An Application of Systems Thinking – Food Systems

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***Abstract* – Most of us make our weekly trip to the grocery store, purchase, and consume our favorite foods without giving much thought into where it came from, the resources used to get it from farm-to-plate, laws and regulations dictating food safety and sustainment, factors influencing price, political pressures, etc. Our modern day food system is one of the most complex systems in society and is facing many challenges that includes feeding a growing population, distribution, managing ecosystems, nutritional value, and water shortages to name a few. To get to the root of these issues, they need to be viewed from a system's point of view, tackled as systemic issues of the food system as a whole, instead of trying to solve these individually. This paper will apply the Systems Thinking framework to create an abstract model of the modern day food system that goes beyond food production, cultivation, distribution, processing, consumption, etc., but also dives into the socioeconomic factors, laws and regulations, environmental impacts, ethics, as well as external systemic impacts. Ultimately, the analysis done here will be used to lead the way into future research and system analysis that will lead to innovative ways to optimize the current food system and further build upon existing models and framework that may be used to help mitigate some of the major known impacts on the food supply.**

Keywords–Systemigram; Interest Map; Context Diagram; Drivers.

I INTRODUCTION

There are many challenges with our current food system, at varying degrees of severity and scale. Some of the major challenges with the food system include sustainment and the ability to feed a growing population with ever increasing strains on water supply, increase in poverty, a changing global environment, wars, political unrest, satisfying laws and regulations, reducing impacts on local ecosystems, and understanding the nutritional needs of the human population. An example of geopolitical pressures straining the food supply is the Russian-Ukraine war currently taking place, which is directly affecting the global supply of grain. Prior to the war, around 90% of Ukraine's agriculture exports were seaborne, but blockades due to the Russian conflict has brought these exports to a virtual standstill, leaving a devastating impact on Ukraine's economy and a significant spike to food prices worldwide [3]. Figure 1 below shows the worldwide impacts (food price index) due to geopolitical instability on the food supply relating to the Russian-Ukraine war. This increase in food price index further stresses an already recessed global economy. This forces nations to find other sources, which may have complications due to a variety of other factors.

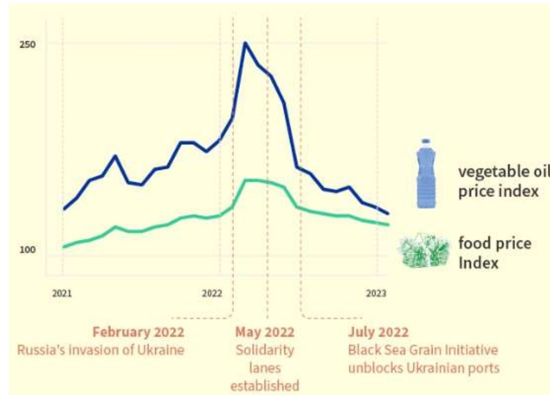

Figure 1. Food Price Index Impacts on Russian-Ukrainian War [3]

Another example is climate change, which is turning what were once fertile lands into dry basins creating the engineering challenge of finding other water sources or conserving existing supplies for crops (as shown in [9] and [10]). In order to dive deep into these issues, one needs to understand the complex relationships and shaping forces that make up the food system with its stakeholders. What interactions and interrelationships impact the food supply chain. How can we improve existing processes, and eliminate non-value added ones? To answer these, first we must answer the question "what is a Food System"?

The first step in understanding the problem that is our "Food System", a formal definition needs to be developed and agreed upon. According to Oxford University, The Food System is a "complex web of activities involving the production, processing, transport, and consumption. Issues concerning the food system include the governance and economics of food production, its sustainability, the degree to which we waste food, how food production affects the natural environment and the impact of food on individual and population health" [1]. By this definition, our food system is not only the processes and technology involved with cultivating, distributing, processing, and consuming food, but also the governance of food, the economics of food, sustainment of the food supply and the environment. All of these aspects are key drivers of the food system. As shown in Figure 2, there is a feedback loop, where the drivers impact the food system (i.e., environmental, and socioeconomic drivers directly impact food system stability and supply) and vice versa (producing more food means more people can be fed, decrease in available water supply to population, and more greenhouse gas emissions).

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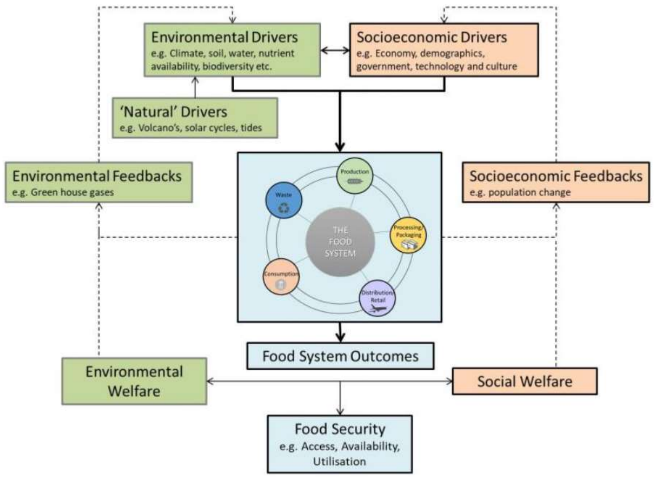

Figure 2. Food System Drivers [1]

As we begin our systems thinking approach to developing a holistic view of the food system as defined prior, this paper will dig deeper into each of these drivers, how they relate to our stakeholders, how they shape our system, what processes work, which ones have areas of improvement, and how we can use these drivers to sustain the food supply. This paper will not solve world hunger, but it will help establish the framework to better understand the knobs and levers that control some of the drivers responsible for world hunger along with other downstream effects to mitigate disturbances to the food supply.

In Section 2, a stakeholder perspective analysis will be performed to identify stakeholders, understand their interactions with the system and their values. In Section 3, value-added (and non-value-added) processing will be identified, as well as the shaping forces that dictate these factors. In Section 4, an analysis of shaping forces will be performed to better understand how external (and in some cases internal) drivers that impact or dictate the system's behavior and limitations. In Section 5, critical properties of the system will be analyzed and interpreted through the use of systemigrams. These types of diagrams help to build a framework of system interdependencies, tying in all stakeholder perspectives to tell a story.

II. STAKEHOLDER PERSPECTIVE ANALYSIS

Earlier, we defined what a food system was and talked briefly about the "drivers" of this system. From here, one can develop a list of considerations for this system of interest.

Table 1 is a list of (key) considerations for the food system per our definition. Some considerations worth noting include Environmental considerations, which not only has to do with the land's ability to yield large amounts of crops, but also the impacts that crops, livestock, factories, etc., have on the local ecosystem. Sustainability which ties into future generations. It is important to have a sustainable food supply for the foreseeable future. Socioeconomic factors like demographics and economy drive the types of food, the quality and scalability of the food sources. Technology allows for larger crop yields but may also have an environmental footprint. Finally, the stakeholders who have a direct stake in food systems, though technically the entire human population can be viewed as stakeholders of such a system, we can still divide this up into discernable categories as shown in the context diagram below in Figure 3.

TABLE I. SYSTEM CONSIDERATIONS

Food System Considerations	
Considerations	**Description**
Environmental	Includes anything from fertility and climate to availability of water supply, environmental welfare, and impacts on local ecosystems
Sustainability	Long term sustainment of resources, land, food supply, trade routes, etc.
Supply and Demand	Ensure a steady supply to meet demand
Costs	Costs due to production, distribution, governing, etc.
Mass Production	Mass production system that is sensitive to demand, ethical, minimal downtime and disturbances, etc.
Distribution	Distribution from trade amongst countries to grocery store deliveries down to the customer
Efficiency	Producing and distributing food costs resources, making efficient use of these resources vital to keep costs reasonable, remain sustainable, keep a steady supply, etc.
Stakeholders	See Figure 3 Context Diagram
Safety and Governance	FDA, world trade laws, etc.
Future Generations	Availability of food supplies in the future
Economy	State of economy impacts food availability
Demographics	Cater food supply to regional demographics
Technology	Technology available in support of food production and distribution

In the context diagram, the Food System boundary is established by the larger lighter shaded yellow circle. The darker yellow circles inside make up some of the key subsystems of the overall food system. The blue squares are the stakeholders where their relationship or connection to the subsystem is established by the arrows pointing to the food system. The green boxes show some of the external systems that directly/indirectly interact with the food system. Though technically the entire human population would be considered a stakeholder, the ones shown here in blue represent a layer of abstraction down from that. These stakeholders can be further extracted, for example "Food Related Appliance/Product Manufacturers" can be broken down into farm equipment, trucks for distribution, and even ovens, air fryers, toasters, etc., for the consumer markets.

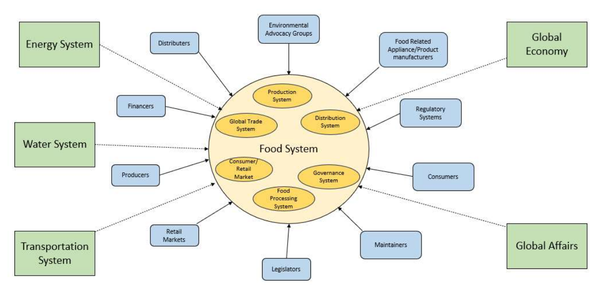

Figure 3. Food System Context Diagram

An interest map (as was done in [7]) can be seen below in Figure 4 that gives a more dynamic depiction between the food system and its stakeholders.

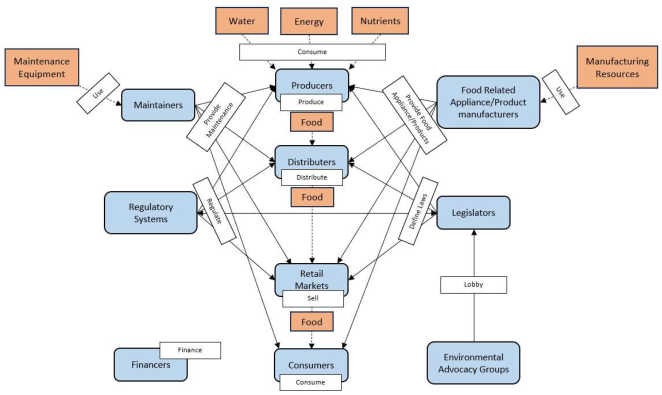

Figure 4. Interest Map Food System

From the interest map shown above, one can get an idea of how the various stakeholders (blue boxes) take part in the food system. We see some stakeholders taking in external objects shown in orange (i.e., producers taking in water, energy, and nutrients). Interactions between such objects and a stakeholder are represented by a dashed arrow. Actions are shown by the white boxes (i.e., legislators define laws, retail markets sell food, etc.), and the straight arrows show the connections between stakeholders and their subsequent actions. Some relationships are two-way (indicated by a two-way arrow) such is the case between legislators and the regulatory systems. This relationship, though abstract, is important because we get a bird's eye view of how a change in one aspect of the system (i.e., regulatory system) can impact various other aspects of the system (i.e., producers, distributors, retail markets, etc.).

III. VALUE-ADDING PROCESSES ANALYSIS

Now that we have established the key stakeholders, defined the system context and dynamic interactions among stakeholders and the system, next we can answer questions like "What is the system trying to achieve?" or "What is it's true value?". How can this system's value be defined in its own terms and connection with other systems it interacts with? What processes are enabling the system's achievement?

In order to answer these questions, it is crucial to start looking at things from the stakeholder's point of view. From the point of view of our producers, the goal is to provide food and generate revenue. It is important for both the producers and governing bodies that food is produced in a manner than meets regulations. It is important for environmental advocates to produce food in an environmentally conscious way. Financers want returns on investments, and distributors want a means of distributing goods and generate revenue. All of these get into the topic of "What do our stakeholders find valuable about food systems"? Table 2 below is a list of stakeholders and their corresponding values or expectations for a food system (as was done in [8]). Note a consistent theme among all the stakeholders (Have Food to Consume), which is necessary for survival.

TABLE II. STAKEHOLDER FOOD SYSTEM VALUES

Stakeholder Food System Values	
Stakeholders	**Food System Values**
Environmental Advocacy Groups	Highly Sustainable System Minimal Disturbance to Local Environment Abides by all environmental protection laws and regulatory guidance Ability to adapt to future energy trends Have Food to Consume
Producers	Provide Food Maximize Profits Meet Demands/Needs Feed population Have Food to Consume
Financers	Low Risk Food System Related Projects Completed Within Cost and Schedule Returns plus interest Have Food to Consume
Distributers	Resources Necessary to distribute goods Follow laws and regulations Provides goods in a timely manner Maximize Revenue Have Food to Consume
Retail Markets	Provide Food to Local Customers Maximize Profits Maintain customer satisfaction Accessibility to Food Have Food to Consume
Legislators	All Food Subsystems Satisfy Regulatory requirements and laws (global, national, and local) Have Food to Consume
Maintainers	Ease of Maintenance of Food Systems Maximize Profits Availability of Maintenance equipment, tools, and materials Have Food to Consume
Consumers	Easy Access to Food Low Cost Nutritional Value Variety Freshness Maintainibility and Supportability of Food Related Appliances and Equipment Safe Sustainable Source of Food for Future Generations Have Food to Consume
Regulatory Systems	Food System satisfies all regulatory requirements Have Food to Consume
Food Related Appliance/Product Manufacturers	Customers/market for food producers and consumers Maximize Profits Sustainable Have Food to Consume

With an understanding of system values, value-added processes can be established. A value-added process, in the context of this paper, is defined as a process of the food system that a particular stakeholder finds valuable. Below is a list of value-adding processes in relation to stakeholder values (The value of this system in its own terms). This list is not all inclusive provided the scale and scope of this system.

1. Growing/Harvesting Crops and Livestock (Farming Process)
2. Trading Crops and Livestock with Other Parties of Interest (Global and Local Trading)
3. Distributing Food to Retail Markets for Consumers
4. Retail Markets selling food and food related products (i.e., Ovens, Toaster, Mixer, etc.)
5. Regulators routinely inspecting food at various points along the supply chain
6. Food Preparation and Processing
7. Rotating Crops (sustainment)
8. Abiding by food related handling Laws
9. Water Irrigation Systems

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10. Food Production Equipment Maintenance and Customer Support

Next, we can define the value of this system in terms of the external systems it interacts with. From our Concept Diagram, some of the external systems of interest include:

1. Energy System
    a. Energy is needed to support the food system in terms of producing, distributing, regulating, selling, and consuming it
    b. Maximizes profits for energy producers
    c. Using energy efficiently and minimizing carbon footprints satisfies stakeholders like regulators, environment advocacy groups, etc.
    d. Provides jobs for those working in the energy system
2. Water System
    a. Crops, livestock, etc., require water
    b. Maximize Profits
    c. Using water efficiently and minimizing waste satisfies stakeholders like regulators, environment advocacy groups, etc.
    d. Provides jobs for those working in the water system.
3. Transportation System/Sector
    a. Transportation is vital to trading and distributing food and food related products
    b. Maximizes profits for trucking, shipping, and rail industries
    c. Provides jobs to those working in the Transportation System
4. Global Economy
    a. Maintaining low food prices reduces food price index, which has a positive effect on global economy.
    b. Lower food prices allow for better quality food to get to impoverished nations.
5. Global Affairs
    a. Trade is what binds nations together
    b. Food variety across nations

Now that the value of food systems has been discussed, it is time to begin thinking about some of the missing value-adding processes from the existing food system. This will also be an opportunity to dive deeper into some of the driver, or “Shaping Forces” of the food system in order to better understand food system influences.

IV. ANALYSIS OF SHAPING FORCES

In this section, an analysis of the shaping forces will be done to get a better understanding of the drivers that impact the system that both shape and dictate some of the system’s general behavior and limitations (as was done in [6]). With this understanding, we can begin to understand how outside (or even internal) influences cause the system to behave the way it does.

In [2], the authors introduce the food system and sector frameworks and then consolidate this into an integrated framework that allows for rapid assessments of impacts on the food system. In this sense, the food system framework is “an application of systems thinking that links the production, processing, distribution, preparation, and consumption of food, with elements of the environment, people, inputs, infrastructure, and institutions. It describes the connections and feedback loops between those elements and processes..” [2]. The sector framework, in the context of the agriculture sectors, defines a set of activities (8 total) and attributes within the agricultural sector that are influenced by socio-economic and environmental drivers [2]. Activities as they relate to the agricultural sector include Production, Value Chain Development, Service Provision, Consumption, Stakeholder Organization, Regulation, Coordination, and Investment [2]. This integrated framework can be conceptualized in Figure 5 .

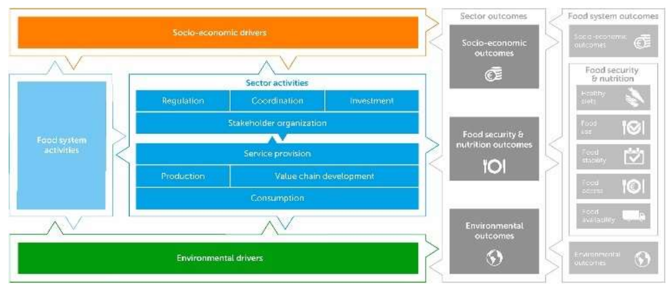

Figure 5. Integrated Food System Framework [2]

Through this integrated framework, there is a feedback loop between the drivers and the food system. The drivers drive the kind of food, the quality of food, the availability of food, and the price of food, food security, etc. The food system itself impacts these drivers by contributing to greenhouse gas emissions, dictating what needs the market has in terms of technology and food quality. Leveraging this integrated framework, we can defined the Shaping Forces of the Food System as:

1. State of Global Economy
2. State of Global Climate
3. Human Population
4. Latest Nutritional Guidelines
5. Food Market
6. Geopolitical Environment (wars, unrest, etc.)
7. Cultures
8. Technology (farming technology, appliance technology, distribution technology, etc.)
9. Availability of Resources
10. Water Source
11. Energy Sources
12. Local Environments

We can also determine some of the missing value-adding processes by analyzing this framework:

1. Integrate agricultural efforts with the existing landscape, as opposed to reshaping the landscape. [4]
2. Implement cultivation techniques that minimally disturb or impacts fertile soil
3. Raising livestock in a more ethical manner (grass fed, free roam, etc.)
4. Utilize green energy where applicable

5. Purchase and consume from local food markets, which cuts costs and energy use due to distribution, removing the “middleman”
6. Re-establish nutritional guidelines more frequently so that they are up to date with latest research
7. Incentivize locally produced food via tax incentive programs
8. Create programs that allow for selling/giving away unused food (reduce food waste)

V. SYSTEMIGRAM ANALYSIS

Finally, in order to present a proper definition and holistic view of the food system that can be agreed upon by all stakeholders, a Systemigram Analysis was performed (as described in [5]). Systemigrams are a system thinking tool used to provide an “inertial frame of reference” of sorts from the perspective of all stakeholders for the system of interest. It can be used to describe the interconnections in a “storyboard” like context. The systemigram for the food system is shown in Figure 6. The system of interest is shown at the top left (Food System) with the end node (bottom right) representing what the food system needs to accomplish in a way that satisfies all stakeholders.

The overarching mainstay of the food system is to produce, distribute, and provide food to meet food demands. The food system contains a consumer market that purchases goods through retail markets to provide products (food and food products) in order to meet demand. The food system also consists of a transportation and distribution system that distributes food for retail markets and consumers. The food production system provides food for distribution. Both food production and distribution systems are regulated by all levels of regulators, which themselves are funded by financers (private, public, and individual). You can also see that food demand has impacts on the environment, availability for future generations, and supply in the market, which dictates prices. The systemigram tells a story about not only the hard systems, but their interactions with the soft systems which is often overlooked.

VI. CONCLUSION AND FUTURE WORK

The modern day food system is one of the most complex systems in human society. Because of its complexity and delicate balance, the food system is at constant risk of disruption, which can have devastating impacts worldwide. A conflict on one side of the world can impact food prices on the other side. A changing climate could strain the supply of a particular food product, forcing the human population to adapt to an alternative food product. Growing populations stress the food system, requires more water and energy, thus impacting an already stressed water supply and contributing to greenhouse gas emissions. A system so vital to human survival requires care, and understanding of all of the forces that shape it.

In this paper, we applied a systems thinking approach to the food system. We defined the system not only in terms of its hard/physical systemic properties, but it’s “soft” properties (social, economic, political, etc.). We established a system context, and stakeholder value list that allows us to better understand the true value of the food system from all perspectives. Understanding the value of this system allows us to eliminate processes we find do not add value, while also allowing us to come up with ways to improve existing processes further. This requires understanding all of the key drivers that shape the system into what it is. We tied all of these together into a storyboard like structure known as a systemigram, which provides us with an agreed upon, inertial frame of reference for the system of interest.

Some of the challenges involved with characterizing such a system had to do primarily with the high complexity and large scope of the Food System. Though the Systems Thinking framework is designed to work with such complexity, understanding the interactions and defining the context such that the system was not boundless due to the scope was a challenge. Further analysis will need to be performed to clear some of the lines of the system boundary. The systemigram also required several iterations before an agreed upon definition of high level system interactions can be established. Future work will involve many more

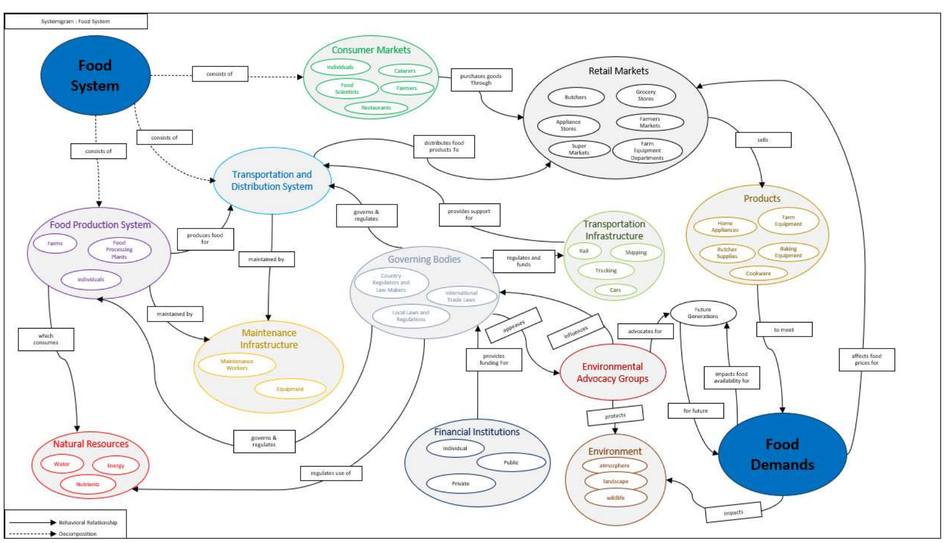

Figure 6. Systemigram of Food System

iterations of the systemigram, and even a breakdown of lower level systemigrams to define some of the lower level interactions of the food system from the perspective of specific stakeholders. From there, we can begin to tackle some of the major issues mentioned earlier in this paper such as sustainment of the food supply for future generations, reducing the environmental impacts of food production, and continue to feed an ever growing population even in the face of major global conflict.

Food is not only critical to survival, but also a business, a hobby, and people’s livelihood. Food brings together cultures, binds nations while also causing conflict for others. Our food system is a delicate balance that has both strengthened and threatened our existence since the beginning of time. Understanding such a complex system can only be achieved through the use of systems thinking.

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