	1.9

Notes: Red: Alert  
Orange: Warning  
Yellow: Moderate  
Green: Stable

## Weighted Average Calculations

				Normalized Data
		100.3	average score	
		7.938372	std dev	
			Z test scores	Weighted Scores
<b>Somalia</b>	<b>1</b>	<b>114.7</b>	1.816264	0.965335
<b>Zimbabwe</b>	<b>2</b>	<b>114.0</b>	1.728085	0.958014
<b>Sudan</b>	<b>3</b>	<b>112.4</b>	1.526532	0.936561
<b>Chad</b>	<b>4</b>	<b>112.2</b>	1.501338	0.933366
<b>Dem. Rep. of the Congo</b>	<b>5</b>	<b>108.7</b>	1.060442	0.855528
<b>Central African Republic</b>	<b>8</b>	<b>105.4</b>	0.644739	0.740452
<b>Guinea</b>	<b>9</b>	<b>104.6</b>	0.543963	0.706767
<b>Ivory Coast</b>	<b>11</b>	<b>102.5</b>	0.279425	0.610041
<b>Kenya</b>	<b>14</b>	<b>101.4</b>	0.140858	0.556009
<b>Nigeria</b>	<b>15</b>	<b>99.8</b>	-0.06069	0.475801
<b>Ethiopia</b>	<b>16</b>	<b>98.9</b>	-0.17407	0.430906
<b>Uganda</b>	<b>21</b>	<b>96.9</b>	-0.42601	0.335051
<b>Niger</b>	<b>23</b>	<b>96.5</b>	-0.4764	0.316896
<b>Burundi</b>	<b>24</b>	<b>95.7</b>	-0.57717	0.281911
<b>Cameroon</b>	<b>26</b>	<b>95.3</b>	-0.62756	0.265146
<b>Guinea-Bissau</b>	<b>27</b>	<b>94.8</b>	-0.69055	0.244925
<b>Malawi</b>	<b>28</b>	<b>93.8</b>	-0.81652	0.207102
<b>Republic of Congo</b>	<b>30</b>	<b>93.1</b>	-0.9047	0.182813
<b>Sierra Leone</b>	<b>32</b>	<b>92.1</b>	-1.03067	0.151348
<b>Liberia</b>	<b>34</b>	<b>91.8</b>	-1.06846	0.142657
<b>Burkina Faso</b>	<b>35</b>	<b>91.3</b>	-1.13144	0.128934
<b>Eritrea</b>	<b>36</b>	<b>90.3</b>	-1.25741	0.104302

Distance Matrix, all distances in NM

	<u>FAILED / FAILING (Distances in NM)</u>																					
<u>HUB LOCATION</u>	Ivory Coast	Rep of Congo	Sudan	Somalia	Sierra Leone	Chad	Liberia	Zimbabwe	Guinea	Burundi	Cent Af Rep	Kenya	Uganda	Ethiopia	Cameroon	Nigeria	Eritrea	Niger	Guinea-Bissau	Malawi	Dem Rep of Congo	Burkina-Faso
Ramstein, Germany	2710	3245	2480	3435	2660	2230	2745	4220	2615	3350	2700	3610	3225	2890	2750	2570	2555	2425	2530	4030	3250	2270
Dakar, Senegal	1045	2305	3045	3655	545	2000	695	3565	480	3045	2305	3435	3175	3415	1895	1495	3395	1220	282	2350	3480	960
Accra, Ghana	305	1175	2135	3045	830	1305	655	2480	870	1960	1220	2350	2090	2400	740	525	2700	565	1045	2350	1175	525
Libreville, Gabon	870	525	1700	2260	1480	830	1350	1740	1525	1305	655	1695	1435	1870	260	610	2045	960	1655	1740	525	960
Gaborone, Botswana	2525	1440	2525	2090	3130	2305	2870	565	3200	1395	1830	1610	1610	2260	2000	2350	2565	2740	3305	785	1395	2525
Mombasa, Kenya	2525	1480	1350	525	3305	1830	3130	1045	3350	655	1460	305	1435	830	1740	2220	1305	2525	3435	700	1480	2695
Djibouti, Djibouti	2960	1970	830	700	3480	1830	3305	1920	3695	1220	1740	785	870	565	2220	2480	740	2740	3695	1700	2045	2785
Tunis, Tunisia	2175	2525	960	3045	2260	1565	2350	3565	2260	2740	2090	2870	2595	2395	2785	1740	2175	1525	2175	3395	2480	1655

## **Appendix B. LINGO Output: Cost Avoidance**

Due to the length of the output files, they have been placed on the Air Force portal under the COP pages. They can be found under “Donaghy GRP Data Results” and the following link:

<https://www.my.af.mil/afknprod/community/views/home.aspx?Filter=23328>

### **Appendix C. LINGO Output: Relative Cost Avoidance**

Due to the length of the output files, they have been placed on the Air Force portal under the COP pages. They can be found under “Donaghy GRP Data Results” and the following link:

<https://www.my.af.mil/afknprod/community/views/home.aspx?Filter=23328>

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<b>14. ABSTRACT</b> Due to the increasing threat of terrorism, particularly from the Sahara region of Africa, as well as a result of the growing strategic importance of Africa to the United States, the United States established Africa Command (AFRICOM). The mission of the Department of Defense's newest combatant command is to aid African development and promote regional security. However, this may not be an easy task, especially due to the lack of an effective and efficient transportation network on the continent. In order for AFRICOM to succeed, it will need to be able to effectively and efficiently transport personnel and goods across the continent. The lack of transportation infrastructure may make this a daunting and expensive task. But, there exists a solution to the problem. The Canadian Operational Support Command (CANOSCOM) developed a mixed integer non-linear programming model based on the <i>Foreign Policy</i> Index of Failed and Failing States that minimizes cost and resources to support their global operations. By applying this model to Africa, AFRICOM planners can determine the optimal number and location of hubs to support operations on the continent. The Failed and Failing states index provides a realistic baseline for where AFRICOM may be involved in future operations. The models' capabilities and limitations are explored, and recommendations are made to assist AFRICOM in the use of the program to aid AFRICOM planners.				
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