

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

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Aldous Huxley's *Brave New World* (1932) was far more prescience 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 creating challenges to effective vigilance and mitigation¹. 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 product²⁻⁴. Here we discuss the effect of "porous-borders" with reference to disease spread 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 assisting 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 again⁵. For several reasons we are seeing an emergence of pleiotropic effects – on animals, on the environment, and on the health of humans, both directly, through the transfer of zoonotic agents, and also indirectly, through the potential compromise of the food supply⁵. 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. Symptoms include acute respiratory distress syndrome (ARDS). Since we also know the most toxic biological threats to the human race are protein toxins produced by bacteria derived from plants and animal protein toxins which target the human respiratory systems, it goes without saying we must monitor for the emergence of possible zoonotic agents into our food supply⁶.

But "firewalls" designed to prevent the emergence of zoonotic diseases are not necessarily as effective as we would like to believe. In 1997, the Food and Drug

Administration (FDA) issued restrictions on animal feed to create such a “firewall” against the spread of Bovine Spongiform Encephalopathy (BSE), known commonly as Mad Cow Disease. 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. Since 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 containing rendered cow, sheep, deer and goat protein. 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 distributors⁷. 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 disease could be spread in the United States. 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 product⁷.

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 nations⁸. 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. Meat, dirt, and wax are simple ingredients needed to create Botulinum. The quantity of Botulinum Neurotoxins (Botulism) found in the ink of one period (.) is enough to kill 30 people. One pound will kill the entire human race⁸. 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 ‘90s infected 200,000 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 day⁹. The U. K. foot and mouth epidemic in 2001 quickly spread from livestock to sheep markets and the cost exceeded **\$5000 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, threat is immediate and devastating. *Given the unthinkable truth that by infecting its environment an entire population can be put at risk or destroyed, Situation Awareness 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 – one 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. *Situation Awareness (SAW)* systems have been successfully used to represent various defense-related scenarios operating in a region of interest^{10,11}. Common to decision fusion efforts used for military analysis and emergency or crisis simulation, the successful situation analysis system provides the ability to meaningfully represent the world of the situation, as well as its evolution over time. This is modeled through ontologies – *domain-specific semantic structures* – rendering a meaningful description of how a set of *entities* and their *relations* work¹². In the situation of food safety, that representation has to announce any *instance* evolution of compromise to the food product during production. Since food production is a highly regulated (formula derived) process, *attributes* and *relations* need to be associated with quality assurance values that can change over time.

Reconstructing the production process gives us a formal definition of the primitives from which effective Situation Awareness knowledge synthesis can begin. *Entities* and *relations* in the food production line would be derived from Hazard Analysis Critical Control Points (HACCP) and Line Inspection Management Systems (LIMS) 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 bi-product 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 engines¹³. 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)¹⁴. *In the armature of safe food production, appropriate pathogen testing and screening targeting tiers of production is essential to announce evidence of compromise and further define strategies for mitigation.*

Effective Situation Awareness demands advancing the following primitives: the first 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 updates antiquated practices for lifetime 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 in order 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 advancing Situation Awareness studies show proven potential to elucidate when and where pathogens, toxins, or intentional threats first appear in the global farm-to-table scenario.

1. Cohn, J. 2004. *The International Flow of Food: FDA Takes on Growing Responsibilities for Imported Food Safety*. [Internet] Available at <http://www.gmp1st.com/foodimp.htm>.
2. Food and Drug Administration, 2001. U. S. Department of Health and Human Services, *Public Health Service*. [Internet] Available at <http://www.cfsan.fda.gov/~dms/fc01-toc.html>.
3. Wilson, T. M., Logan-Henfrey, L., Weller, R. and Kellman, B. Agroterrorism, biological crimes, biological warfare targeting agriculture. *Emerging Animal Diseases* (Brown, C., & Bolin, C., eds.). ASM Press, Washington, DC. 2000;23-58.
4. Buchanan, M. *Nexus: Small Worlds and the Groundbreaking Science of Networks*. Norton, New York. 2002;133-37, 171.
5. Brown, C. *Emerging Infectious Diseases of Animals: an Overview*. ASM Press, Washington, DC. 2000;1:10-11.
6. Morens, D. M., Folkers, G. K., and Fauci, A. S. The Challenge of Emerging and Re-emerging Infectious Diseases. *Nature*. July, 2004;430:242-249.
7. Center for Food Safety. *Mad Cow Disease: Closing the Loopholes in FDA's Feed Regulation*. U.S. General Accounting Office, "Mad Cow Disease: Improvements in the Animal Feed Ban and Other Regulatory Areas Would Strengthen U. S. Prevention Efforts," GAO-02-183. January 2004.
8. American Biological Safety Association/Eagleson Institute Spring Seminar Series. *Bioterrorism and Biosecurity*. 2002.

9. Talbot, D.. *Where's the Beef from?* Technology Review June 2004:48-56.
10. Kokar, M. M., and Wang, J. Using ontologies for recognition: An Example. In *Proceedings of the 5th International Conference on Information Fusion*. 2002:1324-1343.
11. Matheus, C. J., Baclawski, K. P., and Kokar, M. M. 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.
12. Wang, J., Baclawski, K., Brady, D., Kokar, M. M., Lechowicz, L. The use of ontologies for the self-awareness of communication nodes. In *Proceedings of the Software Defined Radio Technical Conference*. 2003.
13. Blei, D. M., Bagnell, J. A., McCallum, A. K. Learning with scope, with application to information extraction and classification. *Uncertainty in Artificial Intelligence*. 2002.
14. Diligenti, M., Coetzee, F. M., Lawrence, S., Giles, C. L., Gori, M. Focused Crawling Using Context Graphs. *26th International Conference on Very Large Databases (VLDB 2000)*.

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