Spring 2017

More Than Food: An Analysis of Multidimensional Relationships in Our Food System

Jessica Erin Newnan
University of New Hampshire, Durham

More Than Food: An Analysis of Multidimensional Relationships in Our Food System

Jessica Newnan

Abstract:

Food is an integral part of everyday life for human beings, thus meriting particular attention from research and education. Looking further in depth at the factors that influence food, it becomes apparent that this is a complex topic that is related to several systems within the constructs of society. Here, the food system is approached with the understanding that several systems influence food consumption options and decisions including the agricultural, economic, education, energy, health, and political systems. To identify the relationships more closely, a three-dimensional model was built to represent the food system and depict several key factors, their relationships, and feedback loops that exist within the system. Overall, 20 factors, 50 relationships, and 4 feedback loops were defined. These relationships were then explored to define not only their existence, but also what influence each factor imposes on the others.

Introduction:

As food is necessary to sustain life, it is an integral part of just about every area of study imaginable. It is connected to economics, life sciences, engineering, arts, philosophy, and much more. This integration into all aspects of society causes food to be a unifying subject through the relationships it exhibits. Within the food system, these relationships become even more apparent. While often viewed as the system of production, distribution, and consumption, the food system in reality includes a far greater number of influencing factors. Agriculture is a single part of the food system. The food economy is another. The health of the consumer is a result of the system. Even education, politics, and energy are involved in determining the food we eat. Each of these influential aspects of the food system is a system of its own of which food is only a part. Thus, the relationships present in the food system appear multidimensional, reaching across topics to link such systems as agriculture and economy or education and health.

Recognizing the interconnectedness of these relationships is especially important when considering the movement for change in the food system that is currently taking place. There is currently work being done in the realm of sustainable agriculture, in the realm of food economies, in the realm of health and nutrition, and in the realm of education. Each of these systems are connected, however, by the relationships that food creates between them. Understanding how the relationships connect these systems is crucial to understanding how the work done in one area will affect the conditions of another. An example of this can be seen through the concept of food accessibility. This factor links agriculture and health through the relationship between being able to access nutritious food and the physical implications of receiving the proper nutrient intake.

The purpose of this project is to identify many of the big picture relationships that link different systems together using food. To do so, I have created a three-dimensional web connecting important factors that affect the food we eat in such a way that a pattern of influence can be visualized. In this way, when considering the consequences of change in one area, it is apparent what impacts the change will have on other areas of the system. The factors included in this web are by no means all inclusive. There are certainly more that could be analyzed. Even with the factors presented in the model, each could be broken down into subsequent parts and analyzed further. The scale at which this project is attempting to understand the relationships within the food system is broad, allowing for a detailed but general understanding of the interconnectedness of the presented factors. The details of the relationships can be found in the second part of this project. This paper gives substance to the simplified representation presented by the model. It is in the understanding of the definition of the factors and the analysis of the relationships that the true purpose of the project is fulfilled.

It is the intention of this project that understanding these relationships will inform work being done in the food system such that meaningful and impactful efforts are made. The previously mentioned areas of work in nutrition, sustainable agriculture, education and economics are all directed towards the same end goal: food that is beneficial to people, the environment, and the economy. Ignoring the fact that these efforts are all connected, however, can result in unintended consequences. An example of this may be the high demand of fruits and vegetables needed to supply proper nutrition causing an increase in agricultural intensity that degrades the soil. This unintended consequence in agriculture resulting from a positive impact on the health system is a potential if the two systems are not considered together to find a solution that benefits both. Thus, the ultimate goal of this project is to create a framework which displays the relationships within the food system in such a way that sustainable solutions may be found in the context of the entire system, thereby limiting the unintended consequences.

Methods:

The analysis of multidimensional relationships requires an understanding of the way in which the relationships are connected beyond individual factors. In some cases, the relationship may involve three or more factors, even generating feedback loops upon further examination. For this reason, the approach to this analysis began with a modeling exercise. A three-dimensional model was created in order to visualize the interconnectedness of the factors selected for analysis. The modeling began with the recognition that the food system is actually made up of many subsystems. The subsystems represented in the model include an agricultural subsystem, an economic subsystem, an educational subsystem, an energy subsystem, a health subsystem, and a political subsystem. These subsystems were used to categorize the various factors examined and place them within the model based on their relationships to each other. Each subsystem was approached individually at first, and was examine to determine what particular factors were relevant to the food system. As each subsystem was analyzed, however, it became apparent that the relationships between the systems were too critical to be added in secondarily. As such, the three-dimensional model began to take shape. The factors were written down and strung up between the posts of a tripod framework. As relationships were recognized, colored yarn and tape was used to create a directional link between the notecards upon which the factors were written. This was the first draft of the model. Later in the process, once all relationships and factors had been finalized, the draft of the model was reconstructed into a more organized and more clearly presented version of the original. A complete list of the factors, subsystems, relationships, and feedback loops can be seen in Table 1.

Since defining the intended meaning of each factor was crucial to the context of this model, the next step to drafting the system web was to create specific definitions. In doing so, new relationships began to become apparent. Defining the factors in and of itself was a refining process for the model. This process established a more finalized version of the web for later analysis. At this point, it is important to mention that the relationships, feedback loops, and subsystems represented in the model are by no means all-inclusive. There are many more factors involved in each subsystem when taken on its own. There are even more components to the food system which may not be included in this model. Even the factors listed could be broken down into more and more specific factors which would present new relationships and feedback loops, potentially even new subsystems. Such is the nature of a systems approach to any given topic.

Table 1. Factors, Subsystems, Relationships, and Feedback Loops Found in the Model

Factor	Subsystem	Influencing Factors	Factors Influenced	Feedback Loops
Agricultural Inputs	Agriculture	Agricultural Intensity, Petroleum Extraction	Food Costs, Soil Health, Yield, Water	Feedback Loop 1
Agricultural Intensity	Agriculture	Consumer Demand, Income, Policy	Agricultural Inputs, Soil Health, Yield	Feedback Loop 2
Consumer Demand	Economy	Food Costs, Income	Agricultural Intensity, Petroleum Extraction, Policy, Waste	Feedback Loop 1
Curriculum	Education	Education Level, Policy	Education Level	
Distribution	Agriculture	Petroleum Extraction, Yield	Food Accessibility, Food Costs, Waste	
Education Access	Education	Income	Education Level	Feedback Loop 3
Education Level	Education	Education Access, Curriculum, Physical Health	Curriculum, Labor	Feedback Loop 3, Feedback Loop 4
Food Accessibility	Economy	Distribution, Food Costs, Income	Nutrition	Feedback Loop 4
Food Costs	Economy	Agricultural Inputs, Distribution, Labor, Land Access, Policy, Yield	Consumer Demand, Food Accessibility, Income	Feedback Loop 1, Feedback Loop 2
Income	Economy	Food Costs, Labor, Policy	Agricultural Intensity, Consumer Demand, Education Access, Food Accessibility, Land Access	Feedback Loop 2, Feedback Loop 3, Feedback Loop 4
Labor	Economy	Education Level, Physical Health, Policy	Food Costs, Income	Feedback Loop 3, Feedback Loop 4
Land Access	Agriculture	Income, Policy	Food Costs, Yield	
Nutrition	Health	Food Accessibility, Soil Health, Policy	Physical Health	Feedback Loop 4
Petroleum Extraction	Energy	Consumer Demand, Policy	Agricultural Inputs, Distribution	Feedback Loop 1
Physical Health	Health	Nutrition	Education Level, Labor	Feedback Loop 4
Policy	Politics	Consumer Demand	Agricultural Intensity, Curriculum, Food Costs, Income, Labor, Land Access, Nutrition, Petroleum Extraction	
Soil Health	Agriculture	Agricultural Inputs, Agricultural Intensity, Waste	Nutrition, Yield	
Waste	Agriculture	Consumer Demand, Distribution	Soil Health, Water	
Water	Agriculture	Agricultural Inputs, Waste	Yield	
Yield	Agriculture	Agricultural Inputs, Agricultural Intensity, Land Access, Soil Health, Water	Distribution, Food Costs	Feedback Loop 2

In the process of defining the model, various multifactor relationships and feedback loops emerged. For example, the relationship between Food Costs and Petroleum Extraction had to be routed through Agricultural Inputs and Distribution as these two factors were directly impacted by Petroleum Extraction which then influenced Food Costs. The structure of these relationships is important to the overall function of the system, making this an aspect of the model which will be critical for analysis. Analyzing the relationships was the next part of the process. Not only is it important to know what relationships exist between these factors in the food system, but also it is important to know the dynamics of the relationships. In other words, it is not enough to know that Petroleum Extraction influences Food Costs, we need to know how Petroleum Extraction influences Food Costs. While some relationships were fairly obvious and required simple research to support the analysis, others required more intense research into peer-reviewed journal articles to garner an understanding of how the relationships work. In all cases, the final step to this exercise was to analyze the identified relationships and feedback loops utilizing peer-reviewed journal articles as well as pertinent governmental publications as support.

Defining the Model:

The three-dimensional model serves the purpose of visualizing the multiple dimensions of the relationships that can be found between the factors that affect the food we consume. When taken individually, each factor has many relationships to other factors. The model clearly shows which factor is having an influence on another by creating a directional relationship. For example, when looking at Food Accessibility, there is a relationship that begins at this factor and ends at Nutrition. This shows that Food Accessibility influences Nutrition in some way. The model's purpose, then is to show the framework of these relationships as factors influence each other, as well as how groups of factors create feedback loops within and between subsystems.

The model is broken down into the six subsystems: agricultural, economic, education, energy, health, and political. Each factor is assigned to a specific subsystem regardless of the fact that it may be involved in more than one. This can be seen in the model through the use of color coding in which agriculture is green, economy is red, education is blue, energy is yellow, health is purple, and political is orange. Understanding the model requires a clear understanding of each factor, the subsystem to which it belongs, and what relationships it is involved with. The following are the definitions as used in this context as well as the existing relationships expressed in the model.

Agricultural Inputs

In the context of this model, Agricultural Inputs will be understood to be the quantity applied of any synthetic application such as, but not limited to, fertilizers, pesticides, and herbicides. Agricultural Inputs are grouped into the agricultural subsystem as depicted through the green color coding of the factors in the model. Though the Agricultural Inputs are related to energy through the influence of Petroleum Extraction as well, this factor has the most relationships with other agricultural factors represented. The key connections displayed for Agricultural Inputs are with Agricultural Intensity, Petroleum Extraction, Soil Health, Yield, and Water. Overall, Agricultural Inputs are influenced by Agricultural Intensity and Petroleum Extraction, and influence Food Costs, Soil Health, Water and Yield. Agricultural Inputs are involved in an overall feedback loop that links the agricultural, economic, and energy subsystems. As there are four feedback loops described in this analysis, this will be referred to as Feedback Loop 1. In this loop, Agricultural Inputs impact the Yield of a crop which then influences the Food Costs associated with that crop. Food Costs then influence the Consumer

Demand which impacts the Petroleum Extraction for the creation of Agricultural Inputs, thus closing the loop.

Agricultural Intensity

Here, Agricultural Intensity represents the degree to which the land is exploited for agricultural purposes. High intensity will be understood to signify a situation in which food production is utilizing the land to the full capacity in terms of space, nutrient availability, and resource extraction. Low intensity will be understood to signify a situation in which food production is utilizing the land in a limited way in terms of space, nutrient, availability, and resource extraction. Practically speaking, high agricultural intensity uses all available space for food production, depletes the soil of its nutrients, and/or overharvests resources from the land. Low agricultural intensity, on the other hand, would use some land for food production and some for alternative purposes, maintain or improve the soil nutrient content, and removes resources from the land at or below the rate of renewal. Agricultural Intensity, then, is placed in the agricultural subsystem in the model. The influencing factors for Agricultural Intensity come from Consumer Demand, Income, and Policy. The degree of Agricultural Intensity has an influence on Agricultural Inputs, Soil Health, and Yield. Agricultural Intensity is part of the second feedback loop identified within this model which will be called Feedback Loop 2. This loop begins with Agricultural Intensity influencing the Yield of a crop which then impacts the Food Costs for that crop. The Food Costs influence the Income of the farmer which then influences the Agricultural Intensity of the following season.

Consumer Demand

Consumer Demand signifies the displayed needs of the consumer, particularly as it relates to quantity and quality of food produced. The display of demand can be seen through purchasing patterns as well as consumer advocacy campaigns. Consumer Demand is an economic factor and is thus incorporated into the economic subsystem of the model, as can be seen by the red color coding. It is generally influenced by other economic factors such as Food Costs and Income. This factor has a significant impact on the agricultural subsystem, however. Consumer Demand influences the Agricultural Intensity and Waste factors found in agriculture. By doing so, Consumer Demand indirectly influences Agricultural Inputs, Soil Health, Water, and Yield, all of which are related to Agricultural Intensity and Waste. Additional influences found from Consumer Demand include the effect it has on Petroleum Extraction and on Policy. Both of these factors have connections which are then influenced by Consumer Demand as well. The relationships between Consumer Demand, Food Costs, and Petroleum Extraction make this factor a part of Feedback Loop 1 which is explained under “Agricultural Inputs.”

Curriculum

Generally speaking, Curriculum is understood to mean the content of an educational process including the topics studied and accompanying assignments. As such, it is a part of the educational subsystem represented in the model by the blue color coding. The content of an education has a clear impact on the result of that education. Thus, Curriculum has a strong relationship with Education Level directly. This relationship is unique, however, in that it can be seen with influence in both directions. Not only does Education Level influence what the content of the Curriculum is, but Curriculum influences the individual’s desire to pursue a higher Education Level. Curriculum for primary education in America is set by national standards, thus making Policy a main influence.

Distribution

In the context of this model, Distribution will be understood to mean the method by which food reaches the consumer including transportation and marketing method. Distribution is placed in the agricultural subsystem of the model as it is the end of the production process that takes place on the farm. It should be noted, however, that the interconnectedness and cyclic nature of the system means that Distribution is also the beginning of another process: consumption. Being a part of the agricultural subsystem, the main influence on Distribution is Yield. Petroleum Extraction influences Distribution as well through the transportation aspect of this factor. As it relates to consumption, however, Distribution influences Food Accessibility, Food Costs, and Waste.

Education Access

Here, Education Access refers to the ability of an individual to receive formal education through an institution such as a public or private school, community college, or university. In the case of this model, this is approached from a financial perspective. Education Access intersects the education and economic subsystems of the model, but has been placed in the education subsystem. In the model, Education Access is influenced by Income and influences Education Level. This is part of a third feedback loop, however, in which Income impacts Education Access which impacts Education Level which influences Labor which influences Income. This loop shall be referenced as Feedback Loop 3.

Education Level

Education Level references the degree of completion of the formal education of an individual, whether it is elementary level, high school diploma, or any level of advanced study. Clearly, this factor can be found in the education subsystem of the model. Education Level can be seen to be influenced by Curriculum, Education Access, and Physical Health based on the financial, physical, and psychological capabilities of an individual to continue obtaining higher and higher degrees of completion. Education Level shows influence on Labor in the model, another relationship involved in Feedback Loop 3, described under "Education Access." Education Level is a part of a fourth feedback loop identified which will be described as Feedback Loop 4. This fourth feedback loop links the health, economic, and education subsystems. In Feedback Loop 4, Income influences the Food Accessibility of an individual which then impacts their Nutrition. Because Nutrition impacts Physical Health, the impact influences the Education Level of the individual as well as the Labor, both directly and indirectly through Education Level. This then influences the Income of that individual, closing the loop and starting the cycle once again. This fourth feedback loop is linked with the third one through Labor, Income, and Education Level. The interconnectedness of the feedback loops, even more than the interconnectedness of each of the presented factors, signifies that the relationships in the overall food system are critical to its functioning.

Food Accessibility

The ability of an individual to obtain and consume wholesome foods, particularly in the case of fresh fruits and vegetables or meat, is what is referenced by Food Accessibility in this model. Here, this ability is approached from both the physical and financial perspectives. Food Accessibility draws on the physical presence of the aforementioned food as well as the capability of the individual to afford this food. Food Accessibility is in the interesting position of being involved in almost every subsystem represented in this model. For this reason, it has been placed in the center of the model to show its intersection into all aspects of the system. In terms of its place in one of the presented subsystems, however, it is coded as economic. This coding has to do with the fact that, of the many relationships that Food Accessibility has, the majority of the other factors also belong to the economic subsystem. Food Accessibility is described in the model as being influenced by Distribution, Food Costs, and Income. It can also be seen that Food Accessibility influences Nutrition, indirectly influencing Physical Health and thus Education Level. This set of relationships make Food Accessibility a part of Feedback Loop 4 identified and described under “Education Level”.

Food Costs

For the purpose of this model, Food Costs are understood to be the price of the food at the time of purchase by the consumer. Costs can be approached from various angles including social costs, environmental costs, etc., but here it is intended in the immediate financial sense of the word. Food Costs are a part of the economic subsystem in the model. They are influenced by many factors outside of the economic subsystem, but ultimately have an economic impact. Food Costs are influenced by Agricultural Inputs, Distribution, Labor, Land Access, Policy, and Yield. The Food Costs resulting from the combination of these factors impacts the Consumer Demand and the Food Accessibility of the consumer, as well as the Income of the farmer. The relationship of Food Costs to Consumer Demand and the influence of Yield on Food Costs both are connections found in Feedback Loop 1, explained under “Agricultural Inputs.” Feedback Loop 2 also includes the relationship between Food Costs and Yield as well as the relationship between Food Costs and Income. This interconnectedness of the two feedback loops through the impact of Yield on Food Costs displays the idea that one relationship may result in multiple consequences.

Income

Income is the quantity of money earned by an individual over a period of time. Regardless of whether this is approached as weekly, monthly, or yearly income, the relationships in this model hold true. Income is an economic factor and thus is part of the economic subsystem. It is influenced by Food Costs, Labor, and Policy while influencing Agricultural Intensity, Consumer Demand, Education Access, Food Accessibility, and Land Access. Income is a part of Feedback Loop 2 based on the impact of Food Costs on the Income of the farmer. The relationships present in this feedback loop are described under "Agricultural Intensity." The relationships between Income, Labor, and Education Access are part of Feedback Loop 3 previously mentioned under "Education Access." Income also is a part of Feedback Loop 4 which is described under "Education Level." Here, the connections between Labor, Income, and Food Accessibility are the key relationships.

Labor

Labor refers to the work done by an individual. This model looks at the factors influencing eligibility of the individual to Labor as well as the influences that Labor has on other factors throughout the system. In this model, Labor is considered to be a part of the economic subsystem, but can be seen as a connection point between the economic, health, and education subsystems. The factors that influence the eligibility of the individual to Labor include Education Level, Physical Health, and Policy. The individual's Labor has a direct impact on Food Costs and Income. The relationship between Labor and Income is another piece of Feedback Loop 3, discussed under "Education Access." Feedback Loop 4 includes this relationship as well, but also involves the connection Labor has to Physical Health and Education Level. Feedback Loop 4 is described under "Education Level."

Land Access

In the context of this model, Land Access is the ability of farmers to obtain property on which they can produce food. This ability entails the affordability and the availability of farmland. Since having the land to farm on is a fundamental part of agriculture, Land Access has been incorporated into the agricultural subsystem in the model. Land Access is directly impacted by Income and Policy. At the same time, it influences Food Costs and Yield.

Nutrition

Though it is generally a much broader subject, Nutrition in this context refers to the quantity of macronutrients and micronutrients consumed by the individual. Nutrition is in a similar situation as Food Accessibility, where it is at the intersection of agriculture, health, economic, and education. For this reason, it has been highlighted in the center of the model along with Food Accessibility. It is, however, a part of the health subsystem overall, as can be seen through the purple color coding. Nutrition is influenced by Food Accessibility, Policy, and Soil Health. Directly, Nutrition has an impact on Physical Health which indirectly has an influence on both Education Level and Labor. This makes Nutrition a part of Feedback Loop 4, explained under "Education Level," through its relationships with Physical Health and Food Accessibility.

Petroleum Extraction

Here, Petroleum Extraction signifies the quantity of petroleum extracted, regardless of extraction method. Petroleum Extraction is the lone component of the energy subsystem which is represented here, as can be seen in its yellow color coding. Although there are many other components of an energy subsystem, all of which would be relevant in some form or another, petroleum is the focus of this model because of the integral way in which it is connected to agriculture and the economy. Petroleum Extraction is tied to agriculture through the influence it has on Agricultural Inputs and Distribution. Petroleum Extraction, then, indirectly influences Food Costs through the impact it has on Agricultural Inputs and Distribution. Petroleum Extraction is influenced by Consumer Demand in several ways, as well as being influenced by Policy. This influence of Consumer Demand on Petroleum Extraction, as well as the relationship it has with Agricultural Inputs, are part of Feedback Loop 1, described under “Agricultural Inputs.”

Physical Health

For the purposes of this model, physical health will refer to the state of the individual’s body. Better health will be understood to mean the proper functioning of bodily systems as well as the ability to perform physical activity without issue. Worse health will be understood to signify the presence of issues with several bodily systems or the incapability of the individual to perform physical activity without issue. Clearly, Physical Health is a factor that can be found in the health subsystem represented in the model. This factor is influenced, for our purposes, solely by Nutrition. Many other factors can be seen as influencing Physical Health that are not represented within the scope of this model. While they are certainly important, they are not directly involved in the food system and thus are not present in this model. Physical Health can be seen as influencing the Education Level of the individual as well as Labor. These relationships are a part of Feedback Loop 4 as described under “Education Level.”

Policy

Policy refers to the legislation or executive orders enacted by federal, state, or local governments. Of all of the factors represented in this model, Policy has the greatest number of relationships. Policy permeates each of the subsystems that are represented here in such a strong way that it had to be placed in the center of the model along with Food Accessibility and Nutrition. Policy is influenced by very little, but influences just about everything else. It would overcomplicate the model to the point of detracting from its purpose to explore every single policy link that exists with other factors. For this reason, Policy is represented as influencing Agricultural Intensity, Curriculum, Food Costs, Income, Labor, Land Access, Nutrition, and Petroleum Extraction. These relationships are highly important to the functioning of this system as a whole. It is also important to recognize that Consumer Demand is the only factor represented as influencing Policy. The lack of feedback Policy receives combined with its connection to all of the subsystems fairly evenly makes it difficult to place Policy in any one of the subsystems present. For this reason, Policy is seen as its own system, or as part of a political subsystem, as can be seen through its orange color coding.

Soil Health

The nutrient content, aggregate structure, water holding capacity, organic matter content, and contamination level of the soil are all components of Soil Health. The combined status of all of these components will be understood as the definition for Soil Health in the context of this model. Soil Health is an integral part of the agricultural subsystem represented in the model. It has mainly agricultural influences, but external implications. Agricultural Inputs, Agricultural Intensity, and Waste impact Soil Health through the effect they have on nutrient content and contamination level of the soil. These relationships then influence Yield through Soil Health. The external implications of Soil Health can be seen in the effects that it has on Nutrition and thus the health subsystem represented.

Waste

Waste refers to the material that is diverted from human use at any stage of production, distribution, or consumption of food. In the context of this model, it is taken as waste from either food, packaging, or animal wastes depending on the relationship being described. Waste is represented as a part of the agricultural subsystem in the model because of the way it affects Soil Health and Water. Though Waste is a subject that could be taken on by itself, it is important that it is mentioned in this context because of these implications. Waste is impacted by Consumer Demand and Distribution based on the limitations resulting from quality standards and location of sale.

Water

Here, Water is approached as the physical presence of water as a resource. The relationships referred to in the model have to do with the contamination level of water as well as the use of water. Water is considered a part of the agricultural subsystem based on its use in irrigation. The relationships depicted in the model show Water to be influenced by Agricultural Inputs as well as Waste. This relationship has to do with the contamination potential of each of these other factors. Water, then, influences Yield through the impact that access to clean water or lack of access, irrigation or lack of irrigation, and the presence of rain or the lack of rain has on the quantity of food that is able to be produced.

Yield

This model utilizes the factor of Yield to represent the quantity of food produced. In some relationships, this is a rate of production, such as tons per acre, where in others it is simply a quantity, such as tons of a crop produced nationally. Yield is another factor that is integral in the agricultural subsystem of the model. It is influenced by the Agricultural Inputs, Agricultural

Intensity, Land Access, Soil Health, and Water. Yield has important influences on Distribution and Food Costs. These two relationships lead to the indirect impact of Yield on Food Accessibility. Yield is also part of Feedback Loop 1 based on its relationships with Agricultural Inputs and Food Costs. This feedback loop is described under "Agricultural Inputs." Feedback Loop 2, mentioned under "Agricultural Intensity," includes Yield as well, in regards to the relationship between Agricultural Intensity, Yield, and Food Costs.

Relationship Analysis:

The relationships and feedback loops presented between the factors listed above and represented in the model are important to understand as being more than simple influences. In order to understand what the influence is or how one factor impacts another, it is important to analyze the relationship between them. Bringing together research from many peer-reviewed journal articles and government publications, the final step in this analysis of multidimensional relationships in the food system is the analysis part itself. A total of 50 relationships were presented in the model. In some cases, the relationships were linked through a feedback loop or through other factors. This analysis will incorporate every one of these relationships by approaching some individually and some as grouped together where it is appropriate and logical to do so.

Agricultural Inputs-Soil Health and Water

The impact seen from applying Agricultural Inputs to the land is exemplified in the contamination of soil and water resources. The pursuit of increased agricultural production has warranted the use of increasing applications of chemicals including synthetic fertilizers, pesticides, and herbicides. These chemicals then have the potential to leach into water resources or remain in the soil profile depending on the chemical being referred to. This potential has been realized in several cases where soil toxicity or water toxicity were studied.

In Costa Rica, for example, copper toxicity resulted from the application of fungicides in what was originally a banana plantation (Thrupp, 1991). Investigation into the management practices of the plantation found that excessive quantities of agricultural chemicals were applied to prevent losses in yield, resulting in an accumulation of copper in the soil (Thrupp, 1991). In this way, the Agricultural Inputs used on the land were directly responsible for the contamination level in the Soil Health. The results of this were witnessed in the failed attempts to cultivate the land. The replanting of bananas, as well as the conversion of the land into rice fields, failed to produce a viable crop because the level of toxicity in the soil had reached the point of causing sterility (Thrupp, 1991).

The impact of Agricultural Inputs on Water can be seen through the study of runoff from agricultural fields. In 1978 a study was done in order to model the runoff of pesticides from agricultural fields in order to predict the implications on water quality (Wauchope, 1978). In the study, different types of pesticides were found in different concentrations in water runoff depending on the storm event that occurred (Wauchope, 1978). The existence of this study as well as the fact that the pesticides were all found in the runoff shows that Agricultural Inputs have an influence on water based on the potential for contamination. Though different types of Agricultural Inputs have different levels of impact, the impact still exists. Pesticide in runoff can impact water quality, as an example of this (Wauchope, 1978).

Agricultural Intensity-Agricultural Inputs and Soil Health-Nutrition

The level of Agricultural Intensity seen for any given piece of land is related to the amount of Agricultural Inputs used and the Soil Health found on that land. High intensity production often is accompanied by the utilization of agricultural inputs to further boost yield as high production levels are the end goal of high intensity. Agricultural intensification has been associated with increases in fertilizer, sewage sludge, and veterinary medicines, all forms of Agricultural Inputs (Boxall et al., 2009). Additionally, herbicides, insecticides, and fungicides are anticipated to increase in response to rising pressure from diseases and pests (Boxall et al., 2009). Not only does this high intensity deplete the soil of its nutrient levels, but it is also subject to contamination from the use of agricultural inputs as previously described. The degradation of soil quality has been associated with agriculture, as well as the loss of soil organic matter (Matson, Parton, Power, & Swift, 1997), exhibiting the effect of Agricultural Intensity on Soil Health.

The combination of direct impact from Agricultural Intensity to Soil Health, along with the indirect impact through the heightened use of Agricultural Inputs, causes the Soil Health to be in such a state that it impacts the nutritional value of the food produced on it. The nutrition in food, both plant and animal based, is derived from the nutrients the organism is able to extract from the food source. Vitamin, mineral, and micronutrient contents in plants are related to the availability of these nutrients in the soil (Lal, 2009). Thus, nutrient deficiencies in the soil will eventually lead to nutrient deficiencies in the food being consumed and ultimately nutrient deficiencies in the human (Oliver & Gregory, 2015). Though this relationship is obvious between soil and plants, the same applies to animals as well. Animal products for human consumption are subject to the same nutrient deficiency situations as plants. Animals that eat plants are able to absorb only as many nutrients as the plant has extracted from the soil. Nutrient deficiencies in plants transfer to animals which ultimately results in nutrient deficiencies in humans as well (Oliver & Gregory, 2015). In this way, Agricultural Intensity influences Soil Health and thus Nutrition as well.

Consumer Demand-Agricultural Intensity

Demand is a principle which is taught in even the most basic of economics classes. The amount of a good that consumers want at a given price will be produced by the supplier so long as the quantity matches the amount that the supplier is willing to produce at that price. Generally speaking, an increase in demand will increase the price and thus increase the quantity of the good that the suppliers are willing to produce. In agriculture, this principle is applicable as well, but there are limits to the capability of the market to expand. The amount of land available for agriculture is one constraining factor to the growth of the food market. There is only so much arable land in the world. Thus, once the limited quantity of land is being utilized, the intensity with which it is utilized must be increased (Lal, 2009). In this way, Consumer Demand for agricultural goods influences the Agricultural Intensity witnessed. Currently, this influence tends towards increasing Consumer Demand and increasing Agricultural Intensity. Both increasing population and a shift in demand towards animal products have caused an increase in the intensity of grain production and animal production (Ericksen, 2008). Because the production of animal products requires first the raising of feed for the animals and then the raising of the animals themselves, more land is needed to complete the process. In order to produce enough to feed everyone, the Agricultural Intensity increases (Ericksen, 2008).

Consumer Demand and Distribution-Waste-Soil Health and Water

The relationships presented between Consumer Demand and Distribution, Waste, and Soil Health and Water are combined here because they represent the potential for environmental pollution through the food system. With Waste being the link between the first two factors and the last two, it is important to understand what it means in this context. Waste here is referring to the food waste generated by all parts of the system as well as the packaging waste from commercial distribution processes and animal wastes from production of animal products. Thus, it can be understood that Distribution contributes to waste by means of packaging, through the use of plastic, glass, aluminum, and cardboard containers. In 2007, a review of food packaging wastes found that total plastic packaging waste had increased from 0.1 million tons in 1960 to 13.9 million tons in 2005 in the US (Marsh & Bugusu, 2007). Additionally, cardboard and glass had practically doubled, and aluminum increased by nearly tenfold (Marsh & Bugusu, 2007). In this way, food Distribution creates Waste.

Distribution also contributes to the Waste generated through food spoilage in transit and in-store spoilage depending on the method of Distribution. At a large grocery store, this may be the produce that gets soft at the end of the week or the meat that isn't sold before the sell-by date. According to one study in the United Kingdom, the food waste associated with distribution and sales is 20% of overall food waste throughout the life-cycle of the food (Parfitt, Barthel, & Macnaughton, 2010). In the US, anywhere from 2-23% of food is lost before consumers purchase it, with the variation based on the crop in question (Parfitt et al., 2010). Even before reaching retail outlets, food waste is an issue. On the farm, there is waste from lack of proper infrastructure to preserve freshness (Parfitt, et al., 2010). Consumer Demand is involved in this because of the quality standards set by consumers. The concept of having aesthetically perfect produce is a significant generator of food waste at the source. Farmers will throw away, or leave in the field, food that does not meet market cosmetic standards (Parfitt, et al., 2010). On the other hand, when the food is an animal product, the waste generated from production according to Consumer Demand can be seen as the excrement of the animals in question. The animal wastes produced in our food system are dealt with in varying ways depending on whether the animals are raised pastorally or industrially (Mallin & Cahoon, 2003). Consumer Demand for animal products is growing, pushing the resource limits to animal production (Ericksen, 2008). In order to exceed the limitations on animal production, industrialization and Concentrated Animal Feeding Operations (CAFOs) were invented (Mallin & Cahoon, 2003). Considering the scale of industrial agriculture and the impact it has on the environment, this is a good place to start understanding the relationship between Waste and Soil Health and Water.

The impact of Waste on Soil Health and Water can be described as the potential for contamination. Wastes of all kinds, including packaging, food waste, and animal waste, if not recycled or disposed of properly, have the capability of contaminating either a water resource or the soil itself. As an example, plastic is a contaminant in many major water resources in the world. One study found that 18 shorelines worldwide had water containing microplastics, or small particles of plastic (Browne et al., 2011). The same study found sewage sludge to be a contributor to this contamination as well as soils treated with sewage sludge (Browne et al., 2011). In this way, Waste from food packaging influences Soil Health and Water through contamination.

Animal wastes carry with them the potential to create eutrophic conditions in water sources as well as contaminating the soil. This depends on the type of system in which the animals are raised, however. Pastoral systems which follow the principle of carrying capacity tend to limit the contamination potential of animal wastes (Mallin & Cahoon, 2003). On the other hand, contamination of soil and water sources can be seen from industrial agriculture. CAFOs have been shown to have a polluting effect through the failure to properly manage the Waste of the animals (Mallin & Cahoon, 2003). Wastes being washed into water sources or leaching into groundwater contribute to nutrient contamination and eventually eutrophication in some locations (Mallin & Cahoon, 2003).

Education Level and Curriculum

The relationship between Education Level and Curriculum is unique in that it is reciprocal. Not only does Education Level impact the content of the Curriculum, but also Curriculum influences the Education Level the individual obtains. The first part of the relationship can be seen quite plainly. At each grade level, a different set of subjects are taught. The Curriculum is the material and methods of instruction that is applied throughout a student's education (Bloom, 1968). Upon reaching higher education, the Curriculum becomes more advanced, mainly being determined by the course of study sought out by the individual. This brings up the second part of the relationship. Curriculum has the potential to impact the Education Level of an individual based on the way it influences the desire of the individual to continue in a formal education. On the one hand, the Curriculum could be interesting and successful in encouraging an individual to pursue further studies on the subject. In one study, the use of games as part of the Curriculum increased student's motivation to learn as well as their academic performance (Liu & Chu, 2010). In this way, the Curriculum influenced the students' desire to learn. On the other hand, the Curriculum could be uninteresting and discourage the individual from pursuing future educational endeavors either on that subject, or entirely. To encourage continued learning and the pursuit of higher education, the Curriculum must prove to be rewarding for the students (Bloom, 1968). In this way, the content of an education and the way in which it is presented has the potential to impact the degree to which an individual pursues their formal education.

Feedback Loop 1: Agricultural Intensity-Yield-Food Costs-Income-Agricultural Intensity

The first feedback loop identified depicts the way in which agriculture and economy work to reinforce each other. It all starts with Agricultural Intensity's influence on Yield. Clearly, how intensely a farmer uses the land determines how much food is produced. If the farmer were to utilize a low Agricultural Intensity, there would be little food production. Conversely, if the farmer were to employ a high level of Agricultural Intensity, more food is produced on the same plot of land. In cereals, the increase in agricultural intensity is estimated to have been responsible for 76-97% of the increase in global supply (Cassman, 1999). Thus, how intensely a farmer chooses to utilize his land determines the Yield of that land. This relationship has a limit, however. Yield potential can only increase so much with Agricultural Intensity, after which factors such as irrigation and crop variety become critical (Cassman, 1999).

Yield, then, influences the Food Costs through the simple principle of supply and demand. A higher Yield is equivalent to a higher supply. According to the principle of supply and demand, as the supply of agricultural goods increases, the price will decrease (Phelps, Carrasco, Webb, Koh, & Pascual, 2013). This becomes important in the next relationship in the feedback loop. Food Costs can also be interpreted as the price the farmer receives for their Yield. The combination of the two factors then influence the farmer's Income. While multiplying price, or Food Costs, by Yield results in the revenue of the farm rather than the Income of the farmer, this revenue has an impact on the Income of the farmer. The illustration of the increase in farmer Income based on an increase in Agricultural Intensity can be seen in the prediction of future conservation costs. One study discovered that the cost of conservation would increase based on the increasing agricultural rents associated with increased Agricultural

Intensity (Phelps et al., 2013). Thus, the cost to offset the Income the farmer would gain from producing on the land rather than leaving it in conservation was shown to increase with intensification (Phelps et al., 2013).

The change in the Income based on Food Costs will determine how the farmer chooses their Agricultural Intensity for the following year. It can change in different ways. If the price is too low because the supply is too high and it causes the Income to decrease, the farmer may choose to utilize a lower Agricultural Intensity to increase his Income. This can be seen in the conservation study where the risk of deforestation, or the expansion of agriculture, decreased with lower Food Costs (Phelps et al., 2013). This would lower the supply, increasing the price and thus having the potential to increase the farmer's Income. Alternatively, if the price is high because the supply is low, the farmer may choose to increase their Agricultural Intensity to earn more money. Again, this was exhibited in the conservation model by the increase in the risk of deforestation (Phelps et al., 2013). This would have the effect of increasing the supply, lowering the price, and potentially lowering the farmer's Income despite their efforts. The influence of the farmer's Income back onto the Agricultural Intensity which started the cycle is where the feedback comes in. The consequences of utilizing a certain Agricultural Intensity eventually make their way back to informing the next decision about Agricultural Intensity.

Feedback Loop 2: Agricultural Inputs-Yield-Food Costs-Consumer Demand-Petroleum Extraction-Agricultural Inputs

In this feedback loop, the primary factor is the Agricultural Inputs. The level of Agricultural Input use has a direct impact on the Yield of the crop. Generally, synthetic fertilizers have been shown to increase the Yield, and are required to maintain proper nutrient levels in intensified agriculture (Matson et al., 2009). Pesticides are used to reduce pest consumption of the crop, thus increasing the Yield (Matson et al., 2009). The Yield, then, influences the Food Costs as described in the previous section on Feedback Loop 1, such that higher Yield means higher supply and therefore lower price or Food Costs. The Food Costs influence the Consumer Demand based on the behavior of demand as an economic principle. The demand for any good is subject to the price, or in this case Food Cost, such that at a lower price consumers will demand more of a product, and at a higher price consumers will demand less of the product. Thus, increasing Food Cost will decrease Consumer Demand while decreasing Food Cost will increase Consumer Demand (Andreyeva, Long, & Brownell, 2010).

Consumer Demand then impacts the Petroleum Extraction. As Consumer Demand increases, the need for petroleum to make chemical inputs for agriculture increases as well. In this way, Petroleum Extraction will increase as Consumer Demand increases, or decrease as Consumer Demand decreases. Currently, Consumer Demand is driving an increase in Petroleum Extraction (Wood, Long, & Morehouse, 2004). This Petroleum Extraction will impact the Agricultural Inputs by providing the petroleum necessary to synthesize them. Agricultural Inputs such as agricultural chemicals and fertilizers have become critically linked with production based on their contribution to higher yields, but have also created a dependency on the petroleum from which they are synthesized (Hatirli, Ozkan, & Fert, 2006). If there is a higher demand, a higher quantity of Agricultural Inputs will be synthesized from the petroleum for application on agricultural land. The process will then start again where Agricultural Inputs impact Yield. If the cycle is followed through its entirety, it is clear that it is a reinforcing feedback loop. This can be seen as an increase in Agricultural Inputs causes an increase in Yield which causes a decrease in Food Costs which results in an increase in Consumer Demand, which would then increase Petroleum Extraction and further increase the Agricultural Inputs.

Feedback Loop 3: Income-Education Access-Education Level-Labor-Income

This feedback loop connects the educational subsystem with the economic subsystem, mainly through higher education. In this case, Education Access is largely determined by Income. This becomes apparent when looking at the present cost of college tuition. Education Access in terms of its affordability is dependent on either the student's Income or their family's Income. If the Income is not sufficient to pay for the price of tuition, fees, textbooks, and all of the other costs associated with college, the education is not affordable, and therefore not accessible. While parental education was a main influence on college enrollment in one study, family income was recognized as another (Ward, 2006). The parental education aspect of this study is pertinent when it comes to the feedback loop being presented here. In this way, an insufficient Income will lead to a low Education Access. On the other hand, if the Income is sufficiently high to make college affordable, Education Access will be higher. This then determines the Education Level of the individual by the fact that if college is unaffordable, the student likely will not go, where if college is affordable, the student is more likely to attend.

Education Level impacts Labor based on the eligibility of the individual for different jobs. Various positions require a certain Education Level, whether that is a GED or high school diploma or some level of college degree. Additionally, the type of degree obtained through college may determine what types of jobs are available to the individual, thus impacting their potential to Labor. This Labor feeds back into Income as the position of the individual largely dictates their salary. Connecting Education Level, Labor, and Income is the fact that positions which require some level of college degree tend to pay higher than those that will accept no education, GEDs, or high school diplomas. This relationship was discussed in a study that looked at income inequality compared to education inequality. In this study, it was said that in the United States the higher the average level of schooling, or Education Level, the less income inequality there was (De Gregorio & Lee, 2002). This means that more education for everyone would decrease the difference in income between people with a high Education Level and a low Education Level (De Gregorio & Lee, 2002). This impact on Income then influences the individual's future Education Access or the individual's children's Education Access. In this way, the influence of parental education discussed in the relationship between Income and Education Access becomes relevant. Once the parent has experienced the relationships in this feedback loop, their resulting Education Level will influence their child's Education Access as well as their Income (Ward, 2006). This too is a reinforcing feedback loop since low Income means low Education Access and thus low Education Level, low eligibility to Labor and further low Income. The same is true if the cycle is started with high Income.

Feedback Loop 4: Nutrition-Physical Health-Education Level and Labor-Income-Food Accessibility-Nutrition

The last feedback loop connects the health, education, and economic subsystems. It all starts with Nutrition which impacts Physical Health. This relationship may seem obvious, but it is made clear through the examples of overnutrition and undernutrition. When a person has too much Nutrition, or intakes more nutrients than are necessary, their Physical Health is impacted. In this case, they may become overweight or obese, limiting their ability to perform activities without issue. A study concerning childhood obesity stated that diets high in fat and carbohydrates are linked with the overnutrition associated with obesity (Donnelly et al. 1996). Another discussed the consequences of a low quality diet, or one lacking nutrition but high in energy density, as leading to the gaining of weight and ultimately obesity (Jyoti, Frongillo, & Jones, 2005). Other physical ailments resulting from overnutrition may be diabetes or heart disease (Donnelly et al., 1996). This shows that Nutrition has an impact on the Physical Health of the individual through the physical structure and body composition as well as the functioning of various bodily systems.

The Physical Health of the individual then impacts the Education Level and the Labor of the individual in much the same way. Having the physical ability to learn or to work is a factor in how far an individual goes in their education or what jobs are available to the individual. Obesity, for example, can be associated with lower levels of education (Donnelly et al., 1996). Good Physical Health facilitates a person reaching a higher Education Level by giving them the tools they need to focus on their studies. That is not to say that people in poor Physical Health cannot attain higher Education Levels, but it is more likely that good Physical Health will encourage better learning. Academic performance can be linked with the quality of the student's diet, thus influencing their potential Education Level (Jyoti et al., 2005). This is exemplified by the link between food insecurity and education. In a study of school children over a period of three years, food insecurity showed an impact on academic performance based on a series of tests administered over time (Jyoti et al., 2005). This same test showed that social skills were diminished by the prevalence of food insecurity in the children's households (Jyoti et al., 2005). This discourages the achievement of higher Education Levels. This impacts Labor through the relationship described under the section on Feedback Loop 3 where higher Education Levels increase the eligibility of the individual to Labor. Labor is also influenced directly by Physical Health based on the physical ability of the individual. A study which explored the costs of various health conditions discovered that many conditions impacted the productivity of the individual as well as the amount of time spent at work (Goetzel, Long, Ozminkowski, Hawkins, Wang, & Lynch, 2004). Many of these conditions or diseases were ones also associated with obesity or food. Examples include hypertension, cardiovascular disease, and diabetes which cost employers approximately $392, $368, and $257 per employee per year respectively (Goetzel et al., 2004). The individual's Labor influences Income based on the relationship described under the section discussing Feedback Loop 3 in which the type of job an individual has determines the Income they receive.

The Income of an Individual influences the Food Accessibility of that individual through affordability. Because Food Accessibility concerns not just the physical presence of food, but the ability of the individual to buy that food, how much money the individual earns as Income determines the affordability of the available food. Thus, Income determines Food Accessibility of the individual. In a study of low income families, affordability proved to be a barrier perceived by participants when it came to increasing the amount of fruits and vegetables they bought (Dibsdall, Lambert, Bobbin, & Frewer, 2002). Subsequently, Nutrition is impacted by Food Accessibility. Since having the fresh fruits, vegetables, meat, and dairy products to consume is the first step to a balanced diet and proper Nutrition, Food Accessibility becomes important. Without access to these foods, either physically or financially, the Nutrition of the individual suffers. The study previously mentioned said that in the UK an income of less than £150 per week resulted in a lower Nutrition intake in the family's diet (Dibsdall et al., 2002). With increased Food Accessibility, both financially and physically, the Nutrition of the individual improves. This is the end of an overall reinforcing feedback loop. This can be seen by following the cycle. Good Nutrition leads to good Physical Health which increases Labor and Education Level potential which increases Income, creating better Food Accessibility for the individual which would improve their Nutrition. The loop would be reinforcing even if the cycle was started with poor Nutrition.

Food Accessibility: The Intersection of Agriculture, Economy, and Health

Of all of the factors presented in this model, there were a few that stood out as being integral to many of the subsystems represented. Food Accessibility was one of these key factors based on its relationships between the agricultural, economic, and health subsystems. Food Accessibility had 4 relationships overall, 2 of which, Income and Food Accessibility and Food Accessibility and Nutrition, have been previously discussed. Under the section on Feedback Loop 4, it is described that Income impacts Food Accessibility because an individual's Income determines what is affordable food for them. Food Costs are linked to Food Accessibility in much the same way. The price of food determines how affordable it is for the consumer. The study which showed the barrier of affordability in increasing the purchase of fresh fruits and vegetables was expressing the intersection of Food Costs and Income for the consumer (Dibsdall et al., 2002). In other words, the Food Costs determine the Food Accessibility for any given food. Also under the section on Feedback Loop 4, the relationship between Food Accessibility and Nutrition is explained to mean the requirement of having the fresh fruits, vegetables, meat, and dairy products to make a diet with enough Nutrition possible. This physical access to foods is influenced by Distribution. The way in which food is transported and distributed to various areas determines the Food Accessibility of each individual location. If Distribution is such that fresh fruits and vegetables as well as meat and dairy products are distributed to an area, then that area has good Food Accessibility. If, however, Distribution is such that these foods are not distributed to an area, then that area has poor Food Accessibility. This relationship is clearly shown through the presence of food deserts in the United States. These are areas in which access to healthy and affordable foods is so limited that it is practically non-existent (Walker, Keane, & Burke, 2010). In many cases, the number of stores with these foods is the issue, thus displaying the importance of Distribution (Walker, Keane, & Burke, 2010). Food Accessibility is the intersection of affordability based on Food Costs and Income, and physical access based on Distribution. Ultimately, all of these factors combined end up influencing the Nutrition of the individual by influencing their ability to obtain the fresh fruits and vegetables as well as meat and dairy products needed to obtain the proper nutrients.

Food Costs: The Intersection of Agriculture and Economy

Because of how it influences the producer as well as the consumer, and based on the number of relationships that can be seen with Food Costs, this factor is another of the key factors for this model. Food Costs brings together the agricultural factors such as Agricultural Inputs and Yield, and economic factors such as Consumer Demand and Labor. It is important, first, to understand which of these factors has an influence on determining what the Food Costs are. In this model, it can be seen that Labor, Land Access, Policy, Distribution, Agricultural Inputs, and Yield are the influential factors. The relationship between Food Costs and Yield was previously discussed under the section on Feedback Loop 1. This relationship was one which reflected the principle of supply and demand, where increased Yield, or supply, would cause a decrease in Food Costs, or price, and vice versa. Most of the other influencing factors reflect a relationship of cost of production. Agricultural Inputs, Distribution, Labor, and Land Access are all factors that the farmer has to pay for to produce the food, thus contributing to the cost to produce the food.

The farmer has to pay for the Agricultural Inputs they choose to apply. The cost of the Agricultural Inputs, then, contributes to the overall cost of production which is then divided by Yield to determine the cost of production of the individual unit of the product. If input costs are high, the cost of production will be high, leading the farmer to make decisions about production based on Food Costs (Godfray et al., 2010). The cost of Distribution for the food is another expense that is taken into account when determining cost of production. If the food is sold locally, the cost may only be the money it takes to run a farm stand or to drive to a farmer's market. If it is sold long distances from the farm, the costs of this travel must be included in the cost of production as well and may prove to be a barrier to wider Distribution (Godfray et al., 2010).

Labor is another important cost of production for food (Gardner, 1975). The Labor costs associated with production of food include the money paid to farm employees as well as the money the farmer pays to themselves. How much Labor is put into the production of food determines how high or low this cost will be. This is the case with all of the costs of production so far. More Agricultural Inputs will lead to a higher cost of production and theoretically higher Food Costs. An increase in the cost of Distribution will also increase the cost of production. Land Access, the final cost of production listed in the model, stands out a bit from these other factors however, in that the relationship between Land Access and Food Costs is not intuitive. The ability of the farmer to have physical access to land, however, is not the side of this factor that is focused on in this relationship, however. Rather, it is the affordability of the land to the farmer which contributes to the cost of production. The cost of agricultural land is increasing, proving to be an expensive investment for the farmer (Godfray et al., 2010). How much a farmer is paying for the land they are farming on will contribute to the overall cost of production on the farm, thus influencing the cost of production of the individual food product. These costs of production influence the Food Costs through a reinforcing relationship. As any one of the costs increases, so too will Food Costs.

Lastly, Food Costs are influenced by Policy. This last relationship is a bit complicated. The basic premise of the relationship is that there are policies within the United States that either set the market price, or Food Costs, or falsely adjust the price of different commodity crops. This is done through a series of government subsidies which guarantee the farmer a certain minimum price for their crop. The cost of the surplus production, then either becomes the burden of the consumer or the burden of taxes (Alston, Sumner, & Vosti, 2008). The prices then appear to be lower for commodity crops on the market (Alston, Sumer, & Vosti, 2008). Overall, Food Cost is ultimately affected by Policy through subsidies that make the price incredibly and falsely low.

The influence of Food Costs on other factors is equally as important as the influences on Food Costs. The factors impacted by Food Costs include Food Accessibility, Consumer Demand, and Income. The relationships between Food Costs and Consumer Demand, Food Costs and Food Accessibility, and Food Costs and Income have been previously discussed in the sections describing Feedback Loop 1, Food Accessibility, and Feedback Loop 2, respectively. Under the section about Feedback Loop 1, it was described that Food Costs influence Consumer Demand based on the principle of demand which says that at a lower price consumers will demand more than at a higher price. Food Costs impacted Food Accessibility because the price of food determines whether it is affordable for the consumer, or not. Income was influenced by Food Costs when coming from the perspective of the farmer because the price of the food determined how much money the farmer would make.

Income-Consumer Demand-Policy

The relationships between Income, Consumer Demand, and Policy are tied together such that they are more clearly understood when presented together. In this case, the Income of the consumer influences the Consumer Demand for food. If the Income of the consumer is low, they will demand food at a lower price in order to fit their financial capabilities. If the Income of a consumer is higher, they will be able to afford higher prices and may not demand lower-priced food. The change in Consumer Demand based on price changes is, then, influenced by consumer Income (Andreyeva, Long, & Brownell, 2010). Thus, the Consumer Demand is influenced by the Income of the consumer. This translates into the influence that Consumer Demand has on Policy. Though the United States employs a system of capitalism, there are still certain regulations that the government employs that interfere with economic matters. No other factor in this model has influence over Policy except Consumer Demand. This is because the advocacy of the consumer through participation in a constituency or an advocacy group has the ability to influence legislators to propose legislation in Congress. An example of the influence of Income on Consumer Demand is the Policy which creates cheap food. Consumers seek out low prices on food while maintaining quality (Grunert, 2005). Policy responds to this Consumer Demand by providing labeling to help consumers ascertain the quality of foods as they view the price at the store (Grunert, 2005). Agricultural subsidies were the resulting Policy of this form of Consumer Demand which showed that cheap food was needed. This Policy will be discussed in a later section.

Income-Land Access

The relationship between Income and Land Access is fairly simple to understand. The Income of the farmer, or aspiring farmer, determines what price range they can look at when trying to buy or lease land for agriculture based on the amount of credit they can obtain (Shalit & Schmitz, 1982). Land Access is about what land is available to the farmer, including what is affordable for the farmer. Thus, if a farmer has a high Income, their Land Access is increased because they can afford more land or higher priced land. Conversely, if a farmer has a low Income, their Land Access is also low because they will not be able to afford expensive land or large acreages. This concept is expressed in the concern that farmland has become inaccessible based on the relationship between rising farmland prices and farmer Income (Pope, Kramer, Green, & Gardener, 1979).

Land Access, Soil Health, and Water-Yield-Distribution

Yield is a key factor in the agricultural subsystem which is influenced by Land Access, Soil Health, and Water. For Land Access, the relationship has to do with the quantity of land that the farmer has. A larger area of land allows the farmer to grow more crops and thus have a higher Yield than a smaller area of land. Productivity of the land use contributes to Yield as well (Cornea, 1985). Farmers with smaller areas of land may use their land more efficiently due to the scarcity of the land where a larger farm may produce a lower Yield per acre because of the abundance (Cornea, 1985). The quality of the land is important as well. This has more to do with Soil Health than Land Access. The nutrient content of the soil, which is a large part of Soil Health, largely determines the productivity of the crop and thus the Yield (Yadvinder-Singh et al., 2004). In this way, better Soil Health, with more nutrients available to the crop, will produce a higher Yield. On the other hand, a poor Soil Health, with fewer nutrients, will produce a lower Yield (Yadvinder-Singh et al., 2004). Lastly, the amount of Water applied will impact the Yield. Water is an essential component of agriculture as it is necessary for plant growth. Low Water applied, whether in the form of rain or irrigation, produces a low Yield. Increased irrigation has, however, been shown to increase crop Yield (Matson et al., 1997). Water has an interesting relationship, however, in that it is possible to have too much. Too much Water will actually decrease the Yield of the crop (Yadvinder-Singh et al., 2004). Therefore, it follows that a very high level of Water application will also produce a low Yield. In this case, it is a balanced amount of Water application that will produce a high Yield.

These factors which influence Yield also indirectly influence the Distribution method that the farm will employ. Yield is a measure of productivity on a farm. If the farm has a high Yield, it is considered productive, where a low Yield would signify that it was unproductive. Depending on the Yield of the farm, they have the ability to utilize different Distribution methods. The smaller or lower Yield farms tend to utilize direct marketing methods (Timmons & Wang, 2010). This may be a farm stand, farmer's markets, or even wholesaler selling to local restaurants and businesses. As the farm gets larger or increases their Yield, they can fulfill larger wholesale orders to local institutions or stores. The really big farms or high Yield farms can move on to utilizing Distribution methods which carry their crops to a location that is further away. This represents the correlation between farm size, and thus Yield, and Distribution method that was discovered by Timmons and Wang (2010).

Petroleum Extraction-Distribution and Agricultural Inputs-Food Costs

This set of relationships has to be linked together because of the directness with which they impact each other. It starts with Petroleum Extraction influencing the production of Agricultural Inputs and supplying fuel for various methods of Distribution. Agricultural Inputs are often petrochemicals, derived from petroleum or petroleum bi-products. The relationship between Petroleum Extraction and Agricultural Inputs has been previously discussed under the section on Feedback Loop 2. Almost all Distribution methods require some form of petroleum whether in the form of gasoline or diesel that fuels the trucks/tractors that haul the crop back to the farm stand, the vehicles driving the food to the farmer's market, or the tractor trailers hauling food across the country. Even in the case of exportation, petroleum is used to fuel the boats, planes, or trains that transport food outside of the country. Thus, the distance travelled from the farm exhibits the relationship between Petroleum Extraction and Distribution through the release of emissions by the vehicles transporting the food (Weber & Matthews, 2008). One study showed that local distribution in the United States had the potential to reduce "food miles," in this case an approximation of greenhouse gas emissions, by about 1000 miles per year (Weber & Matthews, 2008). As described under the section on Food Costs, the Distribution and Agricultural Inputs, then, are part of the cost of production which influences Food Costs.

Policy: The Intersection of All Subsystems

The last of the key factors found which intersects the subsystems is Policy. Policy is influential over the agricultural, economic, educational, energy, and health subsystems, but is only influenced by Consumer Demand. This lack of feedback that Policy receives is an important part of the place it holds in the system. Because of the incredible amount of influence that Policy has and the very little bit of impact that anything else has on Policy, it can be seen as having a significant power over the system. This power is seen in the ability of Policy to influence Curriculum, Income, Nutrition, Food Costs, Labor, Land Access, Petroleum Extraction, and Agricultural Intensity. In each of these cases, there is a Policy which has changed the system through the impact on these factors.

Curriculum is influenced by Policy in that there is legislation concerning what teachers are required to teach in the United States. The Common Core Standards were established to set a standard for primary education. So far, 45 states have made it their Policy that Common Core Standards must be followed (U.S. Department of Education, n.d.). Thus, the Curriculum changes to fit what Policy dictates. Income has a similar situation. Though the government does not intervene in the Income of all individuals, it does set a minimum wage so that everyone who works in some legal capacity will be guaranteed minimum compensation for their time (United States Department of Labor, n.d.). The federally set minimum wage at this time is $7.25/hour (United States Department of Labor, n.d.). This represents the ability of Policy to put a floor on the Income of a worker.

Nutrition is influenced by Policy in several ways. The first is that the USDA determines what will be officially recognized as a nutritious diet. This can be seen in their Dietary Guidelines for Americans publication that comes out every 5 years. Though this is not a piece of legislation, it is certainly a Policy from a government agency that has an incredible impact on what is considered “proper nutrition” (United States Department of Agriculture, n.d.). There is legislation, however, in the form of the Farm Bill, which impacts Nutrition. The Farm Bill is unique in that it impacts Nutrition, Agricultural Intensity, and Food Costs all at the same time. The Farm Bill’s impact on Nutrition is in the form of food assistance programs. Whether this is the National School Lunch Program, the Supplemental Nutrition Assistance Program, or the Women, Infants, and Children Program, the financial assistance given to low-income families is intended to assist with nutritional access (United States Department of Agriculture Economic Research Service, n.d.). While the balance of these nutrients is called into question, there is little doubt that the supplemental food obtained through the program allows for a higher intake of at least some nutrients.

The Policy for government subsidies to farmers is written in the same piece of legislation. The subsidies work to ensure that farmers of commodity crops are paid enough to continue producing. Various forms of subsidies set minimum prices such that farmers are compensated either by the market or by the government depending on the current price of food (United States Department of Agriculture Economic Research Service, 2016). The format of the subsidies, however, favors producers with the highest Yield, thus influencing the Agricultural Intensity. Since high Agricultural Intensity results in high Yield, the Farm Bill also favors high Agricultural Intensity. These subsidies also have the effect of falsely lowering food prices and thus Food Costs to the consumer (Alston, Sumer, & Vosti, 2008). This is because the government is paying for part of the cost of the food. In this way, the consumer is unaware of the full cost and sees only the presented Food Costs.

Policy impacts Labor by setting standards for certain job positions. The clearest example of this is the requirement of teachers, electricians, medical professionals, and more to be certified for their positions. To highlight one, teachers are required to be certified based on standards administered by the US Department of Education, but approved by the government at the state level (New Hampshire Department of Education, n.d.) This creates a limit to eligibility to Labor. Policy creates a similar sense of control on Petroleum Extraction. Policy has the capability to allow oil companies to extract petroleum following certain standards or with exceptions to the standards. Policy can govern the practices of Petroleum Extraction through the Federal Energy Regulatory Commission (Federal Energy Regulatory Commission, 2016). Similarly, governmental Policy may have certain controls over the land that the farmers can use, thus influencing their Land Access. The conservation policies of the government implement certain restrictions on how the land can be used, but also provide incentives for landowners to be involved in conservation (U.S. Department of Agriculture, n.d.). This may make Land Access slightly easier for farmers if the incentives increase affordability.

Conclusion:

It is clear that the food system represents a much larger scale than the typical production-distribution-consumption pattern that is generally thought of when discussing the subject. It includes aspects of several subsystems such as the agricultural, economic, educational, energy, health, and political subsystems represented in this model. The relationships between different factors in each of these subsystems adds to the complexity of the overall food system. The process of identifying the relationships between factors for the model led to the emergence of several feedback loops between the subsystems which showed ways in which they reinforced patterns of action in each other. This can be seen through Feedback Loop 1 in which agriculture impacted economics which impacted energy which fed information back to agriculture, Feedback Loop 2 in which agriculture influenced economics which fed information back to agriculture, Feedback Loop 3 in which economics influenced education which then influenced economics, and Feedback Loop 4 in which health influenced education and economics which then influenced health once again. These feedback loops were important to identify because in most cases they too were interconnected. Thus, the individual relationships that connected the feedback loops illustrated that a single interaction could result in many subsequent interactions. In other cases, the relationships were interconnected even when not involved in feedback loops. This was evident when looking at the relationships between Petroleum Extraction, Agricultural Inputs and Distribution, and Food Costs.

The interconnectedness of the subsystems and the multiple feedback loops present in the model and analyzed in this report serves to illustrate the complex nature of the food system that is in place today. As work to improve the food system has become a focus area for many people at this time, it is important to have a framework which serves to put the food system in context. While this was by no means a complete analysis of all existent interactions within the food system, it does serve to illustrate several important points about the functioning of the system as a whole. The first is the idea of interconnectedness. Food is involved in the many subsystems represented in the model, potentially more. In approaching food system work, it is important to recognize these interactions in order to avoid unintended consequences to one part of the system resulting from actions in another. The second point is that there are patterns of interaction in the form of interconnected relationships and feedback loops which must be likewise considered when trying to change the way in which the system functions. Thirdly, there emerged several key factors that were related to most if not all subsystems represented in the model. These included Food Accessibility, Nutrition, and Policy. These factors showed up at the intersection of nearly all subsystems, making them important places for work to occur. Upon further investigation, they may prove to be leverage points which can be utilize to create cascading impacts on the rest of the system.

This project's purpose was to create a framework for thinking of the food system as a collection of different factors from different systems interconnected and impacting each other to create the state of the food system today. The scope of the project was somewhat limited by time and perspective. It certainly has the potential to be expanded in the future. With the inclusion of several more individuals, each contributing their own expertise to the model, it could be refined, expanded, and analyzed further for a more detailed understanding of the particular workings of the presented relationships. For now, the model is a visual representation of the framework and the analysis adds substance. It is the goal of this project that this will assist those working towards change in the food system to see how they will impact others through their actions with the intention that collaboration and careful planning could lead to the avoidance of unintended consequences.

References:

Alston, J. M., Sumner, D. A., & Vosti, S. A. (2008). Farm subsidies and obesity in the United States: National evidence and international comparisons. *Food Policy, 33*(6). 470-479. doi:10.1016/j.foodpol.2008.05.008

Andreyeva, T., Long, M. W., & Brownell, K. D. (2010). The Impact of Food Prices on Consumption: A Systematic Review of Research on the Price Elasticity of Demand for Food. *American Journal of Public Health, 100*(2). 216-222. doi: 10.2105/AJPH.2008.151415

Bloom, B. S. (1968). Learning for Mastery. *Evaluation Comment, 1*(2). Retrieved from https://eric.ed.gov/?id=ED053419.

Boxall, A. B. A., Hardy, A., Beulke, S., Boucard, T., Burgin, L., Falloon, P. D., …Williams, R. J. (2009). Impacts of Climate Change on Indirect Human Exposure to Pathogens and Chemicals from Agriculture. *Environmental Health Perspectives, 117*(4), 508-514. doi:10.1289/ehp.0800084

Browne, M. A., Crump, P., Niven, S. J., Teuten, E. L., Tonkin, A., Galloway, T., & Thompson, R. C. (2011). Accumulations of microplastics on shorelines worldwide: sources and sinks. *Environmental Science and Technology, 45*(21). 9175-9179. doi: 10.1021/es201811s

Cassman, K. G. (1999). Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. *Proceedings of the National Academy of Sciences USA, 96*(11). 5952-5959. doi: 10.1073/pnas.96.11.5952

Cornia, G. A. (1985). Farm Size, Land Yields and the Agricultural Production Function: An Analysis for Fifteen Developing Countries. *World Development, 13*(4) 513-534. doi: 10.1016/0305-750X(85)90054-3

De Gregorio, J. & Lee, J. W. (2002). Education and Income Inequality: New Evidence from Cross-Country Data. *Review of Income and Wealth, 48*(3). 395-416. doi: 10.1111/1475-4991.00060

Donnelly, J. E., Jacobsen, D. J., Whatley, J. E., Hill, J. O., Swift, L. L., Cherrington, A., …Reed, G. (1996). Nutrition and Physical Activity Program to Attenuate Obesity and Promote Physical and Metabolic Fitness in Elementary School Children. *Obesity Research, 4*(3). 229-243. doi: 10.1002/j.1550-8528.1996.tb00541.x

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environmental Change, 18*(1). 234-245. doi:10.1016/j.gloenvcha.2007.09.002

Federal Energy Regulatory Commission. (2016). *Oil*. Retrieved from https://www.ferc.gov/industries/oil.asp.

Gardner, B. L. (1975). The Farm-Retail Price Spread in a Competitive Food Industry. *American Journal of Agricultural Economics, 57*(3). 399-409. https://doi.org/10.2307/1238402

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., …Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science, 327*. 812-818. doi: 10.1126/science.1185383

Goetzel, R. Z., Long, S. R., Ozminkowski, R. J., Hawkins, K., Wang, S., & Lynch, W. (2004). Health, Absence, Disability, and Presenteeism Cost Estimates of Certain Physical and Mental Health Conditions Affecting U.S. Employers. *Journal of Occupational and Environmental Medicine, 46*(4). 398-412. doi: 10.1097/01.jom.0000121151.40413.bd

Grunert, K. G. (2005). Food quality and safety: consumer perception and demand. *European Review of Agricultural Economics, 32*(3). 369-391. doi:10.1093/eurrag/jbi011

Hatirli, S. A., Ozkan, B., & Fert, C. (2006). Energy inputs and crop yield relationship in greenhouse tomato production. *Renewable Energy*, *31*(4). 427-438. doi:10.1016/j.renene.2005.04.007

Jyoti, D. F., Frongillo, E. A., & Jones, S. J. (2005). Food Insecurity Affects Children's Academic Performance, Weight Gain, and Social Skills. *Journal of Nutrition*, *135*(12). 2831-2839. Retrieved from http://jn.nutrition.org/content/135/12/2831.full.pdf+html.

Lal, R. (2009). Soil degradation as a reason for inadequate human nutrition. *Food Sec.*, *1*, 45-57. doi: 10.1007/s12571-009-0009-z

Liu, T. Y. & Chu, Y. L. (2010). Using ubiquitous games in an English listening and speaking course: Impact on learning outcomes and motivation. *Computers & Education, 55*. 630-643. doi:10.1016/j.compedu.2010.02.023

Mallin, M. A. & Cahoon, L. B. (2003). Industrial Animal Production-A Major Source of Nutrient and Microbial Pollution to Aquatic Ecosystems. *Population and Environment, 24*(5). 369-385. doi:10.1023/A:1023690824045

Marsh, K. & Bugusu, B. (2007). Food Packaging-Roles, Materials, and Environmental Issue. *Journal of Food Science, 72*(3), R39-R55. doi: 10.1111/j.1750-3841.2007.00301.x

Matson, P. A., Parton, W. J., Power, A. G., & Swift, M. J. (1997) Agricultural Intensification and Ecosystem Properties. *Science*, *277*. 504-509. doi: 10.1126/science.277.5325.504

New Hampshire Department of Education. (n.d.). *Certification/Bureau of Credentialing*. Retrieved from http://www.education.nh.gov/certification/index.htm.

Oliver, M. A. & Gregory, P. J. (2005). Soil, food security and human health: a review. *European Journal of Soil Science*, *66*. 257-276. doi: 10.1111/ejss.12216

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of The Royal Society B, 365*. 3065-3081. doi:10.1098/rstb.2010.0126

Phelps, J., Carrasco, L. R., Webb, E. L., Koh, L. P. & Pascual, U. (2013). Agricultural intensification escalates future conservation costs. *Proceedings of the National Academy of Sciences, 110*(19). 7601-7606. doi: 10.1073/pnas.1220070110

Pope, R. D., Kramer, R. A., Green, R. D., & Gardner, B. D. (1979). An Evaluation of Econometric Models of U.S. Farmland Prices. *Western Journal of Agricultural Economics, 4*(1). 107-119. Retrieved from http://www.jstor.org/stable/40987480.

Shalit, H. & Schmitz, A. (1982). Farmland Accumulation and Prices. *American Journal of Agricultural Economics*, *64*(4). 710-719. https://doi.org/10.2307/1240580

Thrupp, L. A. (1991). Long-term Losses from Accumulations of Pesticide Residues: a Case of Persistent Copper Toxicity in Soils of Costa Rica. *Geoforum, 22*(1), 1-15.

Timmons, D. & Wang, Q. (2010). Direct Food Sales in the United States: Evidence from State and County-Level Data. *Journal of Sustainable Agriculture, 34*(2). 229-240. http://dx.doi.org/10.1080/10440040903482605

Walker, R. E., Keane, C. R., & Burke, J. G. (2010). Disparities and access to healthy food in the United States: A review of food deserts literature. *Health & Place, 16*. 876-884. doi:10.1016/j.healthplace.2010.04.013

Ward, N. L. (2006). Improving Equity and Access For Low-Income and Minority Youth Into Institutions of Higher Education. *Urban Education, 41*(1). 50-70. doi: 10.1177/0042085905282253

Wauchope, R. D. (1978). The Pesticide Content of Surface Water Draining from Agricultural Fields-A Review. *Journal of Environmental Quality, 7*(4), 459-472. doi: 10.2134/jeq1978.00472425000700040001x

Weber, C. L. & Matthews, H. S. (2008). Food-Miles and the Relative Impacts of Food Choices in the United States. *Environmental Science and Technology, 42*. 3508-3513. doi: 10.1021/es702969f

Wood, J. H., Long, G. R., & Morehouse, D. F. (2004). *Long-Term World Oil Supply Scenarios: The Future Is Neither as Bleak or Rosy as Some Assert*. Retrieved from https://www.eia.gov/pub/oil_gas/petroleum/feature_articles/2004/worldoilsupply/oilsupply04.html.

Yadvinder-Singh, Bijay-Singh, Ladha, J. K., Khind, C. S. Gupta, R. K., Meelu, O. P., & Pasuquin, E. (2004). Long-Term Effects of Organic Inputs on Yield and Soil Fertility in the Rice-Wheat Rotation. *Soil Science Society of America Jounal*, *68*. 845-853. doi:10.2136/sssaj2004.8450

United States Department of Agriculture. (n.d.). *Dietary Guidelines*. Retrieved from https://www.cnpp.usda.gov/dietary-guidelines.

United States Department of Agriculture Economic Research Service. (2016). *Crop Commodity Program Provisions-Title I*. Retrieved from https://www.ers.usda.gov/topics/farm-economy/farm-commodity-policy/crop-commodity-program-provisions-title-i/.

United States Department of Agriculture Economic Research Service. (n.d.). *Supplemental Nutrition Assistance Program (SNAP) Overview*. Retrieved from https://www.ers.usda.gov/topics/food-nutrition-assistance/supplemental-nutrition-assistance-program-snap/.

United States Department of Labor. (n.d.). *Minimum Wage*. Retrieved from https://www.dol.gov/general/topic/wages/minimumwage.

U.S. Department of Agriculture. (n.d.). *Conservation*. Retrieved from https://www.usda.gov/topics/conservation.

U.S. Department of Education. (n.d.). *College- and Career-Ready Standards*. Retrieved from https://www.ed.gov/k-12reforms/standards.