Food Security Network Modeling

Dr. Kenneth McDonald[1], Joshua Akers[1], Forrest Bartz[1], Daniel Beck[1], Israel Castro[1], and LTC Robert Prins[2]

[1]Department of Systems Engineering
United States Military Academy
West Point, NY

[2]Nuclear Science and Engineering Research Center
United States Military Academy
West Point, NY

Corresponding author's Email: Kenneth.McDonald@usma.edu

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Abstract: Food security creates a complex issue for American interests. Within a constantly expanding operational environment, food security remains a vital lifeline both domestically and abroad. Current methods of mapping an area's food system rely on ad-hoc assessments that produce skewed results and minimal metric analysis. Previous assessments methodologies failed to incorporate components of a food system that influences the overall stability of an area. The research conducted utilized the Systems Decision Process (SDP) to create a value hierarchy and model that provide an assessment for an areas food system. The findings from the research showcase that a food system relies on several variables such as infrastructure, dietary needs, and the national stability of a region. A more enhanced assessment model was developed that placed an overarching value to a food network that allows ground commanders to gain a holistic overview of the condition of an areas food system.

Keywords: Modeling, Assessment, Metric Analysis, Systems Decision Process, Civil Affairs Teams, Food Security, Food System, Food Distribution, System Dynamics

1. Introduction

World population growth has placed food security as a main issue within the national and international realm. Its direct consequences have an impact spanning from foreign relations to regional stability. The U.S. and other major nations have realized the tactical and strategic nature of food security within regional populations and thus have created a process of standardized assessments for local area food systems. The use of these current assessment methodologies through Civil Affairs Teams (CAT's) on site provides limited intelligence on the actual nature of a food system. The need to develop a robust model to assess local food security, so that nations can determine where to place resources is of great importance. The U.S. can also determine where to place its support to certain countries when dealing with food security.

The food distribution network (FDN) problem is a small part of a much larger challenge. This research consisted of a thorough understanding of FDNs and how they play a role in food security using techniques associated with systems dynamics. Additionally, an assessment model was developed that allows food security assessment for a given region. The emphasis is placed on developing an easy-to-use system for users so that assessments can be made quickly and efficiently. The current assessment system(s) are difficult to use and as a result have had limited success. The assessment model developed for this project is the Food Security Assessment Model (FSAM) which quantifies a FDN stability for a region. The model allows users to score each component of the FDN and produces an overall score that can be compared longitudinally over time. This serves as a useful tool and can initiate pre-emptive maintenance and security on a FDN.

2. Methodology

A value-focused thinking approach is necessary for this work and the Systems Decision Process (SDP) was used (Figure 1). The SDP allows a research construct that is extremely flexible, efficient and thorough. The four major phases of the SDP are: 1) problem definition; 2) solution design; 3) decision making; and 4) solution implementation.

Problem definition is arguably the most difficult part of any problem. The initial problem is never the complete problem and defining the problem requires extensive research and information gathering from multiple channels, interviews with key stakeholders, as well as extensive research on the subject. Research allows the intricacies and associated variables to emerge with the assistance of stakeholders. In this process, the problem becomes more defined. Stakeholder analysis, functional and requirements analysis as well as value modeling provide valuable assessments tools, which dive deep into the system and bring out the essential elements and aspects that allow the systems engineer to understand the system and the problem with greater fidelity. The result of this work produces a revised and accurate problem statement.

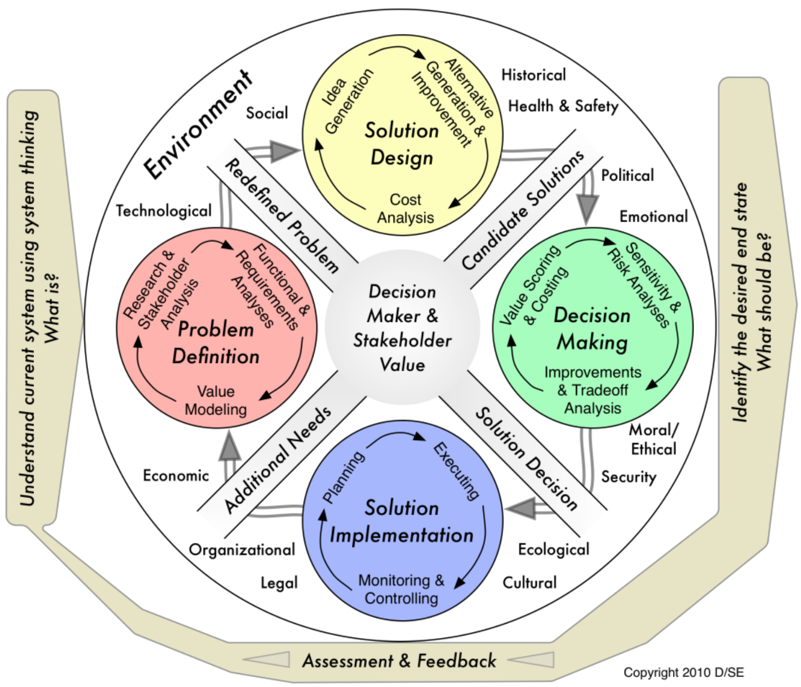


Figure 1. System Decision Process (Parnell, Driscoll, & Henderson, 2010)

Once the problem is defined the solution design process occurs. This process gets to the essential components of possible solutions which will encompass a complete solution to every aspect of the problem. With candidate solutions, the decision making phase develops improvements to the candidate solutions. In the case of this research, the stakeholder gave certain guidelines for a final solution which focused the project to incorporate only portions of the SDP. The beauty of the SDP lies in its flexibility to adjust to specific project dependent requirements.

3. Background

Ensuring a population has access to food remains challenging and perplexing due to the population growth of the modern era. Food Security is defined as "the idea that all people at all times have access (including physical, social, and economic access) to sufficient, safe, and nutritious food necessary to lead active and healthy lifestyles." (McDonald, 2010) The issue of food security relies on three dimensions: availability, stability, and access. (Haering & Syed, 2009) Food availability requires sufficient food supplies being available to meet consumption needs. Stability refers to minimizing the possibility of food consumption falling below consumption requirements. Access is the ease in which the population can acquire food. The effects of globalization on both national and international issues has pushed policymakers to broaden their scope on new forms of security threats that include "health, urbanization, information technology, nuclear proliferation, advanced biological technology development, and environmental degradation." (McDonald, 2010) Food security has quickly evolved into an essential feature of the U.S.'s ability to ensure stability, prosperity, cooperation and growth. The most crucial aspect of food security remains food distribution to a megacity or capital. Massive urbanization has pushed nations to the carrying capacity of their food systems. As incomes rise the demand for food rises and types of food become more processed, perishable, and difficult to obtain. Mapping a region's food distribution system has thus become the key to understanding a nation's food security profile.

3.1 International Approach to Food Security

Food security has been an issue in every aspect of human development. The push toward understanding the broader issues of food security occurred immediately following World War II (WWII). WWII provides an example of how localized hunger, food shortages and destruction of infrastructure can transform strings of compromised local food systems into a global issue. In May 1943, President Franklin D Roosevelt initiated the first step toward tackling this challenge when he convened the United Nations Conference on Food and Agriculture. (McDonald, 2010) The conferences overall conclusion was that the international system relies on the "…secure, adequate, and sustainable supply of food." (McDonald, 2010) Under this pretext, in October 1946, came the development of the Food and Agriculture Organization of the United Nations (FAO). Since its founding, the FAO's recognition and focus has been towards the importance of food security on a broad scale which encompasses the stability of local and international regions. To complicate the issue, food security is more compromised because through its reliance on access and distribution of food via local infrastructure. This can become easily disrupted through conflict or natural disasters. (McDonald, 2010)

Other organizations such as the World Bank and the Global Agriculture and Food Security Program (GAFSP) create initiatives on a global scale. These organizations improve food security and reduce rural poverty through the stimulation of agricultural productivity and overall economic growth. The GAFSP's mission visualizes improving agricultural performance in low-income countries as the most effective way of reducing poverty and hunger. (World Bank Group Team, 2009) The GAFSP has highlighted that enhancing a nation's agriculture system has been two to four times more effective at reducing poverty than growth originating in other sectors. GAFSP's current mission is the support of the medium- and long-term interventions needed to ensure strong and stable policies and increased investment in agriculture in the poorest countries. GAFSP picks up where emergency funding leaves off and works with countries to develop, in a sustainable way, so that they are more resilient to climate, political, and market shocks in the future. GAFSP focuses on agricultural productivity, linking farmers to markets, increased capacity and technical skills. GAFSP is country-led and supports national priorities in their agriculture and food security investment plans and provides a platform for coordinated donor financing around country programs and sustainable private sector investment. GAFSP is already setting a new standard for development effectiveness. It stresses country ownership, good governance, inclusivity, high-quality projects, and intensive monitoring and evaluation. GAFSP focuses on investment in small scale farmers, pushing the need for more sustainable agricultural growth, and research and development. Despite the international system, nations that are being assisted need to create initiatives within their own communities and build off of the framework that organizations such as GAFSP have established. The overall assistance by GAFSP therefore can only be seen as a temporary relief and not a long term solution for a nation's food system. (World Bank Group Team, 2009)

3.2 Food Insecurity

Food insecurity exists whenever the availability of nutritionally adequate and safe foods or the ability to acquire acceptable food in socially acceptable ways is limited or uncertain. (Haering & Syed, 2009) Uncertainty in food security can lead to insufficiency or at best disruptions in availability, stability and access. Disruptions, however, range from political instability, war, civil strife, economic imbalances, trade issues, poverty, and natural events. (Smith, El Obeid, & Jensen, 2000) Each of these disruptions are related to the two major causes of instability: insufficient food availability and access. This breakdown is shown in Smith's model for a framework for food security (Figure 2). In recent adaptations to food security this breakdown has become essential in its ability to narrow the global spectrum down to the individual household. From the global food availability comes the total amount of world food production. The global capability is further narrowed to national availability, and finally to the individual household.

The indicators essential to measure food security at an individual based level are dietary energy balance (DEB), a country's absolute poverty rate, and child malnutrition. Within these three variables comes the ability to understand the basics of food security issues, especially within developing nations. The common theme and catalyst for the issues and indicators remains access and availability. There are multiple breaks in the chain from the global to the local level. Further examination shows that often times the food is produced but is incapable of finding its way from the farm to the market, which has a direct effect on the DEB of a region. (Smith, El Obeid, & Jensen, 2000)

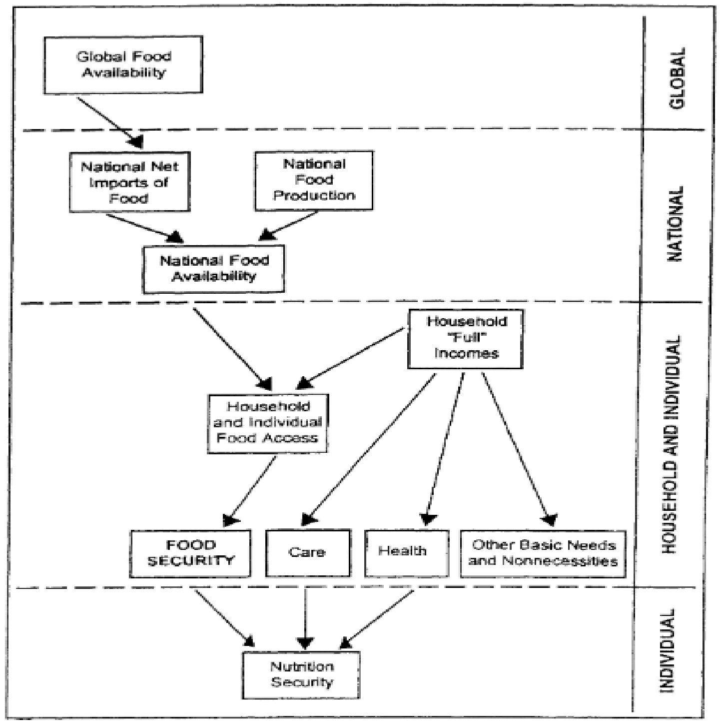


Figure 2. Conceptual Framework for Food Security (Smith, El Obeid, & Jensen, 2000)

Another useful model to analyze the broader spectrum of food security is Campbell's conceptualization of food insecurity and its risk factors (Figure 3). Campbell's model covers the emotional and political aspects of hunger and thus is able to expand the detail of food security. (Campbell, 1991) The model allows the social, psychological, and political aspects of food security to emerge and also allows the recognition of food insecurity to be portrayed as a global issue. Similar to the variables in Smith's model, Campbell's model contains four essential components at the individual and household levels: quantity, quality, psychological acceptability, and social acceptability. The strength of this model is that it provides a broader range of variables that have an effect on the way food is acquired and how it reaches the individual. Campbell's model also relies on the concept of food acquisition which is a main variable that represents the center piece on how food rotates throughout the system.

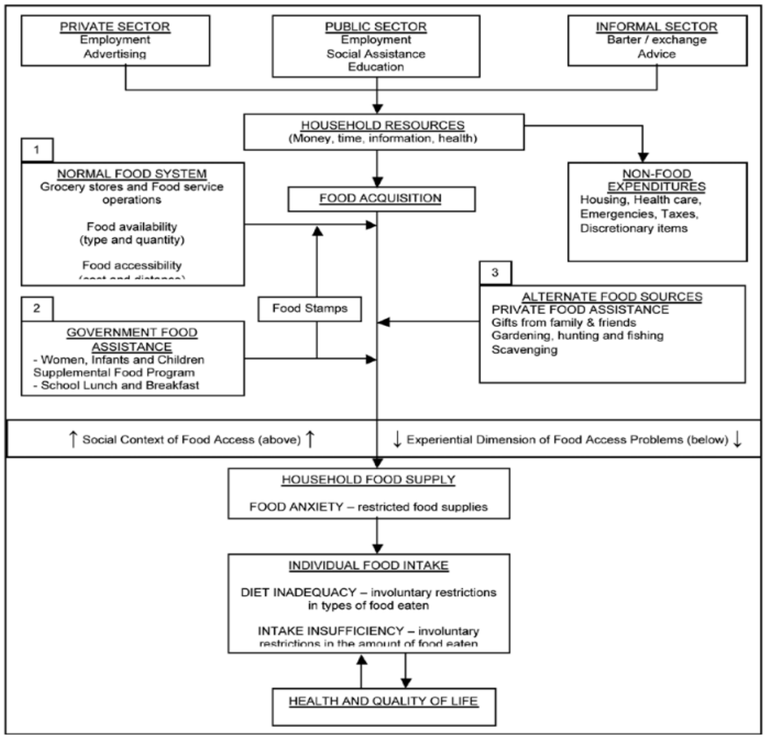


Figure 3. Campbell’s Conceptualization of Food Insecurity and its Risk Factors (Campbell, 1991)

3.3 Development of a Food Network

At the core of these two models is “distribution”. Distribution focuses on the need to continue to move the food supply through the necessary stages. The arrows in both models are the steps the food supply moves. In the past, food distribution was predominately a local issue. Through the 1930’s, the U.S. access to fresh produce from foreign markets was a novelty item. Today, however, the variability and the global market have created a food system that has the capability and consumer desirability to expand food miles. Food miles are defined as “the distance food travels from where it is grown or raised to where it is purchased by a consumer.” (Johns Hopkins School of Public Health, 2016) The extension of food miles, especially within developed nations, supports Bennett’s law which states: “…as income increases, diets diversify from a narrow range of starch-based staples to a broader range of meat, fruit, and vegetables.” (Porter, Dyball, Dumaresq, Deutsch, & Matsuda, 2014) Therefore food is no longer a local issue, but a constantly expanding challenge on a global level.

3.4 Food Distribution

Food distribution, along with the proper infrastructure, is a key link to whether or not a region has stable accessibility to food. Food distributors are the middlemen within the food distribution process. (Johns Hopkins School of Public Health, 2016) Their main task is to transport the food from the “field to retail.” Distributors pick up the food from the agricultural producers and processors. They normally will have a distribution hub where the storing, sorting and shipping occurs. From the distribution hub the food moves to the supermarkets, restaurants, stores, shops and local markets where eventually it is purchased by the individual consumer. In the case of larger more efficient distribution and processing facilities, they are able to force the smaller business out of the market and thus hold an even larger share and responsibility within the FDN. This effect can increase the overall food miles as limited distribution centers create another stop gap within a food transportation system. The complexity of the system increases when it is reliant on ingredients and processes required to ship food.” (Johns Hopkins School of Public Health, 2016)

3.5 Food Distribution Systems

Within a FDN there are several systems. The first system is a local food system. A local food system is defined as "…food that was produced within the geographic region where the consumer lives (roughly 100-250 miles), or food that is sold directly from a farmer to a consumer or nearby retailer." (Johns Hopkins School of Public Health, 2016) This system creates a more direct approach from the producer to the consumer and requires minimal transportation. This model provides stability and lessens the effects of supply disruptions. The local produced goods are also more desirable due to freshness and the added benefit of supporting local economies. The next system is a regional food system, which is the area within roughly a radius of 100-250 miles. Regional food systems represent a broader area that has many forms of distribution, which also includes the local systems. This system is most effective within areas such as urban environments that cannot subsist on the local system. The final system identified is the most expansive food network: the international global market. The global market is a trans-national market that acquires food from the global trade network. The advantages to this system is that it provides a specialization advantage. However there is the potential of vulnerabilities in certain areas. This concept is addressed in the study *Feeding the Capitals: Urban Food Security and Self-Provisioning in Canberra, Copenhagen, and Tokyo*, by John Porter, et al. their research raises the question: how can large and constantly expanding capital regions continue to feed their populations? The study collected data on the production, importation and exportation of a common food commodities consumed in each of three capital regions. The conclusion was that all the cities analyzed participated in a global distribution system. Repercussions associated with this interconnectedness are that cities such as Tokyo will have to increasingly manage their food security "…by tracing the origin of the agro-ecosystems needed to support their consumption." (Porter, Dyball, Dumaresq, Deutsch, & Matsuda, 2014) This means that in order for cities to expand in a responsible, efficient and effective manner they will have to continue to develop capacity to be flexible to the changes in the food supply created by disturbances such as nature events such as droughts or manmade events such as internal conflict.

3.6 Changing Urban Environments

How do we feed an expanding, richer, and more urban population in the U.S. and around the globe? Out of the 9 billion people that are suspected to be on earth by 2050, almost all will be live in urban areas with the majority residing in Asia and Africa. By 2100, the urban population of Asia and Africa will increase by 4.5 billion people. (Garvelink & Wedding, 2013) The repercussions associated with this increase will lead to further instability in regions that are already unstable and will push their limits in terms of food production and carrying capacity. Urbanization today is also vastly different from the past. Historically, urbanization has stemmed from agricultural communities becoming more productive which enabled the excess labor to migrate to urban areas. Today, however, most of the urbanization stems from poverty, food insecurity, and malnutrition from the rural areas. The populations flock to secondary cities that have insufficient resources to deal with the influx. The repercussion of this rampant expansion is that cities are wholly unprepared (inadequate budgets, planning, jobs, or services) to handle this massive population influx. In the case of Africa, already 72% of those living in urban areas live in decrepit or slum conditions. Food security within these urban areas is tied into purchasing power and importation of the goods needed to feed the population. When these cities rely on fragile and ineffective governments the issue becomes further complicated. The infrastructure, distribution system, and electrical grid are all in many places, incapable of supporting the demand of these massive urban areas. (Garvelink & Wedding, 2013)

3.7 Infrastructure

According to the FAO, one third of all food produced in the world is wasted. We lose close to 1.3 billion metric tons annually, which is enough to feed 2 billion people. (Cargill, 2016) This net loss of food is predominately linked to the period after the harvest when food often sits due to inadequate infrastructure which cannot get the food to the population. Cargill, an international food producer has seen the transportation issue as an essential aspect to the issue of global food insecurity. Cargill has focused its efforts towards the supply chain and capacity of developing nations to provide adequate infrastructure and resources to ensure food moves from the farmers, through the supply chain, to the population. The challenges here are quite daunting. Governments, farming practices, transportation, infrastructure and international trade all are encompass food security. Cargill proposes that a significant growth of food production is required but that the infrastructure to transport the product will need to be developed as well. Supply chains are just as essential as the food itself. It takes a significant amount of time and resources to improve a supply chain system which involves building the proper infrastructure (roads, sea ports, airports, electric grids, etc.).

3.8 Food Transportation

Within the U.S., food is moved over long distances to "…feed densely populated areas that could not otherwise acquire enough food locally, and to provide consumers with a greater variety and to capitalize on the advantages of places in producing certain foods." (Johns Hopkins School of Public Health, 2016) The implied repercussions associated with this requirement indicate that as developed countries acquire more wealth, the food miles of an area continue to grow and form more complicated and intricate networks. The main challenge for food transportation is the increase and expansion of megacities. Areas like New York City provide a massive challenge due to the massive food consumption by the population. Even if all the food production of New York went to New York City, it would be dramatically insufficient to feed the population and would amount to only 55% of the city being fed. The use of a local food distribution model in this case would lead to a lack of variety and would not meet current consumer demands for out of season food inventories. Food transport is also necessary because certain regions will only produce unique and distinct foods. For example, "…Vermont has a short growing season, rolling hills and rocky soil… and although Vermont doesn't hold an advantage over Wisconsin, New York, and Pennsylvania, it specializes in producing the food in which it has the least disadvantage." (Johns Hopkins School of Public Health, 2016) This specialization allows for regions to produce the necessary food that is suitable to their climate but in order for consumers to attain certain types of foods, different foods will require transportation across broader distances.

3.9 The Arab Spring

An example of uncontrolled urban growth effecting a fragile state is illustrated with the Arab Spring (2008-10). The Middle East and North Africa have a history of food security issues mainly due to their dependence on the importation of food. (Tree, 2014) This lack of food accessibility was exasperated by urbanization. In 1980 only 48% of the total population was urban but by 2000 it reached 60%. This effect was to spur unrest as food supply networks became overburdened with the rising population densities. To complicate the issue further the amount of unemployed youth and the state dominated economies created a precarious situation. (Tree, 2014) Food insecurity, in this instance, became a catalyst for unrest. Chris Barrett stated if you "…disrupt the food economy and one frays the fabric of society. When people struggle to eat as they have grown accustomed their distress may be more psychological than economic or physiological. When enough people share such distress, individual grievances morph into societal ones." (Barrett, 2013) Ensuring the availability, accessibility, and proper usage of food therefore becomes a national security and domestic stability issue for every country, regime, and functional structure. (Tree, 2014) During this time, price spikes became the most disruptive agent to food security as the unemployed and disenfranchised youth could not afford the rising price of food. The price of food doubled from 2003 to 2008. The increase in price caused the middle class in poorer nations across the Middle East and North Africa to experience food insecurity and thus they retaliated. The wealthier states, however, were able to cope through more balanced infrastructure and wealth that allowed their governments to subsidize and minimize the effects of the increase in regional food prices. (Tree, 2014)

4. Analysis

For the problem definition phase, research and stakeholder analysis was first used to determine what was important to look at for the problem. This initial research and stakeholder analysis drove the development of the systemigram. The systemigram visually depicts the interactions of a network of systems (Figure 4). It allows the engineer to get initial ideas to focus the problem. A systemigram can be as broad or as narrow as needed, depending on what is important. For the purposes of food security, the first and second order effects are considered. First order effects are effects that directly influence food security whereas second order effects indirectly affect food security through their interaction with first order effects and each other.

4.1 Systemigram

The first order net effects were determined to be food distribution, megacities, stakeholders, and trade. Each of these categories had influence arrows going into food security with a different action associated with them. These action labels are important because they allow a stakeholder to determine what they want maximized or minimized. For example the action associated with megacities going into food security is "complicates". The system will therefore run more efficiently if the effect of megacities on food security can be minimized. Conversely the action associated with food distribution "supports" the system which allows the system to run more efficiently if food distribution is maximized.

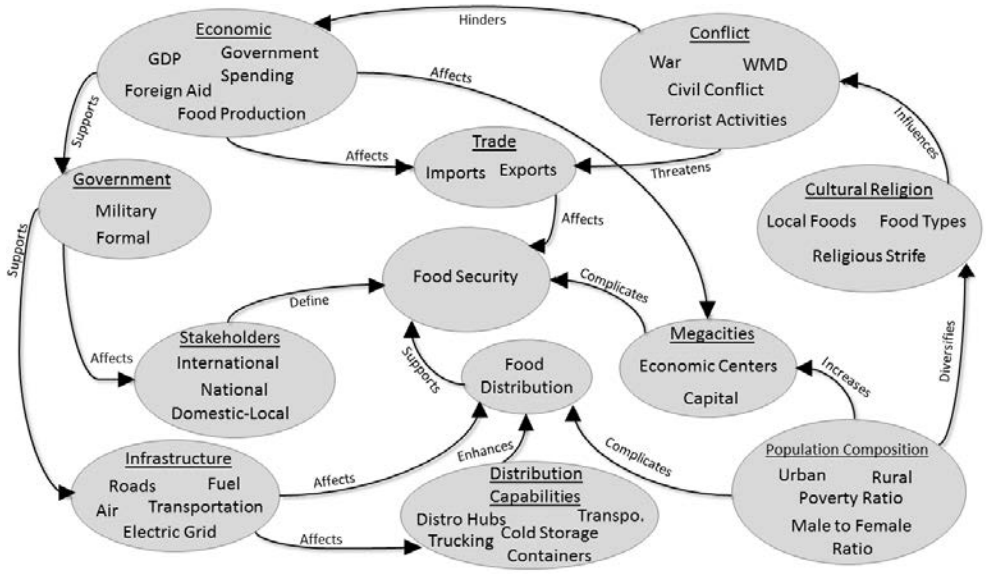


Figure 4. Food Security Systemigram

The influence of second order effects can be described in much the same fashion. These second order effects include economic factors, trade, conflict, culture/religion, population composition, distribution capabilities, infrastructure, and government. Not only do these second order effects interact with first order effects, but they interact with each other as well, and all of these interactions are important to understand when describing the nature of food security for a region.

4.2 Value Hierarchy

Analysis of the food distribution problem required development of a fundamental objective, a functional hierarchy, and a value hierarchy in order to develop the best analysis tool of a food distribution network. The fundamental objective is the building block for all of aspects of the model. Essentially, the fundamental objective is what the model aims to do. The fundamental objective is created by gathering findings from stakeholder interviews and research and transforming them first into conclusions, and then into recommendations. This process condenses the findings into recommendations in order to more easily create a clear, concise fundamental objective. For the food security assessment model, 37 initial findings were condensed into nine conclusions, and finally into three recommendations. The recommendations were created by grouping conclusions based on whether they were related to infrastructure, modeling a system, or usability of the model. These three fields comprise the essential areas of a food distribution model. The fundamental objective is derived from the recommendations, which allows the fundamental objective to envelope all of the crucial components of a food distribution network. The fundamental objective for the food security problem is to "create a versatile and effective model for an urban level food distribution system capable of assessing the strategic or tactical level conditions, which identify potential threats and weaknesses to the food distribution system." This fundamental objective addresses the usability and effectiveness of food distribution while at the same time providing threats and weaknesses of the system.

Once the fundamental objective is established and approved by stakeholders, a functional hierarchy is created (Figure 5). The functional hierarchy breaks down the fundamental objective into top level functions that help achieve the fundamental objective. These functions must be in the form of a verb and a noun combination in order to allow for them to be measurable. The top level functions for this problem are: assess infrastructure, assess dietary needs, and assess national stability. These functions were derived by conducting research to determine what the overarching components of a food distribution network are, and which of these components were necessary to achieve the fundamental objective. In addition to individual research, stakeholders provided input on what components of food security they perceived as a top level function.

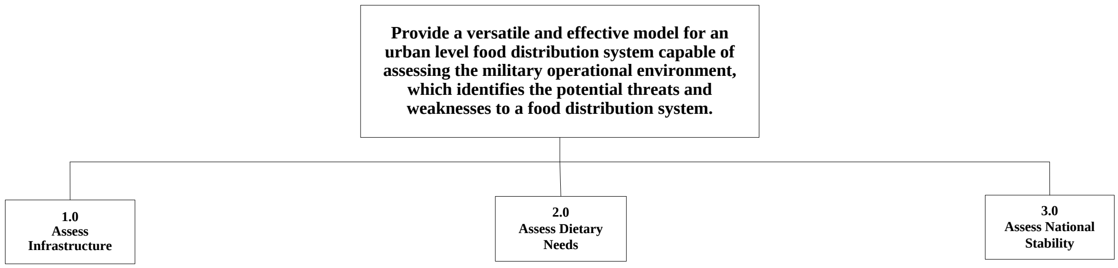


Figure 5. Food Security Functional Hierarchy

The value hierarchy breaks down the functional hierarchy two levels further (Figure 4). First, the functions are broken down into objectives which aim to maximize or minimize a certain component of that function. Whether or not an objective needs to be minimized or maximized comes from the systemigram. Once the objective has been established, each objective was then assigned value measures. Value measures are the way in which objectives are quantified. This allows for the analysis of each objective, and ultimately the model. Without appropriate value measures, it will be impossible to assess the model.

First, each value measure was given a definition. These definitions fuel the scoring mechanism of the value measures. The method that was used is called the waterfall method. Each value measure was given an associated scoring table that ranged from zero to however many components pertained to that value measure. A definition was created for each of the scores in the table. The waterfall method makes this process much less complex. By using the waterfall method, in order for a value measure to be given a score of three on a value measure, all of the aspects of scores zero through two must already have been met. This makes it much easier to develop clear definitions for each of the scores that can be easily identified by a soldier on the ground, which will allow for a much more accurate evaluation of a food distribution network. Creating value measures is one of the most difficult phases of problem definition, and as a result is very time consuming. It requires constant communication between the project team and the stakeholders. Without communication, it is likely that the value measures will not meet what the stakeholder desires.

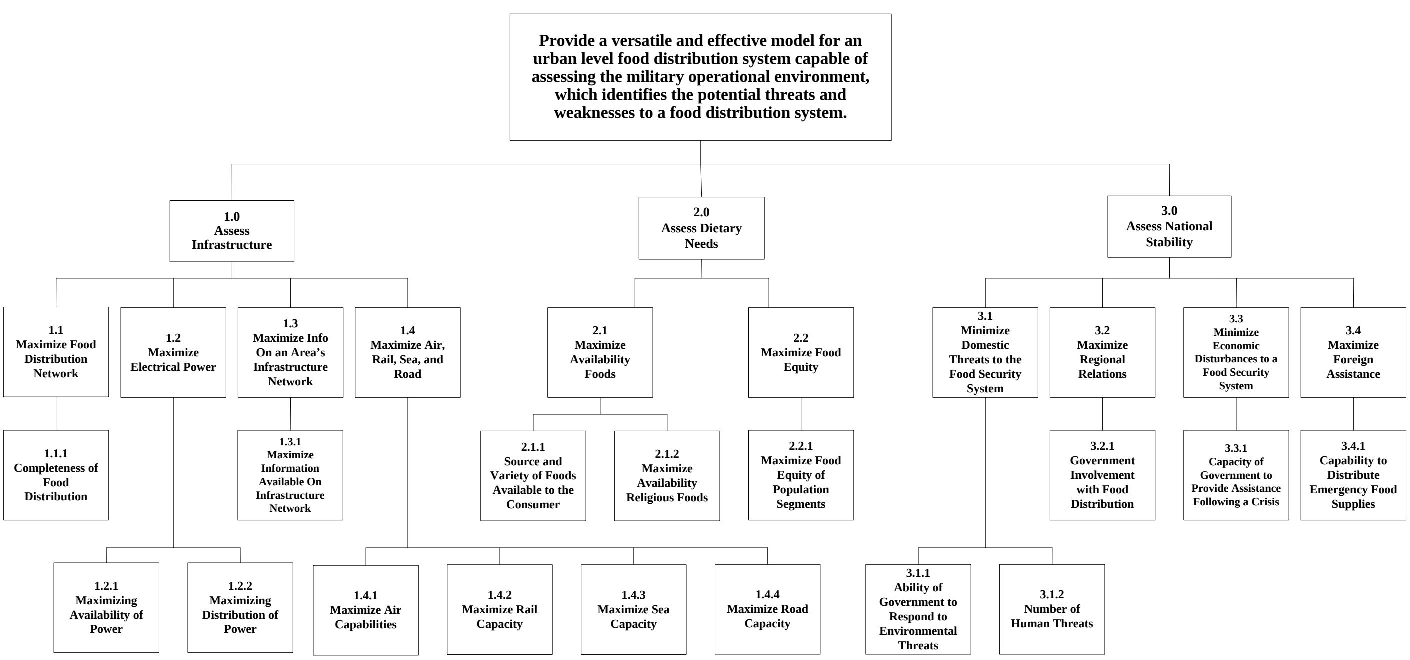


Figure 6. Food Security Value Hierarchy

4.3 Solution Design

In the solution design phase the information that was gathered and synthesized during the problem definition phase is used to determine candidate solutions. Once a list of candidate solutions is developed they must be evaluated for their feasibility. The solution to this problem is limited to a SD application to the food distribution system and an Excel based value focused multi-objective assessment model. The SD analysis is limited to the infrastructure variable identified in the systemigram (Figure 4). The SD analysis allows for a deeper understanding of the impact the infrastructure has on the FDN which further impacts overall food security for a region. The Food Security Assessment Model (FSAM) is an excel based value focused multi-objective assessment model which takes the VMs associated with the VH and uses them to create a simple and effective tool to assess regional food security.

4.3.1 Systems Dynamics Application

The SD approach is ideal when trying to model and understand policy-making and strategic problems. After conducting an exhaustive analysis of FDNs, SD was used to visually depict how the FDN is actually reacting to certain stimulus. As mentioned, the SD portion of the project is focused on the infrastructure component of the systemigram (Figure 4). This analysis highlights the complexities associated with the FDN. SD diagrams take two forms. The more common diagram is a causal feedback loop. Feedbacks capture the real patterns or modes of the system's behavior as they dynamically evolve through time. A causal feedback loop portrays the state of the system through direct and inverse relationships. Causal loop diagrams capture the mental models which managers conceive of a system through positive (reinforcing) and negative (balancing) polarities and stock and flow maps. It is important to emphasize that the plus/minus polarity attached to the arrows depict a direct or inverse relationship rather increasing or decreasing the system. These loops, over time, create balancing or reinforcing feedback loops, which show vulnerabilities in the infrastructure of FDNs. The problem in the reinforcing loop is identified because the system will continue to destabilize if not corrected. In a balancing loop, the system is missing something that is necessary for it to remain stable. The second SD diagram is a stock and flow diagram. This diagram is different from a causal loop diagram in that is shows a stock value, such as new railroads on rail capacities, and inflow and outflow rates. Stocks are a set number (inventory) and the flow is the rate at which this inventory is fed or drained from the system. When applied to the issue of food security SD creates a visual depiction of a system as well as providing another analysis tool. There are a variety of factors that can either increase or decrease the infill or ex-fill of the stock. In a stock and flow diagram the plus/minus polarity represents and increase or decrease, not the relationship. What SDs allow is the creation of a methodological tool to analyze and understand the development and behavior of complex systems over time. SD's potential to be employed to model the feedbacks that both promote and limit food security to assess the impact of various situations to a regional FDN. A SD model can be utilized to examine in greater detail a perspective variable. The following Vensim models utilize SD to showcase how each variable within the FSAM or a food system can be effectively modeled.

4.3.1.1 Rail Capabilities

Rail capacity is increased when new railroads are built (Figure 7). A conscious decision to invest in regional railroads is made. Certain variables that contribute include interest from the labor force and the practicality of rail in the use of shipping and in personal travel. Losses in local rail occur as the railroads age and decay. If they are not repaired then those rails no longer become a viable way of shipping goods or transporting people. They will therefore decrease the overall rail capacity.

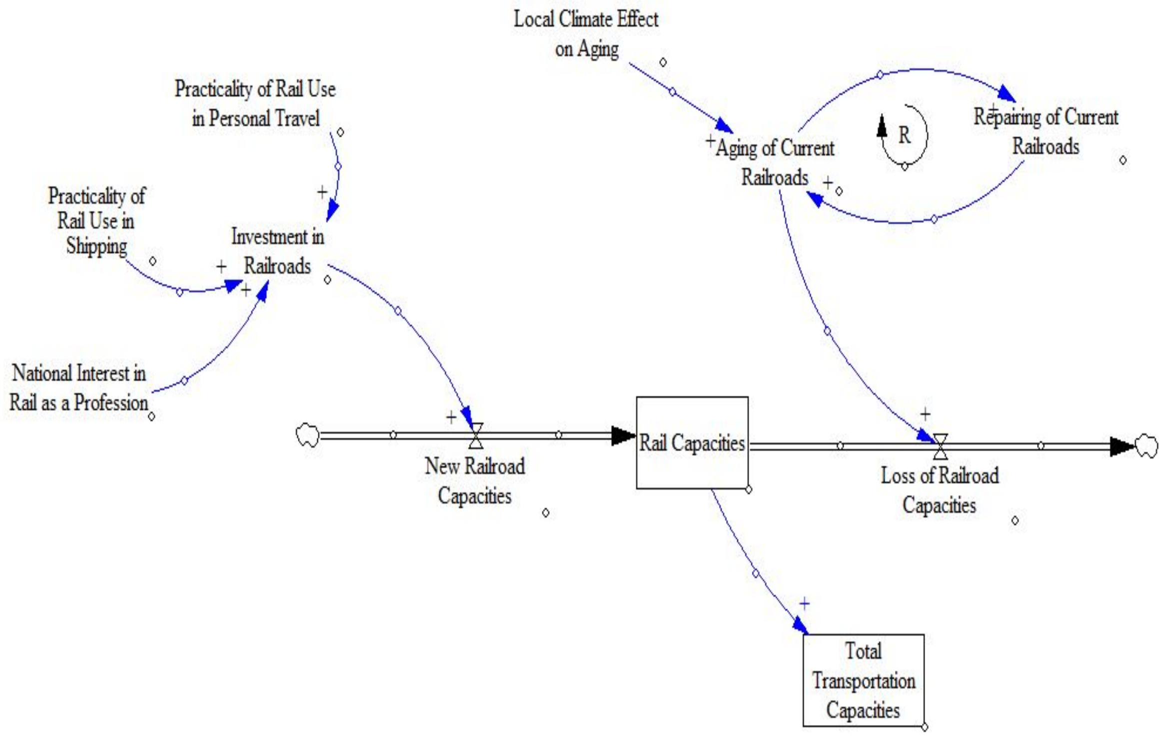


Figure 7. Rail Capacity Systems Dynamics Model

4.3.1.2 Sea Capabilities

Investment into sea transport will create new port capacity (Figure 8). In this case, new ships are built when an investment is made into local ports. Variables that contribute into local investment include interest from the labor force, those members that have the potential to become skilled professionals, the practicality of ocean transport in the use of shipping as well as in personal travel. Losses in local sea capabilities occur as the ships age and decay. If they are not repaired then those ships no longer become a viable way of shipping goods or transporting people. Likewise, dangers associated with shipping will decrease port capacity as ships will be hesitant to come into dangerous ports.

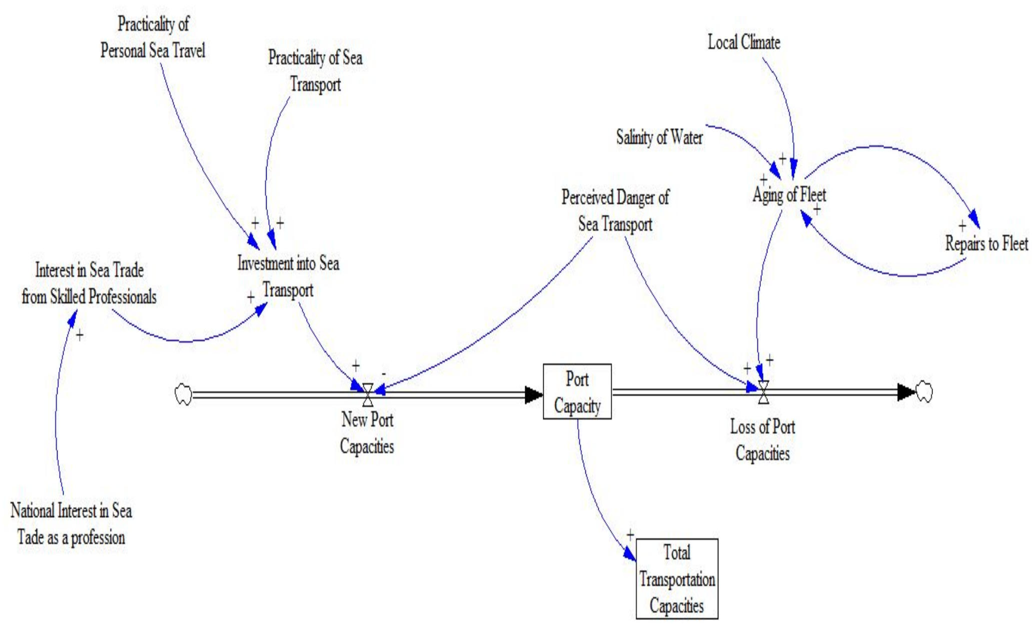


Figure 8. Port Capacity Systems Dynamics Model

4.3.1.3 Air Capabilities

Airport capacity increases when new planes and airports are built (Figure 9). Investment is made into air transport. Variables that contribute into local investment include interest from the labor force, the practicality of air transport in the use of shipping as well as personal travel. Losses in local air capabilities occur as the planes age and decay. Additionally, airports deteriorate over time without investment in maintenance. If planes are not repaired then they will no longer become a viable way of shipping goods or transporting people, which will lead to an overall decrease of airport capacity.

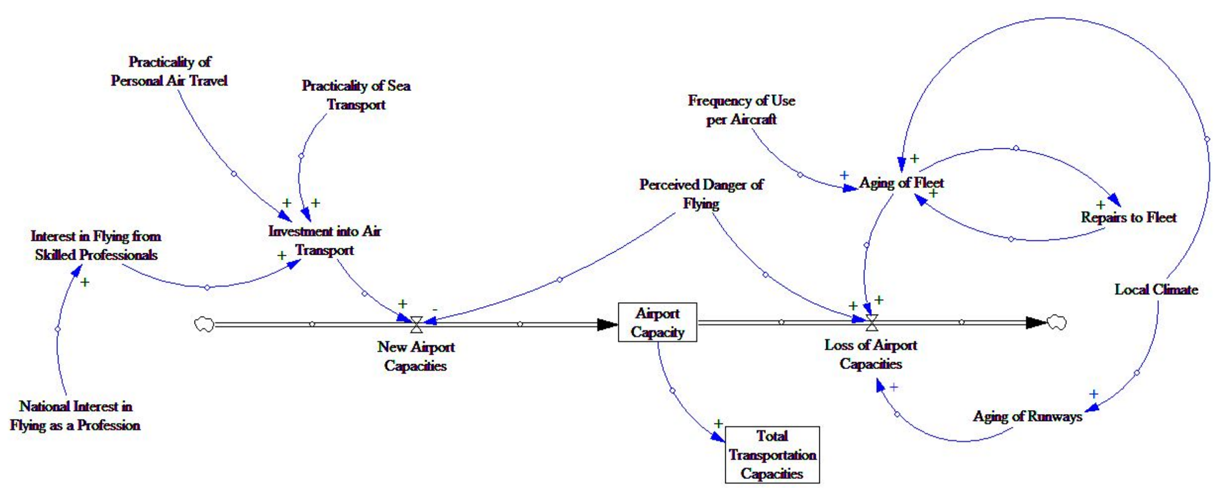


Figure 9. Air Capacity Systems Dynamics Model

4.3.1.4 Road Capabilities

Overland capacity increases when new trucks are bought and when investment is made into roads (Figure 10). Overland travel is the most common form of transport for food. Most FDNs will eventually use road networks to ensure food arrives to regional areas. Investment here is critical. Variables that contribute into local investment include interest from the labor force, the practicality of trucking in the use of shipping as well as privately owned vehicles for personal travel. Losses in local road capabilities occur as the roads age and decay. If they are not repaired then those roads no longer become a viable way of shipping goods or transporting people. This becomes especially important when you have to consider the type of road being used for food transport. A dirt road for example is much more likely to become unusable after a flood than a paved road.

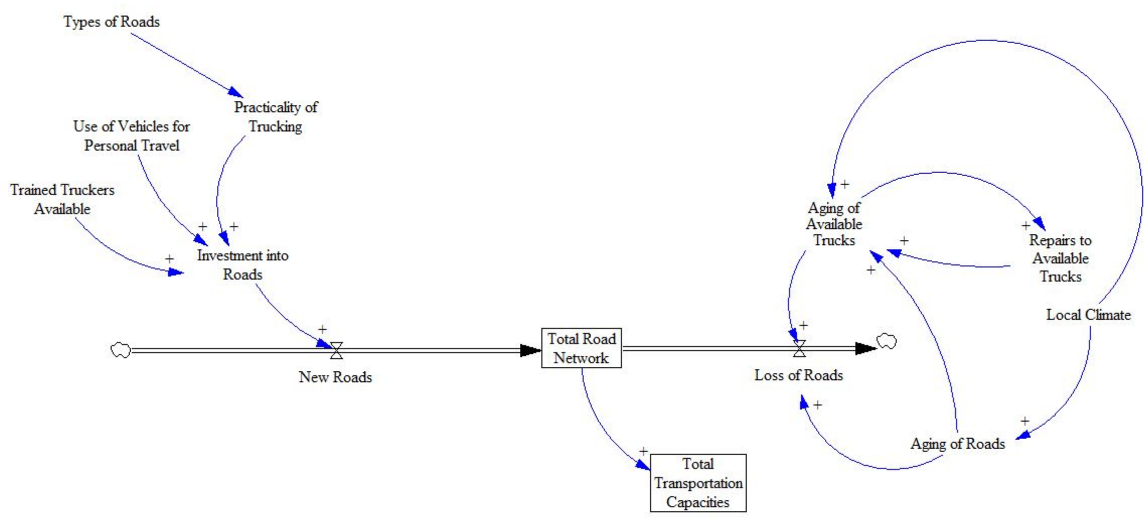


Figure 10. Road Capacity Systems Dynamics Model

4.3.1.5 Electrical Grid

Electrical power is critical for food storage and is the single most important stability factor in regards to food storage (Figure 11). For the electrical grid system, a causal loop diagram adequately represents the complexity of the system. Variables that contribute into local power produced include generators and mobile power trucks. If a grid is not reliable, then the use of local power becomes critical. Variables which affect destruction of power facilities include deterioration of the grid, conflict/terrorist threats and natural disasters. If they are not repaired then the grid no longer become a viable way of providing power to the people.

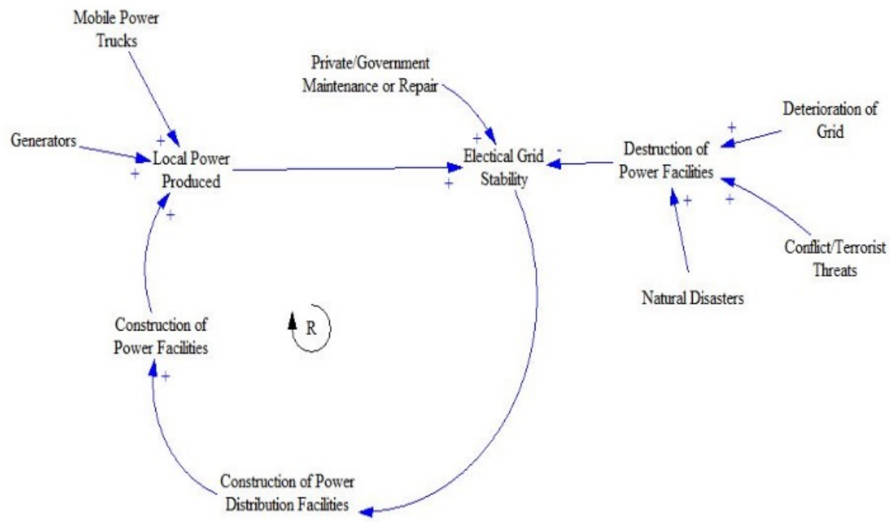


Figure 11. Electrical Grid Systems Dynamics Model

4.3.1.6 Fuel Available

Fuel available is impacted by the external threats such as global market fluctuations, human/terrorist threats, and natural disasters (Figure 12). The feed in variable to the fuel system is fuel distribution. Fuel distribution creates a positive polarity with the availability of fuel. Fuel distribution itself is positively affected by fuel trucks, containers, and finally government management or quality control over the distribution of petroleum products. Fuel available is also positively affected by the influx of an external fuel supply that could be from NGO's, global assistance programs, or in our case, a U.S. military asset or assistance program. This variable remains essential because it can model how an influx of external fuel over a short period of time can affect the stability of the fuel available to a region or local area. Finally the gas stations variable is effected by the positive polarity in the form of fuel quality. The higher the fuel grade and quality is the easier it is to be distributed through gas stations. Gas stations further the fuel available to the local customer.

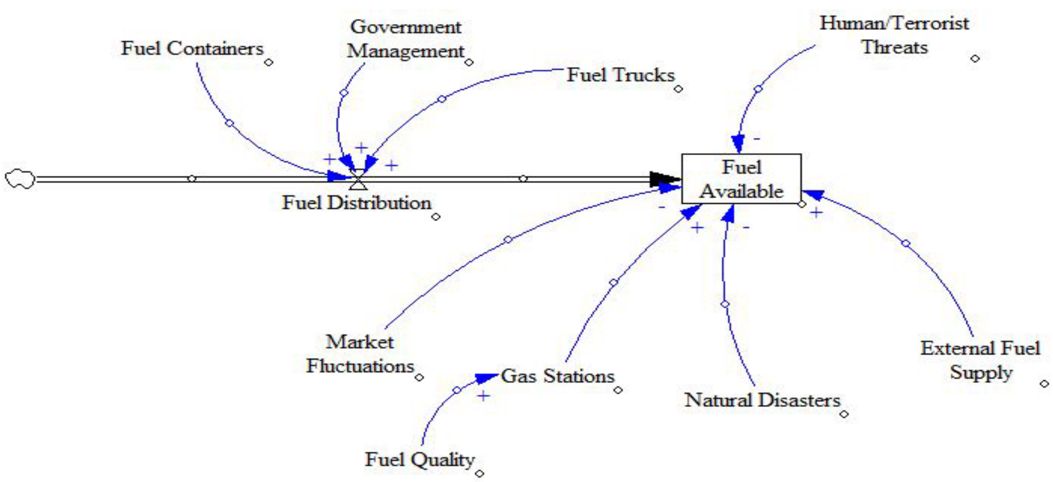


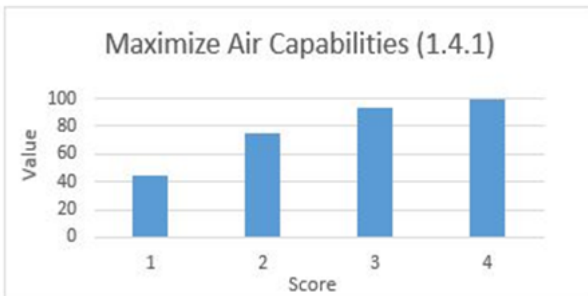
Figure 12. Fuel System Dynamics Model

5. Results

FSAM collects data using a qualitative score provided by a user scoring a food system. The data is then transformed into a quantitative value that allows the user to compare how advanced the food system is and what work needs to be done to improve the system. The model includes an evaluation page that allows the user to determine how well an area's food system compares with an ideal food system, and an archives page so that past results of calculated food systems can be compared to each other as well for a point of real world reference. The FSAM uses a series of equations for each value measure to come up with the final result. The first part of the equation uses the VLookup function of excel, which takes the current user score of a value measure, finds that score in a table for that value measure, and associates that score with its weight on a scale of 0 – 100, (with 0 holding no value and 100 holding maximum value), and looks for an exact match. That score from the table is then multiplied by the weight associated with that value measure on the swing weight matrix. This process occurs for every value measure. The sum of all twenty value measures creates the final score (Figure 13).

1.4.1

Score	Value
0	0
1	45
2	75
3	93
4	100



0- No airport present.
1- Airport present, dirt runway and limited ground staff.
2- Airport present, paved runway, 24 hour ground staff capability.
3- Airport present and operates commercial flights, 24 hour ground staff capability and airport operates as a distribution hub of resources and shipments.
4- Air capabilities currently in use.

Figure 13. Value Measure Metric Graph.

The user is able compare current food system model to an ideal version of a food system. The model creates these charts by comparing the calculated values with the ideal values of the respective value measures. The ideal value measures are created from research and stakeholder input. FSAM then displays these in the form of a bar chart and a radar chart (Figure 14). The bar chart is more useful for side by side comparisons of individual value measures whereas the spider chart is more useful for seeing a holistic view of the differences between the actual and the ideal food system and which gaps need to be reduced.

All previous data is labeled on an archives page so the user can see how the current food system compares to other systems that the model has evaluated. This archives page is also useful so that if the user wants to go back and check all the data from previously evaluated systems, he or she does not have to go through the process of inputting all the data points again. The results that the model produces can be easily interpreted by the user into something that is meaningful. Not only can its performance be judged by the score that the model gives it, but also how the different value measures perform compared to an ideal version of a food system provides real world feedback that the user can interpret as ways of seeing where improvements can be made to an area's food system.

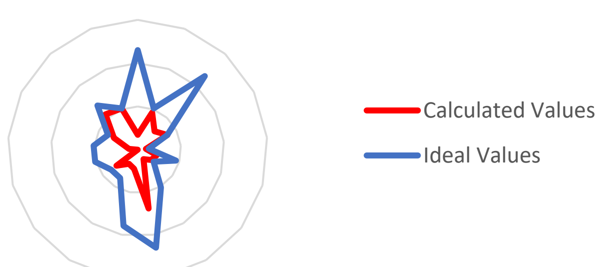


Figure 14. Radar Chart (Food Security Assessment Model)

6. Conclusion

This research confirms that food security is a key component to the stability of countries and whole regions. The complexities of FDNs are becoming increasingly more important as city populations continue to grow and access to local food sources are not enough to sustain populations. The connection of a nation's stability directly to food security cannot be underestimated. Megacities are becoming more common and dominate the global markets and economies. No longer can a city look specifically for national food sources – as populations become more sophisticated and wealthy, their desire for out-of-season food staples becomes acute. As the Arab Spring illustrated, a country that is unable to feed its population will fall to unrest and chaos. The most basic of needs is food and the inability of parents to feed their children will not stand. Providing the population with economically viable and available food sources is a basic requirement of any government. Failure to do so will ultimately lead to the demise of that government. As populations increase, the need for reliable and efficient infrastructure to deliver the food becomes more and more important. The globalization of FDNs adds another layer of complexity. Competing interests for food sources will only increase, which will put more and more pressure on an already taxed system. It is apparent that this challenge is far beyond the scope of this project.

Trends show that food security remains a complex challenge and most likely the most important challenge facing the world today. The complexity of food security highlights the need for a deeper analysis to understand the dynamics of this sophisticated and complex system. The use of SD to analyze the infrastructure component of the FDN proved beneficial in establishing greater understanding of infrastructure system reaction. The SD approach is extremely important to continue to develop because of the value that it provides. SD can simulate through interactions and equations associated with the variables that make up those interactions how a system will progress over time. The current SD for this project only scratches the surface of what can be done using SD for the food security problem.

The FSAM provides an assessment model capable of providing insight into the food security of a region. As a tool, the FSAM can assess and provide information that will allow for prevention techniques to be implemented if food security of a region is in jeopardy. If the problem is identified early enough, approaches to solve these potential challenges can be implemented to lessen the impact of the problem.

Both the SD and FSAM need more work. The initial attempts here have proven beneficial but refinement of both products is essential to improving the analysis and predictability of the tools so they are more effective in providing assistance in solving these very critical challenges. SD models for all aspects of the food security systemigram need to be developed so that the reaction of a food security system over time can be illustrated to its fullest extent. The current work that has been done in SD are only in the infrastructure. All other areas of the systemigram need to be modeled.

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