Structuring Strategic Decisions Through the Analytic Hierarchy Process: A Case Study in the Selection of Warehouse Location for WFP in Ethiopia

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Abstract

Humanitarian logistic organizations struggle to make strategic and tactical decisions due to their lack of resources, the unpredictability of humanitarian events and the lack of readily available information; the existing tools that assist optimal decision making require large amounts of precise information. As a consequence of all these challenges, most of the work in humanitarian logistics concentrates on the operational level that can only offer short term benefits. Alternatively, optimal strategic decisions maximize the resources of humanitarian organizations making them more flexible and effective in the long term; this directly impacts the ability to help the millions of people in need.

This thesis presents a model that assists the largest humanitarian organization in the world, The World Food Programme, to make optimal strategic decisions. The model uses the Analytic Hierarchy Process, a multiple attribute decision tool that provides structure to decisions where there is limited availability of quantitative information. This methodology uses a framework that determines and prioritizes multiple criteria by using qualitative data and it scores each alternative based on these criteria. The optimal alternative will be the one that has the highest weighted score.

This model solves the challenges that The World Food Programme, as any other humanitarian organization face when making complex strategic decisions. The model, not only works with easily acquired information but, it is also flexible in order to consider the ever-changing dynamics in the humanitarian field. The application of this model focuses on the optimization of warehouse locations for the World Food Programme in the Somali region of Ethiopia. However, this model can easily be scaled in order to be used in any other decision making process in the humanitarian field.

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1 World Food Programme Operations in the Somali Region

This thesis was performed in collaboration with the humanitarian aid organization the World Food Programme in the Somali region of Ethiopia. The following subsections give an overview on humanitarian supply chain, the World Food Programme, Ethiopia and the Somali region in Ethiopia.

1.1 Humanitarian Supply Chain

In a traditional supply chain, as products flow downwards through the chain from the supplier to the company and to the customer, there is an opposing flow upstream of money for the goods along with information of the product such as demand patterns and customer requirements. This facilitates the process of coordination among the players in the supply chain. The following figure illustrates the flow of a corporate supply chain:

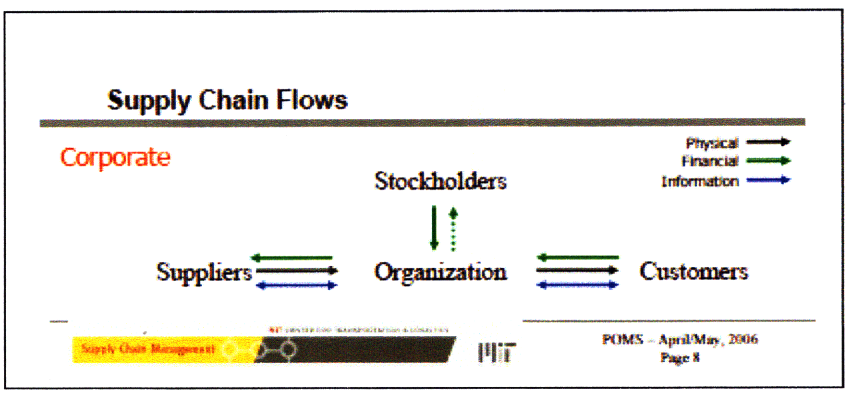

Figure 1 - Traditional Supply Chain Flow. Source - MIT Center of Transportation and Logistics, Humanitarian Supply Chains: A Review

However, in the case of providing humanitarian relief, since the beneficiaries do not pay for the goods and services that are being provided, very little information is being passed back upstream from the beneficiary to the organization. As a result, making optimal supply chain decisions in this setting requires assumptions and intuition as guiding forces. The following figure illustrates the flow of a humanitarian supply chain:

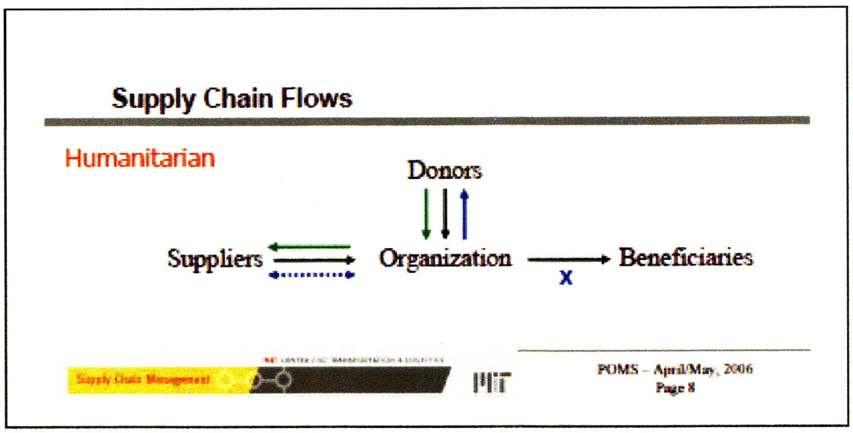

Figure 2 - Humanitarian Supply Chain Flow. Source - MIT Center of Transportation and Logistics, Humanitarian Supply Chains: A Review

Another challenge that humanitarian supply chains face is the unpredictability of events that they will need to assist in. This puts a greater emphasis on designing responsive humanitarian supply chains that are not only efficient but also flexible depending on the specific needs of the beneficiaries. Along with these challenges, there are also frequently not enough resources to fulfill the needs of the beneficiaries, creating a need for the best utilization of the limited existing resources.

1.2 The World Food Programme

The World Food Programme (WFP), the largest humanitarian food aid provider, is currently the head of the logistics cluster for the United Nations. WFP provides food to developing nations during emergencies, and after an emergency, it works towards strengthening the communities in order to mitigate hunger. This organization currently serves 78 nations and provides food for over 102 million people in need (WFP Our Work 2009). WFP has regional offices in every country that it serves and is headquartered in Rome, Italy.

WFP partners with for-profit organizations as well as academic institutions in order to become more efficient in their humanitarian response. As an example TNT, a logistics European provider, has partnered with WFP in order to assist in the optimization of WFP's limited resources, providing warehouse configuration and logistics expertise. Academic institutions also offer strategic advice in order to drive WFP towards the most advantageous utilization of resources that improve the overall effectiveness of the organization.

Currently the WFP is working with Ortec, a supply chain software company, to optimize portions of their transportation network within the Somali region of Ethiopia such as warehouse location and vehicle routing; the process of gathering the data needed to complete this optimization has not been completed at the time this document is written. Also, there is no guarantee that all the information needed for this study can be gathered. Ortec is performing this without charge, but should the WFP wish to optimize other areas within Ethiopia or throughout the world there will be a significant effort to collect the data needed and a time wait associated with it.

The World Food Programme's effort in Ethiopia is currently their second largest initiative next to Sudan with assistance being provided to over five million people within the nation. WFP buys food locally when economically and socially responsible in order to distribute it to places where there is shortage of food to strengthen the economy of the local areas, but also brings in food from other countries when demand exceeds the local capacity. According to WFP officials, the average of local food purchase was 36% for the year 2008.

1.3 Ethiopia

The Federal Democratic Republic of Ethiopia, as it is officially known, is the second largest country in Africa with an estimate population of 85 million people (CIA, The World Fact Book 2009). Ethiopia, whose capital is Addis Ababa, is a landlocked nation located in the East part of Africa bordering Djibouti, Somalia, Kenya, Sudan and Eritrea as can be seen in Figures 3 and 4.

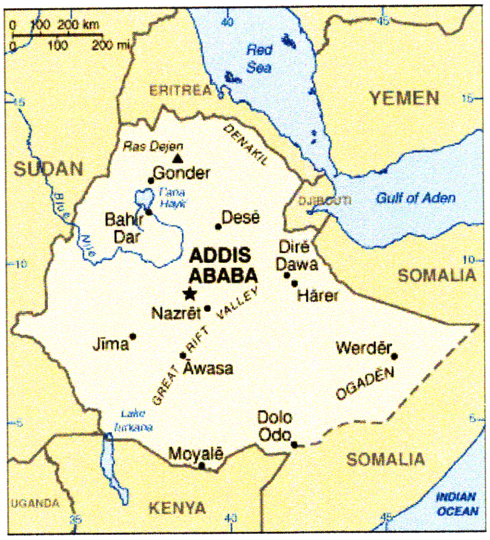

Figure 3 - Ethiopia: Source – CIA, the World Fact Book

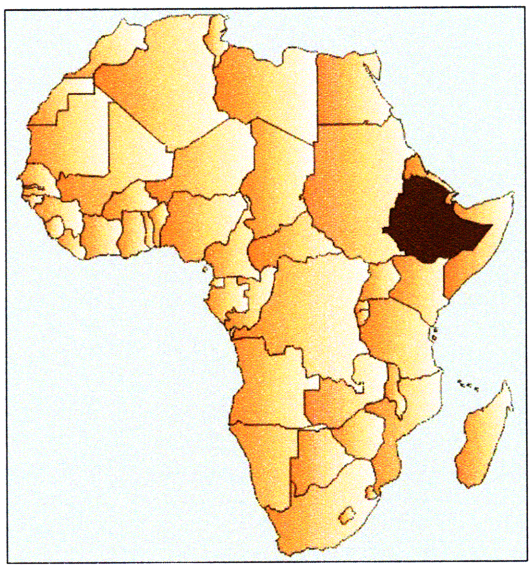

Figure 4 Location of Ethiopia in Africa: Source – NICI in Africa

The most common languages in Ethiopia are Amharic, Oromo, Tigrinya and Somali. Approximately two thirds of the population is considerate illiterate. Ethiopia, Africa's oldest independent country and one of the oldest countries in the world, is unique in the sense that it was never colonized except for a short period from 1931 through 1936 where the country went through Italian occupation from the Mussolini regime (CIA, The World Fact Book 2009).

Ethiopia is one of the least developed countries in the world; it ranks number 170 out of 177 countries available in the list of the 2008 Human Development Report. The economy of the country is primarily based on the agricultural sector as it accounts for almost half of the GDP; which puts heavy dependence on the seasonal rainfalls. Ethiopia has showed a continuous growth in the economy in the past two decades. However, recent policy implementations, a recent war with its neighboring country Eritrea and constant droughts have put the country in a state of famine.

Ethiopia is divided into nine ethnical regions and two self-governing administrative cities. It is further sub-divided into approximately 550 regular woredas, and 6 autonomous woredas. Woredas are the equivalent of a district and have their own local government. The ethnically-based regions in Ethiopia are Afar, Amhara, Benishangul-Gumuz, Gambela, Oromiya, Somali, Southern Nations, Nationalities and People's Region, and Tigray. And the self-governing administrative cities are Addis Ababa and Dire Dawa. The following map illustrates the regional divisions in Ethiopia.

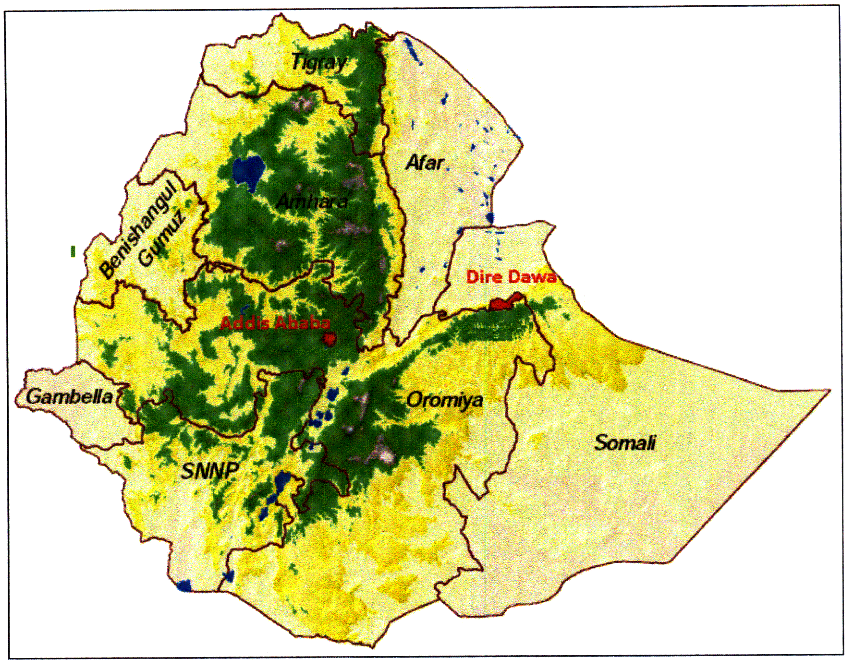

Figure 5 - Ethiopian Divisions – UN OCHA Ethiopia

Ethiopia has 67 airports out of which 16 are paved. As the country does not have a coast line, it mainly uses the ports of Djibouti, Djibouti and Berbera, Somalia. The roadways are mainly unpaved; out of the total 36,469 kilometers of roadways, 6,980 km are paved. The telephone system is scarce; only two percent of the population has either a mobile phone or a fixed line (CIA, The World Fact Book 2009).

Ethiopia is for the most part an extremely fertile nation; however recent droughts, combined with regional civil unrest, have created significant food shortages and malnutrition. Ethiopia has two major harvests, the Belg and the Meher, with different regions being supported by each harvest. In 2006 the Belg and Gu rains which support the Belg harvest never came, resulting in a severe food shortage for Ethiopians relying upon it. Figure 6 illustrates the Ethiopian Harvest Schedule.

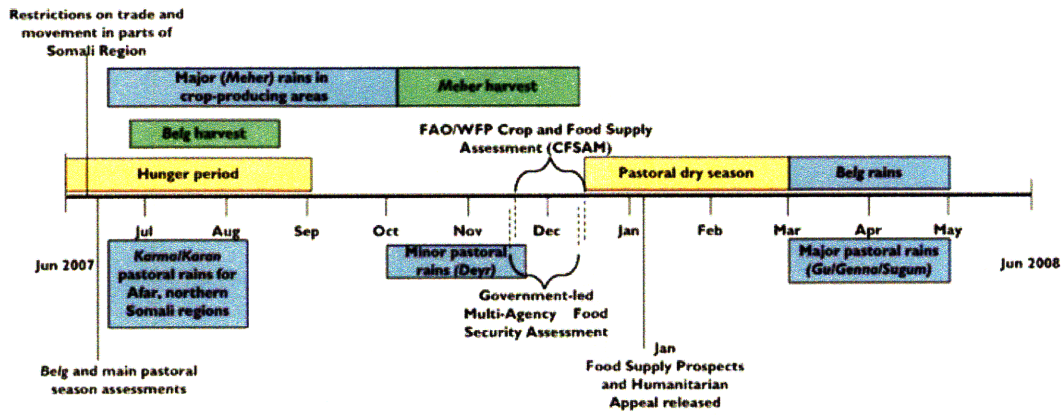

Figure 6 - Ethiopian Harvest Schedule: Source – Famine Early Warning System (FEWS)

The droughts have continued through multiple seasons, and combined with a lack of infrastructure and conflict occurring in some of the pastoral areas the food security crisis is at a high. (FEWS)

1.4 Somali Region

The Somali region in Ethiopia is one of the nine ethnically-based regions in Ethiopia. Its capital is the city of Jijiga and some of the largest cities in the region are Dire Dawa, Nazareth, Jijiga, Gode, Degehabur, Kebri Dahar, Shilavo, Geladin, Kelafo, Werder and Shinile. The Somali region borders with the Ethiopian regions of Oromia, Afar and the charter city (self-governing) of Dire Dawa. It also borders with the countries Kenya, Djibouti and Somalia.

The total population of the Somali region is 4,439,147 according to the 2007 Ethiopian census. The following table has the population for some of the cities in the Somali region according to the Central Statistical Agency census of 2005:

City in Somali Region	Population
Dire Dawa	342,827
Nazareth	228,623
Jijiga	98,076
Gode	68,342
Degehabur	42,815
Kebri Dahar	36,191
Warder	18,357
Kelafo	14,242
Shinile	13,132
Fik	12,911
Geladin	10,795
Shilavo	7,239
Mustahil	5,442

Table 1- Population for selected cities: Source – Central Statistical Agency 2005

The majority of the population in this region is of Somali origin; this has caused a strong internal desire to make this region independent from Ethiopian rule. Since 1992, after the introduction of a federal democratic system in the region, multiple presidents have been removed. All of the governments in the Somali region since this period, which have been from the Ethiopian People's Revolutionary Democratic Front, needed the military presence in order to secure the stability of the region. The ruling of the Ethiopian People's Revolutionary Democratic Front has suffered the opposition of the Ogaden National Liberation front (ONLF). The ONLF advocates for the autonomy of the Somali region justifying it on its cultural independence (Humanitarian News and Analysis 2009).

The following figure illustrates the different zones in the Somali region.

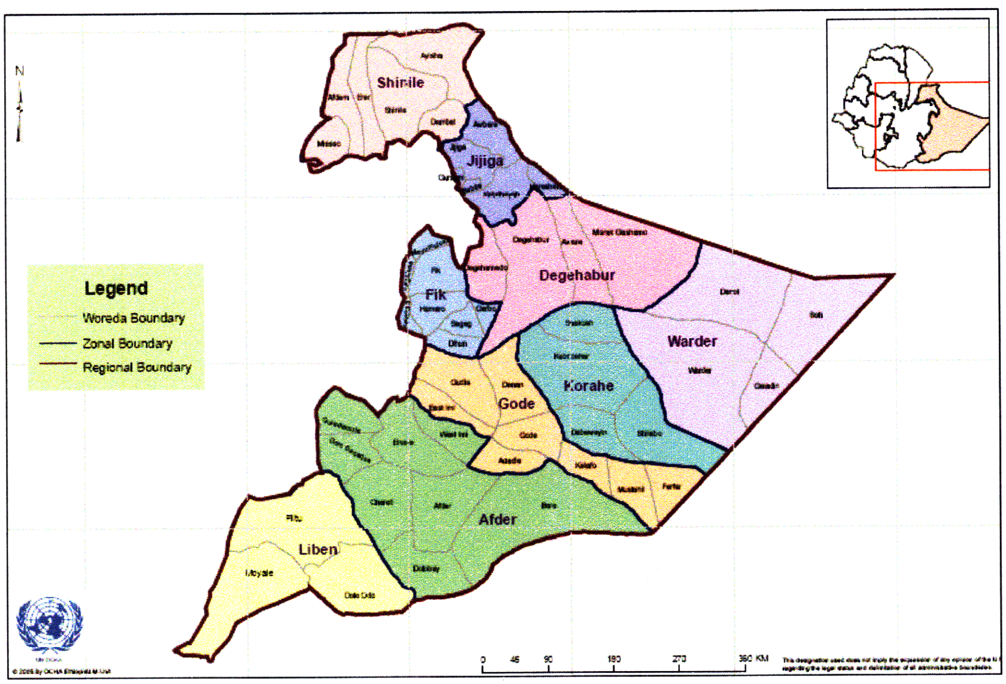

Figure 7 - Somali Region 1: Source – UN-OCHA

Throughout the last four years, the Somali region has been the region most impacted by severe climate changes in Ethiopia. These changes have ranged from serious flooding to droughts that have not only killed hundreds, but have displaced thousands of people from their homes or shelters and have also created an unstable local food supply. The map in Figure 8 illustrates the distribution of the food security in Ethiopia; as it can be seen, the Somali region is in a state of extremely high food insecurity.

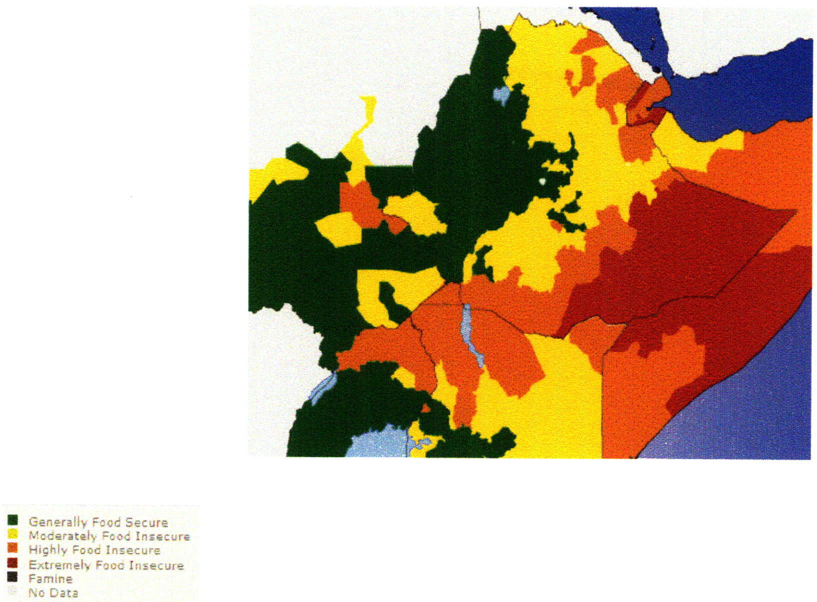

Figure 8 -Map of Food Security in Ethiopia: Source – FEWS

2 Introduction

Providing humanitarian relief entails complex supply chain operations whose effectiveness impacts millions of people in need of assistance. With the need for aid continually exceeding the resources available to provide it, the importance of an efficient supply chain is paramount to maximizing the output from humanitarian aid organization's efforts.

Organizations involved in humanitarian logistics struggle to make strategic and tactical decisions primarily due to the unpredictability of humanitarian events, the perpetual scarcity of resources, and the lack of readily available information to facilitate/support these decisions. State of the art tools that assist in decision making require large amounts of exact information, which requires time, effort, and data, and with humanitarian work being very operationally focused on the issues at hand, strategic decisions are often made on the basis of intuition without sufficient fact driven analysis. However, while work performed on an operational level can only create short term benefits, optimal strategic and tactical decisions maximize the resources of humanitarian organizations making them more flexible and effective in the long term.

This thesis presents a model that assists the World Food Programme in making improved strategic decisions. The model addresses the challenges that The World Food Programme and other humanitarian organizations face when making complex strategic decisions, enabling the incorporation of readily available information, whether it be qualitative, quantitative, or estimations when precise data is not available, while minimizing the amount of time and effort required making a strategic decision. The model develops a multiple attribute decision framework using the Analytic Hierarchy Process to determine relative priorities of the different attributes, bridging the gap between the common decision techniques of cost analysis and intuition. The application of this model has been to optimize the location of a new warehouse in the Somali region of Ethiopia; however, the model presented is flexible such that it can be adjusted to support the decision making process of other strategic supply chain decisions where there is limited quantitative information available for conducting a true optimization.

2.1 Thesis Scope Overview

The scope of our analysis will be to develop a technique to determine improved positioning of warehouse capacity when the World Food Programme (WFP) looks to expand their footprint in a region. Given the difficulty humanitarian organizations face in gathering the required information to make a strategic supply chain decision, the model presented will assist WFP in the decision making process to locate additional warehouse capacity by reducing the effort in gathering extensive amounts of information, and in focusing the data gathering on the most critical factors in warehouse capacity placement to maximize the use of their resources. The Somali region of Ethiopia was chosen as an area of focus primarily as a result of the Ethiopian government's request for the WFP to take on a more aggressive role within that region, as well as the fact that logistics operations within the Somalia region are fairly autonomous from other regions, allowing for a very contained pilot of this model.

The following section of this document reviews some of the existing publications that are relevant to the humanitarian field, to the Somali region of Ethiopia and to the Analytical Hierarchy Process; which is the methodology used to develop the model. The fourth section describes in detail the Analytical Hierarchy Process, and its application for the optimal location of a warehouse. Finally, the fifth section analyses the results obtained from the use of the model developed and it presents possible alternative applications for this model.

3 Review of the Literature

Our thesis concentrates on multiple attribute decision making using limited information in the humanitarian logistics field, a topic that has had certain portions covered previously but as a whole has not been touched on by any publication. Our thesis has three key areas of research. The first one focuses on the best practices in humanitarian logistics; we gathered information in order to present a solution that stays within a framework of superior and feasible practices in the field of humanitarian logistics. The second area of research is the current situation in Ethiopia; this helped us to get a more realistic solution. It also provided information to be used in our methodology. The third area of research relates to the proposed methodology; from here, we understood how to easily collect qualitative data with minimum bias. We also concentrate on how to use this information to implement an Analytic Hierarchy Process model.

3.1 Humanitarian Logistics

Among the sources that offer a general approach to the humanitarian logistics field, the work of Kovács and Spens (2007) provides a high level framework; it discusses preparation, immediate deployment, supply, demand, fulfillment management, and the actors in crisis response. Even though this work does not provide specific information on how to go about making logistics decision in the presence of low quality data, it provides a detailed overview of the previous works within the humanitarian logistics space, helping the reader to understand some of the issues that humanitarians can be faced with when they are in the field. Logisticians have to consider that some areas are more prone to natural disasters or security issues, and this has to be taken into consideration when selecting the optimal warehouse location, which is the application of the model used in our thesis.

Furthermore, Kovács and Spens (2007) emphasize that there are not dedicated journals and frameworks that concentrate on humanitarian logistics. The humanitarian logistics field has received little attention from the academic community as most of the publications are from practitioner journals. Most of the work in the humanitarian field concentrates on funding activities rather than on optimizing the operations of an organization. This emphasizes the need to provide a framework to humanitarian logisticians, which is the aim of this thesis, in order to guide the optimization of resources.

The latest book of Wassenhove and Tomasini (2009), *Humanitarian Logistics*, describes the importance of the coordination among the different parties of a humanitarian supply chain. This includes the non-profit organizations, the private sector, the beneficiaries and the local existing organizations that can assist the humanitarian work. Humanitarian efforts cannot concentrate on the mere logistics of delivering goods; instead they should adopt a shared vision among the players and clear communication channels in order to best utilize resources by minimizing redundancies. This has been clear for more than a decade in the private sector. However, the humanitarian field has much to learn in this new supply chain management approach of coordination among different parties of the chain. Our thesis concentrates on structuring the decision making process in the humanitarian sector by taking into consideration the propositions and requirements of each one of the players in the chain.

There are multiple sources that provide a more specific approach as they focus on specific disasters. This is the case of the work of Arminas (2005), whose work focuses on the lessons learned from the Tsunami in 2004. This is also the case of the publication Disaster Response Based on Production Network Management Tasks. Publications that focus on disaster relief offer a framework that can be used in humanitarian logistics to have the best immediate response in case of a crisis or disaster. However, our work will be focused on continuous operations, known within the World Food Programme as targeted supplementary feedings, and will not be looking at the emergency relief supply chain. This is important since while there are similarities in approach, emergency relief supply chains pay little heed to cost, focusing on pre-positioning and immediate response, in stark contrast to that of continuous operations.

Moreover, case-based sources also concentrate on the operations of certain organizations. As an example, we can mention the work of Lopez (2006). In his thesis, he studies the amount of lead times in all the countries that are served by the World Food Programme. From his work we got an approximate idea of what the lead times in WFP Ethiopia are. This publication shows us how lengthy and cumbersome the process of delivering food in Ethiopia is. This clearly justifies the need to make the strategic decision process within the organization more efficient in order to improve the overall effectiveness of WFP.

Along the same organization-oriented publications, it is worth mentioning the article "Bringing Best Practices to Emergency Food Logistics" (Shister 2004). This publication offers a description on the relationship between WFP and TNT. This article indicates that WFP has mainly focused on operational decisions while there is a great opportunity for improvement when concentrating on strategic decisions. When TNT approached WFP,

WFP was looking to add more warehouses to overcome their capacity constraints. However, TNT was able to expand the utility of the existing warehouses by 42% after performing a logistics study. This avoided the need for the extra investment that WFP would have incurred when opening new facilities. This proves that there is a great opportunity to optimize WFP resources by looking at strategic and tactical decisions.

The article "Humanitarian Aid and Logistics: Supply Chain Management in High Gear" mentions two important aspects of humanitarian logistics that are relevant to our thesis. The first is that while humanitarian organizations are approximately 15 years behind in terms of logistics operations compared to the corporate sector, donors have become more concerned about the efficiency of humanitarian operations and are expecting a level of efficiency and accountability commensurate with the for-profit world. This stresses even more the need to work towards optimization and transparency in the use of the resources of WFP, which our model does by minimizing biases and providing a structured framework for decision making. The second aspect is the fact that humanitarian operations have to be run under a great deal of uncertainty. This dynamic is taken into consideration in our work as we implemented a model with a high degree of flexibility.

Other publications do a reasonable job in optimizing humanitarian logistics operations as it is the case of *Inventory Pre-positioning for Humanitarian Logistics* where the author uses linear programming to optimize the location of a new warehouse. However, these publications do not address the challenges that humanitarians face when they need to collect enormous amounts of data in order to run these optimization models. These models only focus on a quantitative approach that requires the input of accurate and extensive information.

3.2 The Situation in Ethiopia

Among the sources on the current situation in Ethiopia, the book *Poverty Income Distribution and Labour Markets in Ethiopia* offers a quantitative analysis by gathering data with the use of qualitative methods. In this publication, the authors determine the distribution areas of poverty in most need in Ethiopia by using surveys along with quantitative methods. This book presents an analysis based on the changing dynamics of the poverty distribution in Ethiopia. One of the conclusions of the study is that the poverty distribution in Ethiopia has changed throughout the years due to the constant flow of people to the urban areas; this dynamic is stressing the already weak economies of the main cities in Ethiopia. Our proposed model implements a level of flexibility that takes into consideration the food demand changes as the poverty distribution of Ethiopia evolves.

There are also a few sources that provide information on WFP and Ethiopia. The most relevant ones come from the monthly updates of the WFP website. These updates provide general information on the situation of the country regarding its food needs and the current situation of the delivery food aid. The main problems identified by this information source are the dry season, the rural-urban migration and the rising food prices. However, even though these updates offer the latest information on Ethiopia; they offer a very general perspective which is not the aim of our project.

3.3 Analytical Hierarchy Process and Data Collection

Among the sources that provide information on the proposed methodology; we have found the seminal paper for the selected decision support tool, Saaty (1980). In this work, he presents the Analytic Hierarchy Process decision support tool for the first time. Since then, dozens of papers have added onto or applied the model, most notably Saaty (1994) where the nine-point fundamental scale is introduced as a tool for stratifying the scoring. This scoring model enhances the quality of the output by forcing the user to score on a scale that promotes relative priorities between criterions, which we implemented for our prioritization effort.

De Neufville (1990) presents a seminal paper in the use of Analytic Hierarchy Process to locate capital investment, in this case an airport. However, this paper only includes a basic level of sensitivity analysis, which is furthered in Ugboma (2006) using the Expert Choice software suite to develop a sensitivity analysis for port selection, allowing the user a more comprehensive evaluation of the decision model where they can understand how differences in the relative priorities would impact the overall outcome. Ugboma also defines a set of evaluation criterion within the AHP model for port selection that is relatively transferrable to a warehouse location problem. While the availability of the Expert Choice software allows for Ugboma to perform extensive sensitivity analyses, we based our analysis on the ability to use commercially-available freeware, to ensure scalability to all Non-Governmental Organizations.

Zahedi (1986) gives a comprehensive overview of the Analytical Hierarchy Process and he lists some of the areas where this methodology has been used; some of these are economics, energy, health, architecture, project selection and marketing among others. Even though all of these areas are highly unrelated, they all have in common a set of complex decisions to be made. Moreover, the decisions in these areas where AHP was used were based on the use of qualitative data. This validates the Analytical Hierarchy Process as a methodology that can be used in any area where there is a complex decision to be made and the nature of information is more qualitative rather than quantitative. Our extension brings this to a new field however, in humanitarian aid and logistics.

Korpela and Tuominen (1996) use the Analytical Hierarchy Process in order to decide on the optimal warehouse location for an organization. They do this by aligning the corporate objectives with the criteria of selection in the model. This process requires input from all the parties who are impacted by the selection of a warehouse as they all have to agree on the selection of the criteria and its prioritization. Even though the application of our model is also to optimize the selection of a warehouse location as it is the objective of this publication, their model reflects a different set of objectives that apply to a commercial organization. There is a great emphasis on the conditions of the facilities and the reliability of the staff. In our model these aspects have a lower priority as what is important in the humanitarian sector is to service the beneficiaries. Furthermore, this publication makes a subjective explanation on how the scoring was done which makes the model difficult to replicate in case there is a change in the strategy of the company that would translate on a change in the scoring of the alternatives. Our model clearly establishes how the scoring was done from standardized surveys that were translated into quantitative information.

Other publications give an overview of the use of the Analytical Hierarchy Process in specific decision making. This is the case of the work by Min H (1994) and Bagchi (1989). Min describes the use of AHP to assist on the planning decisions of airport facilities, while Bagchi concentrates on carrier selection. Both of these publications follow the same four-step procedure that is used this thesis; however, none of them use a friendly interface to give to the people who are doing the scoring and the prioritization. Our model not only uses standardized surveys to make it easier for the people to score the alternatives, but it also presents an easy-to-use software interface that makes the prioritization process much simpler. Also, as our model uses standard procedures, it also minimizes the bias of the model.

Forman and Gass (2001) make a comparison between the Analytical Hierarchy Process and the Multi-Attribute Utility Theory (MAUT), which is a well-established methodology for decision making. This publication outlines the advantages between using AHP versus MAUT; one of these advantages is the simplicity of the interface of the AHP methodology, where for the MAUT they claim that there is a need for a person with training in decision making, as the MAUT procedure requires the creation of a scale in order to make the judgment of each one of the alternatives. In order to effectively use the knowledge of the people in the humanitarian sector it is essential to make the process of selection and scoring simple to ensure that the person with the knowledge can do this process on their own. In the humanitarian sector, the people who have the information needed to do the scoring and prioritization do not have the experience in decision making. It would be unrealistic to expect them to follow a complicated procedure.

Another important advantage that Forman and Gass describe is the flexibility that the AHP methodology has versus the MAUT methodology. The MAUT procedure requires the decision maker to consider the best and worst values for each one of the alternatives. In AHP this can be used if it is desired; however, it is not necessary. This is a great advantage of AHP over the MAUT methodology as in most of the cases it is not known what the best and worst scenarios are for each one of the alternatives.

Also Forman and Gass talk about the most common criticisms AHP has had in terms of rank reversal. Rank reversal is defined as the change in the rankings of alternatives after an alternative is added or deleted. However, the authors mention how rank reversal is a natural phenomenon that has to occur; when an alternative is added or deleted the criteria selection changes as well as the priorities shift depending on the new alternatives.

Holguin-Veras (1995) performs a comparison between AHP and the Multi-Attribute Value (MAV), a well-known methodology for decision making. He evaluates both methodologies on two areas that are highly relevant to our work; these are practicality and the ability to capture the preferences of the decision makers. Regarding practicality, the author found that the amount of information required for MAV is less than for AHP given that the number of alternatives is more than five. However, the author mentions that the level of abstraction to capture this information is significantly higher by using MAV compared to the use of AHP. In humanitarian organizations, there is a large amount of existent information based on the experiences of the people in the field; however, this information is dispersed throughout a considerably high number of people. In this sense, it is easier to have a lower level of abstraction when collecting the information even if that means that more information will have to be collected.

Other publications give an overview of the use of the Analytical Hierarchy Process in specific decision making. This is the case of the work by Min H (1994) and Bagchi (1989). Min describes the use of AHP to assist on the planning decisions of airport facilities, while Bagchi concentrates on carrier selection. Both of these publications follow a same four-step procedure; however, none of them focus on the user experience or user interface to give to the people who are doing the scoring and the prioritization. Our model not only uses standardized surveys to make it easier for the people to score the alternatives, but it also presents an easy-to-use software interface that makes the prioritization process much simpler. Also, as our model uses standard procedures, it also minimizes the bias of the model.

A common thread between all of these publications is that they are based on highly quantitative scenarios. In our case, because of the lack of information, we will have to gather data relying on whatever is readily available. This data will often be qualitative in nature and we will have to transform it into quantitative information to make it fit the Analytic Hierarchy Process model.

In this case, we need to concentrate on gathering information about how to collect qualitative data accurately. Qualitative data collection started in the social sciences. Fields as psychology and anthropology have had extensive support and development of the qualitative methods. A useful source of qualitative information research is the work of Guba and Lincoln (1985). In this publication, the authors present a procedure on how to conduct surveys to obtain the most accurate data. Their publications explain the best way to design the survey in order to avoid any biases. However, logistics are based on a heavy mathematical approach. Therefore, even though all the publications on qualitative research provide relevant information on how to obtain information from the people being surveyed; these publications do not offer any information on how to convert qualitative data into quantitative data.

In order to answer our research question of how to improve a decision making process with the use of imperfect information, we have to rely on conducting research from multiple areas. There are no publications from one single field that are going to help us to solve our question.

3.4 Literature Review Summary

From this section it is evident that there is a tremendous amount of work surrounding the Analytic Hierarchy Process, warehouse location, and humanitarian logistics, however this will be the first time that these fields are being brought together, utilizing the Analytic Hierarchy Process in the humanitarian logistics sector for a strategic decision such as warehouse capacity location. This is groundbreaking because previous works using AHP have always relied solely on hard data or user intuition and have not taken a blended approach, nor have they placed a focus on the quality of the data as we have done.

4 The Analytic Hierarchy Process and its Application

Given the limited quantitative information available within developing nations and humanitarian efforts, determining a location for additional warehouse capacity using a fully quantitative approach may not yield an optimal solution. Therefore, we must enlist some qualitative tools to assist us, primarily the Analytic Hierarchy Process (AHP), as well as a decision support system to ensure best practices in implementation of the AHP model.

Analytic Hierarchy Process is a technique developed by Thomas L. Saaty in 1980 to help manage complex decisions involving multiple attributes. AHP traditionally involves a four-step process to solve a problem (Zahedi 1986). First, we deconstructed the goal statement into key criteria, which can be more easily evaluated. Then, we prioritized the criteria with respect to their importance in making the overall decision. This was followed by a normalization of the priorities to develop a weighted criteria framework. Next, we scored each alternative relative to each of the criteria, finally normalizing and aggregating the data, rolling all of the scores back up to the goal statement to evaluate the fitness of each alternative.

Commonly Referenced Terminology	
Criteria	One of the five primary measures identified to help deconstruct the goal statement
Attribute	A 'sub-criteria' measure, used to deconstruct criteria that are difficult to evaluate
End-node	Either a criteria with no attributes, or an attribute; the measures evaluated during the scoring phase
Cluster	A group of attributes or criteria indentured to the same parent node

Table 2- List of Common Terms

4.1 Deconstructing the Goal Statement

The first step in the Analytic Hierarchy Process allows us to identify the key criteria upon which the decision of where to place an additional warehouse should be based and to identify the potential alternatives, in this case the potential locations being evaluated. To begin we defined the goal statement, which we determined was 'identifying the best location to place additional warehouse capacity given the current set of resources, constraints, and objectives'. Having a goal statement that all parties have agreed upon is a crucial phase, as we needed to ensure that the question which we were attempting to answer is the one for which the WFP is looking to find a solution. The key here was in understanding whether we were looking to optimize their overall warehouse network, and how many additional facilities we were looking to place. To keep this simple we agreed with the WFP to identify a single location where additional warehouse capacity should be placed; this could be either an expansion of an existing location, in the case of six alternatives being evaluated, or it could be setting up new operations in a location, such as with three of the alternatives.

Once the goal statement was well defined, we worked collaboratively with the World Food Programme to define key criteria through a series of brainstorming sessions, as well as through external research. From the results we then were able to engage in a pre-disqualification process, whereby criteria were removed that were either indentured to other criteria, or lacked relevance in relation to the goal statement. We settled on a list of five criteria for evaluating the quality of a warehouse location, which were 'Adequacy of Infrastructure', 'Location', 'Transportation', 'Cost', and 'Regional Stability'.

While these five criteria most likely represent the most salient factors in evaluating the fitness of a warehouse location, some of them are enigmatic in definition and in nature, making evaluation a daunting task. To alleviate the challenges in evaluation we created an additional tier of 'attributes' that would be indentured to the criteria for those criteria which evaluation was a challenge. To identify these attributes we reviewed similar analyses to determine best practices in evaluation of these criteria, and combined with additional brainstorming efforts composed a list of attributes for each criterion. Then, we engaged in a collaborative process with the World Food Programme similar to that for the criteria identification, pre-disqualifying those attributes which lacked relevance to the evaluation of the parent criteria. Based upon the results of this process we were able to come up with the following list of criteria, attributes (as denoted by being bulleted and indented below a criterion), and definitions to ensure standardization of terminology:

Adequacy of Infrastructure	The quality of warehouses within a location
• Security	Quality of warehouse security infrastructure
• Building Capacity	Ability of location to meet capacity needs of WFP
• Facility Conditions	A measure of the state of disrepair of warehouses at location
• Road Quality	Ability to access location year-round, quality of road (dirt/gravel/tarmac)
Location	The proximity of the location to key areas
• Proximity to beneficiaries	Distance and ease of accessibility to beneficiaries
• Proximity to Ports of Entry	Distance and ease of accessibility to ports of entry
• Access to Support Services	Proximity to support facilities, metropolitan areas
Transportation	The availability and quality of transportation services
• Access to Commercial Markets	Ability to conduct tenders in region based on robust supply base
• Availability of Carriers	Ease of procuring transportation when necessary
• Quality of carriers	Measure of professionalism and diligence exuded by carriers servicing region
Cost	The relative cost of a region per metric ton of warehouse floor space
Regional Stability	A measure of political, social, and economic risk within a location

Table 3 - Security Evaluation Framework

Additionally, we identified which criteria and attributes are end-nodes, meaning they will be evaluated in the scoring phase of the model. We created a rough visual model to assist the WFP in understanding the relationships between the criteria/attributes, and in understanding what will be evaluated. The diagram below illustrates this:

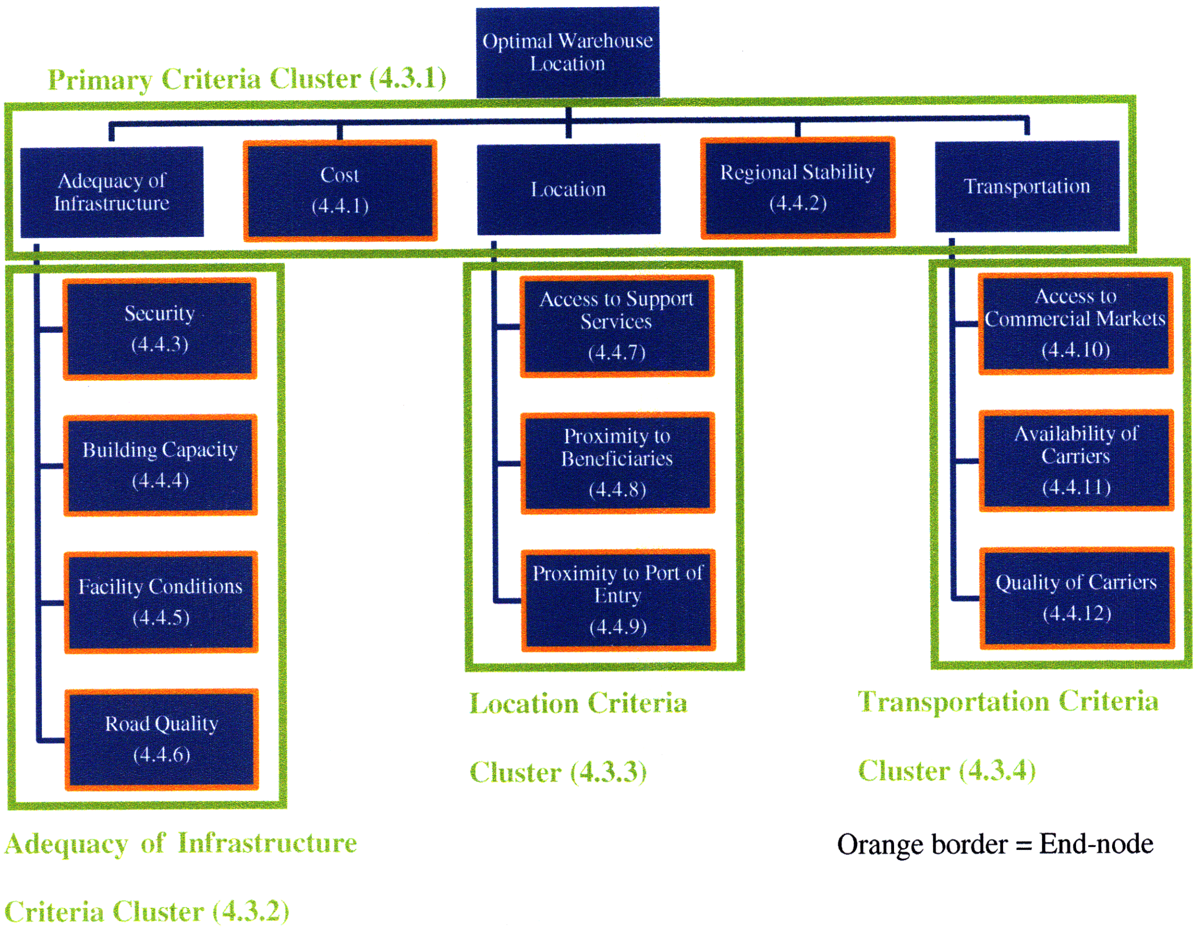

Figure 8 - Hierarchal Layout of Model with End-Nodes Identified

The final piece of this phase was to identify all of the warehouse alternatives to choose. These were determined entirely by the WFP team. They provided an initial list of eight alternatives, with one additional alternative being added during the process to bring the final total to nine locations being evaluated; all of these alternatives are at the city level, since identifying a specific warehouse within a city will be handled during the implementation phase. The list of alternatives is illustrated below:

List of Potential Warehouse Locations (Alternatives)
Nazareth
Kebri Dahar
Degehabur
Dire Dawa
Fik
Gode
Jijiga
Mustahil
Warder

Table 4 - List of Potential Warehouse Locations

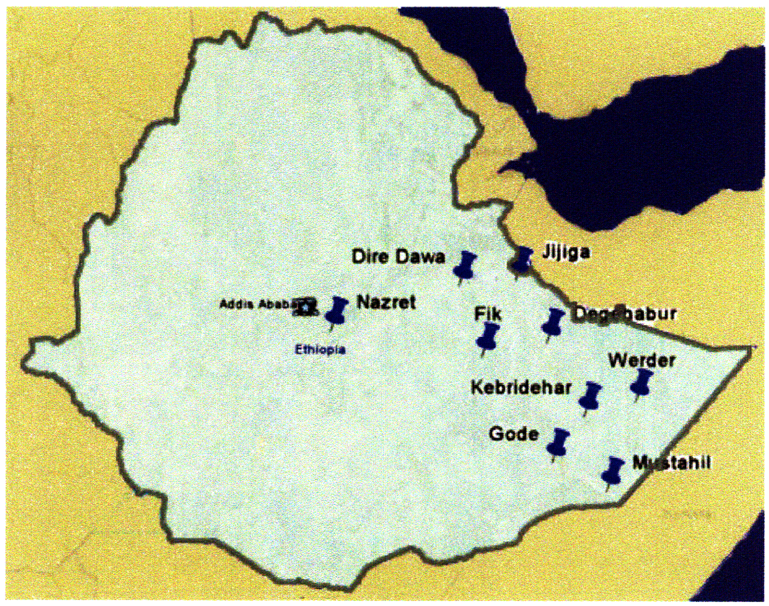

Figure 9 - Map of Potential Warehouse Locations

With the definition of the criteria, attributes, and alternatives finalized, we constructed relational AHP models, the goal of this being to allow for easier visualization of the model as well as to support data entry. Initially, we constructed models based within Microsoft Excel coupled with VBA programming; however to make this a solution that can be easily adopted we needed to use commercially available software that had been fully debugged and that had a user-tested interface, and as a result we selected the SuperDecisions software package (www.superdecisions.com). As a tradeoff we lost some insight into the mechanics of the tool, but we independently tested each pairwise comparison matrix using our own approximation of the mathematical models that drive the Analytic Hierarchy Process and found results to be very consistent, giving us a high level of confidence in the efficacy of the tool. The relational model as created within SuperDecisions is shown in the figure below:

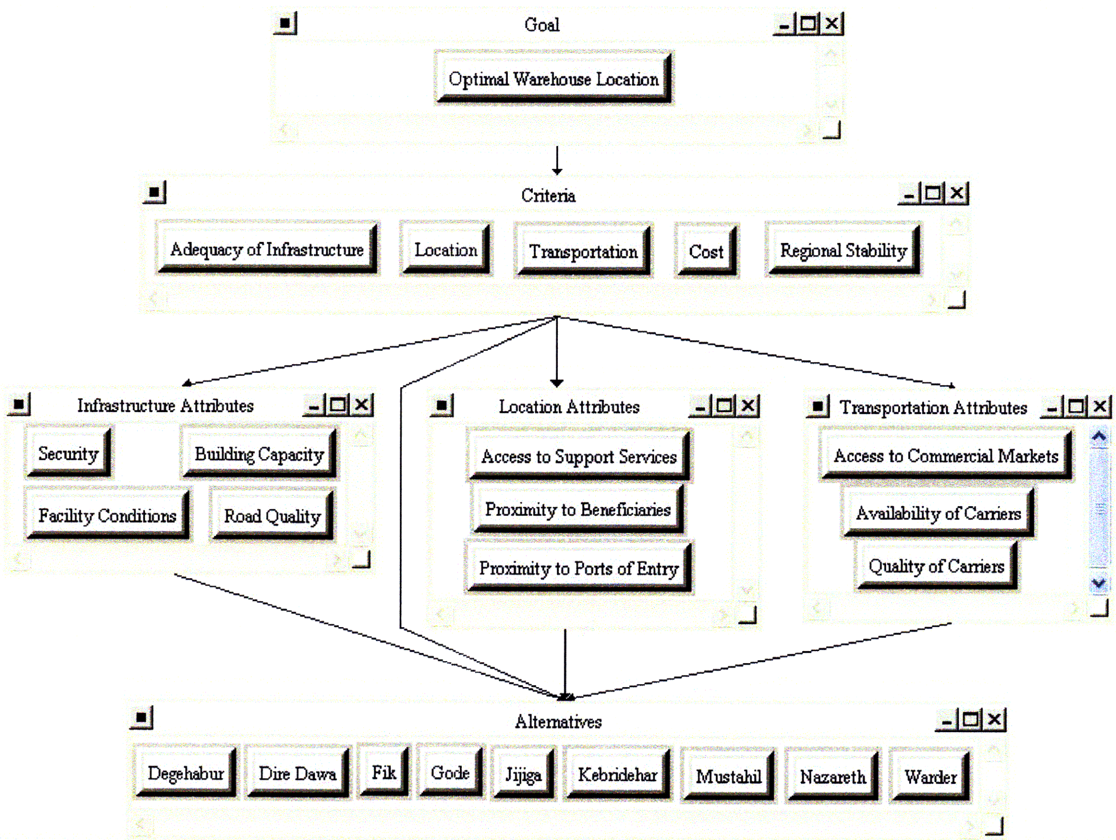

Figure 10 -SuperDecisions Display of Relational Model

4.2 Prioritization

With the goal statement deconstructed into a hierarchal framework, we had the World Food Programme team establish relative priorities using pairwise comparison matrices, prioritizing each criteria or attribute within a cluster relative to its parent function. This means that all criteria are evaluated relative to their importance to the goal statement, and all attributes are evaluated on the basis of their relative importance to the parent criteria (e.g. for Infrastructure Attributes, Security is measured relative to the other three attributes in that cluster relative to their importance in determining the overall adequacy of infrastructure'.) . This process can be illustrated by the use of the following matrix:

	Adequate Infrastructure	Cost	Location	Regional Stability	Transportation
Adequate Infrastructure	1				
Cost		1			
Location			1		
Regional Stability				1	
Transportation					1

Table 5 - Sample Pairwise Comparison Matrix

The matrix is completed by responding to the question for each unique row and column combination, "with respect to the goal, what is the relative preference of w_R to w_c?" (Zahedi) where subscripts R and C represent columns and rows. This is scored based upon Saaty's nine point scale:

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equallyto the objective
3	Weak Importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed adjacent scale values
Reciprocals of above non-zero	If activity i has one of the numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale numerical values to span the matrix	If consistency were to be forced by obtaining n

Table 6 - Saaty's Nine Point Scoring; Source Zahedi (1986), Saaty (1980)

Only the top right portion of the matrix is completed, with inverse scores being calculated such that:

$$For\ all\ w_{Row,Column}:$$

$$w_{Row,Column} = 1/w_{Column,Row}$$

The WFP Team completed this matrix in a much less quantitatively intensive fashion, as SuperDecisions offers a variety of simple interfaces for evaluating relative priorities, using a graphical, textual, or matrix based approach, enabling the user to perform the evaluation in the manner that most suits their method of thinking. The World Food Programme evaluated each of the clusters using the SuperDecisions tool's verbal entry mode shown in Figure 11, which we felt was the most user-friendly approach available within the software package, due to its use of common vocabulary to describe the differences in importance. Figure 11 evaluates the importance of Adequacy Infrastructure versus Cost. In this case Adequacy Infrastructure is moderately to strongly more important than Cost.

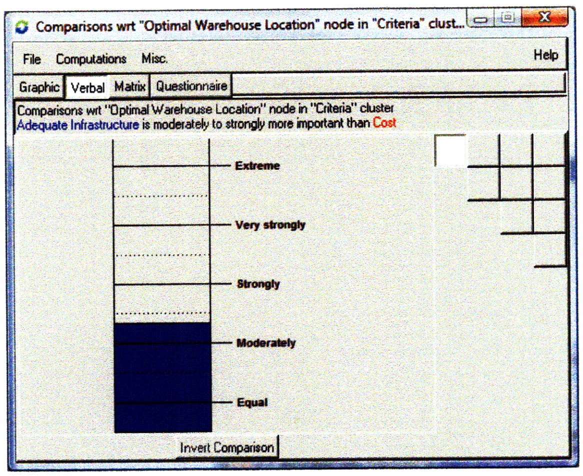

Figure 11 - Display of SuperDecisions Verbal Entry Mode

From the information entered into SuperDecisions we were able to normalize the data to determine relative priorities for each of the criteria as part of the overall warehouse selection decision, as well as determine the relative importance of each attribute in determining the fitness of each criterion. This will be discussed further in Section 4.5.

4.3 Priority Normalization

From the completed pairwise comparison matrices we can use the Eigenvector method to normalize the priorities (Saaty 1980). The detailed mathematical explanation of the Eigenvector method is beyond the scope of this paper, but we can take a very simple approximation of the Eigenvector Method, normalizing the matrices by dividing each cell by the summation of the column that it is within, then taking an average of each row within the normalized table to determine the relative priority of each option. The SuperDecisions tool normalized the matrix for us using the Eigen Vector methodology, although all values were verified manually using the approximation technique to ensure accuracy. Additionally, this method allows us to look at the consistency index of each matrix; the common heuristic is that it is desirable to have a matrix exhibiting a consistency index less than .10.

4.3.1 Primary Cluster

The primary cluster is formed by 5 different criteria as it is illustrated in Figure 8. From Figure 13, we can see that location and regional stability each represent around 35% of the overall decision, with infrastructure, cost, and transportation each taking around 10% of the weight.

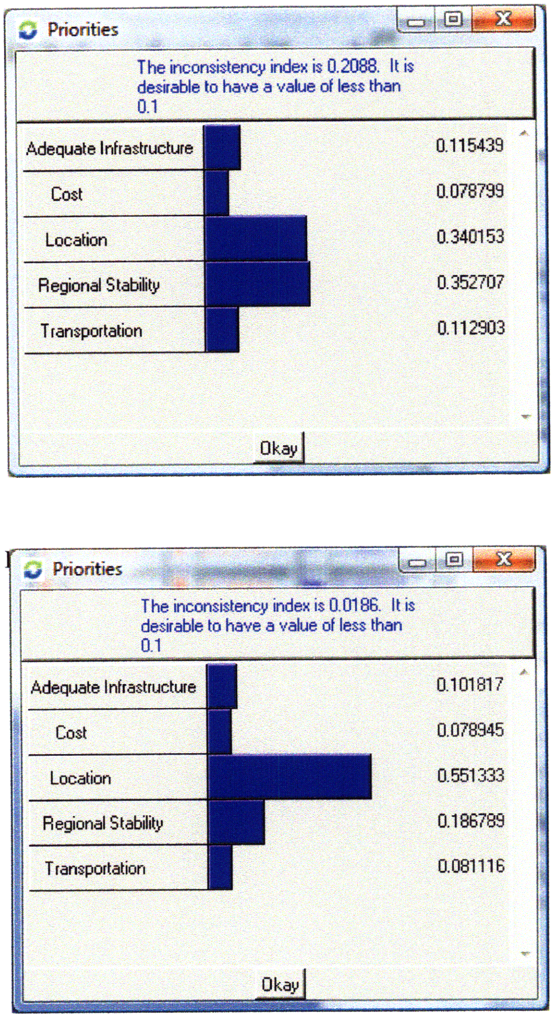

Figure 13 – Prim. Criteria Adjusted Relative Priorit.

The consistency index score of .2088 is well above the threshold of .10, meaning that the validity of this matrix is in question, so adjustments needed to be made to account for this. Additionally, in discussions with the WFP we were able to ascertain that the results may not be reflective of what they believe the true drivers are, since regional stability is not a key concern when identifying a warehouse location. Regional stability is definitely a concern in mitigating food loss and ensuring continuity of services, but the nature of the World Food Programme's work inherently requires that warehouses be placed in areas that are relatively unstable, meaning that the overall importance of this criterion should be significantly reduced when compared to some of the other factors such as Location. With these two items in mind, we worked in collaboration with the World Food Programme to adjust the matrix to increase the overall consistency (by identifying the most inconsistent values and pushing them towards their ideal value), and by reducing the relative importance of regional stability. With these changes performed, we were able to recalculate the relative importance of each criterion as identified in Figure 13 above.

With this readjustment of values we were able to achieve a set of relative preferences much more consistent that passed a 'sanity check' by the World Food Programme. From here we see that location is the key driver of the decision, with Regional Stability still having some importance, but significantly less than it did previously.

The adjustments made brings the validity of the model into question, since the model theoretically eliminates any of the bias and predispositions that a scorer has when evaluating a cluster, however we chose to allow for modification to ensure that consistency was achieved, and to ensure that the model did in fact reflect the intentions of the WFP. To see how the results were impacted due to the adjustments, we conducted a sensitivity analysis (as identified in Section 4.6) where the results using the original values and the updated vales are compared.

4.3.2 Facilities Cluster

Analysis of the facilities cluster shows that Security is the most important factor in evaluating the quality of the facility, representing 54% of the evaluation, with Road Quality coming in second at 26% of the overall evaluation, as shown in Figure 14. This intuitively makes sense, as prevention of food loss is a significant concern in any distribution program, and the ability to access the warehouse location year round on major roads that can support multi-ton trucks in a necessity in determining where to locate a warehouse. The World Food Programme has a practice of upgrading facilities as necessary, meaning that if the Facility Conditions are below their expectations they will invest in upgrades to get the warehouse to a point where it is fully functional, mitigating the importance of the initial Facility Condition.

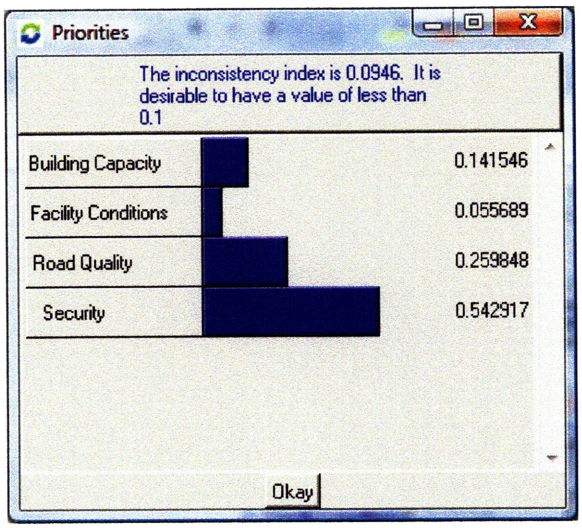

Figure 14 -Facilities Cluster Relative Prioritization

4.3.3 Location Cluster

Given the importance of Location to the overall decision a lot of emphasis was placed on the evaluation of the location attribute cluster. Running the SuperDecisions model yielded us the results in Figure 15.

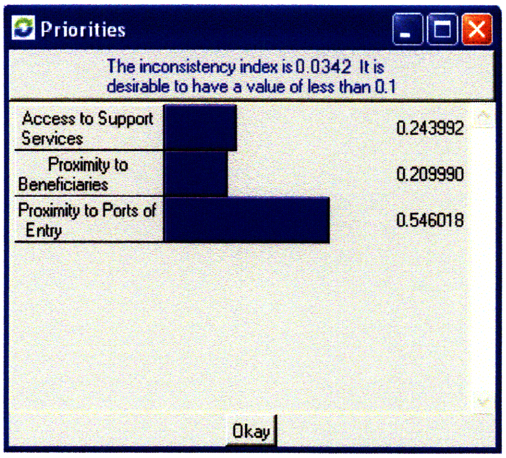

Figure 15 - Location Cluster Init. Relative Priorit.

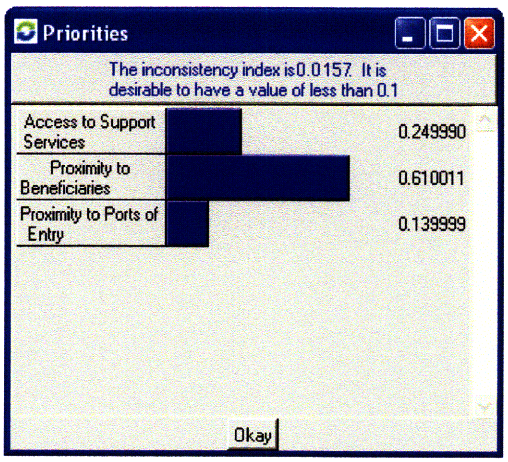

Figure 16 - Location Cluster Adjusted Relative Priorit.

In discussion with the World Food Programme we determined that this did not pass a sanity check, since in order of relative importance the expected results would be to have Proximity to Beneficiaries, then Access to Support Services, and finally Access to Ports of Entry. The Consistency Index of .0157 shows a high level of cardinality, but with the results askew we adjusted the priorities in this cluster based upon the input received to come up with the prioritization shown in Figure 16 above.

This updated prioritization is much more reflective of the World Food Programme's thought process in selecting a location, and with a Consistency Index of only 0.0342 there can be a high level of confidence in the cardinality of this prioritization. Similar to the primary criteria, this brings up concerns over the validity of the model. However, from a practical perspective the modified results are very intuitive, since the overland line haul from the port of entry to the warehouse can be conducted with one large commercial truck, whereas the routes to the beneficiaries require local deliveries to be made with multiple smaller vehicles. From a fuel, time, complexity, and resource perspective it is much more advantageous to the World Food Programme to have the facilities located closer to the beneficiaries than to the port of entry. To see the impact of this, we conducted a sensitivity analysis (as identified in Section 4.6) where the results using the original values and the updated vales are compared in order to gain additional insight into the effect of our modifications.

4.3.4 Transportation Cluster

In analyzing the transportation cluster with the World Food Programme Quality of Transportation, with Availability of Carriers represent 55% of the evaluation and Quality of Carriers 35% of the evaluation, as shown in Figure 17. Given the need to move large quantities of food in short timeframes, Availability of Carriers is naturally the most important driver, with Quality of Carriers coming in second as it plays a key role in mitigating supply risk. While a market that is easy to conduct tenders in is a benefit, paying a premium to be able to deliver food is a compromise the World Food Programme makes on a regular basis, and as such Access to Commercial Markets should have a considerably smaller relative importance.

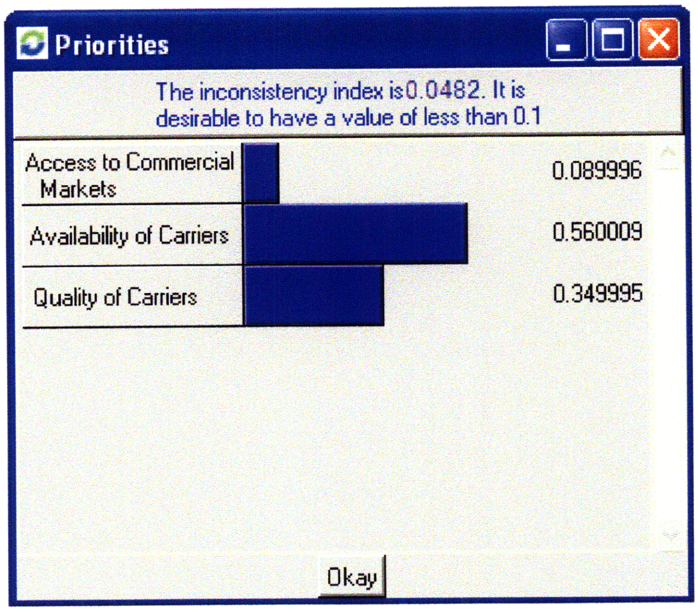

Figure 17 - Transportation Cluster Relative Prioritization

4.3.5 Priority Normalization Summary

Having analyzed each of the clusters within the model, we can view each criterion and attribute by their overall contribution to the selection of a warehouse location. The final model with the corresponding priority weights is illustrated in the following figure:

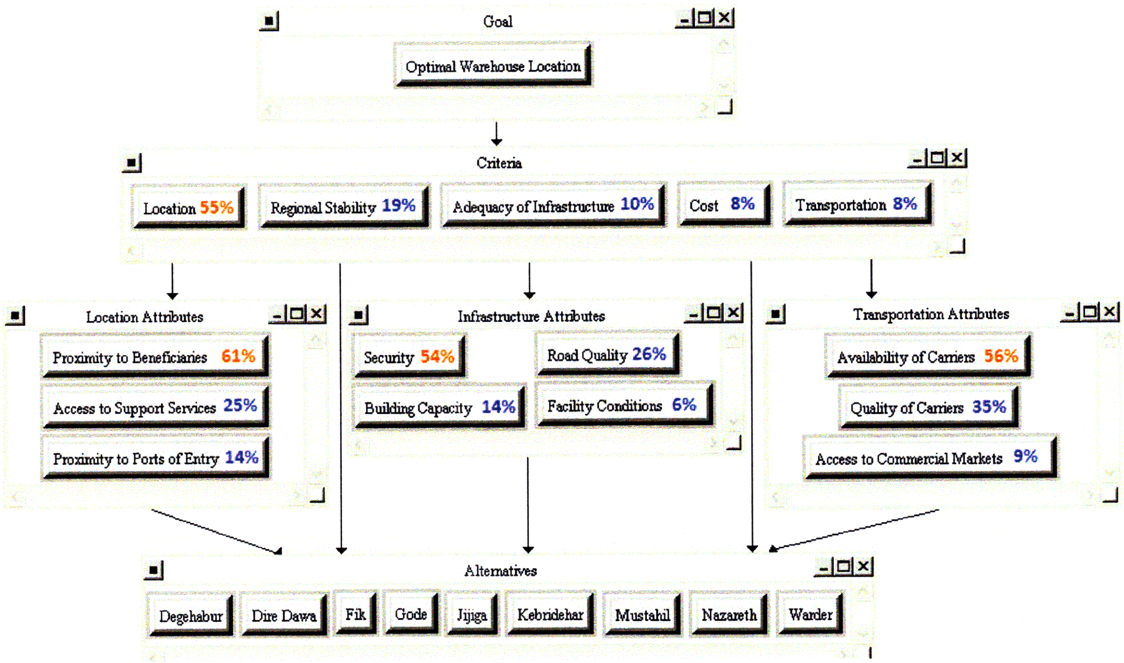

Figure 18 - SuperDecisions Relational Model with Prioritizations Overlaid

To determine the overall contribution of an attribute we multiply the priority of the attribute within its cluster by the priority of the attribute's parent criteria within the primary cluster. The following table shows the relative priorities for the original scoring, as well as the impact of the adjustments made based upon the sanity checks.

		First Iteration	Final Iteration
	Description	Weight Value (%)	Weight Value (%)
Location	The proximity of the location to key areas	34	55
Proximity to Beneficiaries	Distance and ease of accessibility to beneficiaries	21	61
Access to Support Services	Proximity to support facilities, metropolitan areas	24	25
Proximity to Ports of Entry	Distance and ease of accessibility to ports of entry	55	14

Adequacy of Infrastructure	The quality of warehouses within a location	12	10
Security	Quality of warehouse security infrastructure	54	54
Road Quality	Ability to access location year-round, quality of road (dirt/gravel/tarmac)	26	26
Building Capacity	Ability of location to meet capacity needs of WFP	14	14
Facility Conditions	A measure of the state of disrepair of warehouses at location	6	6
Transportation	The availability and quality of transportation services	11	8
Availability of Carriers	Ease of procuring transportation when necessary	56	56
Quality of Carriers	Measure of professionalism and diligence exuded by carriers servicing region	35	35
Access to Commercial Markets	Ability to conduct tenders in region based on robust supply base	9	9
Cost	The relative cost of a region per metric ton of warehouse floor space	8	8
Regional Stability	A measure of political, social, and economic risk within a location	35	19

Table 7 - First and Second Iteration of Prioritization

The following figure illustrates the list of criteria and attributes and their correspondent priority percentage.

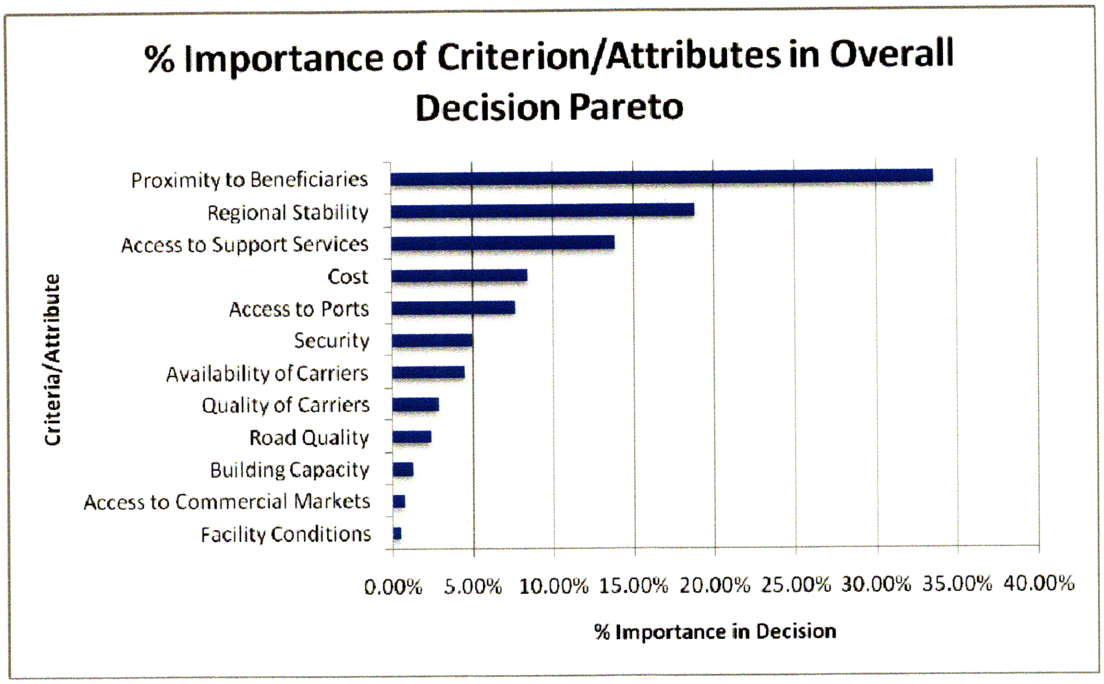

Figure 19 - Importance of Criterion/Attributes in Overall Decision Pareto

From this we can see that Proximity to Beneficiaries is the most significant factor in making a determination, and that this model exhibits the common Pareto distribution, where a few factors comprise the majority of the decision process. In this instance, the top five factors constitute 82.56% of the overall decision. With this knowledge in mind the possibility exists to conduct an abridged version of this analysis if necessary where only the top five criteria/attributes are evaluated, achieving relatively accurate results with less than half the analysis. Given the time available we performed a complete analysis, but in looking at the scalability of the solution this approach could allow for areas with less formalized humanitarian logistics organization make effective decisions with minimal input.

4.4 Scoring

Once the problem was fully deconstructed and the relative priorities were identified and normalized, we identified an approach for evaluating each of the alternatives at the end node. To do so we develop a data collection plan to structure this exercise where for each end node there is a specific metric that we are tying its evaluation to. For each metric we focused on three key criteria:

- **Easily acquired** – Each data set should take no more than 40 person hours to gather to ensure cost feasibility for the WFP. This ensures that the model can be reapplied in future situations without a significant amount of rework, improving the likelihood of long-term adoption
- **Scalable** – The data must be widely available in other regions and nations to ensure that this model can be usefully applied in other instances. This ensures that the scope of the work can move beyond Ethiopia, potentially helping the World Food Programme with decisions throughout Africa
- **Relevant** – The data acquired must be an accurate representation of the attribute/criterion for which we are looking to measure. When identifying data to select, it must demonstrate a significant level of correlation with the attribute

Developing the data collection plan occurred in an iterative fashion, as different sources of information were identified, validated, or discarded when proved to be unreliable or irrelevant. Frequently scoring of alternatives is performed by using pairwise comparison matrices, to allow for relative scoring between the options. But, given the dispersion of knowledge amongst field officers within the Somali region as well as the limited availability of quantitative information, we found that the data collection plan became much more qualitative, relying extensively on a series of surveys completed by field officers in the existing warehouse locations (Nazareth, Gode, Dire Dawa, Degehabur, Jijiga, and Kebri Dahar). Then, we used the data from the surveys to create estimated values for the three newly proposed warehouse locations (Fik, Mustahil, Warder). For these three we used the small amount of data available as a proxy combined with our own intuition.

The use of surveys created some concern over the consistency of the inputs, since there were six different people evaluating six different regions. This may introduce a significant amount of personal bias into the evaluation. However, given the decentralized structure of information within the field, with local officers retaining a significant amount of local knowledge and not necessarily disseminating that effectively up to the central office, this was the most effective approach available. The final version of the data collection plan is shown in Table 8, with the Facilities Evaluation Form and Transportation and Location Evaluation Form located in the appendix. Each of the end-nodes identified will be discussed in a sub-section below.

Criteria/Attributes	Updated methods
Cost	Facilities Evaluation Form
Regional Stability	Inputs from Regional Security Officer, Regional Analysis
Transportation - Availability of Carriers	Transportation and Location Evaluation Form
Transportation - Quality of Carriers	Transportation and Location Evaluation Form
Transportation - Road Quality	Transportation and Location Evaluation Form
Adequacy of Infrastructure - Security	Facilities Evaluation Form
Adequacy of Infrastructure - Building Capacity	Facilities Evaluation Form
Adequacy of Infrastructure - Facility Conditions	Facilities Evaluation Form
Adequacy of Infrastructure - Road Quality	Facilities Evaluation Form
Location - Access to Support Services	Transportation and Location Evaluation Form
Location - Proximity to Beneficiaries	Transportation and Location Evaluation Form
Location - Access to Ports of Entry	Spatial data from WFP Database

Table 8- Final Data Collection Plan

4.4.1 Cost

For Cost, the Facilities Evaluation Form asked for the cost of setting up a facility in the region, and the ongoing monthly/yearly expense of maintaining a warehouse. From this we calculated a five-year net present value, discounting future cash flows at a rate of 10%.

	Nazareth	Degehabur	Jijiga	Kebridehar	Dire Dawa	Gode
Setup Cost	$ -	$ 500,000	$ -	$ 300,000	$ -	$ 500,000
Lease Fees	$ 51,000	$ -	$ -	$ -	$ 151,000	$ -
Five-year npv	$ 193,330	$ 500,000	$ -	$ 300,000	$ 572,409	$ 500,000

Table 9 – Cost Analysis

The data we received back gave us a more comprehensive understanding of the pricing model; for some instances the government will own the facility and provide it at no cost, where in some other locations there is a need to pay a leasing fee. Additionally, some of the locations will be ready to move into, where others will require up to $500,000 in investment to prepare for use. Based upon this data we were able to assess scores for these locations using the formula:

$$Cost\ Rating = \left(1 - \frac{NPV}{\$750{,}000}\right)$$

Additionally, we were able to discuss with the World Food Programme projected costs for each of the proposed locations, and built an overall set of scores based upon these discussions.

	Cost
Degehabar	1.67
Dire Dawa	1.18
Fik	2.5
Gode	1.67
Jijiga	5
Kebridehar	3
Mustahil	2.5
Nazareth	3.71
Warder	1.5

Table 10 - Cost Score

These numbers are very high level estimates; however, we can estimate the cost by having some idea of where the government will sponsor a warehouse, or by identifying areas where the rent/buy decision is fairly straightforward. The model can be adjusted during the implementation phase as quotes are received from warehouses within a location to see how the new numbers impact the decision.

4.4.2 Regional Stability

To evaluate regional stability, we first attempted to look at UN security classifications, which operate on a scale of 1-5, with a score of 1 being a completely safe location, and a score of 5 signaling the need to evacuate all possible personnel. However, the UN security classifications were not sufficiently detailed at the city or woreda level to discern between different portions of the Somali Region. Therefore, as a secondary course of action, we combined information regarding escort requirements with the Famine Early Warning System's food security outlook for the second quarter of 2009, scoring regions with low food security and escort requirements as the least stable, and regions with high food security and no escort requirements as the most stable. Figure 20 shows the map we obtained from the Famine Early Warning System's food security outlook of 2009.

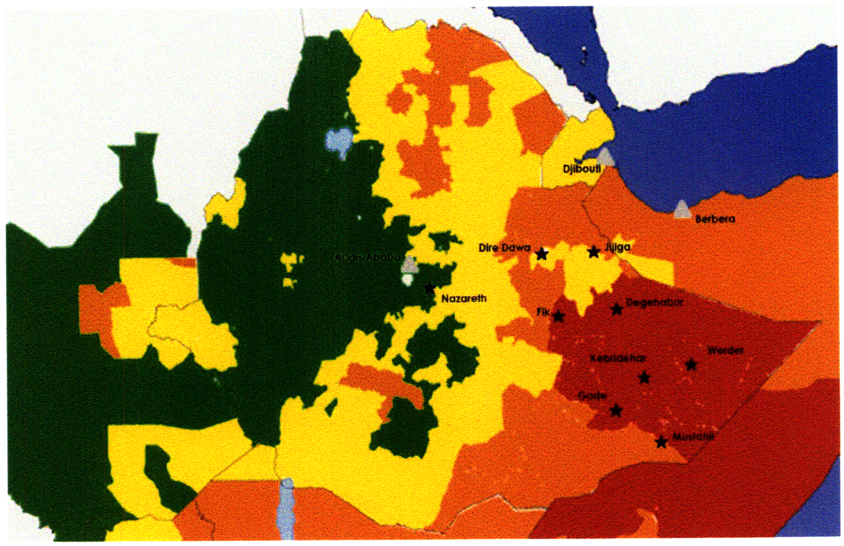

Figure 20 - Food Security Q2 2009 Outlook

There are some inherent flaws in this methodology, as neither of these metrics necessarily has a high level of correlation with regional stability. Escort requirements can be imposed on the basis of unrest in a region, but political motivations can also be a rationale, and routes that travel through an unstable region into a stable region may have an escort the entire way. In regards to the food security, while it would make sense that regions where food security is low would be more prone to civil unrest, it only explains some of the stability in a region since there is a complex political situation occurring in the Somali region that contributes significantly to the regional stability.

With these assumptions in mind, we used this as a starting point to develop baseline scores for each region, blending the escort requirements (as a binary function) with the food security map to determine areas of greatest potential instability. Once the scores were developed, we engaged in a discussion with the World Food Programme where the numbers were adjusted to incorporate their local knowledge of the region, improving the accuracy of our estimations. The results are as follows:

	Regional Stability
Degehabar	2
Dire Dawa	2
Fik	3
Gode	2
Jijiga	2
Kebridehar	1
Mustahil	2
Nazareth	4
Warder	1

Table 11 - Regional Stability Scoring

4.4.3 Adequacy of Infrastructure – Security

To evaluate the quality of the security at the potential facility locations, we came up with a checklist of items that we felt would be significant elements to the security of a warehouse. Table 12 shows the questions that were asked, as well as a rescaled point system, adjusted to account for the fact that none of the facilities had video capabilities. Based upon the response of the field officers, up to nine points were assessed for each of the warehouse locations.

Guard	**3 points**
Off premise security	1
On-premise security	2
On-premise security (armed)	3
Barrier	**2 points**
None	0
Chain link perimeter fence	0.5
Chain link perimeter fence w/	1
Barrier Wall	1.5
Barrier Wall w/ barbed wire	2
Video	**N/A**
Video cameras installed (not active)	N/A
Video cameras w/ live feed	N/A
Video cameras w/ live feed,	N/A
Lighting	**2 points**
No lighting	0
General lighting	2
Motion sensor lighting	2
General lighting w/ motion sensor	2
Access control	**2 points**
No access controls	0
Key and lock system	1
Badge checked by guard	2

Table 12 - Security Evaluation Framework

Proposed locations had security capabilities assessed using population and regional stability as proxies, with larger and less food secure regions having superior security ratings, as shown in Table 13.

	Security
Degehabar	7
Dire Dawa	6.5
Fik	3
Gode	8
Jijiga	5
Kebridehar	4.5
Mustahil	3
Nazareth	4.5
Warder	3

Table 13- Security Scoring

4.4.4 Adequacy of Infrastructure – Building Capacity

Building Capacity was initially measured using the Facilities Evaluation Form, asking for square footage. Upon receipt of the initial results there was discrepancy in measurement, with some answers in metric tons, some in square meter, and some in square footage. As a result of this we chose to standardize to metric tonnage, and the WFP team was able to provide some more accurate numbers based upon this adjusted metric. For the three proposed warehouse locations we modeled the capacity in a linear fashion and found that the numbers were so low as to be unreasonable, so used 1,500 metric tons as a minimum metric tonnage for a warehouse, as shown in Table 14:

	Building Capacity
Degehabar	4,220
Dire Dawa	32,000
Fik	1,500
Gode	5,110
Jijiga	10,000
Kebridehar	1,500
Mustahil	1,500
Nazareth	59,800
Warder	1,500

Table 14- Building Capacity Scoring

4.4.5 Adequacy of Infrastructure - Facility Conditions

For Facility Conditions we used the responses to the Facilities Evaluation Form as our guiding metric, having the field officers assess current facility conditions on the following scale:

Facility Conditions:

Poor	*Below Average*	*Average*	*Above Average*	*Excellent*

Table 15 - Facility Conditions Evaluation

Based upon this response we then drew a correlation between population and geographical location, and extrapolated that into values for the proposed warehouse locations. Based upon this approach we achieved the following results:

	Facility Conditions
Degehabar	4
Dire Dawa	4
Fik	2
Gode	3
Jijiga	3
Kebridehar	2
Mustahil	1
Nazareth	2.5
Warder	2

Table 16- Facility Conditions Scoring

4.4.6 Adequacy of Infrastructure – Road Quality

Initially we researched the potential of using the World Food Programme's existing spatial data that contained route information along with metadata identifying the method of construction of the road (Dirt/Gravel/Tarmac). However, as we progressed through the project we realized that this was not a scalable solution; the quality of spatial data within different regions of Ethiopia, and Africa varies greatly. Therefore, we could not be certain whether this data would be available for other implementations of this model. Instead we determined that local resources could provide similar information, eliminating the need for the spatial data by having the local field officers complete a portion of the Facilities Evaluation Survey.

Road Quality:

Dirt only – Seasonally Affected	*Dirt only – Not Seasonally Affected*	*Gravel Roads – Not Seasonally Affected*	*Tarmac Road*	*> 1 Tarmac Road*

Table 17 - Road Quality Evaluation

It is important to determine two characteristics in order to evaluate road quality; first, the existing conditions of the road and second, if these roads are seasonally affected or not. When the rains in Ethiopia arrive, flooding is common in certain regions, and dirt roads will get wiped away, leaving no path for larger trucks to make deliveries to or from an Extended Delivery Point. The remainder of the options helped us understand the ability for large trucks to traverse the region; this is a proxy for the area surrounding the location as well as location itself (e.g. the presence of more than one tarmac road would signify extensive development within the region). For the three proposed warehouse locations, we assumed that road quality would be a function of population, as areas with higher populations require greater infrastructure to account for the increased trade.

	Road Quality
Degehabar	1
Dire Dawa	3
Fik	2
Gode	1
Jijiga	3
Kebridehar	1
Mustahil	1
Nazareth	4
Warder	1

Table 18 - Road Quality Scoring

4.4.7 Location – Access to Support Services

To evaluate Access to Support Services we determined that a simplistic proxy was required. We chose acquisition of goods outside of the location as our metric, asking the field officers to respond to the following.

Access to Support Services: Proximity to support facilities, proximity to supplies (boxes, office supplies, anything that may be needed in order to deliver the food to beneficiaries), proximity to metropolitan areas.

How easy is to obtain supplies/support?

Score	Description
1	IMPOSSIBLE
2	HARD - Supplies are EXPENSIVE
3	HARD - Supplies are CHEAP

4	EASY - Supplies are EXPENSIVE
5	EASY - Supplies are CHEAP

Table 19 - Access to Support Services Evaluation

Using this information we then worked with the World Food Programme's central team to make determinations as to the accuracy of the data, adjusting for local bias, and then estimated values for the three proposed warehouse locations on the basis of their geographic location, with results being show in Figure 24.

	Access to Support Services
Degehabar	3
Dire Dawa	2
Fik	1.5
Gode	2
Jijiga	2
Kebridehar	2
Mustahil	1
Nazareth	2
Warder	1

Table 20- Access to Support Services Scoring

We found that in almost all cases the procurement of goods proved to be relatively difficult, even in areas such as Nazareth which are relatively close to major metropolitan areas. As a result, the stratification we would seek to see in an end-node was not visible here. This is an important insight which may lead to the conclusion that this should not be a deciding factor as it appears that regardless of location, procurement of support services is a challenge.

4.4.8 Location – Proximity to Beneficiaries

Proximity to Beneficiaries was the most difficult metric to tackle for a few reasons. First, this metric has a high level of significance in the overall decision, making it crucial that the assessment be accurate. Second, there is very limited information available as to where the greatest need exists in terms of population; current WFP delivery numbers provided a basic proxy, but to ensure scalability we chose to avoid the use of this information, since it may not be available in all instances. Instead, we chose to rely on a combination of the Famine Early Warning System's second quarter food security risk outlook and the Transportation and Location Evaluation survey as a basis for evaluation, asking the following question:

How many beneficiaries would be served by a warehouse in this region? How easily could they be reached?

Score	Description
1	NONE
2	SMALL – hard to reach
3	SMALL - easy to reach
4	LARGE – hard to reach
5	LARGE – easy to reach

Table 21 - Proximity to Beneficiaries Evaluation

	Proximity to Beneficiaries
Degehabar	4
Dire Dawa	4
Fik	3
Gode	4
Jijiga	4
Kebridehar	5
Mustahil	4
Nazareth	2
Warder	5

Table 22- Proximity of Beneficiaries Scoring

We received the results above from the local field officers, but in evaluation determined that there were two significant biases that may have affected the numbers. First, the groups of beneficiaries that these locations are servicing may be near them, but that does not necessarily mean that the location is best situated to serve the overall distribution. Additionally, field officers may have only a limited view into the distribution to the final destination points, placing more of a focus on the overland leg of the transportation, since the last leg is typically contracted out and therefore not as closely monitored.

4.4.9 Location – Access to Ports of Entry

To determine the ease of access to ports of entry, the WFP provided us output from ESRI's ArcGIS software tool's Network Analyst extension *(www.esri.com/networkanalyst)* that measured the distance to the three main ports, Djibouti, Berbera, and Addis Ababa (which while landlocked is a source of food aid and is therefore grouped as a port) as well as the average transit time based upon the road types. Our assumption was that paved roads could be traveled on at a rate of 60 km/hr, gravel roads at a rate of 40 km/hr, and dirt roads at a rate of 20 km/hr. Based upon this we then created a weighted average of travel time from the ports, where: $Access\ to\ Ports\ of\ Entry\ Score = 1/(.1 * (Addis\ Ababa\ to\ WH) + .35 * (Berbera\ to\ WH) + .55 * (Djibouti\ to\ WH))$

The assignment of these weights was made on the basis of the relative importance that was determined in discussion with the World Food Programme and on the current distribution numbers by port.

	Access to Ports
Degehabar	0.0920
Dire Dawa	0.1333
Fik	0.0723
Gode	0.0511
Jijiga	0.1226
Kebridehar	0.0637
Mustahil	0.0465
Nazareth	0.0793
Warder	0.0621

Table 23- Ports of Entry Scoring

4.4.10 Transportation - Access to Commercial Markets

To determine the scoring for Access to Commercial Markets we asked the field officers to respond to the Transportation and Location Survey on order to determine the ability to conduct bids in the region and by using the following scale:

Score	Description
1	POOR
2	BELOW AVERAGE
3	AVERAGE
4	ABOVE AVERAGE
5	EXCELLENT

Table 24 - Access to Commercial Markets Evaluation

The following table summarizes the results for each warehouse alternative.

	Access to Commercial Markets
Degehabar	2
Dire Dawa	3
Fik	1
Gode	1
Jijiga	3
Kebridehar	2
Mustahil	1
Nazareth	3
Warder	1

Table 25 - Access to Commercial Markets Scoring

4.4.11 Transportation – Availability of Carriers

The availability of carriers was determined using the Transportation and Location Evaluation Survey, asking the following question:

Approximately how many carriers are available in the region?

Score	Description
1	NONE
2	NONE but carriers may be available within a year
3	SMALL
4	ENOUGH
5	MORE THAN ENOUGH

Table 26 - Availability of Carriers Evaluation

Based upon the results that we received back from the field officers for the existing warehouse locations, we created estimates for the three potential new locations based upon proximity to other cities. Our assumption was that if the location is near one of the existing locations the same set of carriers would be able to service it. Additionally, a factor was incorporated for how remote the proposed location was and the population of the location, in that some of the carriers may not wish to provide service if it is a small site far from other metropolitan locations.

	Availability of Carriers
Degehabar	3
Dire Dawa	3
Fik	1
Gode	3
Jijiga	4
Kebridehar	3
Mustahil	2
Nazareth	4
Warder	2

Table 27 - Availability of Carriers Scoring

4.4.12 Transportation – Quality of Carriers

The quality of the carriers servicing a location was determined using the Transportation and Location Evaluation Survey, asking the following question:

Reliability: On time delivery, goods have not been damaged, professionalism of carriers.

What is the reliability of the carriers within the region?

Score	Description	
1	POOR	
2	BELOW AVERAGE	
3	AVERAGE	
4	ABOVE AVERAGE	
5	EXCELLENT	

Table 28 – Quality of Carriers Evaluation

These answers were then extrapolated to evaluate the three proposed warehouse locations in a fashion similar to the availability of carriers, assuming a shared carrier network and that carriers would provide similar service across locations.

	Quality of Carriers
Degehabar	3
Dire Dawa	3
Fik	1
Gode	3
Jijiga	3
Kebridehar	2
Mustahil	2
Nazareth	3
Warder	2

Table 29 - Quality of Carriers Scoring

4.4.13 Scoring Summary

From this scoring exercise we can see some general trends; remote locations scored higher in proximity to the beneficiaries, but lower in areas surrounding infrastructure and Access to Ports. In Section 4.5 we aggregate these scores using the priorities identified within Section 4.2-4.3 (prioritization) to see how these scores fit into an overall fitness score. Based upon the criteria established within this Section, all the data collected is easily acquired, scalable, and relevant, and while future iterations of the model may increase the accuracy and relevance of the data, this is a great starting point for evaluation.

4.5 Evaluation

Since we elected not to use pairwise comparison matrices, the normalization process was simplified, dividing each alternative score within an end-node by the summation of all alternative scores within that end-node so that all the scores will then add up to one. The following table summarizes the scores for each alternative given the different criteria/attribute.

Alternatives	*Security*	*Building Capacity*	*Facility Conditions*	*Road Quality*	*Access to Support Services*	*Proximity to Beneficiaries*	*Access to Ports*	*Access to Commercial Markets*	*Availability of Carriers*	*Quality of Carriers*	*Cost*	*Regional Stability*
Nazareth	0.1011	0.5105	0.1064	0.2353	0.1212	0.0571	0.1097	0.1765	0.1600	0.1364	0.1632	0.2105
Kebridehar	0.1011	0.0128	0.0851	0.0588	0.1212	0.1429	0.0881	0.1176	0.1200	0.0909	0.1320	0.0526
Degehabar	0.1573	0.0360	0.1702	0.0588	0.1818	0.1143	0.1273	0.1176	0.1200	0.1364	0.0735	0.1053
Dire Dawa	0.1461	0.2732	0.1702	0.1765	0.1212	0.1143	0.1844	0.1765	0.1200	0.1364	0.0519	0.1053
Fik	0.0674	0.0128	0.0851	0.1176	0.0909	0.0857	0.1000	0.0588	0.0400	0.0455	0.1100	0.1579
Gode	0.1798	0.0436	0.1277	0.0588	0.1212	0.1143	0.0707	0.0588	0.1200	0.1364	0.0735	0.1053
Jijiga	0.1124	0.0854	0.1277	0.1765	0.1212	0.1143	0.1696	0.1765	0.1600	0.1364	0.2200	0.1053
Mustahil	0.0674	0.0128	0.0426	0.0588	0.0606	0.1143	0.0643	0.0588	0.0800	0.0909	0.1100	0.1053
Warder	0.0674	0.0128	0.0851	0.0588	0.0606	0.1429	0.0859	0.0588	0.0800	0.0909	0.0660	0.0526

Table 30 - Normalized Scoring Matrix

Once the matrices have been normalized, we then need to perform an aggregation, multiplying the Relative Fitness score of each alternative by the Cumulative Relative Priority of that end node. For each end node that is an attribute indentured to a criterion, this would be the priority of the attribute relative to the other attributes in the cluster indentured to a criteria, multiplied by the Relative Priority of the criteria relative to the goal statement. At this point, we can take a summation of all end nodes for each alternative, to come to a percentage value representing the overall level of fitness of that alternative for the goal statement. This is illustrated in Table 31. As a consistency check, the summation of all end nodes for all alternatives should be equal to 100%.

Alternative	Security	Building Capacity	Facility Conditions	Road Quality	Access to Support Services	Proximity to Beneficiaries	Access to Ports	Access to Commercial Markets	Availability of Carriers	Quality of Carriers	Cost	Regional Stability	Raw Score
Jijiga	0.0057	0.0011	0.0007	0.0043	0.0168	0.0384	0.0131	0.0013	0.0073	0.0039	0.0186	0.0198	0.1310
Nazareth	0.0051	0.0067	0.0005	0.0057	0.0168	0.0192	0.0085	0.0013	0.0073	0.0039	0.0138	0.0397	0.1286
Degehabar	0.0079	0.0005	0.0009	0.0014	0.0253	0.0384	0.0098	0.0009	0.0055	0.0039	0.0062	0.0198	0.1205
Dire Dawa	0.0074	0.0036	0.0009	0.0043	0.0168	0.0384	0.0142	0.0013	0.0055	0.0039	0.0044	0.0198	0.1205
Kebridehar	0.0051	0.0002	0.0004	0.0014	0.0168	0.0480	0.0068	0.0009	0.0055	0.0026	0.0112	0.0099	0.1088
Gode	0.0091	0.0006	0.0007	0.0014	0.0168	0.0384	0.0055	0.0004	0.0055	0.0039	0.0062	0.0198	0.1083
Fik	0.0034	0.0002	0.0004	0.0028	0.0126	0.0288	0.0077	0.0004	0.0018	0.0013	0.0093	0.0298	0.0987
Mustahil	0.0034	0.0002	0.0002	0.0014	0.0084	0.0384	0.0050	0.0004	0.0036	0.0026	0.0093	0.0198	0.0929
Warder	0.0034	0.0002	0.0004	0.0014	0.0084	0.0480	0.0066	0.0004	0.0036	0.0026	0.0056	0.0099	0.0907

Table 31 - Priority Adjusted Normalized Matrix

To place the numbers into a more traditional scoring model, we can then normalize them in terms of fitness relative to the best option by dividing each raw score by the highest ranked alternatives raw score:

Alternative	Normalized Fitness Score
Jijiga	100%
Nazareth	98%
Degehabar	92%
Dire Dawa	92%
Kebridehar	83%
Gode	83%
Fik	75%
Mustahil	71%
Warder	69%

Table 32 - Priority Percentages of each Alternative

4.6 Sensitivity Analysis

Based upon these scores, we can see that there is a strong level of stratification with a fairly constant reduction in scoring between an option and its next best alternative. Given the range of normalized scores from 69% up to 100% we can say with a high level of confidence that the choices are sufficiently segregated for the purpose of evaluation. A key point to mention is that this model is not intended to serve as an end-all to the discussion of warehouse location, but rather establish a framework for prioritizing options. Real world implementation of a solution frequently requires compromise, and so it is essential that the solution is viewed as a list of potential options ranked in terms of fitness as opposed to one single solution.

To gain a deeper level of understanding into the workings of the Analytic Hierarchy Processes decisions in selecting an optimal warehouse location, we ran a series of variations to the model, adding and removing criteria and attributes, and changing the priorities to see whether the results would vary differently. Specifically, we looked at evaluating just the five most important end-nodes to see if an application of the 80/20 rule could simplify the scoring process. We did an evaluation of an alternative's population and its effect on the overall score. And we removed the regional stability to understand how much influence it has in the model given that the level of confidence in the dataset used for evaluation is relatively low. Additionally, we looked at the effect of using the unadjusted relative priorities for the primary cluster and the location cluster, as they were modified outside of the model and therefore they were a potential bias in the model.

4.6.1 Modeling with the Top Five End-nodes

One of the key findings of the prioritization phase was that the top five most important criteria/attributes represented 83% of the overall decision, meaning that the opportunity might exist to make an effective decision looking only at the top five and eliminating more than half of the data collection effort. To test this theory we ran the model removing the lower seven end-node criteria/attributes to see if the results would be drastically different.

Alternative	Normalized Fitness Score	Top 5 Normalized Fitness Score	Spread
Jijiga	100%	100%	0%
Nazareth	98%	92%	-6%
Degehabar	92%	93%	1%
Dire Dawa	92%	88%	-4%
Kebridehar	83%	87%	4%
Gode	83%	81%	-1%
Fik	75%	83%	7%
Mustahil	71%	76%	5%
Warder	69%	74%	4%

Table 33 -12-Criteria Percentage Results versus 5-Criteria Percentage Results

From this we can see that there was not a significant change in the normalized scoring, with a mean absolute change of 3.7%, leading us to believe that the use of just the top five end-nodes would allow for a quick and relatively accurate assessment. To validate this assumption we also reviewed the change in rankings to see if the overall order of warehouse locations was significantly modified:

Alternative	Old Rank	New Rank
Jijiga	1	1
Nazareth	2	3
Degehabar	3	2
Dire Dawa	4	4
Kebridehar	5	5
Gode	6	7
Fik	7	6
Mustahil	8	8
Warder	9	9

Table 34 -12-Criteria Rankings versus 5-Criteria Rankings

From this chart we can see that there was very little movement overall in the rankings, with no option increasing or decreasing by more than one rank. Given the fact that the ranking is not a hard and fast decision but rather a guidance tool, this amount of change is acceptable, and therefore in this instance five metrics would have been effective. The effectiveness of using only five end-nodes empirically remains to be seen, but this allows for the possibility of having a simple heuristic for placing warehouse capacity.

4.6.2 Evaluating the Significance of Population

In addition to identifying the ability to rely upon the five most important end-nodes in making a decision, we can see that when evaluating only the top five nodes, the alternatives that increased most significantly in their ranking were Fik, Mustahil, Warder, and Kebri Dahar. The common thread among these four locations is that they are the four smallest locations within the set of alternatives. While population was used as a proxy in determining scores for the three new locations in the seven less important end-nodes that were not included in the analysis, the fact that Kebridehar's score increased drastically lends credibility to the concept that population may be a key driver in the overall evaluation, specifically with the seven less important end-nodes. To test this we ran a regression of the raw scores against the population for each alternative, as well as the raw score of just the seven less important end-nodes against the population for each alternative. While population only explains 39% of the overall raw score, 65% of the raw score for the seven less important end-nodes was explained by population. A breakdown of correlation by each end-node helps to gain some further insight into why this is:

Alternative	Correlation
Building Capacity	67%
Access to Commercial Markets	59%
Road Quality	58%
Access to Ports	47%
Quality of Carriers	33%
Facility Conditions	33%
Availability of Carriers	27%
Security	14%
Regional Stability	14%
Proximity to Beneficiaries	14%
Access to Support Services	8%
Cost	0%

Table 35 - 12-Criteria Rankings versus 5-Criteria Rankings

Building Capacity, Access to Commercial Markets, and Road Quality, and Access to Ports all show very high levels of correlation to population, which would make intuitive sense, since larger areas typically have superior infrastructure, and are located with access to main ports. The surprising result however is the correlation between Access to Commercial Markets, but the lack of correlation to Availability to Carriers and Quality of Carriers. These would intuitively have a high level of correlation, since in a location where there exists a wide variety of quality carriers issuing a tender should be a fairly routine process. In speaking with the World Food Programme, they stated that they felt that there were not cultural issues that would make tendering easier or more difficult depending on the region or based on population, leading us to question the accuracy of the scoring of Access to Commercial Markets.

4.6.3 Modeling with Regional Stability Removed

Regional Stability proved to be one of the most challenging criteria to obtain reliable data for. Therefore, we chose to run a sensitivity analysis evaluating the impact of removing Regional Stability from the equation.

Alternative	Normalized Fitness Score	W/O Regional Stability Normalized Fitness Score	Spread
Jijiga	100%	100%	0%
Nazareth	98%	80%	-18%
Degehabar	92%	91%	-1%
Dire Dawa	92%	91%	-1%
Kebridehar	83%	89%	6%
Gode	83%	80%	-3%
Fik	75%	62%	-13%
Mustahil	71%	66%	-5%
Warder	69%	73%	3%

Table 36 – Results with and without Regional Stability

These results provide us significant insight into why Nazareth was selected as the second selection, as it is located in the most stable area of any of the locations. In determining the relative priorities of the criteria the World Food Programme had asked us to reduce the importance of Regional Stability, and we had adjusted it to reflect their intentions, however it is possible that the effect of Regional Stability is still too high, skewing our results.

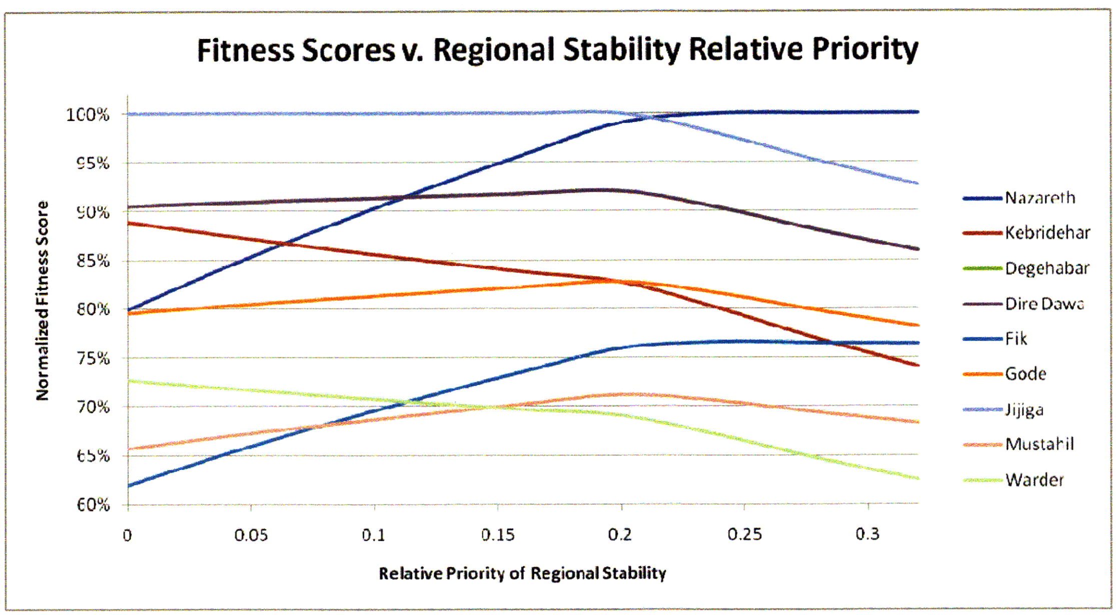

Figure 21 - Normalized Fitness Score versus Regional Stability Relative Priority

Conducting a sensitivity analysis, we can see that when the Relative Priority of Regional Stability is low (<.18) Jijiga is the optimal selection, but as the relative priority increases, Nazareth has the highest fitness score. The normalized fitness scores of the other alternatives see a sharp decline at this point due to the high score Nazareth has in Regional Stability, which serves to raise its raw score significantly as the relative importance increases (since Nazareth's raw score increases at a rate much quicker than those of the other alternatives the normalized fitness shows a decrease). Based upon this analysis, the World Food Programme can re-evaluate the level of emphasis they placed on Regional Stability, and make a determination of warehouse location based upon a given Regional Stability relative priority.

4.6.4 Evaluation Using the Original Primary Criteria and Location Attribute Weightings

Since we had modified the prioritizations of the primary criteria and location attribute clusters during the prioritization (Section 4.2), we need to test to understand the impact on the model. To do so, we inserted the original relative priorities in both instances to see what the impact would be:

Alternative	Normalized Fitness Score	Normalized Fitness Scores - Unadjusted Primary Criteria Weightings	Spread
Jijiga	100%	91%	-9%
Nazareth	98%	100%	2%
Degehabar	92%	85%	-7%
Dire Dawa	92%	82%	-10%
Kebridehar	83%	78%	-5%
Gode	83%	77%	-6%
Fik	75%	70%	-5%
Mustahil	71%	67%	-4%
Warder	69%	61%	-9%

Table 37- Normalized Scores for Original Primary Criteria Prioritizations

By modifying the priorities to reflect the initial results with an increased focus on Regional Stability we achieve a similar result as during our sensitivity analysis where Nazareth takes a clear leadership position due to the high score it received on Regional Stability. This again suggests that the World Food Programme should be taking a very detailed look at the weight that they have attributed to Regional Stability when making this decision.

Alternative	Normalized Fitness Score	Normalized Fitness Scores - Unadjusted Location Attributes Weightings	Spread
Jijiga	100%	80%	-20%
Nazareth	98%	100%	2%
Degehabar	92%	97%	5%
Dire Dawa	92%	85%	-7%
Kebridehar	83%	90%	7%
Gode	83%	70%	-12%
Fik	75%	70%	-5%
Mustahil	71%	63%	-8%
Warder	69%	59%	-10%

Table 38 - Normalized Scores for Original Location Attribute Prioritizations

When using the original relative priorities for the location cluster Nazareth is the clear leader, although Degehabur is in close proximity. Both of these locations are benefiting from the fact that while they have great Access to Ports of Entry, they lack Proximity to Beneficiaries. This seems to be a common tradeoff within this model, as the further the overland line haul, the closer you will be to the end beneficiary. As illustrated on Figure 22, as the relative priority of Proximity of Beneficiaries increases, the disparity of scores decreases as the more remote locations' raw scores increase quicker. This is due to their high ranking in Proximity of Beneficiary as opposed to their lower scores in Access to Ports. With this knowledge the World Food Programme can make the decision as to which of these two attributes is more important, and see how this will affect the scores.

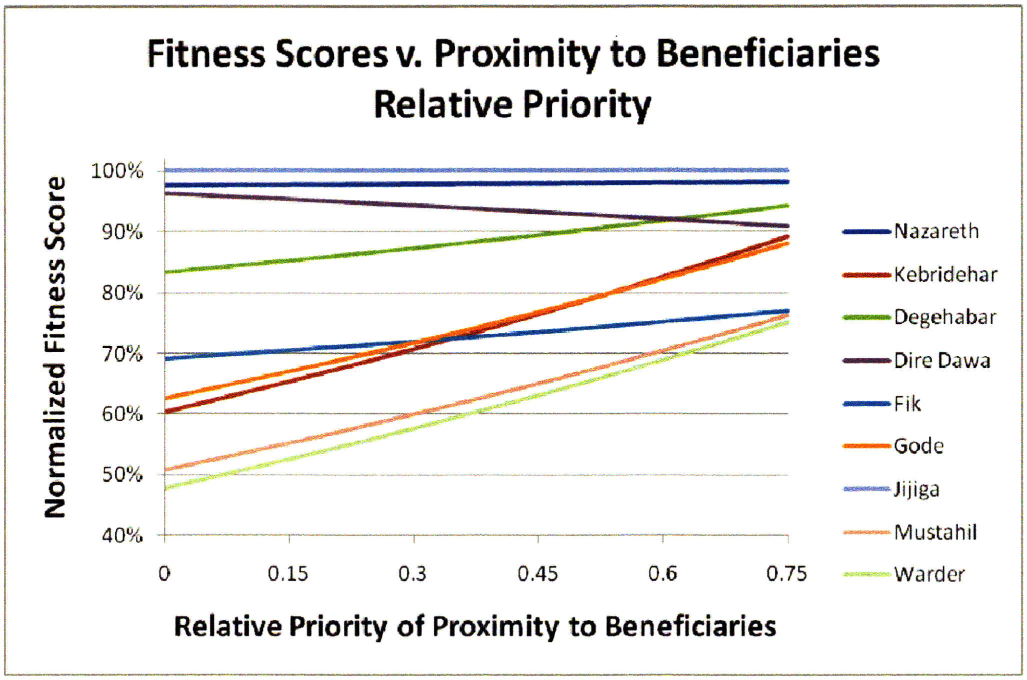

Figure 22 - Fitness Scores v. RP of Proximity to Beneficiaries Tradeoff

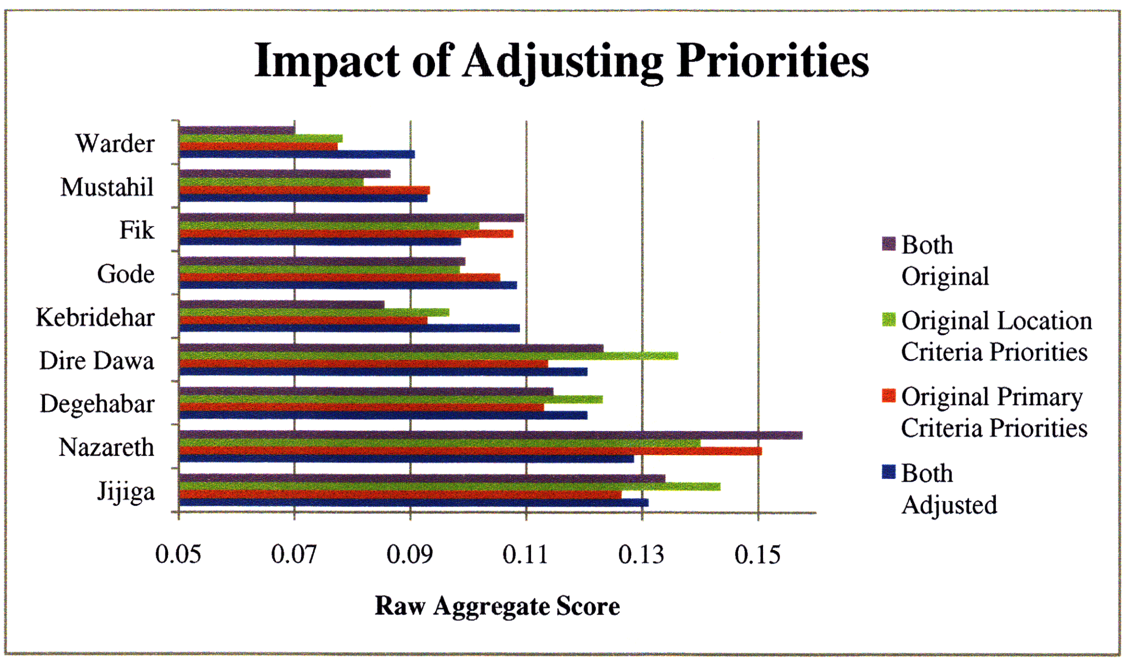

Figure 23 – Summary of Priority Adjustment Results

Alternative	Both Adjusted	Original Primary Criteria Priorities	Original Location Criteria Priorities	Both Original
Jijiga	0.1310	0.1264	0.1434	0.1340
Nazareth	0.1286	0.1505	0.1401	0.1576
Degehabar	0.1205	0.1131	0.1231	0.1147
Dire Dawa	0.1205	0.1137	0.1362	0.1233
Kebridehar	0.1088	0.0929	0.0966	0.0855
Gode	0.1083	0.1054	0.0985	0.0994
Fik	0.0987	0.1077	0.1018	0.1096
Mustahil	0.0929	0.0933	0.0819	0.0866
Warder	0.0907	0.0774	0.0783	0.0698

Table 39 – Raw Scores by Alternative for Original and Adjusted Priorities

5 Conclusion

To conclude we will begin by reviewing the structure and findings of each section within this document, then moving to discuss its contributions, limitations, and extensions of using the Analytic Hierarchy Process for and optimal warehouse location decision before finally wrapping up with some closing remarks.

5.1 Review

In Section 1 (World Food Programme Operations in the Somali Region) we present a discussion of the problem, along with the key actors, and a background of the region in which we are operating within. The key takeaways are that the Somali Region of Ethiopia is in desperate need of assistance, and with budget constraints always existent; getting food aid to beneficiaries in the most efficient manner possible is a must. This is furthered within Section 2 (Introduction) where we outline specifically the problem we have attempted to solve, in placing an additional warehouse within the Somali Region of Ethiopia. In Section 3(Literature Review) we look at the previous works available in the humanitarian supply chain sector, on the current situation in Ethiopia, and surrounding previous uses of the Analytic Hierarchy Process and qualitative data collection. All of these fields have a reasonable amount of literature available, but our work is the first work to bridge the field between humanitarian logistics and multiple attribute decision making for strategic decisions. In Section 4 (The Analytic Hierarchy Process and its Application) we engage in a detailed discussion of the Analytic Hierarchy Process and its application specific to selecting an optimal warehouse location in Ethiopia. We begin by showing the techniques employed to deconstruct the problem into its key criteria and attributes, and we then demonstrate how the WFP engaged in a prioritization exercise using pairwise comparison matrices to identify the relative priority of each end-node. From this, we then discuss how we evaluated each of the warehouse location site alternatives, including the approach, the results, and a discussion of each dataset. Finally, we explained the process to synthesize and aggregate this data into a final output, and finally conducted a sensitivity analysis to look at the effect of removing or adjusting the relative priority of different end-nodes.

5.2 Contributions of the Model

Based upon the analysis conducted there are three key contributions that we feel are worth highlighting, given their somewhat empirical nature and their particular salience to this thesis, which are formalizing the factors for analysis, promoting critical thinking about the strategic decision, and encouraging open team discussion and collaboration.

Formalizing factor for analysis proves to be perhaps the most valuable effect of using the Analytic Hierarchy Process for decisions with minimal information available. Previously, decisions were made in a highly informal manner, with intuition and historic knowledge being the driving forces, but with little discussion of what the true rationale for the decision is, or with the rationale focused around a single driver. What we see with the use of the AHP model is still a pre-causal analysis of the problem (Saaty 1980), we have not conducted sufficient analysis to understand whether the criteria and attributes identified are truly relevant, and if so whether the relative prioritization is correct, but by providing structure to the problem we are able to unfold the decision process currently being conducted, shedding light on how the decision makers are viewing this issue.

Additionally, by creating a hierarchal structure, the decision makers are forced to think critically about how they are conducting the valuation, specifically on whether they are placing the emphasis on the correct issues during the decision making process. Understanding what each of the different areas of evaluation are, and seeing how each alternative fares within each area allows the decision maker to engage in a series of tradeoffs, seeing what they are sacrificing (and gaining) by the selection of an alternative.

Finally, the Analytic Hierarchy Process is a great platform for encouraging fruitful discussion between team members about what truly matters in making a decision, and how different alternatives should be ranked. As a corollary of this, the overall quality of the decision will improve, and buy-in from other members from the organization will be considerably easier to obtain, as they have already played some sort of role in the decision making process.

5.3 Limitations of the Model

In selecting an optimal warehouse location using the Analytic Hierarchy Process there are some clear shortcomings, primarily focused around the prioritization and scoring phases. The complexity of the AHP model creates the possibility that users may misinterpret the interface when determining relative priorities, leading to unexpected results, and within the scoring section the disparate nature of the data and the need to use a significant amount of intuition in evaluation leads to some discussion over the quality of the scoring data.

When completing the pairwise comparison matrices to determine the relative prioritizations of the criteria and attributes, the level of complexity in the model may have made the true process so obfuscated that the correct results were not obtained. We saw this in the prioritization of the primary criteria, as well as in the prioritization of the location attributes, where the expected outcome did not occur. We chose in speaking with the World Food Programme to modify the results to pass a 'sanity check', but in doing so introduced a significant amount of bias into the model. It is entirely possible that even though the WFP felt as though location was the key criteria, regional stability could have truly been the most important criteria.

In a full implementation of the Analytic Hierarchy Process, we would have ideally had all stakeholders complete a prioritization of each cluster to increase the level of confidence of our results, and in a situation like that would have urged the WFP to keep the outcomes, but with only one prioritization being conducted, even though multiple members of the team contributed, we felt that most likely the true intention was not conveyed and chose to make the correction.

The data collection phase also offered up a variety of weaknesses, as most numbers within the evaluation framework relied on survey data from disaggregated sources, or from estimations created using limited hard data and intuition. In both instances the quality of the information can be called into question, and while the fact that we incorporate multiple attributes helps to balance out sets of misleading data, if heavily weighted datasets were significantly askew it could alter the outcome.

5.4 Monitoring and Evaluation

To be able to determine whether this method was truly effective in its goal of selecting the optimal warehouse location, a set of metrics need to be incorporated into the World Food Programme's monitoring and evaluation function to see whether the location we recommended is performing at the level it should be. Given that the prioritization phase uncovered the true drivers behind the location decision, we recommend that monitoring and evaluation should occur based around the five highest ranked end-nodes, which explained 83% of the overall decision (as discussed in Section 4.3.5).

Proximity to Beneficiaries – We recommend that this is measured using a miles or transportation cost / metric ton of food delivered. By normalizing this for the net tonnage distributed by each warehouse facility, we can account for the differences in scale of the warehouses. This is not a perfect measure, as economies of scale in densely populated regions might decrease the overall miles/metric ton, nor does it account for the fact that in an non-optimized network the load is not rationally distributed, but once a baseline is set it will serve to help

Regional Stability – Regional Stability should be measured in a two-pronged approach, looking at comparative loss statistics between locations (at the warehouse as well as within a 50 mile radius of transit surrounding the area) as well as looking at a measure of social unrest. For social unrest we think a proxy could be the level of military presence, since as military presence increases it may signal that they are in the process of defending an area that has become likely for a situation to erupt. These two would blend the two primary concerns, that food is being stolen, and that operations might become disrupted due to rebel uprising

Access to Support Services – The survey method proved to be fairly effective in our initial analysis, however with additional time we would have liked to improve the accuracy by asking about a specific basket of goods, having the field offices respond on the basis of both price and lead time. By looking at these two metrics averaged out over ten common items the World Food Programme should be able to develop a clear picture of the true ease of access for each of the warehouse locations.

Cost – This metric seems straightforward, but costing should occur at a fairly detailed level, beyond what the lease expense might be, to determine the true cost of each location. Labor, maintenance & repair, and depreciation of any capital investment to upgrade the facility should be included in the cost. Cost should not have a significant level of variance over time, but the baseline numbers we established need to be validated once the additional warehouse location has been opened.

Access to Ports – This is a fairly static value, and most likely relying on the geospatial data numbers as a constant is sufficient, but a baseline measure of average truck miles should confirm that the optimized overland route found using the geospatial data analysis package is in fact the one being traveled.

If these five key factors are effectively monitored, it will create two key benefits. First, it will improve the agility of the supply chain in reacting to shifts in demand of food aid, as spikes in miles / metric ton will be identified quickly, allowing for redistribution of the overall load. Additionally, should further increases in capacity be required, a significant portion of the evaluation of the current facilities will be already complete, allowing for an extremely efficient decision making process to occur.

5.5 Future Extensions of Analytic Hierarchy Process

Having seen the benefits of providing structure to a decision to require critical thinking, the two key steps that need to be taken to advance this scope of work are to implement a warehouse location optimization problem in other locations, and to implement alternative decisions using the AHP methodology in the same location. Implementing this model for a warehouse location optimization decision in other regions where the World Food Programme works allows us to see whether the priorities as they have been defined within this exercise are empirical, or regionally dependent. The impact of this would be that if the priorities are relatively empirical, a formalized framework for deciding on a warehouse location can be implemented into the World Food Programme's standard operating procedures, ensuring that warehouses locations are being optimized throughout their entire distribution network.

Additionally, by implementing the AHP framework for other decisions allows us to test the robustness of the model. The location of a warehouse is a fairly capital intensive decision, and would be categorized as strategic, but we should also be examining the opportunities to employ it for tactical decisions such as selecting an optimal port of entry to supply a warehouse, or even for operational decisions such as solving a vehicle routing problem. Current vehicle routing optimization programs use shortest distance algorithms, but if spatial data could be introduced that would allow for other factors to be included in the optimization a true total cost of delivery could be determined.

5.6 Concluding Remarks

No model is without its weaknesses, and in addressing a complex multiple attribute decision there is rarely one single approach or solution that is 'correct'. Rather, it is in the ability to structure the decision in a fashion that encourages critical thinking and allows for intuition to be developed that the Analytic Hierarchy Process derives its value. From this analysis there isn't a definitive best solution, but rather an array of alternatives with varying levels of fitness, whose levels of fitness are relative functions of the priorities of the end-nodes. In understanding this fact however we can come to some clear conclusions about the factors that a decision of this nature should be based upon, as well as determining a list of locations in a ranked format to assist with implementation.

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Reference List

Akkihal, A. R. (2006). *Inventory pre-positioning for humanitarian operations*. (Master's thesis, Massachusetts Institute of Technology, 2006).

Arminas, D. (2005, January). *Supply lessons of tsunami aid.* Supply Management, 10(2), 14. ABI/INFORM Global database.

Bagchi, P. K. (1989). *Carrier selection: The analytic hierarchy process.* Logistics and transportation review, 25(1), 63. ABI/INFORM Global database.

Bigsten, A., Shimeles, A., Kebede, B. (2005). *Poverty income distribution and labour markets in ethiopa*. Nordiska Afrikainstitutet.

Chinonye, U., Ogochukwu, U., Innocent C. O. (2006). *An analytic hierarchy process (AHP) Approach to port selection decisions - Empirical evidence from Nigerian ports.* Maritime Economics & Logistics, 8(3), 251-266. ABI/INFORM Global database.

Central Intelligence Agency (CIA): *The World Factbook 2009 – Ethiopia* [WWW Document] URL

https://www.cia.gov/library/publications/the-world-factbook/geos/et.html. (visited 2009, May 2).

Fews.Net (2008). : Food Security Outlook October 2008 – March 2009 [WWW Document] URL http://www.fews.net/docs/Publications/FEWS%20NET%20Food%20Security%20Outlook%20poster%20October%202008-March%202009.pdf (visited 2008, November 13).

Forman, E., Gass, S. (2001).Except from the *Analytical Hierarchy Process – An Exposition.* Operations Research 49.4: 469(18).

Humanitarian News and Analysis 2009: *Africa – Ethiopia* [WWW Document] URL http://www.irinnews.org/IRIN-Africa.aspx. (visited April 28, 2009)

Kovács, G., Spens, K. M. (2007). *Humanitarian logistics in disaster relief operations.* International Journal of Physical Distribution & Logistics Management, 37(2), 99-114. ABI/INFORM Global database.

Korpela, J., Tuominen, M. (1996). *A decision aid in warehouse site selection.* International Journal of Production Economics, *45*(1-3), 169-180.

López, M. (2006). *A study on the lead-times in the United Nations World Food Programme supply chain: a focus on the country offices* (Master's thesis, Massachusetts Institute of Technology, 2005).

Marinoni, O. (2004). *Implementation of the analytical hierarchy process with VBA in ArcGIS.* Computers & Geosciences, 30(6), 637-646.

Min, H. (1994). *Location planning of airport facilities using the analytic hierarchy process.* Logistics and Transportation Review, 30(1), 79. ABI/INFORM Global database.

Goentzel, J., Blanco, E. (2006). Traditional Supply Chain Flow. MIT Center of Transportation and Logistics. *Humanitarian Supply Chains: A Review* (2009) [WWW Document] URL http://ctl.mit.edu/public/mit_slides_humanitarian_sc_a_review_poms2006_blanco_goentzel.pdf. (visited 2009, May 3).

Mr. Simon Hacker, (phone conversation, October 22, 2008).

Shister, N. (2004, February). *Bringing best practices to emergency food logistics*. World Trade, 17(2), 36-38. ABI/INFORM Global database.

Saaty, T.L. (1980). *The Analytic Hierarchy Process*, McGraw-Hill Book Co., New York, NY

Saaty, T.L. (1977). *A scaling method for priorities in hierarchical structures.* Journal of Mathematical Psychology 15, 231–281.

Smirnov, A., Levashova T., Pashkin M., Shilov N., Komarova, A. (2007). *Disaster response based on production network management tasks*. Management Research News, 30(11), 829-842. ABI/INFORM Global database.

Wassenhove, V., Tomasini, R. (2009). *Humanitarian Logistics (INSEAD Business Press).* Palgrave Macmillan.

United Nations Office for Coordination of Humanitarian Affairs: *Ethiopia (UN OCHA-Ethiopia)* [WWW Document] URL http://www.ocha-eth.org/. (visited 2009, May 3).

Wassenhove, V. (2005, December). *Humanitarian aid logistics: Supply chain management in high gear*. Journal of the Operational Research Society.

World Food Programme. (2008).: *WFP Annual Report 2007* [WWW Document] URL http://www.wfp.org/policies/annual_reports/documents/2007_Ann_Rep_English.pdf (visited 2008, October 31).

World Food Programme. (2009).: *WFP Our Work* [WWW Document] URL http://www.wfp.org/our-work. (visited 2009, February 10).

Appendix

Sample Facilities Evaluation Form

Location Name: ____________________

Warehouse Name: __________________

Security Checklist:

Guard	
Off premise security	
On-premise security	
On-premise security (armed)	
Barrier	
None	
Chain link perimeter fence	
Chain link perimeter fence w/ barbed wire	
Barrier Wall	
Barrier Wall w/ barbed wire	
Video	
Video cameras installed (not active)	
Video cameras w/ live feed, no recording	
Video cameras w/ live feed, recording	
Lighting	
No lighting	
General lighting	
Motion sensor lighting	
General lighting w/ motion sensor lighting	
Access control	
No access controls	
Key and lock system	
Badge checked by guard	

Building Capacity:

__________________Square Feet

Cost:

Setup Cost - $ ____________

Lease Fees - $ ____________

Facility Conditions:

Poor	*Below Average*	*Average*	*Above Average*	*Excellent*

Road Quality:

Dirt only – Seasonally Affected	*Dirt only – Not Seasonally Affected*	*Gravel Roads – Not Seasonally Affected*	*Tarmac Road*	*> 1 Tarmac Road*

Sample Transportation and Location Evaluation Form

Location Name:

Warehouse Name:

Date:

Transportation – Availability of Carriers (Quantity):

Score	Description	
1	NONE	
2	NONE but carriers may be available within a year	
3	SMALL	
4	ENOUGH	
5	MORE THAN ENOUGH	

Approximately how many carriers are available in the region?

Transportation – Quality of Carriers:

Reliability: On time delivery, goods have not been damaged, professionalism of carriers.

What is the reliability of the carriers within the region?

Score	Description

1	POOR	
2	BELOW AVERAGE	
3	AVERAGE	
4	ABOVE AVERAGE	
5	EXCELLENT	

Transportation – Access to Commercial Markets:

Access to Commercial Markets: Ability to conduct bids in region based on robust supply

Rate the access to commercial markets:

Score	Description	
1	POOR	
2	BELOW AVERAGE	
3	AVERAGE	
4	ABOVE AVERAGE	
5	EXCELLENT	

Transportation – Access to Support Services:

Access to Support Services: Proximity to support facilities, proximity to supplies (boxes, office supplies, anything that may be needed in order to deliver the food to beneficiaries), proximity to metropolitan areas.

How easy is to obtain supplies/support?

Score	Description	
1	IMPOSSIBLE	
2	HARD - Supplies are EXPENSIVE	
3	HARD - Supplies are CHEAP	
4	EASY - Supplies are EXPENSIVE	
5	EASY - Supplies are CHEAP	

Transportation – Access to beneficiaries:

How many beneficiaries would be served by a warehouse in this region? How easily could they be reached?

Score	Description	
1	NONE	
2	SMALL – hard to reach	
3	SMALL - easy to reach	
4	LARGE – hard to reach	

5	LARGE – easy to reach	

Growth of beneficiaries:

The predicted number of beneficiaries is likely to:

Score	Description	
1	STAY CONSTANT With Possibility of slight Increase	
2	INCREASE 25%	
3	INCREASE 50%	
4	INCREASE 100%	
5	INCREASE more than 100%	