Enhancing Food Defense: Risk Managers' Perceptions, Criticality Assessments, and a Novel Method for Objectively Determining Food Systems' Criticality

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Dedication

This dissertation is dedicated to my brothers in arms 1st Platoon 1-194 Combined Arms Battalion, Battling Bastards of Bataan, Joint Task Force Bravo, Night Stalkers, and the 1st Battalion 228th Aviation Regiment. I will never forget our hardships and miraculous accomplishments. Just remember, when your omnipotent command sends you through the most dangerous places on the face of the Earth, to fetch meaningless war trophies, that you always have the ability to make the world better, as long as you think about and then reflect upon the future.

Corripiendi sunt inquieti,pusillanimes consolandi,
infirmi suscipiendi,

insidiantes cavendi,
imperiti docendi,
desidiosi excitandi,
contentiosi cohibendi,

superbientes reprimendi,
desperantes erigendi,
litigantes pacandi,
inopes adiuvandi,

oppressi liberandi,
boni approbandi,
mali tolerandi,
omnes amandi.

St. Augustine

Dissertation Abstract

This research focused on evaluating the perceptions of food defense risk management by state officials, evaluating the validity of a criticality assessment created by the National Center for Food Protection and Defense (NCFPD), and developing a new geographic information system (GIS) based criticality assessment method. Specific objectives included: (1) investigating and reporting the history of food and agriculture criticality assessments; (2) conducting a survey to identify state officials' risk perceptions related to food and agriculture criticality; (3) analyzing the data collected by the most widely used criticality assessment method (i.e., Food and Agriculture Systems Criticality Assessment Tool); and, (4) developing a new method to objectively measure food system criticality.

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Chapter One: History of Food Defense

The challenge of security is not identifying all of the potential targets, threats, and bad actors, but the challenge of security lies in identifying the most critical assets to the nation, and creating resiliency around them.

Historical Context of Food Defense

The attacks on September 11, 2001 by the terrorist organization Al-Qaeda forever changed the United States (U.S.) and the world. These terrorist actions were momentous as they changed the U.S.' perceptions of the world and created a new paradigm coined as the new normal (Abrams, Albright, & Panofsky, 2004) The new normal is the period of time that follows uncontrollable, catastrophic, and traumatic events. During the acclimation to the new normal, the U.S. populace and government's schema of threats and hazards dramatically changed. Consequently, the U.S. examined all potential and known hazards to critical infrastructures, which ignited a new interest in bioterrorism (e.g., the use of bacteria, viruses, prions, and toxins as weapons), chemical terrorism (e.g., the use of acute chemicals that cause tearing, vomiting, psychological disruption, blistering, choking, or nervous system disruption), and the intentional use of these agents to contaminate food and water systems.

Biological agents have been used as a military tactic for millennia (Jacobs, 2004). The use of biological agents has centered on four main strategies: (1) disseminating inoculated blankets or clothing, (2) launching infected materials into enemy positions, (3) inoculating traditional weapons with potentially infective materials, and (4) contaminating food or water supplies. Of the aforementioned strategies, utilizing the enemy's food and water as a vehicle for biowarfare has been a successful military tactic throughout history.

Similarly, chemical agents have been used as weapons since the classical era (Costigliola & Quagliata, 2010). The use of chemical weapons has centered on four main strategies: (1) launching highly flammable chemicals into enemy positions, (2) contaminating large areas with gases to prevent the enemy from operating efficiently or to prevent occupation of an area, (3) including chemical irritants with conventional weapons to enhance the weapon's effectiveness, and (4) contaminating food or water supplies. Akin to bioterrorism, chemical warfare has been and continues to be an effective weapon against civilian populations, water systems, and food systems.

Food Defense: Pre World War I

Throughout human history, there are multiple examples of introducing chemical and biological agents into the water and food systems as a means to attack, weaken, and disrupt enemies. The Assyrians reportedly poisoned the wells of their enemies with rye ergot in 600 B.C. (Frischknecht, 2003). Ergot is a fungus that produces an alkaloid (mycotoxin) that causes muscle cramps, vomiting, gangrene, and hallucinations and is toxic to humans (Fung & Clark, 2004). In 590 B.C., the Athenian politician Solon dumped the herb purgative hellebore into the city of Cirrha's water aqueduct causing intractable diarrhea and Cirrha's soldiers subsequently deserted their posts (Lane & Borzelleca, 2008). In roughly 200 B.C., Carthaginians contaminated wine with mandrake, which contains tropane alkaloids and cause hallucinations and retrograde amnesia, to sedate their enemies (Smart, 1997). Barbarossa contaminated the enemy's water supply with the bodies of dead soldiers in 1155 A.D. (Poupard & Miller, 1992). The Spanish military in 1495 A.D. used a similar tactic as the Carthaginians and gave wine tainted with leprosy-infected blood to French soldiers (Smart, 1997). During the American Civil War Confederate forces deliberately contaminated the Union's water supplies by dragging killed farm animals to their drinking ponds (Lesho, Dorsey, & Bunner, 1998). History has demonstrated that chemical and biological agents are relatively easy to use as a weapon and can cause high numbers of casualties. Therefore, society should take reasonable preventative measures to prevent attacks on food and water supplies.

Food Defense: World War I

As science progressed over time, so did the available methods for biowarfare. During World War I, a series of biowarfare events occurred. While some of the following events are more representative of agroterrorism (malicious attacks against plants and animals used in the production of food), some of these attacks were targeted at the animals' feed and are worthy of discussion. First, Major Franz von Papen, a German military spy in Washington D.C., unsuccessfully attempted to contaminate the feed for horses and cattle that were to be exported to aid Allied Forces in England (Jacobs, 2004). Later, Anton Dilger, a German surgeon educated in the U.S., was discharged from the German military after a nervous breakdown in 1915 and he subsequently transported cultures of *Bacillus anthracis* and *Burkholderia mallei* to sabotage the production of warhorses in the U.S. (Wheelis, 1998). Bacteria cultured in Dilger's laboratory in Maryland were given to Captain Frederick Hinsch, who used the agents to inoculate horses in Baltimore before they were shipped to Allied forces in Europe (Woolsey, 1941). In 1916, German covert agents attempted to infect sheep bound for Russia with *Bacillus anthracis* and *Burkholderia mallei*. The covert agents were caught, and their cultures were confiscated from them. In 1917, a German saboteur was arrested for allegedly infecting 4500 mules with glanders (Poupard & Miller, 1992).

Food Defense: World War II – Cold War Era

From World War I to World War II there were significant advancements technology (microbiology and chemistry) that enabled people to launch more severe biological and chemical attacks (Mowery & Rosenberg, 1999). During World War II (WWII), the Japanese contaminated Chinese wells and river water with *Salmonella typhimurium*, and gave Chinese children chocolates laced with *Bacillus anthracis* (Burrows & Renner, 1999; Harris, 1992). During WWII and the Cold War, the U.S., United Kingdom, France, Germany, Soviet Union/Russia, and Iraq developed biological weapons programs and conducted biological weapons research.

Although many nations developed biological weapons during the Cold War, none of the Cold War era weapons that were developed were ever used on a large scale (Christopher, Cieslak, Pavlin, & Eitzen Jr.,1997). However, there were many acts of intentional food contamination committed by individuals. In Japan in 1964, Dr. Mitsuru Suzuki, a bacteriologist, contaminated sponge cakes and other foods with *Shigella dysenteriae* and *Salmonella typhimurium* to exact revenge against his coworkers (Anderson, Friedman, & Bendinelli, 2006). In 1972, Chicago police arrested two teenagers who were days away from contaminating Chicago's municipal water supply with *Salmonella typhimurium* (Carus, 2001). The two teens created a white supremacist organization named RISE, and planned to start a new master race by vaccinating the group's members against selected agents so that they would not be affected by the group's contamination of the Chicago area water system. The leaders of RISE had only recruited and vaccinated a handful of members when two of the new recruits informed the police of the pending attack. Subsequent criminal investigations revealed that the founders had stocks of *Salmonella typhimurium*. In 1977, a Norwegian nurse Arfinn Nesset poisoned and killed at least 22 patients with the muscle relaxer Curacit (Ansumana, 2010).

In September and October of 1984, an epidemic of *Salmonella typhimurium* caused 751 cases of gastroenteritis in The Dalles, Oregon (Carus, 1997). Although an extensive epidemiologic outbreak investigation conducted by the Oregon Public Health Division and the Centers for Disease Control and Prevention (CDC) associated the source of the outbreak to salad bars in local restaurants, government officials discovered a year later that the epidemic was the result of deliberate food contamination by the Rajneeshees cult. Officials learned that the cult planned to sicken the community in an attempt to reduce voter turnout during an upcoming election in Wasco County. The group decided to conduct a trial run of the attack, and during the trial run the Rajneeshees

repeatedly and deliberately contaminated numerous local salad bars, restaurants, and grocery store produce with *Salmonella typhimurium* resulting in the 1984 epidemic. Two members of the Rajneeshees cult were eventually convicted for their role in the first successful act of bioterrorism on U.S. soil (Török, Tauxe, Wise, Livengood, Sokolow, Mauvais, ... & Foster, 1997).
In 1989, the South African Civilian Cooperation Bureau allegedly launched a failed cholera attack on Namibia's water supply (Burgess & Purkitt, 2001). In 1990, *Giardia lamblia* was used to contaminate water tanks in Scotland (Mobley, 1995). These examples of intentional food contamination and bioterrorism demonstrate the threat and vulnerabilities to the global food system.

Food Defense & Bioterrorism: 1991 to Present

Despite the fact that most Cold War era weapons were destroyed or have remained under adequate protection and control since the end of the Cold War, 70% of the biological crimes (biocrimes) and biological terrorism (bioterrorism) of the 20th century occurred after 1990 (Jacobs, 2004). The rise in bioterrorism since 1990 can be attributed to increasing technological sophistication, increased resources, and fluctuating motives of the perpetrators of bioterrorism.

More sophisticated bioterrorism threats and attacks emerged during the 1990s. In 1992, a right wing anti-government terrorist group in Minnesota, named the Patriots Council, manufactured ricin and the solvent dimethyl sulfoxide. The Patriots Council planned to murder federal and local law enforcement agents by mixing the ricin with the dimethyl sulfoxide to enable the ricin to be more quickly absorbed through dermal tissue. These terrorists extracted the ricin from castor beans using instructions and beans they obtained via open sources. Members of the Patriots Council were later convicted and sentenced to prison for their role in the plot, becoming the first convictions under the Biological Weapons and Antiterrorism Act of 1989 (Tucker, 1996). Although the bioterrorism plan was disrupted by law enforcement, this bioterrorism operation demonstrates the dedication and technical ability of would be terrorists.

The Japanese apocalyptic terrorist organization Aum Shinrikyo drew international attention in the spring of 1995 after the terrorist group performed a well-coordinated attack using the nerve gas sarin on the Tokyo subway system, killing 12 and injuring 5000 people (Laqueur, 1996). This incident demonstrated that terrorist organizations had the resources and capability to covertly launch highly effective attacks on civilians. Additionally, this group was found to be in possession of a hydrogen cyanide aerosol distribution device, cultures of Ebola and anthrax, botulinum toxin, and many other miscellaneous chemicals and weapons that could be used to launch a wide variety of chemical, biological, and kinetic attacks.

Larry Wayne Harris was arrested in 1995 for illegally obtaining stocks of *Yersinia pestis,* which was the cause of the plague (Stern, 1999). Harris ordered the pathogen from the American Type Culture Collection (ATCC) in Rockville, Maryland. Only when he complained about a delay in the shipment were employees at the ATCC suspicious enough to report him. Harris claimed that the cultures were part of his plan to find a cure for plague and protect citizens from the Iraqi biologic weapons threat. Harris was convicted of fraud in acquiring the cultures, and sentenced to 18 months probation. Harris may have also been responsible for a disruptive explosion of anthrax hoax letters mailed in 1998 and 1999. Harris was arrested again in early 1998 for possession of anthrax. Although the anthrax strain proved to be a harmless veterinary vaccine strain, it is unclear if Harris had any terrorist intent in either of the events. The bioterrorism acts discussed in this section do not include all bioterrorism attacks executed; the bioterrorism acts discussed indicate that the bioterrorism threat is real and has increased since 1990.

One of the most underreported food defense events occurred in 1996. In 1996, a terrorist revealed that chlordane (an organochlorine pesticide) had been used to contaminate liquid animal fats produced at a Wisconsin factory (Foxell Jr., 2001). Many of these animal fats had already been shipped to more than 4,000 dairy farm customers in Illinois, Michigan, and Minnesota. Subsequently, the contaminated milk was shipped to cheese, butter, and ice cream manufacturing plants in northern Illinois and Wisconsin. Fortunately, the prompt interdiction of subsequent shipments prevented contaminated products from reaching consumers. However, this incident caused $4 million in damages to companies. Later that year, a disgruntled laboratory employee, Diane Thompson, at the St. Paul Medical Center hospital in Dallas, Texas contaminated blueberry muffins and doughnuts with a laboratory strain of *Shigella dysenteriae* type 2 (Dembek, 2010). The contained muffins were disseminated to her colleagues causing everyone that consumed the pastries to become ill (12 people). These incidents demonstrated the devastating losses food companies can incur from intentional food contamination events and that insider attacks can be highly effective and difficult to prevent.

The capabilities of these terrorist groups and deranged individuals demonstrate that terrorist organizations and individuals may be able to launch deadly foodborne bioterrorist attacks. If terrorist groups can gain access to government funded biologic weapons programs (as may have happened in the U.S. anthrax attacks of 2001), achieve the technical expertise necessary to successfully weaponize environmentally persistent biological agents, or manufacture toxic chemicals, then the current threat environment includes a multitude of hypothetical attacks with numerous modus operandi (Inglesby, O'Toole, Henderson, Bartlett, Ascher, Eitzen, ... & Tonat, 2002). With an infinite amount of potential targets, agents, and terrorist motivations, the history of bioterrorism indicates that the enemy has the advantage, and this tremendous advantage will persist into the future. Thus, policy makers and risk managers tend to want to identify all of the potential targets, threats, weapons, and bad actors. This is why policy makers and risk managers tend to focus on the consequences of bioterrorist attacks and focusing on bioterrorism consequences enables these people to make difficult resource allocation decisions to mitigate bioterrorism risks.

Chapter Two: The Development and Use of the Food and Agriculture Systems Criticality Assessment Tool (FASCAT)

After the terrorist attacks of September 11th, the United States (U.S.) government established a policy to identify critical infrastructure, including food and agriculture production systems, to protect them from terrorist attacks. Criticality is defined as the negative impact that an attack on or failure of a given infrastructure would have on the nation if it were compromised or destroyed. Food and agriculture systems were identified as one of 18 critical infrastructures. Identifying which food systems were the most critical to the nation was an enormous task since the food and agriculture sector is almost entirely privately owned, is comprised of an estimated 2.1 million farms, has over 1 million production facilities, and accounts for roughly one-fifth of U.S. economic activity. To assist the Department of Homeland Security in determining which food systems were the most critical to the nation, the National Center for Food Protection and Defense developed the Food and Agriculture Systems Criticality Assessment Tool (FASCAT) to support states' identification of critical systems. The FASCAT documented, evaluated, and compared 731 disparate complex food and agriculture systems across 39 states to determine their criticality. The objective of these FASCAT assessments was to prioritize the allocation of threat mitigation resources to the most critical systems. Prior to the use of FASCAT, no food and agriculture systems were identified as critical in the U.S. Now with the use of FASCAT, many food and agriculture systems have been added to the criticality list. This article discusses why the FASCAT was built, how it has evolved, and how the process currently works.

INTRODUCTION

In 2003, the Homeland Security Presidential Directive 7 established a national policy for federal government departments and agencies to identify and prioritize United States (U.S.) critical infrastructure and key resources to protect them from terrorist attack (Bush, G. W., 2003). The food and agriculture sector is one of eighteen critical sectors that is almost entirely privately owned and is composed of an estimated 2.1 million farms, approximately 880,500 companies, and over 1 million facilities, and accounts for roughly one-fifth of the U.S. economic activity (Department of Homeland Security, 2009d). The 2009 National Infrastructure Protection Plan states that the government and the private sector are jointly responsible for protecting complex, globally distributed, and highly integrated components of food and agriculture systems (Department of Homeland Security, 2009c). This declaration was made due to a widespread concern that the food system could be used as a vehicle to poison, maim, or kill thousands, if not hundreds of thousands, of people or to cause significant economic harm. The joint responsibility for protecting food and agricultural systems requires a partnership between the government and private sector to identify critical assets. Criticality is defined as the negative impact that the destruction of a critical infrastructure would have on the nation (Theoharidou, Kotzanikolaou, & Gritzalis, 2010). Therefore, protecting those assets by first identifying which food and agriculture systems are more critical is essential (Department of Homeland Security, 2010a). Furthermore, it is vital to determine which systems are most essential in terms of consequences to public health (both psychological and physical), the economy, and the government.

The Food and Agriculture Government Coordinating Council and Sector Coordinating Council (GCC/SCC) partnered with one of the Department of Homeland Security's (DHS) Centers' of Excellence, the National Center for Food Protection and Defense (NCFPD), to develop an assessment to assist states in determining and documenting the most critical elements, sub-systems, and systems within food and agriculture infrastructure (Department of Homeland Security, 2009c). The tool developed by NCFPD is called the Food and Agriculture Sector Criticality Assessment Tool (FASCAT). FASCAT provides state officials responsible for protecting food and agriculture with: (i) a means to identify systems that are critical to each state's commodity supply chains and food distribution systems; (ii) a method to prioritize state or private sector vulnerability assessments and protective measures for asymmetrical threats to food and agriculture systems; (iii) documentation and improved characterization of each state's food and agriculture systems' risk profile; and, (iv) a method to provide critical food and agriculture infrastructure component information to DHS's National Data Call.

Unlike many other critical infrastructures (e.g., nuclear reactors, government facilities, and dams), states generally do not have system specific data on all the elements of the food and agriculture infrastructure. While most food and agriculture facilities are inspected, licensed, and regulated by multiple state and federal government agencies, they are owned and operated outside of the government (Stewart & Gostin, 2011). Consequently, partnerships across state agencies and with the private sector are the only way to successfully and completely characterize the food and agriculture infrastructures to assess and determine which infrastructure systems are the most critical. FASCAT is an assessment of consequence and system characteristics that provides a comparative analysis of vastly disparate systems, sub-sectors, and sub-systems (e.g., comparing the criticality of the fluid milk system to the potato system) (Tuncel & Alpan, 2010). It is important to realize that FASCAT was not developed as a stand-alone risk assessment or vulnerability assessment tool. Traditional risk and vulnerability assessments typically focus on individual facilities in the food production system, and the results of these assessments do not enable the user to make comparisons between systems. FASCAT considers a multitude of factors, which enables users to determine which systems should be prioritized for vulnerability assessments, implementation of protective controls, risk mitigation, and emergency response planning.

To be successful, state officials must engage with representatives from multiple government agencies and privately owned food systems operators that have direct working knowledge of food and agriculture infrastructure to obtain the necessary information to complete criticality assessments (Lemieux & Regens, 2012; Spink & Moyer, 2011). Required collaborators may include: agencies responsible for agriculture (e.g., inspection program leads, emergency response leads), animal health experts (e.g., state veterinarians), environmental scientists, public health professionals (e.g., environmental inspectors, foodborne illness outbreak traceback and traceforward investigators, epidemiologists), transportation managers, law enforcement personnel, and homeland security representatives (Hennessey, Kennedy, & Busta, 2010). Representatives from the private sector, or associations that represent the food production systems, must be involved in the criticality assessment process, and the criticality assessment team should include the companies that own the food system being evaluated (e.g., farm bureaus, animal agriculture associations, food processing associations, etc.) (Hoffman & Kennedy, 2007).

The information generated by FASCAT enables the owners and operators of food and agriculture systems to coordinate and collaborate with each other, and state and federal government agencies to assist in protecting these critical infrastructures. Based on NCFPD's evaluation of FASCAT use, the most efficient approach to obtain the necessary representatives from the government and private sector is to have state governments lead the effort (Huff & Kennedy, 2012). In situations where the state officials are not familiar with the food and agriculture systems in their state, the first step to successfully completing a FASCAT assessment is to conduct a training session with all of the appropriate government and private sector leaders to familiarize them with the assessment and to review their available food and agriculture systems' data. Meeting with SMEs and participating in a FASCAT training session may not be required if the state officials already have detailed knowledge of the food and agriculture systems in their states. After updating or adding to their food and agriculture system data, the second step is to host a working session to populate FASCAT to specify an initial characterization of the infrastructure and to assess what is most critical in the state. Through the use of FASCAT, the sector owners and operators, states, and the nation have been able to identify and understand which systems are most critical in the food and agriculture sector. The information gained through engagement and FASCAT analysis allows for security resources to be focused on increasing the protection of the most critical systems from man-made, natural, or accidentally occurring threats (Roberts, 2007). When implemented, these efforts will assist in reducing the probability of successful use of the food system as a weapon to attack our nation, increase our ability to rapidly identify threats to complex food systems, and to assist in recovery to normalcy in the event of a successful attack (Kennedy & Busta, 2007). While an early limited-application spreadsheet-based version of the tool is available to the public on the NCFPD webpage (FASCAT Version 2.0), the more advanced, comprehensive, and easy-to-use interface version of the FASCAT (Version 3.0) is only available through the protected and secure FoodSHIELD web portal. Because the intended users are state agencies, FASCAT Version 3.0 resides in FoodSHIELD to prevent unauthorized or malicious people from accessing the potentially sensitive data, and to protect the confidentiality of the owners' data.

FASCAT OVERVIEW

FASCAT has been used by 39 states to determine and compare the criticality of food systems within their jurisdictions, and it was used most heavily by states that contain high proportions of the nation's food and agriculture systems (Huff & Kennedy, 2012). During the FASCAT process, each state's food official gathers the subject matter experts (SMEs) for each commodity within their state (e.g., milk, eggs, grain, frozen pizza, pasta sauce). Often the SMEs are employees of the companies that own the food system being evaluated or regulators from state or local government agencies. Typically, SMEs are the best source of information related to prioritization of food system and production risks (Bertolini, Antonio, & Maurizio, 2007). First, the state officials ask questions provided by the FASCAT to the SMEs (e.g., the type of food system, threats, consequences, impacts of disaster, probability of the threats, footprint of a disaster). After SMEs are asked questions, the SMEs debate among each other until a consensus can be obtained for each commodity and question in the FASCAT. When consensus is reached, the state official responsible for food and agriculture protection records the agreed-upon answer in the FASCAT software. As the answers to questions are recorded in FASCAT, the commodity's criticality score is calculated by the software and is displayed as each question is answered, until all of the questions in FASCAT are completed. Typically, the first FASCAT assessment takes state officials and industry SMEs approximately 3 hours to complete. As familiarity and proficiency with the FASCAT method increases, subsequent assessments typically take an hour or less. Despite the opportunity cost associated with learning the FASCAT, it was used in over 731 food systems criticality assessments throughout the U.S.

FASCAT Version 1.0 & 2.0

FASCAT has been revised twice since it was first developed. All versions of FASCAT were developed in cooperation with food industry, government, and academic SMEs. FASCAT Version 1.0 and 2.0 were constructed using a commercially available spreadsheet and collected food systems characteristics data (e.g., commodity type, threat profile, state government point of contact), which would generate a score on an ordinal scale between 0 and 200. The score generated by FASCAT 1.0 enabled state officials to compare disparate food systems to select systems to protect first. Then, the scores could be used to prioritize vulnerability assessments, protective measures, and threat mitigation strategies. FASCAT Version 1.0 was used for 2 years and was decommissioned after the development of FASCAT Version 2.0. Retrospectively, the data collected by FASCAT Version 1.0 did not meet the requirements of measuring criticality due to broad generalizations and the lack of variation in threats and consequences. Later, in FASCAT Version 3.0, threats and consequences were more clearly defined and accounted for all of the elements that SMEs believed to contribute to food and agriculture systems' criticality. The lack of operational definitions of key terms in FASCAT 1.0 probably contributed to poor inter-rater and test-retest reliability and increased the potential or facilitator/trainer bias; however, development of the first version of FASCAT enabled state governments to begin thinking critically about their food and agriculture production systems.

The lack of sufficient variability in food system characterization in Version 1.0 (e.g., system description, threats, consequences, and vulnerabilities) reduced the users' ability to effectively discriminate between disparate systems. Version 2.0 had many new additions and revisions (i.e., additional commodity flow charts, enhanced threats, consequences, and vulnerabilities), which enabled users to adequately characterize food systems, and enabled FASCAT to better discriminate between closely related food systems. As a result of these improvements, FASCAT was better able to identify which food systems were the most critical to the states.

FASCAT VERSION 3.0

In 2010, the FASCAT received many updates and revisions. This was partly to minimize the immense data-reporting burden on state government agencies, and remedy the difficulty in manipulating FASCAT 2.0's spreadsheets. During FASCAT 3.0 development, FASCAT's users (state officials) were required to continue their annual submission of data to the DHS's Office of Infrastructure Protection (IP). To comply with IP's Annual Data Call, state governments are required to report critical infrastructure information to IP on all 18 critical infrastructure sectors, and the reporting of critical infrastructures information is a monumental and time consuming task for state officials. NCFPD sought to minimize the burden on state officials for reporting food and agriculture critical infrastructure information to DHS through FASCAT. FASCAT 3.0 was able to overcome the challenge of assembling complex and analogous data consistently by developing a single software platform for identification, analysis, and comparison of systems' criticality for the state's submission to DHS. FASCAT 3.0 software provided a standardized format to identify, collect, and record food systems data, a process to convert recorded data to a standardized reporting format, and a method to characterize and calculate food systems criticality.

Taxonomy

One of the problems in reporting data to the federal government is that different federal agencies use different terminology and taxonomies to describe food and agriculture production. It was difficult for state officials to determine the correct terminology for reporting to each federal entity. The U.S. government's data reporting requirements led to the development of resources like the Infrastructure Data Taxonomy (IDT) and the Infrastructure Data Collection Application (IDCA) tool (Department of Homeland Security. 2010b). The IDT standardized the language used to describe critical infrastructures for the state governments and the IDCA made the transfer of information from states to IP an easier process. To compare similar infrastructures, IDT was developed by IP to ensure that similar infrastructure components were identified similarly between states (e.g., maize processing and corn processing). By using a common terminology and method for categorizing information, the IDT allows critical infrastructure data to be more easily compared and contrasted by the federal government. FASCAT uses the IDT to ensure that consistent terminology between state and federal agencies is used when identifying the food system being evaluated for criticality. Thus, state officials only need to identify the system in FASCAT, and then FASCAT translates the selected food type to the terminology used by each federal entity. This FASCAT upgrade ensured that all of the parties involved were using similar nomenclature, saved government entities time, and was essential to effectively determining food and agriculture criticality.

Data Reporting

NCFPD further reduced the burden on state officials by enabling FASCAT Version 3.0 to create IDCA reporting forms for state officials. As users complete the FASCAT assessment, the IDCA preamble, assessment, and justification scenario is created under the IDT taxonomy. In Version 3.0, the user can then download the finished IDCA document. This helped state officials collaborate with the sector specific agencies or state and territorial homeland security advisors to nominate their food and agriculture systems for selection as a DHS Level 1 or Level 2 Critical Infrastructure Key Resource (CIKR) asset. In some cases, the nomination as a DHS Level 1or 2 CIKR asset resulted in the federal government's assistance in securing the asset by providing additional security resources. The ability of FASCAT 3.0 to generate the IDCA report saved many state government agencies' and food defense managers' time by quickly characterizing their food systems' characteristics and threat profile, and then providing the characteristics in the IDCA reporting format.

Data Collection

FASCAT was converted from a spreadsheet-based tool to a web-based graphic user interface (GUI) to ease the collection of data, to improve the quality and consistency of the data collected, and to make the entry of data more intuitive for the FASCAT's users. Additionally, more detailed commodity flow charts that illustrated the food system supply chains and manufacturing processes were included as a reference in FASCAT Version 3.0 to assist state officials in identifying, characterizing, and evaluating the criticality of food systems in their jurisdictions.

State officials collect data on a wide array of food systems and they also collect the system operators' contact information. The collected information is used to calculate and compare systems criticality, and to develop an emergency contact list. Also, the data collection process of FASCAT fosters communication between the private sector systems operators, commodity specific subject matter experts (SME), and state officials, and is essential for rapid and effective communication with the food industry in case of an intentional contamination event (Glass, et al., 2011). While the ability to characterize food systems is important to determine food and agriculture systems' criticality, having a unified, independent, and secure database of food systems owners and operators helps facilitate communication between the private sector and state officials in the event of unintentional or intentional contamination of food systems (Degeneffe, Kinsey, Stinson, & Ghosh, 2009). By establishing relationships with SMEs and systems owners and operators, and by collecting and storing their contact information through FASCAT, people responsible for food defense are able to rapidly identify and communicate with the necessary people during unintentional or intentional food contamination events.

System Characterization

To characterize the criticality of a system, FASCAT collects information detailing the food product types within the system. These food products could be processed foods like canned vegetables, pasta sauce, or frozen pizza, or they could be minimally processed foods like fresh produce, chicken broilers, or ground beef. During this step in the FASCAT process, the number of facilities in the supply chain is recorded from farm to fork. This can be useful to estimate the size of system in combination with other factors and data collected in FASCAT. After the system being evaluated is identified in FASCAT, the program uses this information to weight the criticality score. The weighted criticality score may be useful in differentiating systems criticality by spreading out the distribution of scores; however, FASCAT also calculates a cumulative criticality score where weighting by commodity type does not occur. This gives the state official responsible for food and agriculture defense the ability to give preference to theoretically risky or fragile systems, or to compare systems without a priori knowledge using the cumulative score. In either case, FASCAT provides a means to compare the criticality of disparate systems.

Criticality Scoring

After the type of system is identified and recorded in the database, FASCAT uses an all hazards approach to determine system criticality. Specifically, FASCAT enables the users to examine and determine the likely threats, initial consequences, 2nd and 3rd order consequences, and the impacts that an attack or disaster would have on the system. In FASCAT, the users are able to select multiple possible threats to the system being evaluated (e.g., foreign animal disease, chemical/toxin, plant pests, pathogen contamination, cyber threat). As each threat is selected, points are added to the cumulative criticality score, and the amount of points assigned for each threat is based upon the severity of the threat to the selected commodity (e.g., if fluid milk was being evaluated and chemical/toxin was selected, the cumulative score would increase by 3). Threats that are not plausible for the selected commodity are inactivated by the software and cannot be selected. For example, if fluid milk is the system being evaluated, a user cannot select plant disease as a primary threat, which prevents users from gaming the tool by selecting all of the threats to the commodity to increase the food system's criticality score. After the threats are selected the users may justify their threat selections or provide any additional pertinent information in an open text comment box. Similarly, the user repeats this process for consequences (e.g., loss of tourism, long term shutdown, economic loss, mass human casualties), and 2nd and 3rd order consequences (e.g., damage to tax base, disease spread to others, loss of public confidence) and selection of these factors increases the cumulative and weighted scores.

The process of selecting the impacts of the attack or disaster is similar to the previously described threat selection process (e.g., greater than 1 year to recover, at least 10,000 human casualties, more than 5 states impacted); however, the factors selected have a multiplicative effect on the weighted score which measures the size of the footprint of the consequences and helps determine if the food and agriculture system meets the criticality thresholds defined by the DHS Homeland Infrastructure Threat and Risk Analysis Center (e.g., when a *specific food system* is being evaluated and *10,000 human casualties* is selected and *more than 5 states impacted* is selected under impacts, the weighted score increases by 1.75 times). The cumulative and weighted scoring process within FASCAT is completely transparent as each manipulation of any factor immediately changes the scores and the scores are continuously displayed.

After these data are collected, FASCAT prompts the user for information on the ease of attack (i.e., low, medium, high), probability of disaster (i.e., low, medium, high), scale/size of component at risk (i.e., small, mid-size, large, very large, more than 5 states), recovery/return to normalcy (e.g., less than 3 months to not probable), and concentration (i.e., highly concentrated, moderately concentrated, dispersed within a region, widely dispersed, less than three total components). All of these data contribute to the criticality score in an additive fashion. The ability to collect these types of data on complex food systems and characterize food systems in terms of their unique threats, consequences, and impacts enables FASCAT to compare the criticality of disparate food systems on an ordinal scale.

CONCLUSION

The NCFPD developed the FASCAT to assist states in objectively determining which food systems were the most critical to the nation to protect them from terrorist attacks. Since FASCAT was developed, it has been used in over 731 criticality assessments in 39 states to identify, document, evaluate, and compare disparate complex food systems, which resulted in the addition of multiple food and agriculture systems to the DHS critical infrastructure list for the first time in history. Some of the food systems analyzed with FASCAT received additional resources from DHS to mitigate potential food defense threats. FASCAT enables its users to determine systems' criticality and then prioritize the allocation of food defense resources or threat mitigation strategies.

FASCAT has several limitations. First, the use of subject matter expertise to determine the probability of threats, vulnerabilities, consequences, and magnitude of systems failures needs to be validated. The probability of large-scale naturally occurring threats (i.e., hurricanes, and floods) can be determined using more objective methods (e.g., spatial risk analysis) instead of relying on the subject matter experts' subjective opinions. Potentially, the group consensus method used in FASCAT was biased by groupthink, or influenced by subject matter experts with strong personalities. If future research discovers that these two limitations of FASCAT substantially affect the outcomes of FASCAT analysis, then alternatives to the use of subject matter experts to quantify criticality need to be explored.

Despite FASCAT's limitations, FASCAT cannot be conventionally validated without a series of catastrophic events. Instead, the FASCAT data can be used to determine FASCAT's reliability, construct validity, content validity, and internal validity. Fortunately, the broad use of FASCAT across multiple production systems, commodity types, and geographic areas allows the collected data to be analyzed and tested. The ongoing analysis of the FASCAT process and data will help determine if the FASCAT method is valid and of value to its users. Even though FASCAT has not yet been empirically validated, NCFPD has continued to make improvements to FASCAT. To better meet the food defense needs of state officials and the private sector. Future research needs to be conducted to determine if the FASCAT method is a reliable measure of criticality, and to determine if bias or significant sources of error exist in the FASCAT process. Although FASCAT has imperfections, it has greatly helped the federal and state governments identify critical food and agriculture systems as part of how they dedicate precious resources to protect them from adverse events.

Chapter Three: State Officials' Perceptions of the Food and Agriculture Sector Criticality Assessment Tool (FASCAT), Food-system Risk, and Food Defense Funding

Determining food system criticality is necessary to mitigate risks to the nation's food supply and prioritize and allocate funding. The Food and Agriculture Sector Criticality Assessment Tool (FASCAT) is a tool used broadly by state governments to determine the criticality of food systems throughout the U.S. State officials (SOs) responsible for food defense (n = 32) were surveyed to determine whether FASCAT is of value to food defense and to determine SOs' security beliefs, values, and practices related to food defense. Results indicated that: (1) SOs believe FASCAT is easier to use than other forms of risk assessment; (2) FASCAT training may have introduced bias into assessment of probability, threat, vulnerability, and consequences; (3) FASCAT is valuable to SOs; (4) SOs do not routinely follow security management best practices; (5) SOs believe that intentional biological threats to the food system are the most probable threats, though without supporting evidence; and (6) SOs believe food defense risk mitigation is not adequately funded by state or federal governments. These findings indicate that even though bias was potentially introduced to FASCAT assessments, SOs believe FASCAT has been useful to determine food system criticality. SOs indicate that more funding is needed from state and federal governments to adequately mitigate and manage food defense risks, and that they require more comprehensive training from food defense subject matter experts in threat assessment, risk mitigation, and security management to reduce the possibility of bias from FASCAT training.

INTRODUCTION

United States' (U.S.) food systems are vulnerable to disruption. For example, the Department of Homeland Security is concerned that a hurricane could destroy areas vital to the food supply chain, that floods or drought could make inoperable the dams necessary for the transportation of food, or that the food system could be used as the delivery mechanism for a terrorist attack. To identity and mitigate these risks, food systems must be analyzed to identify relevant threats, estimate probabilities of identified threats, identify the magnitude of consequences of these likely threats, and then assign criticality scores to enable comparison of disparate food systems. Many types of risk assessment are used in food defense, but the final goal of these tools should be to directly compare different food system types to prioritize allocation of scarce security resources. Food systems are national in scale and connect across state boundaries. However, individual states are responsible for reporting critical infrastructure to the Department of Homeland Security.

Nearly all states have an employee responsible for food defense. State officials (SOs) responsible for food defense share responsibility for protecting U.S. food systems. These SOs serve as arbiters and intercessors between the federal government and private sector food firms on food defense, security, and preparedness issues. Often, SOs work closely with private sector food firms, the Department of Homeland Security (DHS), the United States Department of Agriculture (USDA), and the Food and Drug Administration (FDA) to ensure protection of food systems within their states (Food and Drug Administration, 2008). SOs nurture productive partnerships with these federal government agencies by establishing food defense best practices, reaching out to the food industry, and facilitating information sharing between food firms and the federal government. They allocate and coordinate allocation of government security and food defense resources to food and agriculture (e.g., security training, specialized equipment, and analysis methods), which enhances the resilience of food systems. SOs accomplish these tasks with limited funds by leveraging and using food protection tools and resources (Read & Starkey, 2012).

State officials can use software tools (e.g., Organization Risk Management, CARVER + Shock, and FASCAT) to help gather and share food system information. However, software can be difficult to use and may be subject to user error and biases. Software usability surveys are intended to assess the ability of users to complete tasks using the software, the quality of the software's output, the levels of human and computational resources consumed performing tasks, and the users' subjective reactions to the software (ISO, 1998). Many software usability surveys since the mid 1990s have suggested problems with navigation, interpretation, and data entry. These surveys have used Likert scales to assess user satisfaction and effectiveness and efficiency of the software (Brooke, 1996).

Software usability is typically easy to test and correct, but in software assessment the user must also be objective and unbiased. Few people in the U.S., if any, have any firsthand knowledge of the actual probability of terrorist threats facing the U.S. food system (Brown & Cox Jr., 2011). No one knows what destructive acts terrorists are covertly planning in their homes. For many, knowledge of terrorist threat probability is restricted to information obtained via open sources of unknown validity. When terrorist threat information is perceived to be inadequate, individuals often search to find additional information. However, by the time new threat information is discovered it is often too late to take action to mitigate risks (Fischer, Kastenmüller, Greitemeyer, Fischer, Frey, & Crelley, 2011).

Even if SOs routinely engaged in food defense and security management best practices, they may have individual cognitive biases related to risk perception (e.g., availability heuristic, belief bias, and subjective validation) (Lemyr, Turner, Lee, & Krewski, 2006). If food industry SMEs and SOs share similar cognitive biases regarding perceived risks, then biased data could be entered into software tools without being adequately challenged or evaluated by a peer review process. Biases regarding threat, probability of occurrence, and severity of impact is highly problematic because such inaccurate risk perceptions could distort results and impact mitigation strategies. These pooled cognitive biases could lead SOs to emphasize less probable food contamination event types and thus implement risk management strategies that are not effective against more probable but overlooked event types (e.g., chemical or physical contamination), thus reducing preparedness and response effectiveness.

Food defense and security management plans are only as effective as the strength of underlying risk and criticality assessments (Franco & Sell, 2012). SOs and SMEs must engage in security management and food defense best practices to effectively mitigate intentional food system threats (Manning, Baines, & Chadd, 2005). Even if SOs are using tools to mitigate risk, they need to evaluate the risks of each food system separately, implement threat mitigation technologies and strategies for each food system, and reevaluate risks to food systems after threat mitigation. Only by routinely engaging in security management and food defense best practices will SOs and SMEs be able to reduce risks to food systems.

Security management and food defense research and practice often require funding from the U.S. government. Accordingly, the government has invested many millions of dollars in food defense initiatives. For example, in 2008 the USDA received $91 million, in 2009 the FDA received $42 million, and in 2009 the Food Safety Inspection Service (FSIS) received $51 million for enhancement of their food and agricultural defense initiatives (United States Department of Agriculture, 2001). To have an effective food defense strategy, resources are required for private and public sector food defense education and to develop risk mitigation technologies and deploy them to private food companies and state governments. With large amounts of money appropriated to federal agencies for food defense, it is imperative to determine if investments in critical infrastructures were appropriately allocated. This study examines the usability and value of one software tool, the Food and Agriculture Systems

Criticality Assessment Tool (FASCAT) by studying SOs and potential biases introduced during FASCAT training and use.

BACKGROUND

The Food and Agriculture Systems Criticality Assessment Tool (FASCAT) is software developed by the National Center for Food Protection and Defense (NCFPD). FASCAT is leveraged and promoted extensively to the food industry by SOs to measure the criticality of their food systems. Despite the widespread use of FASCAT by SOs, there has been concern among the scientific community and federal government agencies that FASCAT's application to food systems could potentially result in biased criticality scores (Huff, Kircher, Hoffman, & Kennedy, 2013).

FASCAT Training and Data Collection Process

From 2008 to 2012, food industry subject matter experts (SMEs) and SOs were provided FASCAT guidance documents and received in-person FASCAT training from National Center of Food Protection and Defense (NCFPD) and DHS staff during the FASCAT data collection process (Huff, Kircher, Hoffman, & Kennedy, 2013). During the training sessions, NCFPD and DHS staff, the SOs, and food industry experts used a crawl, walk, and run training method to teach the FASCAT process while completing actual FASCAT assessments. This instruction process involved a guided discussion with SOs and SMEs related to probability of attack, specific threats, ease of access to food systems' critical control points, and the consequences of a failure to these food systems and society. Occasionally, SMEs and SOs did not come to consensus on responses to questions in FASCAT. In these cases, NCFPD and DHS trainers offered suggestions on how to respond to questions in FASCAT, possibly introducing facilitator bias into assessment of attack threat type and probability, ease of attack, and attack consequences. Some of the results from FASCAT assessments completed during NCFPD and DHS training sessions were submitted to DHS as justification for nomination of food systems as critical infrastructure. This is problematic because potentially biased FASCAT results could have omitted some critical food systems from DHS consideration as a critical infrastructure.

Potential Biases

Combining training and data collection sessions was a reasonable and efficient approach in the training of SOs in FASCAT use and the collection of FASCAT data from SMEs (Torkzadeh, Pflughoeft, & Hall, 1999). However, the combined training and data collection method potentially introduced observer and social biases (Da Cunha, Stedefeldt, & De Rosso, 2012). If SOs and SMEs had limited access to valid or reliable food system threat probability information, NCFPD and DHS trainers could potentially introduce social bias through cognitive distortions (Dalziel, 2011). For example, it was directly observed that some NCFPD and DHS trainers oversimplified terrorist threats to make them more compelling to the audience, behavior that numerous psychological and security training studies have shown can elicit confirmation bias (Chadwick & Edwards, 2009; Greitzer, Andrews, Herz, & Wolf, 2010; James, Demaree, &

Wolf, 1984; Salmon, Park, & Wrigley. 2003; Schulz-Hardt, Frey, Lüthgens, & Moscovici, 2000). These information biases presented by NCFPD and DHS trainers could potentially cause SMEs to provide biased responses to SOs during or after FASCAT training. If this did in fact happen, then this would produce biased FASCAT results.

STUDY OBJECTIVES

The usability and value of FASCAT software, SOs' risk perceptions, and food defense practices of SOs were examined. No previous studies have evaluated how SMEs are used to collect data related to risk or criticality assessment, or how information presented during risk or criticality assessment training could bias SMEs' and SOs' food systems criticality assessments. Furthermore, few studies have examined the risk perceptions of SOs, their beliefs about levels of funding for food defense, and their self reported food defense and security management practices. Rather, most studies have focused on retail managers' or consumers' perception of risk (Yoon & Shanklin, 2007). Specifically, the present study aimed to: (1) directly examine the usability of FASCAT software; (2) measure FASCAT's perceived value among SOs; (3) determine if social biases could have been introduced to SOs during the FASCAT training and data collection process; (4) evaluate SOs' risk perceptions; (5) evaluate SOs' perception of the adequacy of their funding; and (6) assess SOs' food defense management practices to determine if they are congruent with security management best practices.

Hypotheses were: (1) SOs would find FASCAT software simple to use; (2) FASCAT would be of value to SOs; (3) practices that could introduce social biases were present during the FASCAT training and data collection process; (4) SOs' would perceive equal probability of biological and chemical risks to the food system; (5) food defense is perceived as adequately funded by SOs; and (6) SOs have strong security management practices.

METHOD

Participants

The study population consisted of 91 government managers responsible for food defense in 2012, who were invited to participate in the study based on their identification as the designated SO in NCFPD's FoodSHIELD database. Because the study was completely anonymous, the Institutional Review Board (IRB) at the University of Minnesota, Twin Cities Campus, ruled it exempt from IRB review process. In accordance with standard research protocol, participants had to read a paragraph that stated the purpose and volunteer nature of the study and consent to the survey before any data were collected. Participants who completed the electronic survey were included in the study (n = 32). Participants were not compensated in any way. During construction of the survey, one investigator (AGH) traveled with NCFPD and DHS trainers to observe four training sessions to determine if social biases were present and to inform survey construction.

Materials

An email containing a hyperlink to the electronic survey was sent to all SOs in the FoodSHIELD database (n = 91). The survey was constructed to measure the participants' perceptions of FASCAT's usability and value, the potential for the introduction of social biases to SOs during FASCAT training sessions, SOs' risk perceptions to threats, SOs' perceptions of food defense and security funding, and SOs' food defense practices.

Procedure

Survey data were stored in an Internet hosted spreadsheet prior to analysis. FASCAT social bias questions were asked in a closed format (yes/no), and the remainder of the survey questions required participants to rank their degree of agreement with the provided statements on a 1 to 5 Likert scale: 1 = strongly disagree, 3 = neither disagree/nor agree, and 5 = strongly agreed. Participants' survey responses were tested to assess whether their perceptions differed on average from the suggested non-committal value of 3.

All statistical tests were completed with SPSS 19 (SPSS Inc., Chicago, IL, USA). All questions were analyzed using one-sample *t*-tests, which measures if SOs tended to differ from the suggested Likert scale non-committal value of 3. Since the electronic survey forced participants to answer all questions, there was no variation in the response rate between questions. Thus, no data were excluded from the analysis.

RESULTS

Response Rate

Of the 91 state officials responsible for food defense invited to complete the online survey, 32 people responded and completed the survey. Ten of the 91 emails sent were returned as undeliverable. All of the responses were usable, yielding a response rate of 39.5%.

Demographics

Demographic data were not collected to prevent identification of specific SOs' responses to sensitive security questions. By making the survey completely anonymous, response bias due to fear of reprisal for releasing sensitive or discommodious information among SOs was reduced (Jensen, Li, & Rahman, 2010). The contact list of state FASCAT users was obtained from the FoodSHIELD database (n = 91). By examining the demographic data available in the database, some generalizations can be made about the survey population. The people sent the survey were predominantly male (n 71%), and used FASCAT at varying rates. Based on job titles available in the FoodSHIELD database, 19% of the people in the FoodSHIELD database were security managers (n = 17), 15% were program administrators (n = 14), 14% were government veterinarians (n = 13), 13% were emergency managers (n = 12), and 39% did not report their job title (n = 35).

Survey Results

SOs were neutral in their review of FASCAT usability (Table I). There were no significant differences from the non-committal value of 3 regarding FASCAT usability. SOs are generally using the FASCAT food systems flow charts (Item 5, *Mean* = 1.81, t = -7.82, p < .001), and SOs judged that FASCAT was easier to use than other forms of risk assessment (Item 2, *Mean* = 3.28, t = 2.06, p = .048).

Table I: FASCAT's Usability

Item	*t*	*p* value	Mean	SE
1. Compared to other forms of risk assessment, the FASCAT tool is easier to understand.	.892	.379	3.13	.140
2. Compared to other forms of risk assessment, the FASCAT tool is much easier to use.	2.06	.048*	3.28	.136
3. FASCAT is very easy to use.	.649	.521	3.09	.145
4. The FASCAT flow charts contained complete and accurate supply chain data.	1.60	.118	3.25	.156
5. The FASCAT flow charts were not used during the assessment.	-7.82	< .001*	1.81	.152
6. The FASCAT instructions were easy to understand.	3.04	.005*	3.41	.134

* Indicates that the *p* value is significant at the .05 level

SOs' evaluation of FASCAT's value did differ from the neutral value of 3 (Table II). SOs judged that FASCAT aids them in identifying critical food systems (Item 3, *Mean* = 3.84, t = 5.40, p < .001), aids them in identifying vulnerable food systems (Item 2, *Mean* = 3.47, t = 2.79, p = .009), enhances their understanding of the commodity supply chain (Item 8, *Mean* = 4.00, t = 7.87, p < .001), and enables their organizations to complete criticality assessments for food and agriculture (Item 4, *Mean* = 4.21, t = 7.39, p = < .001).

Table II: FASCAT's Value

Item	*t*	*p* value	Mean	SE
1. Compared to other forms of risk assessment, the FASCAT tool is more valuable.	2.18	.037*	3.28	.129
2. FASCAT helps my organization determine the specific food systems that are the most vulnerable to an attack.	2.79	.009*	3.47	.168
3. FASCAT helps our organization identify critical infrastructures.	5.40	< .001*	3.84	.156
4. FASCAT is a valuable tool that enables my organization to complete critical infrastructure assessments for food and agriculture.	7.39	< .001*	4.21	.164
5. My organization does not understand what the FASCAT scores represent.	-1.79	.083	2.63	.209
6. My organization is extremely dissatisfied with FASCAT.	-7.00	<.001*	2.13	.125
7. Our organization is extremely satisfied with FASCAT.	2.25	.032*	3.34	.153
8. The FASCAT flow charts enhanced my organization's understanding of the commodity supply chain.	7.87	< .001*	4.00	.127

* Indicates that the *p* value is significant at the .05 level

SOs judged that they were in a position to be biased by NCFPD and DHS trainers (Table III): 1) 87.5% of the SOs surveyed received in-person assistance while conducting FASCAT assessments; 2) 50.0% of SOs reported receiving help from somebody that might have influenced their responses to FASCAT; 3) 78.1% of SOs received help completing FASCAT assessments from others who were trained by NCFPD staff; and 4) 75.0% of SOs received training from NCFPD.

Table III: Potential Sources of Bias

Item	% Yes
1. Did you receive help in person from the National Center for Food Protection and Defense's (NCFPD) staff while using FASCAT?	87.5
2. Did you receive help via telephone from the National Center for Food Protection and Defense's (NCFPD) staff, Core-shield Staff, or anybody else that might have influenced your answers while using FASCAT?	50.0
3. Did you receive help while using FASCAT from a person who previously was trained by NCFPD's staff on how to use FASCAT?	78.1
4. During your FASCAT session, did anyone participating in the risk assessment receive any kind of training from the National Center for Food Protection and Defense (NCFPD)?	75.0

SOs' risk perceptions differed from the suggested neutral value of 3 (Table IV). SOs believe that food and agriculture systems are at high risk of unintentional contamination (Item 3, *Mean* = 1.47, $t = -15.28$, $p < .001$) and biological terrorist attack (Item 2, *Mean* = 1.50, $t = -11.17$, $p < .001$), but they tend not to believe that food and agriculture are at high risk of chemical terrorist attack (Item 1, *Mean* = 3.28, $t = 1.47$, $p = .152$). SOs tend to be neutral about whether their organizations understand the National Infrastructure Protection Plan (Item 4, *Mean* = 3.44, $t = 2.03$, $p = .051$) (United States Department of Homeland Security, 2009).

Table IV: State Officials' Risk Perceptions

Item	*t*	*p* value	Mean	SE
1. Food and agriculture are at high risk of a chemical terrorist attack.	1.47	.152	3.28	.192
2. Food and agriculture are not at much risk of a biological terrorist attack.	-11.17	< .001*	1.50	.135
3. Food and agriculture are not at risk of unintentional food contamination (i.e., E–coli).	-15.28	< .001*	1.47	.100
4. My organization's risk assessment team knows and understands the National Infrastructure Protection Plan.	2.03	.051	3.44	.215
5. The risk scores that FASCAT generates are not realistic.	-.812	.423	2.88	.154
6. The scores that FASCAT generates make sense.	3.26	.003*	3.44	.134

* Indicates that the *p* value is significant at the .05 level

SOs' food defense practices differed from the neutral value of 3 (Table V). SOs are conducting risk assessments as a food defense or security strategy (Item 4, *Mean* = 3.56, t = 3.14, p = .004); however, SOs do not describe themselves as being zealous in mitigating the risks identified by FASCAT (Item 2, *Mean* = 3.25, t = 1.28, p = .211). When risks are identified by FASCAT, SOs perceive that they do not have the funding to mitigate risks (Item 3, *Mean* = 1.84, t = -7.11, p < .001), and states are not conducting secondary FASCAT assessments after mitigation strategies are employed (Item 1, *Mean* = 2.22, t = -5.58, p < .001).

Table V: State Officials' Practices and Funding

Item	*t*	*p* value	Mean	SE
1. After risk mitigation strategies are employed, my organization conducts a second risk assessment with FASCAT.	-5.58	< .001*	2.22	.140
2. My organization attempts to mitigate the risks identified by FASCAT.	1.28	.211	3.25	.196
3. My organization has the funding to mitigate the risks identified by FASCAT.	-7.11	< .001*	1.84	.163
4. Risk assessment is a major part of my organization's security management strategy.	3.14	.004*	3.56	.179

* Indicates that the *p* value is significant at the .05 level

DISCUSSION

The results indicated that: (1) FASCAT is easier to use than other forms of risk assessment; (2) bias in assessment of probability, threat, vulnerability, and consequences may have been introduced by the NCFPD and DHS trainers during FASCAT training; (3) FASCAT is valuable to SOs; (4) SOs do not report routinely following security management best practices; (5) SOs inaccurately believe that the food system is at high risk from intentional biological threats; and (6) SOs believe that food defense risk mitigation is not adequately funded by state or federal governments.

FASCAT Usability

Determining the usability of risk or criticality assessment software is important. By determining food defense software usability, adoption rates of software can be partially estimated (Ammenwerth, Iller, & Mahler, 2006). There have been no known usability studies of current food defense risk or criticality assessment software (e.g., Food Defense TQ, Food Defense Assessment Tool, CARVER + Shock, and FASCAT). SOs reported that FASCAT's instructions were easy to understand and that FASCAT was easier to use than other forms of food defense risk or criticality assessment, but did not find FASCAT exceptionally easy to use. Improvements to the interface that make navigation of FASCAT simpler and reducing the number of open text fields will enhance the usability of FASCAT. While no analysis was performed of the usefulness of the floating boxes that provide FASCAT users with operational definitions of terms used in FASCAT, future research should be conducted to determine the effectiveness of the floating boxes' definitions in clarifying potentially ambiguous terminology. Several SOs directly communicated to us that the display of supply chain flowcharts was of great value to SOs and industry during FASCAT assessments. The commodity supply chain flowcharts were used often, but they did not always contain information that accurately described the commodity or food product being evaluated. This is problematic because inaccurate flow charts could potentially cause SOs to incorrectly characterize the food commodity being evaluated, leading to biased information for FASCAT analysis. Additional and more accurate commodity flowcharts should be available in FASCAT to improve its overall usability.

FASCAT's Value

SOs and industry have multiple food defense risk and criticality assessment software platforms to choose from (e.g., Food Defense TQ, Food Defense Assessment Tool, CARVER + Shock, and FASCAT) (Yadav & Sharma, 2010). Despite the plethora of assessment tools, no analyses of the value of these products to SOs or industry have been published in refereed journals. This study found that SOs are satisfied with FASCAT and perceive FASCAT to be of more value than other forms of risk assessment. Specifically, FASCAT enables SOs to identify critical food and agriculture systems and to determine which food systems are most vulnerable to attack. The systems perspective used in FASCAT, to the degree that the commodity flow charts were accurate and were used, enhanced SOs' understanding of the commodity supply chain and food system distinctively compared to other food defense software. Most importantly, FASCAT enables SOs to comply with DHS directives and federal government critical infrastructure regulations, and to develop new and meaningful relationships with food systems owners (Slenning & Tickel, 2010).

Possible FASCAT Bias

During the observation of multiple training sessions conducted by NCFPD and DHS, this study observed that NCFPD and DHS trainers behaved in ways that may have introduced unwanted cognitive and social biases. Before SOs entered data into FASCAT, NCFPD and DHS trainers routinely engaged in conversations with SOs and food industry SMEs that appeared to affect the way that SOs responded to FASCAT assessments. For example, when the group was slow to respond, the DHS or NCFPD trainer would tell the group what the most probable threats and consequences were. As in numerous psychological studies, these facilitator biases became more prevalent in the afternoon as the group fatigued, or became stressed, or when there was an unusual amount of controversy within the group (Hallion & Ruscio, 2011; Mogg, Mathews, Bird, &

Macgregor-Morris, 1990). Additionally, this study observed that individuals with dominant personality types would persuade other group members to support their position, thus defying the consensus required for a valid assessment. During these arguments, individuals that did not have argumentative or dominant personality types would defer to the de facto group leader. These observations are consistent with earlier findings regarding group consensus methods (Mullen, 2003). These procedural problems were observed during FASCAT training sessions, which could mean that most FASCAT assessments did not reflect an independent determination of the food system's criticality. However, this procedural problem is not unique to FASCAT; all other food defense software relies upon similar subjective metrics, subject matter expertise, or group consensus. In the future, having each member of the group submit answers to FASCAT questions independently could eliminate these unwanted procedural problems. Specifically, after the group discusses each question the software could be modified to average the group's scoring of the perceived threats, vulnerabilities, and consequences, thus eliminating some of the aspects of these procedural problems.

The survey indicated that the used procedures had a high potential to bias SOs during the FASCAT training and assessment sessions. Most of the SOs (78.1%, Table III) reported that they either received help from NCFPD trainers before or during FASCAT use. This is problematic because NCFPD trainers had the greatest potential to bias SOs and FASCAT assessments during that process. However, the degree to which bias was potentially introduced was not measured in this study. Ideally, a study that compares FASCAT outcomes between FASCAT assessments completed with DHS or NCFPD assistance versus FASCAT outcomes completed independently, would better measure the degree of facilitator bias.

State Officials' Risk Perception

There are multiple potential contamination risks to the food system (e.g., chemical, biological, radiological, and physical). It is likely that SOs perceive food and agriculture risks based on their own first hand recall of food contamination events in their states. SOs perceive that food and agriculture systems are not at risk from intentional chemical attacks, but are at high risk of biological attacks. Of course there is no way to determine which intentional contamination event is the most probable without accurate intelligence of a pending attack, but chemical, radiological, and physical attack types are more likely to be successful since many food systems are not designed to mitigate these threats. For example, some food companies actively test for biological agents and some food processes have *kill-steps* to prevent biological agents from persisting through the system. In contrast, numerous chemical agents are heat and pressure stable so they will survive most kill-steps and are thus expensive and difficult for food companies to mitigate. For these reasons, chemical, physical and radiological attacks on any food system are more likely to be successful, and thus are more probable. SOs may have been biased by repeated exposure to the government and media's bioterrorism messaging, DHS or NCFPD trainers' preference for biological terrorism, or by some combination of the two.

Regardless of where potential bias to risk-type originates, SOs are required to know and understand the National Infrastructure Protection Plan (NIPP). Understanding the NIPP is important because it demonstrates familiarity with minimally acceptable risk management practices, the diversity of enemies that threaten critical infrastructures (including food and agriculture), and the many methods available to attack these systems. SOs perceived that their risk assessment teams do not understand the NIPP to a high degree. While having a high degree of understanding of the NIPP is not the best metric to measure risk management practices and knowledge, it is essential at the state government level to ensure that society is at least minimally protected by routinely engaging in security management best practices. Future research should examine the breadth and depth of security knowledge in SOs and others who are responsible for managing critical infrastructure risks.

State Officials' Practices and Funding

Society relies upon valid forms of risk and criticality assessment to identify risks and to quantify the degree of risk reduction after the deployment of mitigation strategies or technologies.(26) Fortunately, SOs are using risk and criticality assessments as part of their organizations' security management strategies. Despite SOs' use of risk and criticality assessments to identify risky food systems, SOs perceive that they are not mitigating these risks and that they do not have adequate funding to mitigate the identified risks. The amount of money state governments receive for food defense training and risk mitigation has been a highly contentious issue during the past several years. Despite the ongoing battle between states to obtain scarce security resources from the federal government, SOs perceive that they have not received adequate training or funds to improve the resiliency and security of food systems. Future research should be conducted to determine the level of training SOs have received related to food defense, the level of funding that SOs receive to mitigate food defense risks, and why SOs are not receiving the funding necessary to mitigate serious risks to the food system.

Limitations

This study had several limitations. The response rate was low (39.5%). Self-reports were used to measure risk perceptions, beliefs, and behaviors instead of more objective measures of these concepts, and due to the high turnover rate of SOs, risk perceptions may change over time. The FoodSHIELD database may have contained incorrect SO contact information, potentially limiting the distribution of surveys. SOs missing from the FoodSHIELD database and not surveyed were probably more resource deprived compared to SOs who participated in the study.

CONCLUSION

Risk perception studies are important to determine actual risk and reasons for allocation of scare security resources. One challenge is the potential for introduced biases in that assessment. This study found that SOs felt that FASCAT was easier to use and more valued compared to other forms of risk assessment available to SOs. Despite FASCAT usability and value, NCFPD and DHS trainers may have unintentionally introduced bias in assessment of probability, threat, vulnerability, and consequence during the FASCAT training sessions. SOs inaccurately perceive that intentional biological threats to the food system are the most probable threat and tended to believe that state or federal governments do not adequately fund food defense risk mitigation at the state level. Even if FASCAT trainers did unintentionally bias SOs, the magnitude of bias is difficult to quantify. Future studies that examine the distribution of FASCAT scores by food system type and determine if SO type (e.g., veterinarians, administrators, security managers) and food system type are strongly related to FASCAT scores will help assess bias of different SOs.

Chapter Four: Empirical Evaluation of the Food and Agriculture Sector Criticality Assessment Tool (FASCAT) and the Collected Data

To protect and secure food resources for the United States (U.S.) and prioritize funding for these protection efforts, it is crucial to have a method to compare food systems' criticality. In 2007, the U.S. government funded development of the Food and Agriculture Sector Criticality Assessment Tool (FASCAT) to determine which food and agriculture systems were most critical to the nation as required by Homeland Security Presidential Directives 8 and 9. FASCAT was developed in a collaborative process involving government officials and food industry subject matter experts (SMEs), collecting data and quantifying threats, vulnerabilities, consequences, second and third order consequences, and the impacts on the U.S. from failure of evaluated food and agriculture systems. In the past 4 years FASCAT has been used to evaluate the criticality of 804 disparate food commodity and product systems in the U.S. With the aid of FASCAT, multiple state governments successfully nominated food and agriculture systems as Department of Homeland Security Critical Infrastructure or Key Resources (CIKR). Despite the successful nomination of food and agriculture systems as CIKR, the FASCAT method has not been examined to determine its distinctiveness compared to the Department of Homeland Security risk assessment method, its utility for determining food and agriculture system criticality, or the validity of the questions used in FASCAT. To examine FASCAT's validity, linear regression models were used to determine (1) which groups of questions posed in FASCAT were better predictors of cumulative criticality scores; (2) whether the items included in FASCAT's criticality method or the smaller subset of FASCAT items included in DHS's risk analysis method predicted similar criticality scores. Akaike's Information Criterion (AIC) was used to determine which regression models best described criticality, and a mixed linear model was used to shrink estimates of criticality for individual food and agriculture systems. The results indicated that (1) some of the questions used in FASCAT strongly predicted food or agriculture system criticality and many questions used in FASCAT did not strongly predict criticality; (2) the FASCAT criticality formula was a stronger predictor of criticality compared to the DHS risk formula; (3) the cumulative criticality formula predicted criticality more strongly than weighted criticality formula; and (4) the mixed linear regression model did not change the order of food and agriculture system criticality to a large degree. The FASCAT criticality method is a distinct method to determine food and agriculture systems criticality and many of the questions used in FASCAT are strongly predictive of criticality. Despite the strong predictive nature of the questions used in FASCAT, the FASCAT algorithm can nonetheless be refined to increase its predictive power and utility as a security resource prioritization tool.

INTRODUCTION

Identifying and evaluating critical food infrastructures and key resources is needed to allocate mitigation funds (Rinaldi, Peerenboom, & Kelly, 2001). Multiple methods to evaluate critical infrastructure and key resource risks and criticality have been developed over the past decade, and these methods have been used to allocate scarce threat mitigation resources (Haimes, Kaplan, & Lambert, 2002). The all hazards criticality assessment method relies upon identifying all plausible threats, the associated vulnerabilities, the probability of threat occurrence, and the consequences of the threats to the infrastructure. After the all hazards assessment method has been applied, risk managers can allocate threat mitigation resources to the most critical infrastructures or key resources. Some criticality assessment methods rely on subjective qualitative assessments. Other criticality assessment methods attempt to be more quantitative by using combinations of stochastic, deterministic, cost-benefit, consequence-based, or vulnerability risk analysis methods. Regardless of the type of qualitative or quantitative or criticality assessment selected, all rely on assumptions that potentially undermine the validity of the assessment. Despite the weaknesses of relying on assumptions in criticality assessment methods, these assumptions are necessary due to the lack of high quality data on many of the threats (e.g., terrorism).

One of the advantages of qualitative criticality assessments over quantitative methods is that they can be applied rapidly and efficiently to critical infrastructure systems (e.g., public health systems, financial systems, food and agriculture systems). One problem that the government and private industry have in applying risk or criticality assessment methods to large systems is the exorbitant number of individual facilities, processes, and sub-systems that need to be individually analyzed. To conduct a risk or criticality assessment for an entire system requires an immense amount of data, and collecting these data requires time from government officials and private sector employees. Often private sector companies are reluctant to share sensitive information with the government. The amount of time, money, and resources required to perform quantitative risk or criticality assessments for all sub-systems and facilities is great and likely unrealistic. In part, this is why the government has used qualitative criticality assessment to evaluate critical infrastructure systems in preference to quantitative assessments, despite its nherent subjectivity.

Homeland Security Presidential Directives 8 and 9 require that the government identify the threats, vulnerabilities, and risks to critical infrastructures and determine which food and agriculture systems are most critical to the nation, but they do not specify a method for analyzing critical infrastructures (Bush, 2003; Bush, 2004). To accomplish this monumental task, the United States (U.S.) Department of Homeland Security (DHS) mandated that all states identify and report critical infrastructures and key resources, including food and agriculture systems, to the Office of Infrastructure Protection. Initially, states were required to identify their critical infrastructures to comply with HSPD-9. The primary objective, as seen by the White House's Homeland Security Council, was to help states ensure that they had collected the necessary data to access

DHS grants across all critical infrastructure sectors. Previously, these grants primarily went to police, fire, medical, financial, and energy sectors, as they had been clearly defined as critical infrastructure and the need for additional resources was not difficult to articulate. No grants went to the food and agriculture sector because criticality data was not collected. This was mainly attributable to the lack of a standardized method to collect and compare food and agriculture systems' data. To help state and federal governments identify critical food and agriculture systems, the National Center for Food Protection and Defense (NCFPD) developed the Food and Agriculture Sector Criticality Assessment Tool (FASCAT) in 2007 (Huff, Kircher, Hoffman, & Kennedy, 2013). In 2008, the National Infrastructure Protection Plan named FASCAT as a priority program for identification of critical food and agriculture systems (Department of Homeland Security, 2010). Although FASCAT was named as a priority program by DHS, several organizations within the federal government contested the use of FASCAT for determining criticality until they realized that the food and agriculture sector needed to be analyzed like other critical infrastructure systems (e.g., electric grid, financial system; Anonymous, personal communication, June 13, 2012).

FASCAT is a structured interview and criticality scoring software program for analyzing food and agriculture systems. To use FASCAT, government officials typically convened a group of relevant subject matter experts (SMEs) from private industry to review the food and agriculture system. SMEs were used in the process because academic and government food and agriculture system stakeholders (e.g., Critical Infrastructure Partnership Advisory Council) thought these SMEs could reasonably estimate food system vulnerabilities, potential threats to food systems, the consequences if food or agriculture systems were contaminated or destroyed, the magnitude of the impact on society that the consequences could have, and second and third order effects that would follow the systems' disruption. The SMEs would deliberate and come to a consensus on each section of FASCAT. The person responsible for each state's critical infrastructure assessments would record the answers in FASCAT. After data input, a criticality score on an ordinal scale was calculated. The higher the FASCAT's score, the more critical the food or agriculture system under evaluation was deemed to be. After criticality scores were generated for multiple systems in each state (37 states participated), state government officials would select the most critical systems as identified by FASCAT to be nominated to DHS as critical infrastructure or key resources. Over the course of 8 years, state officials and SMEs evaluated 804 food and agriculture systems with the aid of FASCAT.

Despite FASCAT's apparent transparency and relevance to food systems criticality (i.e., face validity) and broad use by state governments, the present study was concerned about the validity and ability of FASCAT to accurately measure food and agriculture system criticality (i.e., construct validity). Initially, during government and industry food and agriculture meetings, many scientists asked DHS to operationally define criticality (Dunn, 2005; Wise & Nader, 2002). Critical infrastructures are the assets, systems, and networks, physical or virtual, that are so vital to the U.S. that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof (Critical Infrastructures Protection Act, 2006). Before FASCAT, criticality was not mathematically defined for *systems*, yet facility level criticality was used as the metric to determine which infrastructures are of the greatest importance to the U.S. and its people. FASCAT measures criticality using the formula:

$$Crit = T + C + C_{23} + I + V + S + Co + P + A$$

where $Crit$ = criticality, T = threats, C = consequences, C_{23} = 2^{nd} & 3^{rd} order consequences, I = impact of event(s), V = vulnerabilities, S = scale of event, Co = concentration of event, P = probability of the selected events occurring, A = size of the geographic area affected, each of these items being evaluated on a numeric scale and then added together as in the formula. It could be argued that FASCAT is nothing more than a DHS-defined risk assessment formula:

$$R = T \times V \times C$$

where R = risk, T = threats, V = vulnerabilities, C = consequences, which are multiplied as in the formula. Potential values to the variables listed above are available in Appendix B. Although there are obvious differences between the components of the risk and criticality formulas, the operational definitions of the individual components of FASCAT's formula were more precisely defined than those of the traditional risk assessment formula. The consequences in the criticality formula were clearly separated to indicate the magnitude, the scale, the second and third order consequences, and the duration of potential harmful disruptions to the food or agriculture system. With these additional and more precisely defined inputs, FASCAT's criticality formula could potentially provide different and more valuable information than the risk assessment formula.

Regardless of whether qualitative risk or criticality assessments are actually a bifurcation of the same underlying construct (i.e., valuable and vulnerable systems), determining which food and agriculture systems are most critical to the nation gives people with an interest in risk and criticality assessment a general guideline on how to prioritize future assessments of specific food system types and thus allocate scarce resources (Ayyub, McGill, & Kaminskiy, 2007). Other studies have persuasively argued that using rank ordering to allocate threat and vulnerability mitigation resources is not effective (Cox Jr., 2008; Cox Jr., 2009). These studies have proposed alternative risk assessment methods that are more logically sound than the methods used in the DHS risk or FASCAT methods, but these proposed alternatives are not feasible or scalable for assessing the vast quantity of food and agriculture systems. Highly variable and broadly distributed food and agriculture systems require a quick and perhaps necessarily unsophisticated method for assigning risk or criticality; more complex risk analysis methods (e.g., hierarchical optimization, probabilistic models, decision tree models, game-theory models) would be extremely cost prohibitive (with existing technology) to apply to 2.1 million farms and 28,000 food production companies in the U.S. (United States Department of Agriculture, 2007; U.S. Department of Commerce, 2008). When assessing risk, there is a clear cost (e.g., speed, time, and money) trade-off between risk assessments with high validity versus those with lower validity (Tetlock & Mellers, 2011). Some people have persuasively argued that terrorism risk assessments cannot be validated due to the asymmetric and non-stochastic nature of terrorism events (Vleck, 2013). However, this argument leaves policy makers with no means of making resource allocation decisions.

The FASCAT data includes repeated assessments of 94 different food system types and 804 food systems. These data represent the largest collection of systems-based qualitative risk assessments conducted in the U.S. These data provide a unique way to evaluate FASCAT's utility and areas for improvement in the collection of risk assessment data of food and agricultural systems.

Despite the potential strengths of the FASCAT formula and process, there appear to be problems with FASCAT's software taxonomy, i.e., the way food and agriculture systems were defined. To make the underlying constructs of the FASCAT assessment more specific and reliable, FASCAT's developers provided operational definitions for key terms in the FASCAT software. However, the definitions were at times overly complex, difficult to interpret, or not mutually exclusive. Consequently, researchers observed that the overlap between food and agriculture systems in the FASCAT taxonomy made it unnecessarily difficult for analysts to determine what type of system was actually being evaluated (e.g., dairy product manufacturing, dairy product (except frozen) manufacturing, fluid milk manufacturing). With the intent of collecting more specific and reliable data from food industry SMEs, FASCAT's developers may in fact have made measurements of the underlying constructs (e.g., threats, vulnerabilities, consequences) less specific and reliable by creating poorly worded operational definitions (i.e., the definitions of key terms that were provided to SMEs).

FASCAT is used by individual states to measure food and agriculture systems' criticality in a manner that has several weaknesses (e.g., weak operational definitions, potentially biased data collection methods). DHS requires that individual states report all critical infrastructures on a bi-annual basis. However, food and agriculture systems often span multiple states and indeed are often part of a global system, while few assessments have been conducted on even a regional, let alone national, scale. Thus, different states often conduct repeated assessments on sections of the same food and agriculture system and then submit duplicate assessments of food and agriculture systems to DHS as part of the *Data Call* (a process that collects critical infrastructure and key resource data from states). The most important implication of this is that food and agriculture systems that are broadly distributed could be overlooked because the amount of critical infrastructure present and measured within individual states could be deemed insufficient to gain the attention of state or federal government officials. This is especially true if a state contains important elements of a system that are small within the state but critical for the overall larger system.

A wide variety of data types were collected in FASCAT (e.g., emergency contacts, state government agency, primary rater's occupation, criticality, threats, consequences, 2nd & 3rd order consequences, impact of event(s), vulnerabilities, scale of event, concentration of event, probability of the selected events occurring, size of the geographic area affected). Data were collected not only on food and agriculture systems, but also on characteristics of the people who were responsible for leading FASCAT data collection sessions, collecting data required for FASCAT assessments, and submitting completed FASCAT reports to DHS. Five different types of vocations were entered into FASCAT (security professionals, veterinarians, administrators, food defense managers, emergency managers) and these vocational data can be used to determine whether people holding different jobs tend to perceive criticality differently. If differences between vocational rater types exist, then even highly manual data collection and criticality scoring processes like FASCAT's may need to be adjusted to accurately assign criticality scores to infrastructures. An evaluation of these measurement, taxonomy, and data type weaknesses is central to improving U.S. criticality assessments methods.

This study seeks to address the complex measurement of food-system criticality by evaluating the existing FASCAT tool and the data collected by this tool. The goals were fourfold namely to determine: whether the FASCAT method of criticality assessment is valid; if the FASCAT criticality assessment method is different from other traditional forms of risk assessment; which food systems are most critical to the nation; and, which method of criticality scoring is most effective.

Specific objectives were: (1) describe food and agriculture system characteristics; (2) determine if raters with different occupations rated food and agriculture systems' criticality differently; (3) determine the best predictors of criticality score by category type; (4) compare risk and criticality formulas and compare cumulative and weighted scores; (5) identify significant predictors of criticality; and (6) determine which food and agriculture system types are most critical to the U.S. on average.

Our study's results will broadly inform food protection and defense policy by comparing food system criticality scores. Additionally, this study will evaluate the FASCAT tool used to measure food systems' criticality and suggest ways to improve this tool.

METHOD

Data collected with FASCAT from 2010 to 2012 were analyzed using: descriptive statistics to characterize the food systems that primarily comprise the U.S. food supply chain and to determine how people with varying job types rated systems criticality; regression analyses to compare the DHS risk formula framework to FASCAT's criticality formula; and regression analyses to determine which types of inputs (e.g., consequence, threats, impacts) contribute most to FASCAT's criticality formula.

Participants & Data

During the data collection process, a state would convene a group of SMEs (5 to 25 SMEs on average) to determine their state's food and agriculture systems' criticality or in limited cases complete the FASCAT assessment without SMEs from the private sector (Huff, Kircher, Hoffman, & Kennedy, 2013). During the data collection process, SMEs and state officials would answer the questions provided in FASCAT and would provide open text field responses to further clarify their responses, as necessary. The data analyzed contained FASCAT assessments from 94 food and agriculture system types (see Figure V) [1] collected by 37 different states from January 2008 to July 2012. FASCAT generates cumulative and weighted criticality scores for each food and agriculture system. The cumulative score is the sum of all the responses and the weighted score weights the impact variables in FASCAT by 1.5 times for each impact variable selected.[2] To protect the privacy of states' criticality data, ID numbers were assigned to states in random order. A third party vendor stored collected data.

Procedure

To determine food and agriculture system criticality, SMEs from 37 states were asked to identify the threats, consequences, 2nd & 3rd order consequences, impacts of identified consequence(s), vulnerabilities, scale of events, concentration of events, probability of the selected events occurring, and the size of the geographic area affected, in that order. In cooperation with DHS, State officials and the National Center for Food Protection and Defense collected the data analyzed in this study from 2008 to 2012. The scores assigned to each of the possible responses are provided in Appendix B (Tables B1 through B6).

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[1] Figure V contains an inclusive list of the food and agriculture system types evaluated by states. Food and agriculture1system types were obtained from the North American Classification System (NIACS) and not all of the food system types available in the NIACS were analyzed by SMEs.

[2] The cumulative criticality formula is $Crit = T + C + C_{23} + I + V + S + Co + P + A$ and the weighted criticality formula is $Crit = T + C + C_{23} +(I \times 1.5) + V + S + Co + P + A$.

After the data were collected, missing records (77 instances) were removed because FASCAT cannot generate a criticality score from an incomplete assessment.

For objective 1, descriptive statistics were computed with SPSS 19 (SPSS Inc., Chicago, IL, USA). For objectives 2-5, ANOVA and regression analyses were performed with R version 2.13.1 (R Foundation for Statistical Computing, Vienna, Austria).

Occupations were categorized into six independent groups (i.e., administrator, emergency manager, food defense manager, security professional, unknown, and veterinarian). ANOVA was used to compare the differences in criticality assessment by rater type (objective 2).

Controlling for raters' indicated job-type, location, and food or agriculture system type, linear regression models and ANOVAs were used to determine which groups of questions posed in FASCAT were better predictors of cumulative criticality scores and whether the items included in FASCAT's criticality method, or the smaller subset of FASCAT items included in DHS's risk analysis method, predicted similar criticality scores (objective 3).

For objective 4, Akaike's Information Criterion (AIC) was used to determine which regression models best-described criticality. Many of the food and agriculture system types evaluated had few ratings by SMEs (i.e., small sample sizes), so a mixed linear model was used to shrink estimates of criticality for individual food and agriculture system types to develop a better description of the food and agriculture system types that the data indicate are most critical (a detailed explanation is provided in Appendix C).

To assess significant predictors of criticality (objective 5) we fit a multiple linear regression with *cases* (observations) being ratings of individual systems (n = 731), outcome (dependent variable) being FASCAT cumulative score, and one binary (yes/no) predictor for each of the possible threats. The analysis estimated, for each threat type, the average difference between cumulative scores when that threat was present versus when it was absent, adjusting for all other threat types, and provides a test of whether that average difference can be distinguished from unexplained variation in the cumulative scores. State, rater type, and system type were also controlled for.

Finally, a linear model was fit controlling for state and rater type to determine which food system types are the most critical to the U.S. (objective 6). In the FASCAT data, some food and agriculture system types had erroneous entries. Food system types with small sample sizes with extreme values were incorrectly identified as being highly critical. For example, in one case where the system was based upon vegetable production, loss of herd or flock was selected as a consequence (artificially inflating the criticality score) and this is not physically possible. To correct for the system types with small sample sizes and extreme values, a linear mixed effects model, fit by restricted maximum likelihood, with a random effect for food and agriculture system type (94 groups) was used to shrink systems with small sample sizes and extreme criticality scores; for an individual system type, the estimated cumulative score from this analysis will be shrunk from its average toward the values implied by its predictor values, in this case state and rater type (a detailed explanation is provided in Appendix C).

RESULTS

Objective 1: Food System Characteristics

The weighted FASCAT scores, by food and agriculture system type (n = 731), had a median of 110, a standard deviation of 37.06, and a range of 15 to 184. The cumulative FASCAT scores, by food and agriculture system type (n = 727), had a median of 87, a standard deviation of 22.17, and a range of 15 to 123. The difference between weighted FASCAT scores and cumulative scores is due to the weighting of the impacts of a food defense event. The overall distribution of weighted scores was left skewed and unimodally distributed and the cumulative scores were more symmetrically distributed but with some left skewing (Figures I & II). In states that performed multiple assessments, scores were mostly symmetrically distributed (Figure III).

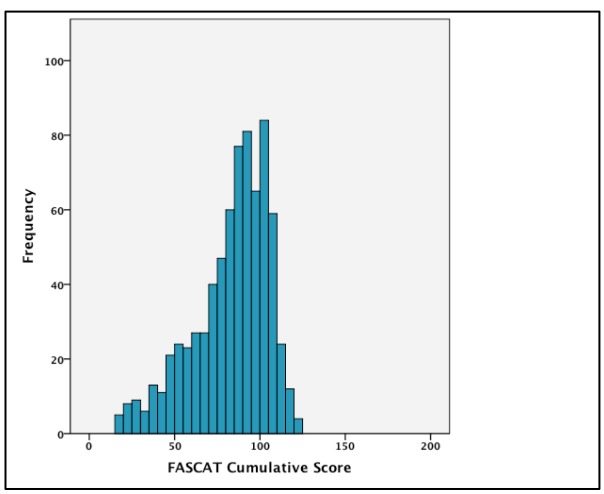

Figure I. Distribution of FASCAT cumulative scores.

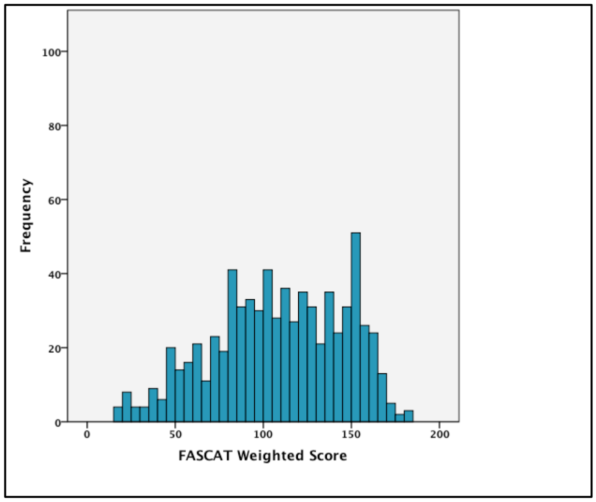

Figure II. Distribution of FASCAT weighted scores.

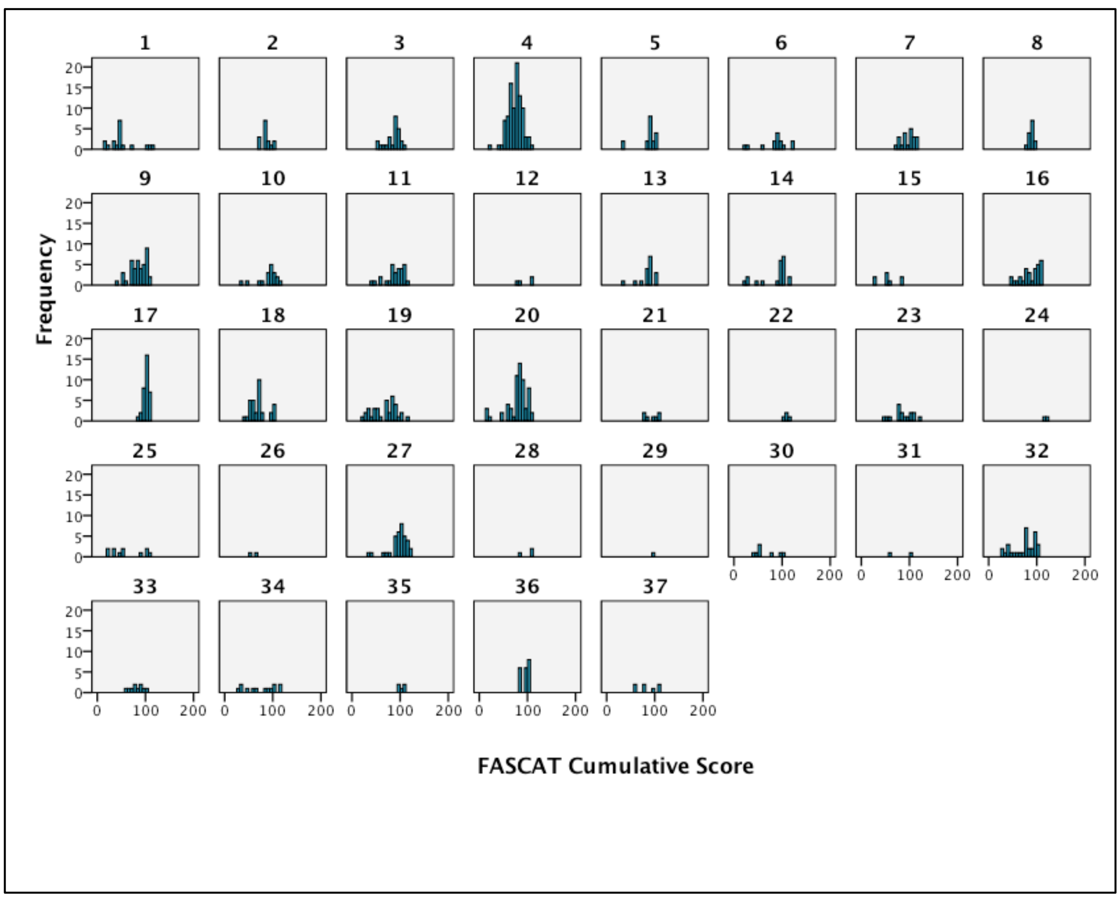

Figure III. Distribution of criticality scores by state.

Objective 2: Differences in Scores by Rater Type

Food defense managers rated food system criticality lower on average than all other groups, while emergency managers and administrators tended to rate food systems as having higher criticality compared to the other groups. ANOVA was also calculated on weighted scores and the findings were similar to the cumulative scores (Figure IV). ANOVA indicated that SMEs' ratings of food and agriculture systems (cumulative scoring) significantly differed by job type, $F(5, 721) = 16.20$, $p < .001$.

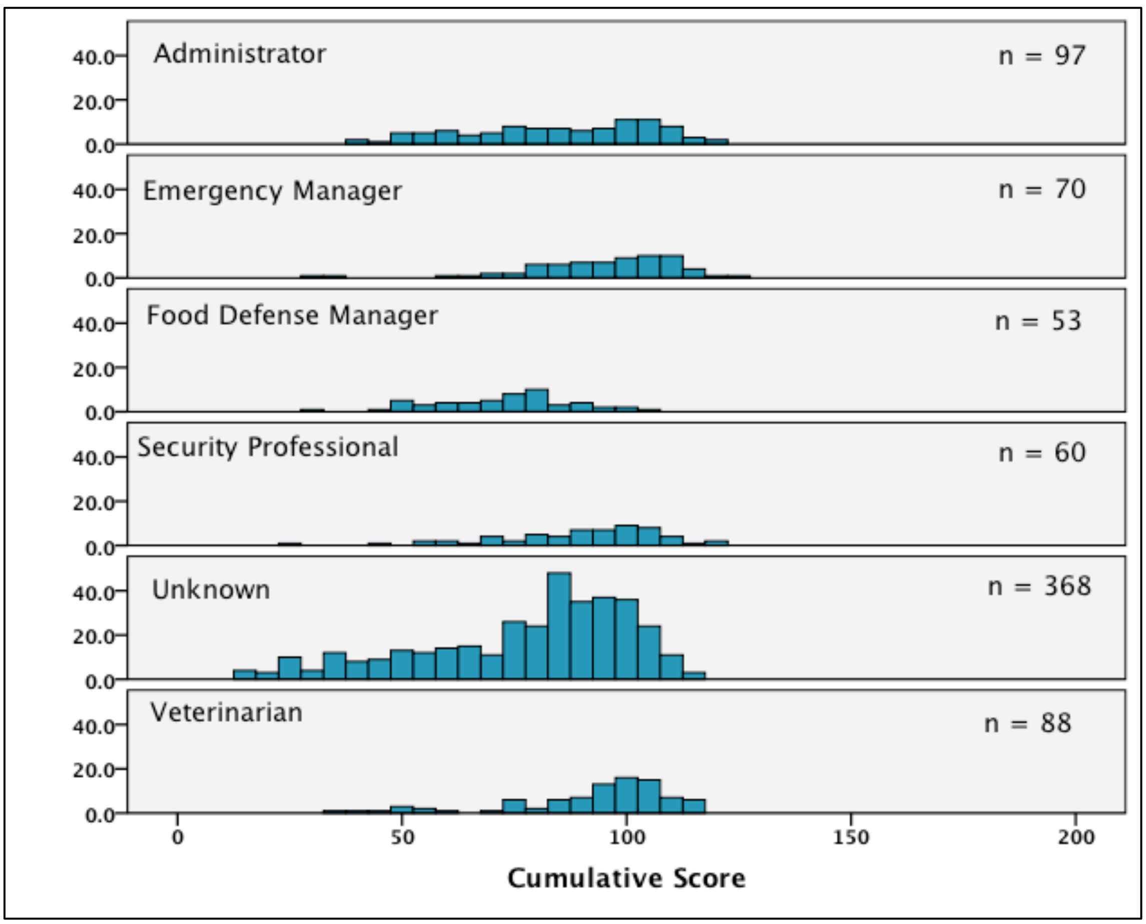

Figure IV. Distribution of cumulative criticality scores by job-type.

Objective 3: Best Predictors of Criticality Scores by Group Type

Threats, consequences, 2nd and 3rd order effects, and impacts are supposed to be considered by SMEs in their ratings of criticality. We analyzed FASCAT cumulative scores to see which specific threats, consequences, 2nd and 3rd order effects, and impacts are in fact associated with these scores. For the analysis of threats, a multiple linear regression was performed with cases (observations) being ratings of individual systems (n = 731), outcome (dependent variable) being FASCAT cumulative score, and one binary (yes/no) predictor for each of the possible threats. The analysis estimated, for each threat type, the average difference between cumulative scores when that threat was present versus when it was absent, adjusting for all other threat types, and provides a test of whether that average difference can be distinguished from unexplained variation in the cumulative scores (i.e., noise). State, rater type, and system type were controlled for. Analogous analyses of consequences, 2nd and 3rd order effects, and impacts were performed. A Tukey's post-hoc test was used to adjust the significance tests to control the chance of false-positive findings.

Tables VI, VII, VIII, and IX illustrate results for threats, consequences, 2nd and 3rd order effects, and impacts, respectively. For example, in Table VI, chemicals, drought, loss of operation rights, loss of access, misinformation, radiological contamination, food pathogens (vegetable), food pathogens (non-vegetable), and foreign animal diseases were associated with higher criticality scores. Interestingly, intentional adulteration of food and agriculture products was not identified as significant contributors to food and agriculture criticality scores. These mixed results indicate that the way threats to food and agriculture systems are evaluated in FASCAT should be altered, or that state officials and food industry subject matter experts might not be reliable and valid predictors of threats to the food and agriculture systems. Specifically, naturally occurring and anthropogenic threats should be considered independently of each other.

Table VI: Association of threats in FASCAT with the cumulative score, in the order that they were presented to the SMEs.

Item	Mean Squares	*F*	*p* value	*p*-value from Tukey's HSD
1. Animal rights activists	517	2.77	.096	.142
2. Chemical/toxin	11,412	61.23	< .001*	< .001*
3. Destruction	1,403	7.52	.006*	.064
4. Drought	2,346	12.58	< .001*	.006*
5. Exotic plant pest or disease	1,246	6.68	.009*	.081
6. Loss of operation rights	5,294	28.41	< .001*	< .001*
7. Loss of access	3,604	19.33	< .001*	.001*
8. Misinformation	3,731	20.02	< .001*	.010*
9. Radiological contamination	5,425	29.10	< .001*	< .001*
10. Cyber attack	162	.870	.351	.408
11. Food pathogens vegetable	3,084	16.54	< .001*	.002*
12. Intentional adulteration	1,352	7.25	.007*	.134
13. Food pathogen non-vegetable	3,503	18.79	< .001*	.007*
14. Native plant disease or pest	1,318	7.07	.008*	.189
15. Production disruption	264	1.41	.234	.446
16. Plant pests	146	.783	.376	.693
17. Theft	364	1.95	.162	.302
18. Foreign animal disease	5,408	29.01	< .001*	. < .001*

* Indicates that the *p* value is significant at the .05 level

In Table VII, short-term system shut down, reduced output, product shortage, mass casualty, and contamination of herd or flock were significantly associated with higher criticality scores. Contrary to the majority of speculative and subjective literature related to the major consequences of food contamination events, loss of capital, loss of access to customers, economic loss, loss of access to credit, and cost of response were not strongly associated with food and agriculture system criticality scores. Similar to FASCAT's threats, these mixed results indicate that the way threats to food and agriculture systems are evaluated in FASCAT should be altered, or that state officials and food industry subject matter experts might not be reliable and valid predictors of threats to the food and agriculture systems. For example, reduced output and loss of key output are essentially the same consequence; therefore, there is a reasonable expectation that their *p values* should be similar and they are not. Contrary to popular belief, the economic loss questions in FASCAT are not associated with food and agriculture system criticality. This indicates that economic loss criticality metrics do not provide any additional information on food and agriculture systems criticality; therefore, the collection of this type of information is likely unnecessary to correctly rank-order food and agriculture systems.

Table VII: Association of consequences in FASCAT with the cumulative score, in the order that they were presented to the SMEs.

Item	Mean Squares	*F*	*p* value	*p*-value from Tukey's HSD
1. Short-term system shut down	1,051	5.34	< .001*	< .001*
2. Reduced output	10,337	52.52	< .001*	< .001*
3. Product shortage	2,986	15.17	.001*	.012*
4. Mass casualty	9,043	45.95	< .001*	< .001*
5. Loss or contamination of herd or flock	4,440	22.56	< .001*	< .001*
6. Loss of tourism	1,374	6.97	.008*	.051
7. Loss of labor	636	3.23	.072	.203
8. Loss of seed source	186	.945	.331	.453
9. Loss of key output	147	.747	.387	.600
10. Loss of key input	661	3.35	.067	.222
11. Loss of capital	2,003	10.18	.001*	.096
12. Loss of access to customers	368	1.87	.171	.426
13. Economic loss	658	3.34	.067	.364
14. Loss of access to credit	1,966	9.98	.001*	.055
15. Cost of response	621	3.15	.076	.427

* Indicates that the *p* value is significant at the .05 level

In Table VIII, damage to the government's tax base, damage to customers, disease spread to others, loss of access to insurance, and loss of public confidence were associated with food and agriculture system criticality. Loss of market access, government cost to respond, hazardous waste disposal, and the cost of litigation were not associated with food and agriculture system criticality scores. Similar to the consequence questions, questions related to economic losses were not associated with food and agriculture criticality scores. Therefore, the inclusion of economic metrics in food and agriculture systems criticality has limited value in differentiating food and agriculture systems from each other.

Table VIII: Association of 2nd and 3rd order effects in FASCAT with the cumulative score, in the order that they were presented to the SMEs.

Item	Mean Squares	*F*	*p* value	*p*-value from Tukey's HSD
1. Loss of public confidence	12,324	59.15	< .001*	< .001*
2. Loss of market access	1,331	6.38	.011*	.119
3. Loss of access to insurance	10,388	49.86	< .001*	< .001*
4. Government cost to respond	850	4.07	.043*	.264
5. Disease spread to others	4,923	23.64	< .001*	.001*
6. Hazardous waste disposal	14	.068	.794	.814
7. Damage to government's tax base	2,608	12.52	< .001*	.026*
8. Damage to customers	4,744	22.77	< .001*	< .001*
9. Cost of litigation	51	.245	.620	.667

* Indicates that the *p* value is significant at the .05 level

In Table IX, several factors were predictive of criticality: the loss of supply, loss of sub-system, limited to 1 state, 10,000 human casualties, more than 5 states impacted, and more than 1 year to recover were associated with food and agriculture systems criticality scores. Not surprisingly, less than 5 states impacted and less than 1 year to recover were not associated food and agriculture systems criticality scores as they do not mathematically contribute as much to criticality scores. The questions asked in the impact section seem to best differentiate food and agriculture system criticality.

Table IX: Association of impact items in FASCAT with the cumulative score, in the order that they were presented to the SMEs.

Item	Mean Squares	*F*	*p* value	*p*-value from Tukey's HSD
1. Loss of supply	11,077	50.68	< .001*	< .001*
2. Loss of sub-system	3,223	14.75	< .001*	.007*
3. Limited to 1 state (geographic extent)	1,805	8.26	.004*	.020*
4. 10,000 human casualties	4,666	21.35	< .001*	.003*
5. More than 5 states (geographic extent)	6,110	27.95	< .001*	< .001*
6. Less than 5 states (geographic extent)	266	1.21	.270	.402
7. Less than 1 year to recover	264	1.20	.271	.411
8. More than 1 year to recover	3,836	17.55	< .001*	.023*

* Indicates that the *p* value is significant at the .05 level

Objective 4: Comparison Between Risk and Criticality Formulas

Scientists, managers, and policy experts from government, academia, and industry have argued that criticality analyses lack construct validity because risk and criticality analyses are measuring the same underlying construct. To determine whether including FASCAT's additional items for criticality, beyond those included in the DHS risk formula, did in fact contribute to FASCAT's cumulative and weighted scores, risk and criticality formulas were compared to determine if these formulas had different outcomes under cumulative and weighted scoring. To compare risk and criticality in this way, a multiple linear regression for each formula type (risk and criticality) within each scoring type (cumulative and weighted) was performed controlling for location, rater type, and system type (Tables X and XI; see methods). For both weighted and cumulative scoring types, the items in FASCAT's criticality formula (R^2 = .825 and R^2 = .836, respectively) were better predictors of FASCAT scores compared to the items in the DHS risk formula (R^2 = .763 and R^2 = .780, respectively). Also, DHS risk and FASCAT criticality items predicted cumulative criticality scores (R^2 = .780 and R^2 = .836, respectively) better than weighted scores (R^2 = .763 and R^2 = .825, respectively). Using Akaike's Information Criteria (AIC; smaller scores are better and AIC levies a penalty for each additional predictor in the criticality formula) gave results similar to R^2 (AIC for DHS risk items = 6,697.40 and 5,690.30 for weighted and cumulative scores respectively; AIC for criticality items = 6,317.06 and 5,529.35 respectively).

These results indicate that the additional predictors in the criticality formula do in fact differentiate criticality from risk (Table X and XI). The adjusted R^2 from the regressions performed in Tables X and XI, indicates that the questions asked in FASCAT explain more of the variance in criticality scoring compared to the DHS risk formula, and that the cumulative scores explain more of the variance in criticality scoring compared to weighted scoring. This regression analysis indicates that the cumulative scoring method is the most representative of criticality in food and agriculture systems, and it is also supported by the visual inspection of the data discussed below.

In Table XIII, a few examples are provided to demonstrate how cumulative and weighted scoring methods affect food and agriculture system criticality ranking. An excellent example of where weighted scoring underperforms is the comparison between a poultry farm (cumulative score 105, weighted score 158) and a poultry processor (cumulative score 105, weighted score 157.5). The food defense risk is in fact higher at the processor due to the types of vulnerabilities and it is closer in proximity to the consumer in the supply chain. The differences in food and agriculture criticality scoring methods (outcomes), and the effect it has on food and agriculture systems criticality ranking, are discussed later (see discussion section).

Table X: Comparison of regression models based upon weighted scoring.

Model Type	*df* for error	R^2	Adjusted R^2	AIC
Risk [a]	510	.763	.671	6,697.40
Criticality [b]	485	.825	.746	6,317.06

[a] Risk: Analysis including risk items only (i.e., items describing threat, vulnerability, and consequences)
[b] Criticality: Analysis including items in the *Risk* model and also items describing probability and impacts

Table XI: Comparison of regression models based upon cumulative scoring.

Model Type	*df* for error	R^2	Adjusted R^2	AIC
Risk [a]	510	.780	.695	5,690.30
Criticality [b]	485	.836	.762	5,529.35

[a] Risk: Analysis including risk items only (i.e., items describing threat, vulnerability, and consequences)
[b] Criticality: Analysis including items in the *Risk* model and also items describing probability and impacts

Table XII: Selected examples where weighted scoring alters the food and agriculture criticality ranking (partial list).

Cumulative Score	Weighted Score	System Type
105	158	Poultry Farm
105	157.5	Poultry Processing
105	157	Apple Farm
103	155	Vegetable and Melon Farm (Except Potato)
103	154.5	Dairy Cattle Farm
103	154.5	Dairy Cattle Farm
103	154	Brewery
101	152	Swine Farm Finishing
101	151.5	Poultry Farm
101	151.5	Poultry Processing
101	151	Beef Farm/Ranch
99	149	Poultry Farm
99	148.5	Dairy Processing
99	148	Government Laboratory
97	146	Dairy Processing
97	146	Vegetable and Melon Farm
97	145.5	Dairy Processing
97	145	Dairy Processing
93	140	Poultry Farm
93	140	Poultry Processing
117	140	Grain Warehouse
93	139.5	Dairy Processing
115	138	Frozen Food Processing
115	138	Swine Farrow Operations
91	137	Fruit Farm
91	137	Grain Processing
91	136.5	Grain Processing
91	136.5	Grain Processing
91	136	Beef Processing

Objective 5: Significant Predictors of Criticality

To determine which questions (predictors) could be eliminated from FASCAT's criticality formula and data collection process and to make the evaluation process more efficient, FASCAT cumulative scores were analyzed to see which specific threats, consequences, 2nd and 3rd order effects, and impacts contributed significantly to the criticality scores. Sixteen questions in FASCAT significantly contributed to criticality scores ($P < 0.05$ without adjustment for multiple comparisons; Table XIII). These results imply that many of the questions in FASCAT could be removed since only the questions in Table XII differentiate food and agriculture systems relatively strongly. In a future study, item response theory can be used to definitively determine which questions, if any, can be removed from FASCAT.

Table XIII: Significant contributors to cumulative criticality scoring, in the order that they were presented to the SMEs.

Item	Estimated effect	*SE*	*p* value
1. Ease of Attack - High	23.20	6.26	< .001*
2. Ease of Attack - Medium	25.58	6.58	< .001*
3. Scale – Mid -size	-30.87	15.60	.048*
4. Threat – Chemical/toxin	-29.28	6.14	< .001*
5. Threat – Loss of operation rights	4.16	1.75	.018*
6. Threat – Radiological contamination	3.32	1.45	.022*
7. Threat – Food pathogen vegetable	7.07	1.98	< .001*
8. Threat – Pathogen contamination	4.08	1.60	.011*
9. Threat – Theft	3.69	1.39	.008*
10. Consequence – Mass casualty	4.70	1.37	< .001*
11. Consequence – Loss of heard or flock	4.08	1.59	.011*
12. Consequence – Loss of labor	-26.04	5.66	< .001*
13. Consequence – Loss of capital	6.35	2.32	.006*
14. 2^{nd} & 3^{rd} Order effect – Disease spread to others	4.42	1.46	.002*
15. 2^{nd} & 3^{rd} Order effect – Damage to customer base	-6.05	2.34	.010*
16. Impact – More than a year to recover	4.35	1.86	.020*

* indicates that the *p* value is significant at the .05 level

Objective 6: Food and Agriculture Systems' Criticality

Scientists, managers, and policy experts from government, academia, and industry often argue about which food system types are most critical in the U.S. without any objective analyses to inform their opinions. The mixed linear model did not shrink the estimates of individual system types to a large degree, indicating that their average cumulative scores did not differ from the values predicted by state and rater type (Figure V).

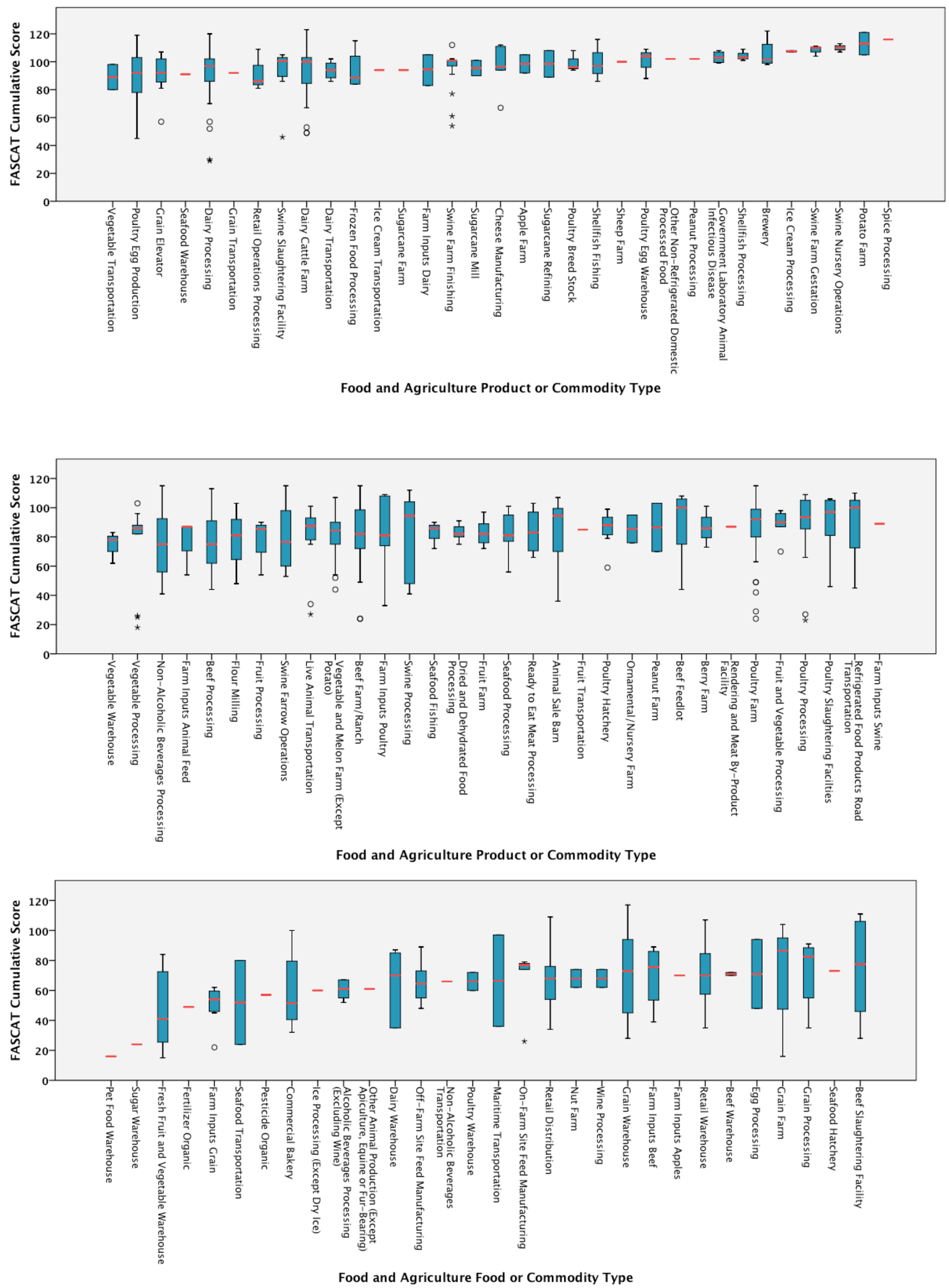

Figure V. Box plot cumulative criticality scores by commodity type arranged from high to low.

DISCUSSION

This study is concerned with whether the FASCAT method of criticality assessment is valid. Validation in the truest sense would require a comparison of FASCAT outcomes to a gold standard or to a series of actual negative events in food and agriculture systems. So in fact there is no validated criticality analysis standard to compare FASCAT to. The second objective was to determine if the FASCAT criticality assessment method is different from other traditional forms of risk assessment and the analyses indicate that they are in fact different. The analyses indicated that FASCAT is able to determine which food systems are the most critical to the nation in rank order, but that the number, type, and quality of the questions in FASCAT can be improved. Lastly, the analyses performed indicate that the criticality scoring method is more predictive than the DHS risk method in determining criticality; however, the underlying information collected in each assessment method is different and thus this finding is not incredibly surprising.

The FASCAT data does have some limitations; incorrect data could have been entered into FASCAT. Some state officials may have unintentionally selected threats or consequences that could not possibly apply to the system being analyzed (e.g., foreign animal disease as a threat to apple production). Also, some states might try to game FASCAT to artificially increase the criticality scores of some food and agriculture systems in hope of receiving federal grant dollars to mitigate risks. On the other hand, some states could have intentionally not indicated threats or consequences hoping that their state would escape increased federal regulatory oversight or administrative burden. Fortunately, statistical methods can help identify some of these anomalies. Regardless of the sources of bias and error in the FASCAT data, better data and methods exist for answering some of the questions posed by FASCAT to SMEs (Brady et al., 2012).

One weakness in the data collected by FASCAT is that many people did not provide their job type and were classified as having an unknown job type. Also, some individual food and agriculture system types had relatively few assessments (e.g., spice processing). Further, there were some potentially erroneous responses to the questions posed in FASCAT. Even though these potential problems with FASCAT were identified, FASCAT appears to do certain things well.

Our analysis found that the distribution of cumulative criticality scores approximated the normal distribution more closely than weighted criticality scores (Figures I & II). Currently, the data entered into FASCAT is not heavily scrutinized and the weighted FASCAT score is used without question when nominating food and agriculture systems as critical infrastructures. If the cumulative score is used to determine criticality, rather than the weighted score, then simple procedures for identifying statistical outliers could alert an analyst to carefully examine the data entered (looking for potentially erroneous data entries) to more objectively identify the most critical food and agriculture systems. When the distributions of scores were examined from individual states the cumulative criticality scores resembled the normal distribution (Figure III). Several observations suggest that the weighting in the weighted criticality-scoring algorithm increases the criticality score of food and agriculture systems in an arbitrary manner, apparently because of SMEs selecting impacts (and thus weights) differently for similar systems. For example, two different but similar milk systems were evaluated by SMEs. For one system, they indicated that there could be at least 10,000 human casualties, while for the other they indicated that there would not be at least 10,000 human casualties. However, data provided in the descriptive open text fields indicated that if either system were attacked there could be over 10,000 casualties in both systems. Instances like this illustrate how weighting criticality scores can increase the amount of bias and error present and can lead to the suboptimal appropriation of scarce risk mitigation resources.

Even though critical food and agriculture systems can be identified with standard outlier detection methods, some data suggest that there are some problems with FASCAT's data collection. Most notably, people with different types of occupations tend to respond to the questions differently (objective 2). If FASCAT assessments were used to determine which food and agriculture systems were most critical to the nation, then some of the differences in criticality scores could be attributed to the risk perceptions of the rater in each state, rather than actual differences in food system criticality.

Despite the weaknesses in the FASCAT data collection method, enabling states to gather and collect data about food and agriculture systems helps state and industry partners determine where they are potentially vulnerable, helps states become more knowledgeable about their food and agriculture systems, and provides a forum for government and private sector food and agriculture system stakeholders to engage and work together to improve food and agriculture system security (Huff, Kircher, Hoffman, & Kennedy, 2013). Collecting food and agriculture systems criticality data via the distributed user method enables efficient collection of highly variable food and agriculture systems data, and the uniform and structured data collection process helps reduce biases and noise in the collection of survey data, despite the bias which is potentially introduced by the group consensus method of collecting data (Huff, Kircher, Hoffman, & Kennedy, In Press). FASCAT's results make fundamentally different food and agriculture systems comparable in terms of criticality and then rank orders systems by their criticality score. Some risk experts have opined that rank ordering risks and criticality is not a valid method (Cox Jr., 2008; Cox Jr., 2009; Lakoff & Klinenberg, 2010; Stewart, Ellingwood, & Mueller, 2011). However, besides saving in time and effort that it allows, the FASCAT method also may aid people that have limited understanding of risk or criticality analysis in the tough process of allocating scarce threat mitigation resources at federal and state levels.

In a previous and related study, Huff et al. (2013) observed that each FASCAT assessment takes roughly an hour to complete on average (Huff, Kircher, Hoffman, & Kennedy, 2013). In this study, the goal was to identify which questions were the strongest predictors of criticality, to make the FASCAT data collection more time efficient (Objective 5). Currently, FASCAT requires SMEs to deliberate about and answer 50 questions. Of the 50 questions analyzed, only 16 were significantly associated with cumulative criticality scores (Table XIII). In the design of future criticality analysis methods, it may be more effective to have SMEs only respond to questions that clearly contribute to cumulative criticality scores, such as those in Table VII.

Interestingly, some items that national security experts strongly believe to be directly proportional to criticality in food and agriculture systems did not test significant in this analysis, e.g., Scale – Mid size and Threat – Chemical (Shea, 2011). This is not to say that chemical threats or mid-sized systems are not critical, rather that the population of SME opinions analyzed here tended to not rate chemical threats as a risk to critical food and agriculture systems. A strong argument can be made that chemicals are in fact potentially a high threat due to their persistence in food and agriculture products, their lack of or masked taste[3], and their potential for high mortality and morbidity. If a correction to criticality scoring for this apparent problem could be justified, then one way to correct this problem would be to educate SMEs on the risks posed by chemicals and have them rescore chemical threats for all systems (although this would be highly impractical). In contrast, one overarching risk that SMEs reported is the potential for radiologic and infectious agents to be used as a weapon, and these agents have been identified as high risk in previous research and government reports (Table I, Table VII) (Cleland, Lindner, Rakestraw, & Resnick, 2011).

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[3] Many chemicals have flavor; however, their taste is masked by the food product since many chemicals taste salty, sweet, or like spices.

The analysis indicated that throughout the various sections in FASCAT, SMEs were concerned with enteric pathogens in all food types, endemic and exotic zoonoses, and anthroponoses (Table I, II, III, & VII). For good reason, SMEs should be concerned about these types of anthropogenic and naturally occurring hazards disrupting food and agriculture systems, as they have caused billions of dollars in damage to the world's economy, caused the unnecessary deaths of millions of animals, and caused much human suffering (Newell et al., 2010; Scallan et al., 2011). In conclusion, there is tremendous heterogeneity in criticality scoring, which arises from SMEs' perceptions of threats, consequences, 2nd & 3rd order consequences, impact of event(s), vulnerabilities, scale of event(s), concentration of event, probability of the selected events occurring, and the size of the geographic area affected. It is likely that the heterogeneity of cumulative criticality scoring makes the food and agriculture systems with small sample sizes appear to be more critical than they actually are.

To correct for the small sample sizes for some food and agriculture system types, a linear mixed effects model was used to *shrink* estimates for individual food and agriculture system types, even though as it turned out the mixed effects model did not shrink the estimates for individual food and agriculture system types to a large extent. This suggests that the analysis indicated which food and agriculture system types were the most critical in a way that is not at the mercy of extreme averages occurring for systems with small sample sizes (Figure V). Interestingly, individual food and agriculture system types with many repeated measurements appear to have normally distributed criticality residuals (e.g., poultry farms). Although the linear mixed effects model corrects for small sample sizes across food and agriculture system types, some food system types appear to be highly critical when they are commonly thought to be not highly critical in terms of potential public health consequences (e.g., apple farms, sugarcane farms, and seafood warehouses). While these particular examples are probably not high-risk and high-consequence food and agriculture system types in terms of public health, they are highly critical in terms of regional economics. The high criticality of these systems is probably due to the high geographic density of these systems' facilities and the geographic distribution of the food and agriculture products that are derived from them. In contrast, the model indicated some food and agriculture systems types that are in fact potentially high-risk to human health were highly critical (e.g., retail processing operations, other non-refrigerated domestic processed foods), which further adds to the face validity of the criticality scoring method used in FASCAT.

FASCAT provided an initial attempt to measure and compare the complex and disparate food and agriculture systems. Despite the apparent face validity of criticality as measured by FASCAT, the results from FASCAT's criticality scoring method and data collection process can be improved. Specifically, the analysis of criticality scoring by job-type indicates that people with different job-types respond to the same questions differently. To address this problem, state officials with similar job-types could be identified to use the FASCAT in each state; however, this recommendation is not practical. The analyses also indicated that many of the questions asked in FASCAT do not significantly contribute to criticality scoring. Further, the cumulative scoring method statistically outperforms the weighted scoring method, and visual inspection of the data verifies that the weighted criticality ranking of food and agriculture systems is altered in manner that artificially inflates criticality. For example, in Table XII a government laboratory has a cumulative criticality score of 99 and a weighted criticality score of 148. It is difficult to imagine any single government laboratory that could single handedly cause over 10,000 human casualties impact more than 5 states, have a loss of supply, and lose the sub-system.

Despite the need to measure criticality and risk more objectively in national security paradigms, the reliance upon SMEs to measure criticality was an acceptable approach, given current political and economic constraints, to identifying critical food and agriculture systems with limited time and money (Huff, Kircher, Hoffman, & Kennedy, 2013). However, instead of asking SMEs to decide about the probability and consequences of events that have been well studied (e.g., earthquakes, hurricanes, drought, floods), risk analysts and the government should use one of the many existing models to objectively and precisely measure the probability of naturally occurring threats to food and agriculture systems and incorporate the results of those types of analyses into criticality scoring (Aven & Renn, 2009; Parnell, Smith, & Moxley, 2010). Generally, SMEs' opinions can be flawed, and their opinions should be replaced with objective data when it exists (e.g., hurricanes model data, earthquakes model data). Therefore, SMEs' informed subjective judgment should only be used when objective data does not exist, when their judgment can be applied to a central problem (e.g., terrorist attacks, of which there are relatively few), and when their judgments can be broadly applied to many systems.

In summary, if the government chooses to continue measuring food and agriculture systems criticality in a way similar to the method used in FASCAT, then the number of questions asked in FASCAT should be reduced by only asking questions that significantly contribute to cumulative criticality scoring. Also, the FASCAT criticality analysis method does not specifically take into account any risk mitigation strategies that have been deployed within the food and agriculture systems being evaluated; the software does not contain questions that remind the SMEs to consider the possible effects of risk mitigation activities. Therefore, inevitably some food and agriculture systems have been inadvertently misclassified by the SMEs when responding to the FASCAT, and data collected in the open text fields related to kill-steps and other risk mitigating activities supports this conclusion. Another area for improvement is that SMEs should not be estimating the likelihood of terrorism threat types (e.g., chemical, radiological, biological) unless they have actual intelligence or other information to suggest that these types of threats are in fact likely and plausible in the food and agriculture system selected. Only a handful of the threats in FASCAT significantly contribute to criticality scoring (Tables VI and XII). Therefore, these threat related questions do not help FASCAT differentiate between food and agriculture systems. As previously stated, there are many instances in the data were threats where selected by SMEs and state officials that were not plausible based upon the system being evaluated. These issues could be resolved by removing these types of questions from FASCAT altogether and not asking SMEs to estimate the likely types threats and agents used in an attack on the food or agriculture system being evaluated.

If FASCAT in its current form is continued, then more comprehensive and structured training should be provided to SMEs and state officials by a neutral third party (which may help prevent erroneous or implausible responses to questions in FASCAT), and the operational definitions provided in FASCAT should be revised to be more consistent and concise. Instead of having SMEs focus on attack agent types and threats (since they do not help differentiate food and agriculture systems from each other), having SMEs determine the amount of contaminated servings per batch could be a better measure of the criticality of the system related to human health and would be a better use of their time. This metric could then be used to estimate the number of contaminated servings distributed by the food and agriculture system type. Many states mentioned in the open text fields that the systems they analyzed spanned multiple states. Also, the data collected by FASCAT could be more reliable if SMEs and states routinely evaluated food and agriculture systems across state boundaries instead of within each state's jurisdiction, since many food and agriculture systems span multiple states. When previous analyses of FASCAT are considered with this analysis, states should have a software platform that allows them to work on criticality assessments in cooperation with each other and does not require SMEs and state officials to travel to conduct assessments with each other.

One potential limitation of the present study is that determining validity of SME ratings of food and agriculture systems is impossible without a standard to which direct comparisons can be made. Also, it is possible that some of the criticality data evaluated in this study were measured repeatedly and over-represented in individual states, thus potentially biasing the results of this study. Further, the data collection process used in FASCAT enables FASCAT trainers to potentially influence the pooled responses of SMEs and state officials. Additionally, people with different job classifications (occupations), which is closely related to many individual psychological constructs, perceive and report criticality differently from each other. However, half of the people that performed FASCAT assessments did not provide their job-type, and were thus lumped together as having job type "Unknown." Another problem was that some individual food and agriculture system types had only a few assessments (e.g., spice processing). Also, some potentially erroneous responses to the questions posed in FASCAT were found. Even though these potential problems with FASCAT were identified, FASCAT appears to perform more or less as it should.

The use of FASCAT requires time and money from private corporations, and state and local governments to collect the necessary data. It would be advantageous to develop a new method of criticality assessment that is more objective. In the future, a software program that collects the necessary criticality data in a distributed manner, directly from state officials and from the food facilities that comprise the food and agriculture systems, would greatly improve data accuracy and collection efficiency. If a spatial network model were constructed of each food and agriculture system evaluated, then it is possible to more objectively determine risks to food and agriculture systems. If these spatial food systems network data were then combined with spatial risk layer data (i.e. geographic overlays containing risk data), it may be possible to more objectively measure the threats, their probabilities of occurrence, and the likely impacts that these negative events could have on food and agriculture systems. This would eliminate the need for subjective and potentially biased SME and state official input in criticality data collection. This proposed data collection and analysis method has challenges. First, food and agriculture companies and state governments would have to spend non-trivial amounts of money to adopt this type of new type of data collection technology. Also, the organization that holds the spatial food systems network data would have to be highly protected and access to these data would have to be tightly controlled. Whether new and more objective methods of criticality analysis are developed in the future, FASCAT's criticality assessment method has greatly assisted state and federal governments in attempting to measure a complex problem and the present study's results can help future risk and criticality methodologists develop algorithms and methods that are better at predicting criticality or risk to keep the nation’s food system safe.

Chapter Five: The Development of a Novel Method for the Spatial Analysis of Criticality

In the context of National Security, multiple methods to quantify risk and criticality have been developed and deployed over the past 14 years to protect the nation's most vital infrastructures and systems. These methods included a wide variety of forms (e.g., qualitative and quantitative) and were targeted at various levels and types of critical infrastructures (e.g., individual facilities, sub-systems, and systems). One consistent problem is that these methods relied upon subjective and likely biased inputs from subject matter experts (e.g., data estimates; generalized supply chain structure; perceived threats, probabilities, and consequences). To address these problems, there is a need for novel data collection that has the potential to eliminate the subjectivity and bias in data collection currently used in risk and criticality assessments. Specifically, this novel method employs a user-generated, spatially explicit software platform for data collection and criticality assessment. This method does not require any subjective estimation of supply chain structure or of disruptive events (e.g., hurricanes, floods, etc.) from subject matter experts, thus reducing bias introduced by subjective opinion.

INTRODUCTION

Criticality assessments have been used in multiple academic and professional disciplines to identify which complex systems components are essential to system functionality (Stoneburner, Goguen, & Feringa, 2002; Erdmann & Graedel, 2011). More recently, criticality assessments have been used to identify critical processes or assets, sub-systems, and systems in the United States' (U.S.) portfolio of national infrastructure to mitigate any associated risks (e.g., food and agriculture systems, water systems, chemical supply chains, public health systems, transportation, energy systems). During criticality assessments, analysts use qualitative and quantitative methods to systematically evaluate multiple aspects of complex systems (Kaplan & Duchon, 1988; Niehaves & Stahl, 2006). Over the past several years, these methods have been used to filter through a tremendous amount of critical infrastructure data to prioritize risk mitigation resources to make these infrastructures more resilient to failure (Katina & Hester, 2013). When criticality assessments are used with risk analysis and risk management, then the end result is the successful application of risk mitigation resources, which in turn creates more resilient complex systems.

Criticality assessments methods are fraught with problems, particularly with data collection procedures and standard definitions. Even operational definitions of criticality are vague, inconsistent across groups, and difficult to implement. Even if operational definitions are precise, then who or what organization decides what is critical? It is extremely difficult to clearly define the boundaries and the relationships of the system in which the asset or sub-system is embedded. For example, a highway may have more importance to a multi-state region than to a county or small state's economic activity. Therefore, a federal organization may prioritize this infrastructure differently than a state or county organization. Also, collecting the necessary data can be extremely difficult, expensive, and time consuming as the individual assets are often privately owned and these private owners are often reluctant to collect or share the necessary and relevant information with government agencies. Even when the necessary data are easily accessible from open sources, the data can be difficult to integrate efficiently (e.g., spatial data can be in different projections and reference systems, thus making the merging of spatial data time consuming). The operational definition of assets is also ambiguous. For example, a milk processing facility, a bulk milk tank, and a milk transportation vehicle can all be considered assets and determining the appropriate level of aggregation is unclear.

Due to inconsistencies in data collection and management, criticality assessment methods and criticality metrics have been contentious issues in the Federal government and academic community (Bristow, Fang, & Hipel, 2012). In the government, this has been predominantly due to the overuse of quantitative methods that used terminology and operational definitions that were highly subjective and inconsistent. When scientifically based solutions have been offered by independent scientists to determine criticality, government officials have not been receptive to the solution, as they wanted the ability to independently assign criticality without relying on scientific methods (Anonymous Senior DHS official, personal communication, 2012). For some people in federal government agencies, determining criticality may mean quantifying criticality in a way that matches their predefined political agenda of threats, vulnerability, and consequence, and then potentially dismiss objective and scientific analysis. This highlights the political reality and difficulty in attempting to objectively quantify criticality in an objective way. Despite some federal government agencies' inability to accept empirically based solutions for the determination of criticality, the federal government has been receptive to the development of new methods to objectively and empirically quantify criticality.

Criticality assessments are useful despite the weaknesses in criticality assessment methods. Although criticality assessments are not well defined or highly structured, they are comprehensive in their ability to holistically evaluate assets, sub-systems, and systems. They help systematically establish and define the causal relationships in a supply chain or complex system (e.g., causes and effects of failure in a system during a disruption) over multiple disruption types (e.g., cyber attacks, physical disruption, natural disasters). Importantly, criticality analysis is most useful for identifying individual critical points and the most likely types of disruptions in sub-systems and systems.

Criticality analysis takes many shapes depending on the audience, the operational definitions constructed for key terminology, and the nature of the data available for analysis. Currently, most criticality analysis relies on subjective information collected from industry and government subject matter experts, government databases, and other forms of open source data. Many of the sources of information and data used in criticality assessments are subjective, biased, or have unknown validity. Also, these assessments are unable to neatly define the geographic extent of the area being examined, the extent of the systems network, and the assets that make up sub-systems and systems. While many of the existing criticality assessment methods are technically scalable, the ability to rapidly and precisely adjust the scale of the assessment, from a single sub-system to multiple sub-systems, does not exist.

FASCAT DEFICIENCIES

The previous chapters identified many weaknesses of one criticality-assessment tool, the Food and Agriculture Systems Criticality Assessment Tool (FASCAT). These weaknesses are caused by the FASCAT training process, the FASCAT data collection process, and by problems in FASCAT itself. To properly use FASCAT, state officials and subject matter experts received training from the National Center for Food Protection and Defense (NCFPD) and Department of Homeland Security (DHS) trainers. The training sessions required several hours of time on the part of all state officials and subject matter experts, who actually provided the data collected by FASCAT. This is problematic because other currently available methods (the other currently available methods for calculating criticality are discussed later in this chapter) are better suited to more quickly measure food and agriculture system criticality. Additionally, the monetary cost of sending subject matter experts and FASCAT trainers to training sites is thousands of dollars (e.g., transportation, lodging, meals, lost wages, and facility fees) and there are less costly currently available methods to calculate criticality that do not require convening state officials and subject matter experts (the other methods for calculating criticality are discussed later in this chapter). Lastly, training state officials and subject matter experts must occur on a regular basis because these employees change positions within their organizations and become unfamiliar with FASCAT without continual use because DHS only collects critical infrastructure data on a biannual basis.

Sometimes food and agriculture systems criticality data were collected during FASCAT training sessions as a means to reduce the costs associated with performing additional data collection sessions with state officials and subject matter experts. However, when training and data collection cannot be combined the costs associated with data collection are exorbitant. In some cases, this resulted in state officials using FASCAT without subject matter experts. This is problematic because state officials often do not fully understand the food and agriculture systems within their states and thus may have entered inaccurate data into FASCAT. Subsequently, whether critical or not, these FASCAT data may have been used within states to justify the nomination of a food and agriculture system or facility for consideration as United States' critical infrastructure or key resources. States that used FASCAT may have incorrectly rank-ordered their own infrastructures. Then, these states may have submitted nominations of these incorrectly rank-ordered food and agriculture infrastructures to DHS. Therefore, DHS could have potentially allocated significant resources to infrastructures that were not critical.

The costs and problems associated with FASCAT data collection were compounded by the biases introduced by FASCAT trainers, state officials, and subject matter experts. FASCAT trainers often influenced or potentially biased state officials or subject matter experts responses to the questions posed in FASCAT. When training sessions and data collection occurred simultaneously, FASCAT trainers were either asked or gave strong suggestions about how state officials and subject matter experts should respond to the questions posed in FASCAT. Also, state officials and subject matter experts were sometimes inclined to protect their special interests and would intentionally provide inaccurate subjective answers to either decrease or increase FASCAT's criticality score (Personal observation, Andrew Huff, 2012). This could have resulted in biased estimates of the food and agriculture systems being evaluated. It is possible to game FASCAT by manipulating the subjective responses to questions, which is problematic for DHS. DHS had the difficult task of identifying biased or highly subjective critical infrastructure or key resources state nominations (nominations that may have relied upon underlying FASCAT assessments in as many as 37 states) and comparing them to other unbiased (in theory) state nominations for allocation of security mitigation resources. This could bring FASCAT's reliability into question at DHS and to other government stakeholders (Food and Agriculture SCC/GCC Spring Quarterly Meeting, DHS, 2012).

In addition to biases introduced by FASCAT users, FASCAT was not systematically used across the United States. This was due to the large geographic extent of some food and agriculture systems, the unwillingness of some states to use FASCAT, and lack of necessary resources and expertise (whether real or perceived) to conduct the assessments. In some instances, it is possible that multiple states used FASCAT to evaluate the criticality of the same food and agriculture systems, since many food and agriculture systems are national in scale. This could have resulted in DHS receiving multiple criticality assessments for the same food and agriculture system from multiple states. Also, the lack of systematic use of FASCAT created large gaps in criticality data about food and agriculture systems that DHS had available for assigning risk mitigation resources in states that did not use FASCAT.

FASCAT itself had many limitations. First, the operational definitions in FASCAT are poorly worded and are confusing to users. This could result in unsystematic error in state officials' and subject matter experts' responses depending on how the group interpreted the meanings of these imprecise definitions, thus altering the food and agriculture systems' criticality scores in FASCAT. Another problem inherent to FASCAT is its use of ordinal scaling in criticality scores. Not knowing the measurable and practical difference between adjacent criticality scores (i.e., the difference between a criticality score of 100 and 101) makes justifying risk mitigation resources difficult for DHS. Moreover, FASCAT requires state officials and subject matter experts to speculate on the probabilities, frequencies, and consequences of natural disasters and negative anthropogenic events, which food and agriculture subject matter experts often cannot accurately assess. Lastly, FASCAT is costly to maintain.

MITIGATING CRITICALITY ASSESSMENT DEFICIENCIES

Data Collection and Linking Spatial Data

Because of the many deficiencies identified in FASCAT, a new method to determine criticality in food and agriculture systems was sought. The new criticality assessment goals were to increase objectivity, efficiency, and accuracy. One of the first deficiencies identified was the amount of time required to train state officials and subject matter experts on the use of FASCAT. To decrease the amount of time required to train multiple state officials and subject matter experts, a web-based criticality assessment method, which did not rely on state officials or subject matter expertise for data collection, was chosen for development. Instead of collecting food and agriculture systems criticality data from state officials and subject matter experts in a group setting, state officials and subject matter experts can each independently access a web-based graphic user interface to provide data on their portion of the food and agriculture system. The data each user provides have a series of attributes (Table XIV). Since most people providing the data necessary to determine food and agriculture system criticality only know a small portion of the system (e.g., who their company procures products from and who their company sells their products to), the underlying criticality assessment software links the system together based upon the spatial attributes of each facility in the food and agriculture system (Table XIV). Thus, the food and agriculture systems structure data (i.e., supply chain data) that is necessary to determine food and agriculture system criticality is collected from individual users at their convenience and is linked together by the software, thus saving time.

This new data collection method resolves several limitations identified in FASCAT. First, this new data collection method decreases the amount of training time and data collection cost for DHS, state governments, and private industry since training and data collection meetings are not needed. Also, as state officials and subject matter experts move into other positions within their organizations, or leave their organizations altogether, there is no need to spend time and money retraining users on criticality assessment methods like FASCAT since this new criticality assessment method relies on the food and agriculture systems' spatial attributes. In FASCAT, state officials and subject matter experts had to work together to figure out how the food and agriculture systems' products flowed through the system. In this new method, state officials and subject matter experts do not need to know how the whole supply chain works: they only need to provide their system's structure data, thus greatly reducing the burden to state governments and to private industry.

Improvements to Biased, Subjective, and Incorrect Criticality Scoring

Three of the primary concerns identified in the preceding analysis of FASCAT were that it was possible for FASCAT users to provide biased, subjective, or incorrect criticality data to FASCAT. These concerns were further exacerbated by the fact that the operational definitions to key terms provided by FASCAT were confusing to FASCAT's users, which likely contributed to the amount of error present in the FASCAT criticality data. To improve upon these identified weaknesses in FASCAT, this new criticality assessment method relies on spatial risk layers (see Criticality Scoring Method) to estimate the probability, frequency, and severity of natural disasters. Instead of asking state officials and subject matter experts to deliberate and estimate the likelihood and magnitude of consequences of natural disasters (about which these people are not experts), the new method derives the criticality score from the summation of the risk layers (see Criticality Scoring Method). Ideally, the spatial risk layers that are selected for criticality assessment contain empirically based, quantitative, and predictive risk estimates and probabilities (e.g., National Oceanic and Atmospheric Administration flood risk layers). By using spatial data and risk estimates to calculate food and agriculture system criticality can thus greatly reduce or eliminate the amount of biased, subjective, or incorrect data used in the determination of criticality. Compared to FASCAT, this new method has the added benefit of increasing the reliability of criticality scoring. In FASCAT, the food and agriculture criticality assessments had different raters (i.e., state officials and subject matter experts) for each state and for each food and agriculture system type. In the new criticality assessment method, criticality for all states and for all food and agriculture system types is calculated from the same underlying spatial risk data. Therefore, the new criticality assessment method produces more objective, reliable, and comparable food and agriculture systems criticality assessment results.

Multi-state Criticality Assessments

One of the problems identified in FASCAT was that it was difficult for states to conduct food and agriculture criticality assessments across multiple states, and that multiple states likely evaluated the same food and agriculture systems multiple times. The new criticality assessment method resolves these issues since state officials and subject matter experts only need to submit the data on the infrastructures they control, and are not asked to evaluate an entire food and agriculture system (even if the system spans multiple states). Since this new criticality assessment method links these spatially related facilities and systems together without considering administrative boundaries (i.e., state boundaries), system criticality can be determined across state lines and nationally. Potentially, with enough private industry and foreign cooperation, criticality scores could be calculated internationally since this new method can calculate criticality regardless of administrative boundaries. The ability to perform criticality assessments across state and national boundaries, without requiring the travel of multiple state officials and subject matter experts is a significant advancement over FASCAT. Since some states have chosen to not use FASCAT (for reasons that are unknown), enabling state officials and private industry to submit their data electronically may eliminate these gaps in data collection.

Critical Interdependencies and Anthropogenic Events

FASCAT was not able to evaluate food and agriculture systems critical interdependencies (e.g., electricity, water, and waste disposal). Critical interdependencies are systems that other critical infrastructures rely upon to operate. Since this new method of criticality assessment uses entity relationship database architecture (Figure VII), this new method of criticality assessment can evaluate the relationships between critical food and agriculture systems and their critical interdependencies (e.g., the spatial relationship of a water node or electricity node in the network). This ability gives the users a new capability to analyze critical interdependencies, without requiring the users to conduct an entirely different assessment on critical interdependencies, and is a capability that was not present in FASCAT.

For the first version of this criticality assessment method, earthquake risk, flood risk, hurricane risk, landslide risk, and volcano risk layers were used. However, future versions of the criticality assessment method can easily use other types of spatial risk layers (e.g., tornado, economically motivated adulteration, infectious disease, critical interdependency, cyber threat, and threat intelligence risk layers). When intelligence agencies, private industry analysts, or academic analysts detect locations (whether domestic or foreign) that are engaging in nefarious activities, this information can be converted to a shapefile and loaded as a spatial risk layer into the new criticality analysis method. This type of information can dramatically help the government and private industry decide where to invest scarce risk mitigation resources.

Based upon the identified gaps in criticality assessment methods, the goal of this project was to develop a criticality analysis method that: 1) reduces the subjectivity in the assessment process; 2) is spatially explicit; 3) is rapidly and precisely scalable to different network topologies; and, 4) is quickly and precisely scalable to different geographic areas. In the following sections the overall design, concepts, and details of the criticality analysis method is discussed.

MODEL PURPOSE

Current criticality analysis methods are subject to user bias and subjective opinion. Therefore, an objective and novel criticality analysis method is needed to reduce bias in criticality scores. A novel criticality analysis model was developed to provide objective more objective criticality scores compared to the existing survey based criticality assessment methods. The specific purpose of this criticality analysis method is to: 1) enable users to easily build and design a fully customizable network model which completely and accurately represents a complex product supply chain without relying upon any generalizations or assumptions; 2) determine which facilities are critical to the functioning of the supply chain; 3) identify which facilities may require risk mitigation based upon spatial risk; and, 4) enable an analyst to make comparisons of overall criticality between independent supply chains.

ENTITIES, PROCESSING, & SCALING

Entities & Scaling

Entities and their attributes in the model have specific characteristics (Table XIV). Similar to actual supply chains, each entity in the supply chain can have one-to-many, or many-to-one relationships. The spatial extent of these relationships is flexible and is based solely on the spatial extent of each entity in the model, and is used only for model visualization. For example, if the user defines two entities from neighboring zip codes, then the spatial model is automatically scaled to fit the extent of the two entities in the model. Similarly, if the entities had geolocations on different continents, then the model would automatically scale the extent of the model to a global-scale when projected for visualization. As the user constructs the model, the data is automatically saved. The users can store different versions of the model as necessary.

Spatial Risk Layers for Risk Scoring

To determine risk scores for individual entities, global spatial risk layers were loaded into the model. Specifically, global spatial risk data were obtained from the Center for Hazards and Risk Research (Dilley, 2005) for model development and testing purposes (i.e., hurricane, flooding, earthquake, volcanic). These ASCII datasets use 2.5 by 2.5 minute raster, with values ranging from 1 to 10. The higher the ranking in each raster cell, the greater the relative frequency compared to other raster cells. When an individual entity is selected, the risk score from the selected spatial risk layer is retrieved and displayed. When users select multiple entities, the model displays the sum of all selected entities' risk values. If the user selects multiple entities and multiple risk layers, then the sum of all risks and entities is calculated and displayed.

Critical Entity Identification

To identify and rank order the criticality of entities in a supply chain, or complex system, the model uses an algorithm developed by Arulselvan, Commander, Elefteriadou , & Pardalos (2009) to detect critical entities. This is a heuristic-based method that can efficiently identify critical entities in a supply chain and rank orders them based upon their connectivity. This method has been used across disciplines and has been tested and validated (Shen, Nguyen, Xuan, & Thai, 2012).

Table XIV. Entity attributes

Entity Attributes	Value	Required (Yes/No)	Notes
Zip code	Integer	Yes	
Address	Integer	No	if entered, the address is georeferenced and the zip code is populated
Coordinates	Float	No	if entered, the coordinates are georeferenced and the zip code is populated
Object Name/Type	Integer	Yes	
Owner/Point of Contact	String	Yes	
Product Name/Type	String	Yes	

DESIGN CONCEPTS

Basic Principles

The goal of this model is to streamline complex systems' data collection and decision analysis for non-modelers. The basic principle of the model and analysis is derived from systems dynamics and is well founded in systems theory (Forrester, 1994; Karnopp, Rosenberg, & Perelson, 1976). However, in systems dynamics, assumptions must be made to simplify the complexity of the system and cope with the paucity of data. In many types of models, these assumptions are often invalid and yield results that are not generalizable or useful in the real world (Carson, 2002). To deal with this problem, this model has the users collect and populate the actual supply chain structure. If the user only knows part of the systems' structure, then systems' structure is inferred and populated based upon geolocation (discussed later in this text). Since the structure is a complete representation of the actual world, no assumptions of network topology are required. The mechanics of the model building software are illustrated in Figure VI.

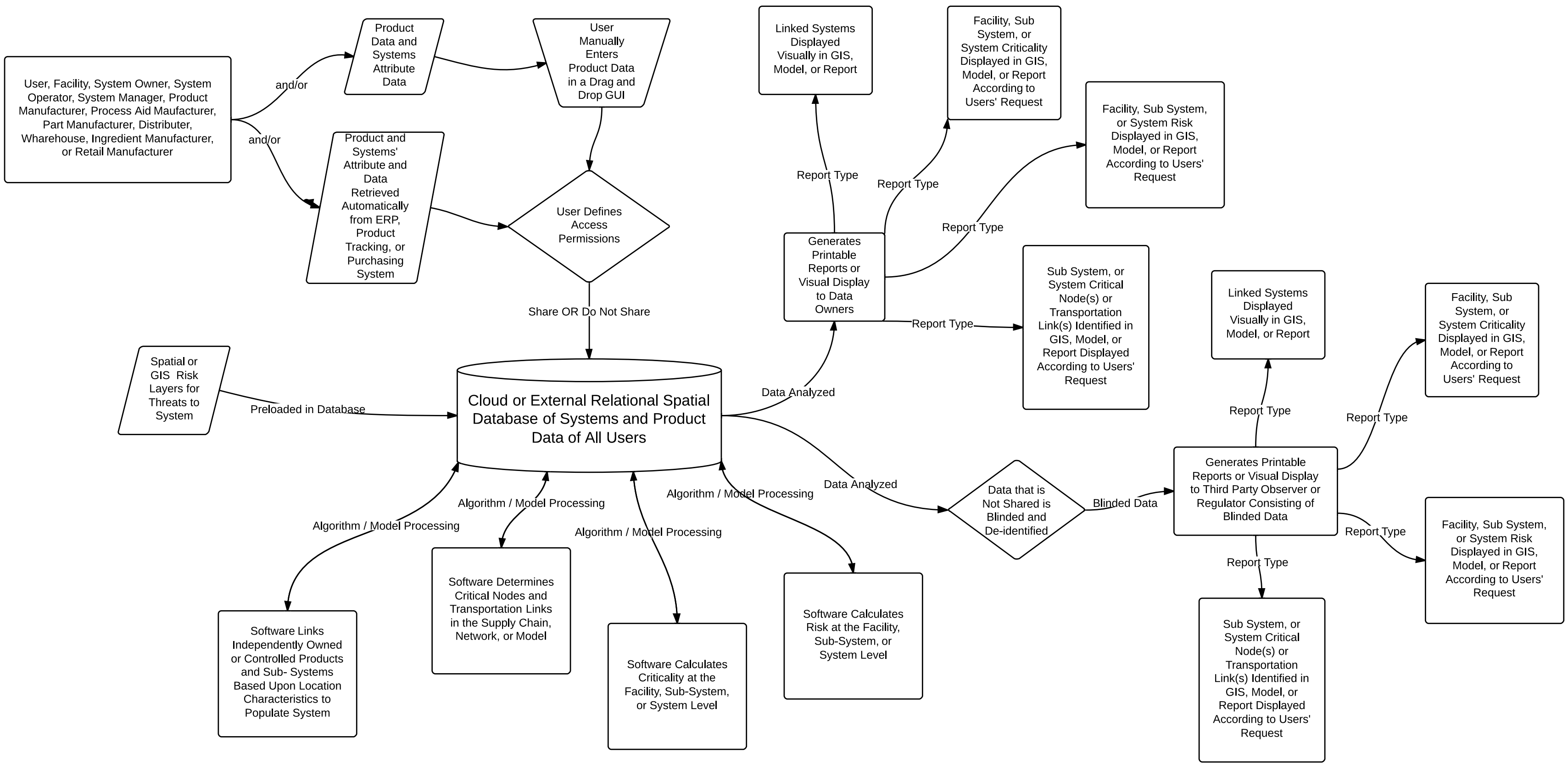

Figure VI. Process and mechanics of the criticality software.

Linking Networks

In many supply chains, the user likely knows whom he is buying from or selling to. This is problematic since any single user is not able to entirely populate the complete network model. To address this obvious problem, the data entered by individual users is stored in a central database. When a user creates new entities in the model, the software detects whether there are existing entities (stored in the database) that are spatially proximate. When these entities are detected as being spatially related, the software prompts the user building the new model to verify that they supply chains are in fact related. When the software indicates that multiple models are potentially related, the user is able to select the related supply chains from a drop down menu. By spatially linking networks, the models will be more complete and representative.

Data

Large food and agriculture companies, as part of their routine operations, create and maintain data describing routine business transactions that consists of: (1) where products, ingredients, or process aids are obtained; (2) between their own facilities; and, (3) where their products are shipped to. The data held by these companies describes the relationship between nodes (e.g., facilities) and the volumes of product flowing between the nodes over time. Data that are necessary for the models are: the name of the product moving through the system, the locations of the entities that are in the system, and the relationships of the entities in the model (direction of product movement). The data are entered into the previously described graphic user interface and the users can *opt-in* or *opt-out* to share the data contained in their model with other users. If the user opts-in to sharing then the data stored is available for other users to access and relate to their model(s), and data are stored in a secure cloud based server. The data are stored and retrieved according to the entity-relationship in diagram (Figure VII).

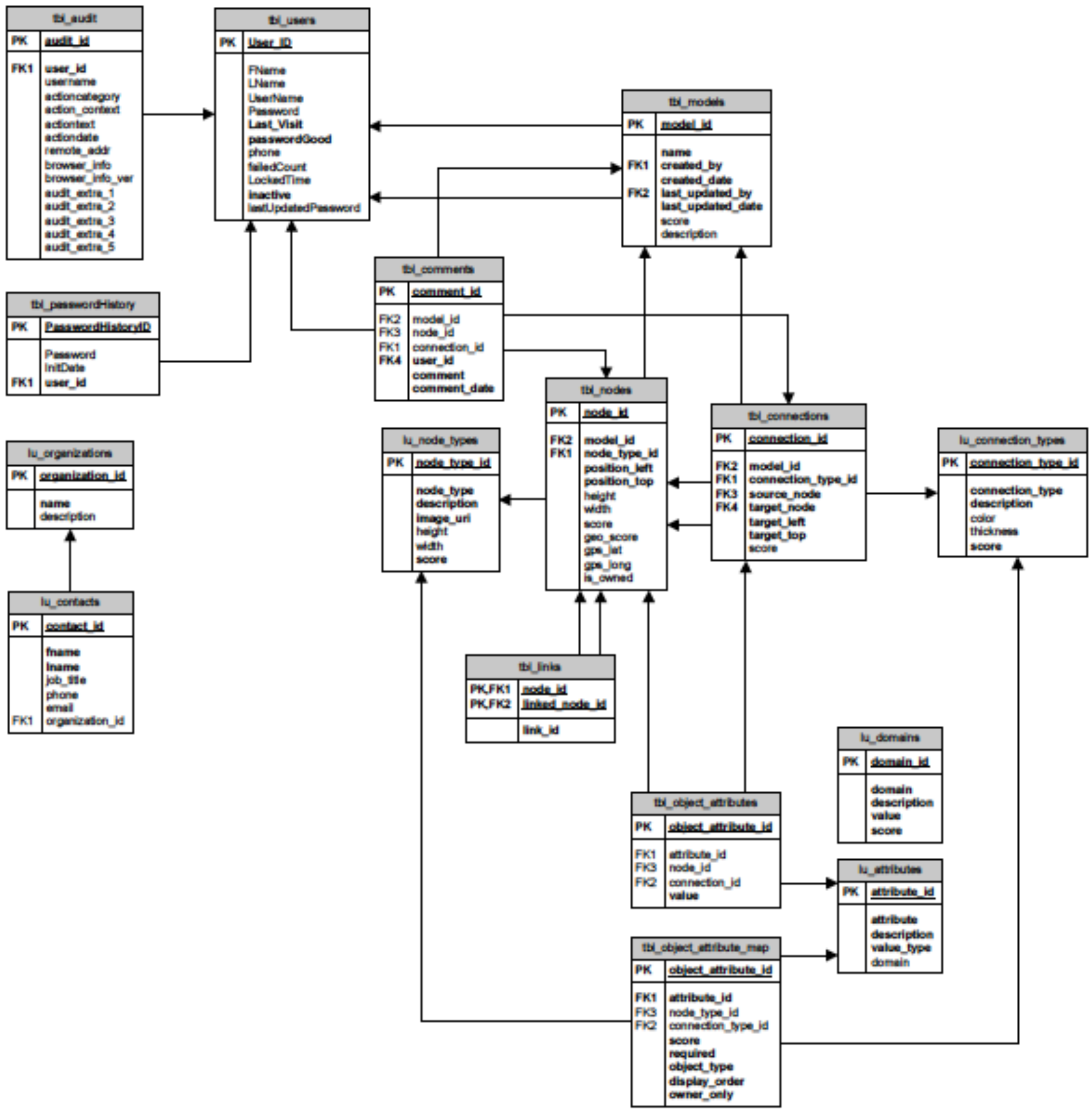

Figure VII. Entity-relationship diagram of the modeling software

Prediction

This software makes predictions on the frequency or impact of naturally occurring hazards to supply chains based upon the previously described spatial hazard data. By relating data from independently owned facilities, the user is able to identify which individual facilities, sub-systems, and supply chains are at higher risk of disruption upstream or downstream of their portion of the supply chain. Users of this software can see potential weaknesses in the system and are able to collaborate with business partners to make their supply chains more resilient to identified hazards.

Criticality Scoring

This software calculates the criticality of a user's facility, sub-system, or system. Criticality of a user's facility is calculated as:

$$Crit = \Sigma\, E, F, H, L, V$$

where *Crit* = criticality, *E* = earthquake risk, *F* = flood risk, *H* = hurricane risk, *L* = landslide risk, *V* = volcano risk. Criticality of a user's sub-system or system is calculated:

$$Crit = \sum\nolimits_{Loc}^{n} (E_n, F_n, H_n, L_n, V_n)$$

where *Crit* = criticality, *Loc* = location defined by the graticule from the Google Mercator projection, *E* = earthquake risk, *F* = flood risk, *H* = hurricane risk, *L* = landslide risk, *V* = volcano risk.

End Use

In reality, many supply chains are highly complex and taking the time to evaluate hundreds of individual facilities in a user's supply chain is costly (money, time and required training of personnel). By looking at the criticality score for each supply chain, users are able to quickly compare and identify which supply chains have more critical entities and risk. Then, the user can collaborate with suppliers and buyers to make modifications to the number of suppliers (in situations where there are few critical suppliers), invest in engineering solutions to make facilities more resilient to hazards, and make informed decisions about business relationships.

DISCUSSION

This criticality assessment method is an advancement over existing qualitative criticality assessment methods since this novel method is able to determine criticality based upon actual system structure and without the use of subjective and biased survey data. Criticality must be derived from the sum of the systems' actual parts and be precisely defined to objectively measure the criticality of a system. Criticality cannot be objectively, scientifically, or empirically determined without knowing the entirety of a system's structure and the structure of the systems they are being compared against. The method and software described in this text lays out a path to measure criticality in an additive, objective, and empirical manner. By measuring criticality in an additive, objective, and empirical manner, then an analyst can objectively compare the criticality of facilities, sub-systems, or systems against each other.

This data collection and criticality analysis method has many potential uses and is potentially very powerful. This software can be used by logistics personnel to spatially identify where products originate and where they are distributed; enabling them to determine more efficient warehouse locations and choke points in the supply chain. People responsible for enterprise risk management can use this software to identify which supply chains and facilities are at risk and critical to the functioning of their business. Risk managers will be able to mitigate risk through collaboration with newly identified upstream business partners and engineering solutions. This software could have value to supply chains where traceability is concern (e.g., food supply chains). For example, if the companies in a food supply chain had to rapidly identify where contaminated food or ingredients moved, then the user could query the database to determine where contaminated products were sourced and allow for trace forward movement. Regardless of the type of supply chain, there are many potential uses for this type of analysis and software (e.g., system dynamic modeling, simulation, trace-forward and trace-back investigations, spatial network analysis).

Despite the many potentially beneficial uses of the software, some companies may be hesitant to use software that shares their proprietary information and supply chain structure with third parties. This may be due to the perceived competitive advantage of their supply chain structure or the perception that their supply chain data could be used in a nefarious manner (e.g., a criminal uses the information to steal from or coerce a company). Companies that want to use the software but do not want to share their information are able to opt-out of sharing data. The ability for the user to opt-out of information sharing is necessary for many different types of potential users. Although the ability to opt-out is important for many users, this could result in incomplete supply chains. Future model development should address ways to anonymize entity attributes to allow for complete supply-chains in cases where users opt-out. Potentially, this could be accomplished by using access and identity management software, or by using a reference table with database rules, or a combination of both.

Storing different users' related supply chain structure data in one location has some risks. If the database is compromised many companies could lose their competitive advantage due to the unmasking of exclusive business relationships. Furthermore, stolen information can be used by nefarious people (i.e., terrorists) to exploit the identified vulnerabilities in the supply chains. However, with the proper information protection measures (e.g., encryption, multi-factor authentication, access and identity management) the probability of successful information thefts can be greatly reduced (Olden, 2002; Subashini & Kavitha, 2011).

CONCLUSION

Over the years multiple methods to quantify risk and criticality have been developed and deployed to identify critical infrastructures and systems. These methods were qualitative and quantitative, and one consistent problem was that these methods relied upon subjective and likely biased inputs from subject matter experts. To address these problems, a novel method and software for data collection that can potentially eliminate the subjectivity and bias in data collection was developed. Specifically, the novel method employs a user-generated, spatially explicit software platform for data collection and criticality assessment that can be broadly applied to multiple types of supply chains. Model output can be used to prioritize resource allocation, and aid in decision-making and investigations.

Chapter Six: Summary of Dissertation

Motivating Research Question

Food and agriculture systems are vital to the economic livelihood and to the public's health in the U.S. Simply, society cannot survive without nutritious, safe, and reliable food sources. For these reasons, food and agriculture systems are, and will continue to be, targets for attacks by deranged individuals, terrorist organizations, and foreign militaries. These enemies' goals can be accomplished by disrupting the food and agriculture system through physical attacks on food and agriculture system infrastructures or by using the food system as a delivery mechanism for radioactive, biological, and chemical agents. Food and agriculture systems are often terrorist targets and can be efficient delivery mechanisms for a wide variety of attack agents. Determining which food and agriculture facilities, sub-systems, and systems are at risk is necessary to protect the public and to allocate scarce food defense resources. While identifying critical food and agriculture systems is necessary, determining criticality is a continuous, difficult, and resource consuming process. To maximize efficiency, it is important to know what biases are present from those who collect food and agriculture systems data, which criticality assessment methods work the best, and to identify how criticality assessment methods can be improved.

Chapter 1: Introduction to Food Defense

The attacks on September 11, 2001 reignited the United States' concern of bioterrorism attacks. One of the primary bioterrorism concerns was that the U.S. food supply could be attacked. This concern is well justified since there is a long and well-documented history of intentional contamination events on food and water systems

Prior to World War I, the Assyrians poisoned their enemies with mycotoxins in rye, the Athenian's contaminated their enemies water with the herb purgative hellebore, the Spanish military gave wine tainted with blood infected with Leprosy, and during the American Civil War Confederate forces deliberately contaminated the Union's water supplies by placing dead animals in their ponds. From World War I to World War II, much technological advancement occurred in biological and chemical warfare and several covert biological attacks occurred during this timeframe.

From World War II to the end of the Cold War, several interesting and high profile food defense incidents occurred. In an act of revenge Dr. Mitsuru Suzuki contaminated sponge cakes and other foods with *Shigella dysenteriae* and *Salmonella typhimurium*, two teenagers who were days away from contaminating Chicago's municipal water supply with *Salmonella typhimurium* were arrested, Arfinn Nesset poisoned and killed at least 22 patients with the muscle relaxer Curacit, and in a trial run attack the Rajneeshees repeatedly and deliberately contaminated numerous local salad bars, restaurants, and grocery store produce with *Salmonella typhimurium* resulting in the 1984 epidemic.

From 1991 to current day, there were several significant bioterrorism events, and further technological advancement in bioterrorism attacks. First, the Patriots Council manufactured ricin and the solvent dimethyl sulfoxide in a plan to murder federal and local law enforcement agents. Later, the terrorist organization Aum Shinrikyo performed a well-coordinated attack using the nerve gas sarin on the Tokyo subway system, killing 12 and injuring 5000 people. In 1996, a large and under reported attack on the food system occurred where chlordane (an organochlorine pesticide) had been used to contaminate liquid animal fats produced at a Wisconsin factory resulting in 4 million dollars in damages to industry.

All of these attacks demonstrated that the risks to food and agriculture systems are real and are significant. With an infinite amount of potential targets, agents, and terrorist motivations, the history of bioterrorism indicates that the enemy has the advantage, and this tremendous advantage will persist into the future. Thus, policy makers and risk managers tend to want to identify all of the potential targets, threats, weapons, and bad actors. This is why policy makers and risk managers tend to focus on the consequences of bioterrorist attacks and focusing on bioterrorism consequences enables these people to make difficult resource allocation decisions to mitigate bioterrorism risks.

Chapter 2: The Development and Use of the Food and Agriculture Systems Criticality Assessment Tool (FASCAT)

After the terrorist attacks of September 11th, the U.S. government established a policy to identify critical infrastructure, including food and agriculture production systems, to protect them from terrorist attacks. In this chapter, the method of how identifying critical food and agriculture systems was discussed. Identifying which food systems were the most critical to the nation is an enormous task since the food and agriculture sector is almost entirely privately owned, is comprised of an estimated 2.1 million farms, has over 1 million production facilities, and accounts for roughly one-fifth of U.S. economic activity. To assist the Department of Homeland Security in determining which food systems were the most critical to the nation, the National Center for Food Protection and Defense developed FASCAT to support states' identification of critical systems. The FASCAT documented, evaluated, and compared 731 disparate complex food and agriculture systems across 39 states to determine their criticality. The objective of these FASCAT assessments was to prioritize the allocation of threat mitigation resources to the most critical systems. Before FASCAT, no food and agriculture systems were identified as critical in the U.S. Now with the use of FASCAT, many food and agriculture systems have been added to the criticality list.

Chapter 3: State Officials' Perceptions of the Food and Agriculture Sector Criticality Assessment Tool (FASCAT), Food-system Risk, and Food Defense Funding

Determining food system criticality is necessary to mitigate risks to the nation's food supply and prioritize and allocate funding. FASCAT is a tool used broadly by state governments to determine the criticality of food and agriculture systems throughout the U.S. State officials (SOs) responsible for food defense (n = 32) were surveyed to determine whether FASCAT is of value to food defense and to determine SOs' security beliefs, values, and practices related to food defense. The results of this chapter indicated that: (1) SOs believe FASCAT is easier to use than other forms of risk assessment; (2) FASCAT training may have introduced bias into assessment of probability, threat, vulnerability, and consequences; (3) FASCAT is valuable to SOs; (4) SOs do not routinely follow security management best practices; (5) SOs believe that intentional biological threats to the food system are the most probable threats, though without supporting evidence; and (6) SOs believe food defense risk mitigation is not adequately funded by state or federal governments.

These findings indicated that even though bias from FASCAT trainers and by individual trainers was potentially introduced to FASCAT assessments, SOs believe FASCAT has been useful to them in determining food system criticality. SOs indicated that more funding is needed from state and federal governments to adequately mitigate and manage food defense risks, and that they require more comprehensive training from food defense subject matter experts in threat assessment, risk mitigation, and security management to reduce the possibility of bias from FASCAT training. Policy makers can use the information learned in this chapter to determine how to better train state officials in food and agriculture criticality assessment and to eliminate bias in the data collection process used in FASCAT.

Chapter 4: Empirical Evaluation of the Food and Agriculture Sector Criticality Assessment Tool (FASCAT) and the Collected Data

To protect and secure food resources for the United States (U.S.) and prioritize funding for these protection efforts, it is crucial to have a method to compare food systems' criticality. In 2007, the U.S. government funded development of the FASCAT to determine which food and agriculture systems were most critical to the nation as required by Homeland Security Presidential Directives 8 and 9. FASCAT was developed in a collaborative process involving government officials and food industry subject matter experts (SMEs), collecting data and quantifying threats, vulnerabilities, consequences, second and third order consequences, and the impacts on the U.S. from failure of evaluated food and agriculture systems. In the past 4 years FASCAT has been used to evaluate the criticality of 731 disparate food commodity and product systems in the U.S. With the aid of FASCAT, multiple state governments successfully nominated food and agriculture systems as Department of Homeland Security Critical Infrastructure or Key Resources (CIKR). The FASCAT method was examined to determine its difference from to the Department of Homeland Security risk assessment method, utility for determining food and agriculture system criticality, and validity of the questions it uses. To determine FASCAT's validity, linear regression models were used to determine (1) which groups of questions posed in FASCAT were better predictors of cumulative criticality scores; (2) whether the items included in FASCAT's criticality method or the smaller subset of FASCAT items included in DHS's risk analysis method accounted for similar fraction of variation in scores assigned by FASCAT users. Akaike's Information Criterion (AIC) was used to determine which regression models best described criticality as determined by FASCAT users, and a mixed linear model was used to shrink estimates of criticality for individual food and agriculture systems.

The results indicated that (1) some of the questions used in FASCAT strongly predicted food or agriculture system criticality and many questions used in FASCAT did not strongly predict criticality; (2) the FASCAT criticality formula was a stronger predictor of criticality compared to the DHS risk formula; (3) the cumulative criticality formula predicted criticality more strongly than weighted criticality formula; and (4) the mixed linear regression model did not change the order of food and agriculture system criticality to a large degree indicating that the cumulative scoring algorithm in FASCAT performs as it should. The FASCAT criticality method is a sufficient method to determine food, and agriculture systems criticality and many of the questions used in FASCAT are strongly predictive of criticality scoring. Despite the strong predictive nature of the questions used in FASCAT, the FASCAT algorithm can be refined to increase its predictive power and utility as a security resource prioritization tool.

Chapter 5: The Development of Novel Method for the Spatial Analysis of Criticality

In the context of National Security, multiple methods to quantify risk and criticality have been developed and deployed over the past 14 years to protect the nation's most vital infrastructures and systems. These methods included a wide variety of forms (e.g., qualitative and quantitative) and were targeted at various levels and types of critical infrastructures (e.g., individual facilities, sub-systems, and systems). One consistent problem is that these methods relied upon the subjective and likely biased inputs from subject matter experts (e.g., data estimates; generalized supply chain structure; perceived threats, probabilities and consequences). To address these problems, there is a need for novel data collection that has the potential to eliminate the subjectivity and bias in data collection used in risk and criticality assessments. Specifically, this novel method employs a user-generated, spatially explicit software platform for data collection and criticality assessment. Specifically, this software collects supply chain structure data directly from privately owned companies, and then the software links these independent data together based upon spatial characteristics to objectively analyze criticality based upon the actual supply chain structure. This method does not require any subjective estimation of supply chain structure or of disruptive events (e.g., hurricanes, floods, etc.) from subject matter experts, thus reducing bias introduced by subjective opinion.

Closing Statements & Recommendations

Even though significant advancement in risk and criticality assessment methods have occurred over the past thirteen years, many vulnerabilities still exist in food and agriculture systems. In the United States, these problems are difficult due to the legal and regulatory environment in which food systems exist, and this environment makes constructive collaborative relationships between academia, the government, and the food industry extremely difficult. Despite the difficult environment in which we operate, academics, government officials, and the food industry need to continue to work together to create effective food defense risk mitigation technologies.

In the future, research should be focused on collecting actual real time data directly from privately owned food companies. These data will enable the almost instantaneous traceback of food contamination events and aid in the epidemiologic investigation of foodborne outbreaks. If it turns out that collection of these data is not feasible, then methods that can derive system structure from open source data need to be developed. Future analysis of the taste, flavor, and olfaction of chemical, biological, and toxins will help determine which agents are actually threats in a food system. If the system structure is known, and the number of agents of concern can be identified, then sensor technology can be developed and placed at specific points in the food system to dramatically reduce food defense risks.

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Appendix A: Institutional Review Board Exemption Letter

The IRB: Human Subjects Committee determined that the referenced study is exempt from review under federal guidelines 45 CFR Part 46.101(b) category #3 PUBLIC OFFICIALS; SURVEYS/INTERVIEWS; OBSERVATION OF PUBLIC BEHAVIOR.

Study Number: 1203E11087

Principal Investigator: Amy Kircher

Title(s):

Food and Agriculture - Information Sharing Environment

This e-mail confirmation is your official University of Minnesota RSPP notification of exemption from full committee review. You will not receive a hard copy or letter. This secure electronic notification between password protected authentications has been deemed by the University of Minnesota to constitute a legal signature.

The study number above is assigned to your research. That number and the title of your study must be used in all communication with the IRB office.

Research approved in this category can be completed without documentation of consent.

This exemption is valid for five years from the date of this correspondence and will be filed inactive at that time. You will receive a notification prior to inactivation. If this research will extend beyond five years, you must submit a new application to the IRB before the study's expiration date.

Upon receipt of this email, you may begin your research. If you have questions, please call the IRB office at (612) 626-5654. You may go to the View Completed section of eResearch Central at http://eresearch.umn.edu/ to view further details on your study.

The IRB wishes you success with this research.

Appendix B: FASCAT Scoring & Mixed Model Results

Table B1: Scores for all threat items in FASCAT.

Variable type	Name	Score
1. Threat	Foreign animal disease	5
2. Threat	Destruction	2
3. Threat	Lost access	1
4. Threat	Drought	2
5. Threat	Food pathogens vegetable	4
6. Threat	Misinformation	2
7. Threat	Chemical/toxin	3
8. Threat	Loss of operation rights	2
9. Threat	Pathogen Contamination	3
10. Threat	Plant disease	1
11. Threat	Radiological contamination	3
12. Threat	Cyber threat	2
13. Threat	Intentional adulteration	3
14. Threat	Theft	1
15. Threat	Production disruption	2
16. Threat	Plant pests	1
17. Threat	Exotic plant pest or disease	4
18. Threat	Economically motivated adulteration	2

Table B2: Scores for all consequence items in FASCAT.

	Variable type	Name	Score
1.	Consequence	Short-term system shut down	1
2.	Consequence	Loss of key output	1
3.	Consequence	Loss or contamination of herd or flock	2
4.	Consequence	Product shortage	2
5.	Consequence	Loss of tourism	2
6.	Consequence	Cost of response	2
7.	Consequence	Long-term system shutdown	4
8.	Consequence	Loss of access to customers	2
9.	Consequence	Mass casualty - human	5
10.	Consequence	Reduced output	1
11.	Consequence	Loss of capital	2
12.	Consequence	Loss of seed source	2
13.	Consequence	Loss of key input	1
14.	Consequence	Loss of plant or breed stock	3
15.	Consequence	Mass casualty - animal	2
16.	Consequence	Brand damage	2
17.	Consequence	Credit access	1
18.	Consequence	Economic loss	3

Table B3: Scores for all 2^{nd} & 3^{rd} Order Effects items in FASCAT.

Variable type	Name	Score
1. 2^{nd} & 3^{rd} Order Effects	Damage to customers	2
2. 2^{nd} & 3^{rd} Order Effects	Damage to tax base	2
3. 2^{nd} & 3^{rd} Order Effects	Loss of public confidence	3
4. 2^{nd} & 3^{rd} Order Effects	Disease spread to others	4
5. 2^{nd} & 3^{rd} Order Effects	Government cost to respond	1
6. 2^{nd} & 3^{rd} Order Effects	Loss of market access	2
7. 2^{nd} & 3^{rd} Order Effects	Loss of access to insurance	2

Table B4: Scores for all impact items in FASCAT.

Variable type	Name	Score
1. Impact	Short-term system shut down	1
2. Impact	Loss of key output	1
3. Impact	Loss or contamination of herd or flock	2
4. Impact	Product shortage	2
5. Impact	Loss of tourism	2
6. Impact	Cost of response	2
7. Impact	Long-term system shutdown	4
8. Impact	Loss of access to customers	2

Table B5: Scores for all consequence items in FASCAT.

Variable type	Name	Score
1. Consequence	Less than 1 year to recover	1
2. Consequence	Less than 5 states impacted	1
3. Consequence	Greater than 1 year to recover	2
4. Consequence	Loss of supply	2
5. Consequence	Limited to 1 state	1
6. Consequence	10,000 human casualties	3
7. Consequence	More than 5 states impacted	3
8. Consequence	Loss of sub-system	2

Table B6: Scores for sub-system characteristics.

Variable type	Responses available	Scores
1. Ease of Attack	easy, medium, high	1, 2, 3
2. Probability of disaster	low, medium, high	1, 2, 3
3. Size of component at risk	small, medium, large, very large, > 5 states, national, international	1, 2, 3, 4, 5, 6, 8
4. Critical Components	Yes, No	5, 0
5. Recovery	< 3 months, < 6 months, < 12 months, > 12 months, not probable	1, 2, 3, 4, 5
6. Concentration	10,000 human casualties	1, 2, 3, 4

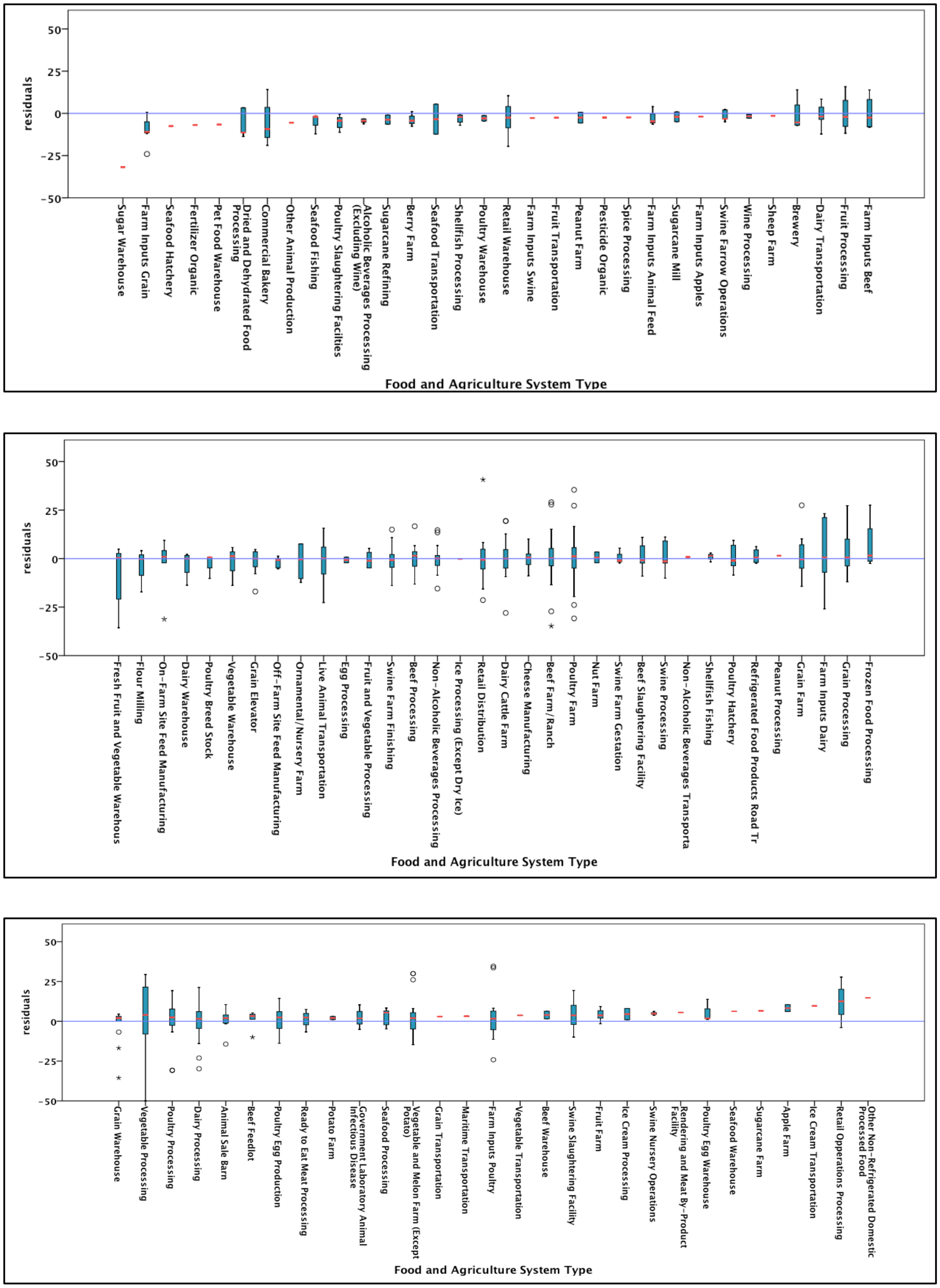

Figure B1. Random effects model residuals, by food and agriculture system type, sorted from low to high, by the median of the system's residuals.

Appendix C: Explanation of Mixed Model Approach

The FASCAT data contains several food and agriculture system types that have small sample sizes and extremely high or low criticality scores (e.g., spice processing, swine nursery operations). This is potentially problematic because the observed average criticality of food and agriculture systems types may due to the arbitrary evaluation of a single (or few) but abnormally critical (or uncritical) food or agriculture systems (i.e., spice processing).

When examining the differences between food and agriculture system types (rank ordering by criticality scores), each food and agriculture system might be measured a number of times (e.g., farm inputs dairy). Some food and agriculture system types (e.g., spice processing) will consistently score higher than others for reasons other than whether they are critical or not. In testing the fixed effects (all variables that contribute to FASCAT criticality scores), controlling for a "random" effect of individual system differences controls for error due to small sample sizes within food and agriculture system types.