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Farm-to-table: A Situation Awareness Model for Food Safety Assurance for Porous Borders

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ABSTRACT: Aldous Huxley's *Brave New World* (1932) was far more prescient to the situation of food safety today than we dare to consider. When people are seduced rather than compelled to live in harmony, evil is not so obvious because no one is looking. In the instance of food safety, changes in world trade, consumer demand for variety, and an increasingly complex regulatory system create challenges to effective vigilance and mitigation. It remains a critical reality that in any "farm-to-table" scenario, multiple sources, suppliers, and steps along the process pose a threat to the safety of the product. Here we discuss the effect of "porous borders" with reference to spread of disease and bio-threats to food fabrication practices and regulatory agencies. We show that understanding correspondences between the morphology of global food production and product tracing/tracking technologies are critical to the real-time performance of situation awareness prediction systems. Our reconstruction of the events associated with securing safe food opens a pathway to advancing the primitives necessary for an appropriate real-time knowledge-sharing system for start-to-finish data sources that assist detection/prediction assurance models.

More than a hundred years ago, Rudolf Virchow first proposed the idea of "one medicine," basing his conclusions on work with zoonotic diseases and his observations of the ease with which etiologic agents could move from animals to humans and back again (Brown 2000). For several reasons we are seeing an emergence of pleiotropic effects—on animals, the environment, and the health of humans—both directly, through the transfer of zoonotic agents, and also indirectly, through the potential compromise of the food supply (Brown 2000). Some of these reasons include the overall increase in global human population. With domestic sprawl, habitat destruction, and fragmentation, we have seen the aggregation of wild animals (particularly migrating species that can harbor disease) into smaller and isolated patches, increasing the contact rate within species and exposing animals and humans to potentially new pathogens. Avian influenza epidemics, such as the recent one (H7N7) in The Netherlands in 2003, caused 80 confirmed cases of human H7N7 influenza virus infection. In headline news as of February 23, 2005, World Health Organization officials urged governments "to act swiftly to control the spread of the bird flu, warning that the world is in grave danger of a deadly pandemic triggered by the virus" (WHO 2005). Symptoms include acute respiratory distress syndrome, a life-threatening condition with a 20% to 30% fatality rate. Because we also know the most toxic biological threats target the human respiratory system, it goes without saying that we must monitor for the emergence of possible zoonotic agents into our food supply (WHO 2005).

"Firewalls" designed to prevent the emergence of zoonotic diseases are not necessarily as effective as we would like to believe. In 1997, the U.S. Food and Drug Administration (FDA) issued restrictions on animal feed to create a firewall against the spread of Bovine Spongiform Encephalopathy (BSE), known commonly as Mad Cow Disease (Cohn 2004). The 1997 rule prohibits the feeding of ruminant (cattle, sheep, deer, goat) material to other ruminants, but allows the feeding of ruminant material to pigs and chickens, and rendered pig and chicken material to ruminants. The same 1997 rule also permits cattle blood, poultry litter, and salvaged pet food to be fed to cattle and other ruminants. Because BSE is spread through the feeding of rendered animal byproducts back to livestock, the FDA designed the 1997 regulations to address the risk of spreading the disease by clearly labeling animal feed that contains rendered cow, sheep, deer, and goat protein (FDA 2001). But in 2002, the General Accounting Office released a report finding serious flaws in the FDA's inspection and review of animal feed renderers, manufacturers, feed haulers, and distributors (Center for Food Safety 2004). So, in fact, the firewall that the FDA has implemented to protect the American public from BSE is full of loopholes, and animal feed remains a route by which the

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disease could be spread in the United States. According to the U.S. General Accounting Office report GAO-02-183 from January 2004, even heavily regulated borders can be porous where "silent carriers," such as pigs and chickens infected with Transmissible Spongiform Encephalopathy (TSE), threaten contamination of the animal food product (Center for Food Safety 2004).

As the FDA has learned, designing effective firewalls, especially those that might prevent the deliberate home manufacture, collection, and delivery of lethal biological agents is virtually impossible. The World Directory of Collections of Cultures and Microorganisms, for instance, serves 453 worldwide repositories in 67 nations (American Biological Safety Assn. 2002). Fifty-four repositories ship or sell anthrax; 18 ship or sell plague. Acquisition of etiological agents can also be gained through field samples or clinical specimens, commercial biological supply houses, and university or foreign labs. Anthrax, for example, exists in soil as a spore. One hundred thousand whitetail deer die from anthrax annually in the United States. Cattle harboring anthrax appear healthy until a few hours before death. Rabbits can be carriers of *Francisella tularensis* (Tularemia), a highly infectious aerosol agent, and resistant to desiccation and extremes of temperature (a typically reliable decontamination method for many food process designs). Biological toxins such as *Ricinus communis* (Ricin) can be easily constructed from a home recipe including castor oil beans (American Biological Safety Assn. 2002) Given the ease with which amateurs can harvest these agents, advances in DNA testing at various tiers of production and distribution are essential to significantly screen and monitor products for the presence of unwanted pathogens.

Combinations of pathogen screening, standards setting, product tracking, and tracing can build faith in global food distribution. But some borders—such as economic ones—are simply too porous to mitigate. News of a premature frost covering the coffee bean crop in South America immediately impacts the coffee futures announced in Chicago, and the economic butterfly effect is felt around the world. The Mad Cow outbreak in the United Kingdom during the 1980s and 1990s infected 200000 cows and resulted in the precautionary killing of some 4.5 million more. The outbreak resulted in 150 human deaths, and some export markets remain closed to U.K. farmers to this day (Talbot 2004). The U.K. foot and mouth epidemic in 2001 quickly spread from livestock to sheep markets and the cost exceeded $500 million. The threat of porous borders is particularly terrifying given the scenario that by 2050, 8 billion of the world's 9.5 billion people will be living in developing countries. One thing is certain: the threat to the world's economic health should the world's food supply be a target of intentional, or unintentional, manipulation is immediate and devastating. Given the unthinkable truth that through infection of its environment an entire population can be put at risk or destroyed, Situation Awareness (SAW) targeting any farm-to-table (start-to-finish) process demands an understanding of real-time correspondences between the morphologies of global food production, detection, and monitoring technologies and knowledge management strategies.

We propose a new paradigm for our research: focusing on understanding these correspondences in a designed and methodological approach with the goal of creating an information fusion system capable of managing these many data sources in real time. SAW systems (or situation assessment in computer data terminology) have been successfully used to represent various defense-related scenarios operating in a region of interest (Kokar and Wang 2002; Matheus and others 2003). Common to decision fusion efforts used for military analysis and emergency or crisis simulation, the successful situation analysis system provides the ability to represent the world of the situation meaningfully, as well as its evolution over time. This is modeled through ontologies—domain-specific semantic structures (topical knowledge specified within hierarchical and relational systems for interpretation and implementation)—rendering a meaningful description of how a set of entities and their relations work (Wang 2003). In the situation of food safety, that representation must announce any instance of change of compromise to the food product during production. Because food production involves a highly regulated process (every food fabricated has its own formula lending to critical checkpoints for monitoring), attributes and relations need to be associated with quality assurance values that can change over time.

Reconstructing the production process provides a formal definition of the primitives (a low-level object from which higher-level, more complex objects and operations can be constructed) from which effective SAW knowledge synthesis can begin. Entities and relations in the food production line would be derived from Hazard Analysis Critical Control Points and Line Inspection Management Systems monitoring and recording data for every food product fabricated. Regulatory compliance permitting, such as the FDA's Good Manufacturing Practices, provides data on the handling of any discharged or byproduct material, such as in-plant waste streams surveys and spill/emissions reports, to safeguard the environment and the workers. Still other entities and relations capture production outside the line including wastewater and storm water collection, management and storage, industrial hygiene, and pollution prevention—all critical information streams to assure a safe and healthy interface between workers, the product, and the environment. Likewise, air intake and distribution, worker and product movement, drop-offs and deliveries, are all required data streams if we are to secure the production environment. Linking data from the outside of the production plant to the ontology is accomplished through an inference engine and the use of automated indexing and searching, as done by popular search engines (Blei and others 2002). This resolves critical elements from a range of sources, including reconnaissance intelligence (which might detect illegal crop dusting over a feedlot) and public health news (which reports higher levels of mercury in a soil sample) (Diligenti and others 2000). In the armature of safe food production, appropriate pathogen testing and screening that target tiers of production is essential to announcing evidence of compromise and further defining strategies for mitigation.

Effective SAW demands advancing the following primitives: the 1st necessarily requires cutting-edge sensor architectures be in place in the production process so that the transduced signal is readily converted to a microprocessor compatible voltage, the modern era's signal processing coin-of-the-realm. The second significantly modernizes food-to-fork tracking (a bar-coded "passport") to include DNA, or other appropriate pathogen screening, along with product tracing and tracking of every food product grown, fattened, caught, or produced in the world. Finally, an automated system with an ontology of detection, reasoning, and notification must be in place to warn of the probabilities of an upcoming disaster. Just as war scenarios or crisis prediction simulation can help us plan for and stage mitigation practices, it would behoove us to consider the problem now, rather than after the fact. And by advancing SAW studies, we will be able to identify when and where pathogens, toxins, or intentional threats 1st appear in the global farm-to-table scenario.

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References

American Biological Safety Assn. 2002. Eagleson Inst. Spring Seminar Series: Bio-

terrorism and Biosecurity; 2002 May 7-8; Philadelphia Pa.: American Biological Safety Association.
Blei DM, Bagnell JA, McCallum AK. 2002. Proceedings of the 18th Conference in Uncertainty in Artificial Intelligence; 2002 Aug 1-4; Univ of Alberta, Edmonton, Alberta, Canada.
Brown C. 2000. Emerging infectious diseases of animals: an overview. Washington, D.C.: ASM Press. 1:10–1.
Center for Food Safety. 2004. Mad cow disease: Improvements in the animal feed ban and other regulatory areas would strengthen U.S. prevention efforts. In: Mad cow disease: closing the loopholes in FDA's feed regulation. U.S. General Accounting Office GAO-02-183. January 2004.
Cohn J. 2004. The international flow of food: FDA takes on growing responsibilities for imported food safety. GMP Institute (division of Society for Life Science Professionals). U.S. General Accounting Office GAO-02-183. January 2004. Available from: http://www.gmp1st.com/foodimp.htm
Diligenti M, Coetzee FM, Lawrence S, Giles CL, Gori M. 2000. Focused crawling using context graphs. 26th Intl. Conference on Very Large Databases (VLDB 2000). 2000 Sept 10-4; Cairo, Egypt.
[FDA] Food and Drug Administration. 2001. Public Health Service. Washington D.C.: U.S. Dept. of Health and Human Services. U.S. General Accounting Office GAO-02-183. January 2004. Available from: http://www.cfsan.fda.gov/~dms/fc01-toc.html.
Huxley A. Brave New World. 1998. New York: Perennial Classics. (Originally published in 1932 by Harper and Brothers) 218 p.
Kokar MM, Wang J. 2002. Proceedings of the 5th Intl. Conference on Information Fusion; Using Ontologies for Recognition: An Example; 2002 July 8-11; Annapolis, Md. p. 1324–43.
Matheus CJ, Baclawski KP, Kokar MM. 2003. Derivation of ontological relations using formal methods in a situation awareness scenario. In: Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications. SPIE 2003:298-309.
Morens DM, Folkers GK, Fauci AS. 2004. The challenge of emerging and re-emerging infectious diseases. Nature 430:242–9.
Talbot D. 2004. Where's the beef from? Technology Review 107(5):48–56.
Wang J, Baclawski K, Brady D, Kokar MM, Lechowicz L. 2003. Proceedings of The Software Defined Radio Technical Conference. The use of ontologies for the self-awareness of communication nodes; 2003 Nov 17-9; Orlando, Fla.
[WHO] World Health Organization. 2005. Bird flue pandemic is imminent. MSNBC News Services. Available from: http://www.msnbc.msn.com/id/6861065/. Accessed 23 February 2005.
Wilson TM, Logan-Henfrey L, Weller R, Kellman B. 2000. Agroterrorism, biological crimes, biological warfare targeting agriculture. In: Brown C, Bolin C, editors. Emerging animal diseases. Washington, D.C.: ASM Press p 23–58.