Informatics to Support International Food Safety

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Abstract

Diseases and pathogens in the food supply cause large numbers of illnesses annually. One example was the enterohemorrhagic *Escherichia coli* (EHEC) outbreak in Germany which resulted in approximately 4,000 people infected and nearly 50 deaths in 2011. The estimated economic impact of foodborne illnesses is significant. Governments and the private sector seek to minimize food safety risks. Informatics plays an increasing role in dealing with the big data generated, which must be analyzed to support risk assessment, prevention, and mitigation programs to optimize food safety outcomes. However, economic and organizational issues require attention. Public and private sector collaborations are necessary to identify food safety outbreaks as a starting point, and to then trace the potential causes to their sources. The GLOBALG.A.P. initiative is an international public-private sector collaboration, headquartered in Germany, to assure product safety throughout the food supply chain to the retail level. Another preventive approach to food safety is the United States implementation of the 2011 FDA Food Safety Modernization Act. Informatics plays a key role in providing the analytic framework and procedures at the multiple levels needed to successfully assess and control the risks involved as food is tracked through the supply chain. This paper provides additional examples of individual company and international collaborations to harness big data, provide the analytics, and implement improved food safety protocols. One issue which must be resolved between producers and companies selling the digital information systems incorporated into farm machinery working the fields is who owns and controls the data generated.

1. Introduction

Every year, there are large numbers of illnesses and deaths caused by diseases and pathogens in the food supply. This is true in developed countries as well as in developing countries. For example, in the United States alone there were an estimated 48 million cases of foodborne illnesses (about 1 in 6 citizens), 128,000 hospitalizations, and 3,000 deaths in 2011 [1]. Fresh produce, meat and poultry, dairy and eggs, and fish and shellfish are primary sources of these illnesses. More than half the hospitalizations and deaths are caused by unspecified agents, and these agents also account for four times as many illnesses as known agents. The latter group includes noroviruses – which sicken the greatest number of people, and are thus also among the small set of pathogens estimated to cause the most fatalities; *Salmonella* and *Listeria* are also in this group.

The estimated economic cost of foodborne illness is an important factor in guiding food safety policy. These cost estimates also help focus strategies for preventing and mitigating such illnesses and for establishing programs to monitor the effectiveness of risk-reduction measures, including broad information-sharing initiatives. In 2012, two studies found that five U.S. foodborne pathogens were the most costly in terms of medical care, lost work time and premature deaths in the United States. Of the 14 major pathogens responsible for over 95% of foodborne illnesses, hospitalizations and deaths in the United States these five account for 85% of the cost [2].Economic impacts of food safety incidents are significant, and government as well as private sector programs seek to minimize food safety risks. Informatics plays a crucial role in addressing

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food safety issues, with large amounts of data being collected and analysed to support an extensive suite of risk assessment, prevention, and mitigation programs.

Recent advances in information and communication technology have redefined what comprises food safety data and how these data are captured, shared, and managed. The volume, velocity and variety of big data create challenges for its efficient use in decision making by both the private and public sectors. Informatics approaches and tools are being developed and applied to identify, combine, and manage data from multiple sources to create information that is directly useful to decision-makers, and advanced analytic models will facilitate predictions that can optimize food safety outcomes [3].

One example of a severe food safety outbreak occurred in Germany, where the deadliest outbreak of enterohemorrhagic *Escherichia coli* (EHEC) resulted in approximately 4,000 people infected and nearly 50 deaths in 2011. Researchers immediately started working with the big data gathered during that outbreak to prevent a repeat and improve chances of survival for future patients. They were concerned about finding the bacterium’s reservoir, how far the pathogen may have spread, how likely it was to persist, and what made this particular EHEC so dangerous. More than 100 German patients received Eculizumab, an antibody that targets a protein involved in regulating the human immune system. By pooling data of patients treated with Eculizumab in clinics in four different cities, researchers set out to determine its efficacy. This is a daunting task because of the need to consider numerous confounding factors such as other treatments received, lab tests, and prior illnesses of the patients that might have influenced the EHEC-patient outcome. The challenge is to determine how to evaluate novel treatments in a disciplined, ethical and useful manner when such rare catastrophic emergencies occur [4].

But food safety incidents are an ongoing and not infrequent concern, in spite of scientific progress in understanding the causes of foodborne illnesses and programs in the public and private sectors to mitigate them. Examples of efforts to quickly identify and squelch food borne illness outbreaks in the United States include two web based tools created by the US Centers for Disease Control and Prevention (CDC)—FoodNet and PulseNet. FoodNet brings together a number of sites maintained by professionals across the United States to track the ebb and flow of food safety incidences. CDC can then examine in depth the big data coming from those sites to better understand foodborne diseases. PulseNet relies on DNA fingerprinting to track illness-causing bacterial strains that researchers have examined and scan this big data for patterns. The researchers can then track epidemiology, which has allowed them to detect many multistate outbreaks beyond what might have been detected without the PulseNet tool. As CDC continues to improve its use of the tools, they are better able to respond to a potential outbreak as well as promote better understanding of how to manage and prevent outbreaks of foodborne illnesses [5]. By linking these information systems, CDC is able to identify patterns in the big data sets that would not be apparent to researchers working in isolation within their own institutions or collaborating with one or a few others.

Of course, the metrics applied to big data generally involve correlation, which is not causation. This means that patterns detected can serve as an early warning system of developing problems. Still further investigation by scientists understanding various aspects of potential foodborne illnesses is required before decisions can be reached about likely sources of contamination involved in an outbreak. Certainly the availability of the data sets and the creation of informatics-driven data discovery environments make it possible to quickly sort out the important features of the data set without a lot of preparation [6]. The rapidity of developing preliminary results increases the chance of heading off more severe outbreaks through continued exposure and therefore reduces the impact on consumers.

2. Global food safety context

While technological capacity to aggregate and analyze the big data related to foodborne illnesses is available, economic and organizational issues may present some challenges. Sharing the cost of the specialized skills to develop analytics needed to take advantage of big data will likely be problematic within the agricultural and food arena, just as in other industry segments. Thus, while between-firm collaboration may be limited, the desire for spreading the costs may lead to consolidation within the supply chain to bring together the resources needed. For example, Monsanto acquired US-based Climate Corp. to obtain access to localized weather forecasts based on historical weather data which were generated in the course of developing insurance offerings to protect farmers against weather related production problems [7]. Monsanto's ownership of Climate Corp. enables it to offer prescriptive farming solutions to increase yields through better timing of fertilizer applications, insecticide and pesticide treatments, and other field activities which are weather dependent for successful outcomes.

Previously, US land-grant universities and the US Department of Agriculture would likely undertake with public funding the research and development to take advantage of big data possibilities. In today's economic climate, private firms in the agricultural and technology sectors collaborating with public institutions will need to do that research and development. Sonka believes that success will be driven by organizational and managerial strategies as much as by technological capacity [3].

Public and private sector collaborations are necessary to identify food safety outbreaks as a starting point, and to then trace the potential causes to their sources which can be eliminated or at least mitigated. Unfortunately, under current conditions, by the time the source of an outbreak has been identified, many implicated food products are usually already in the hands of consumers, and it is often too late for any recall to be effective, especially if the food is perishable (such as lettuce or cantaloupe). For this reason, preventive measures are greatly preferred to dealing with outbreaks after they occur. One example of such a proactive program is GLOBALG.A.P., an international public-private sector collaboration headquartered in Germany, that is working to establish preventive measures through standardized best practices in agricultural production to assure product safety throughout the food supply chain to the retail level. GLOBALG.A.P. was established in 1997 by food retailers as EUREPGAP to address consumer's growing concerns about product safety, environmental impact, and safety of agricultural workers and animals. Retailers set out to harmonize their own standards and procedures and develop an independent certification system for Good Agricultural Practices (G.A.P.). The standards help producers meet Europe-wide accepted criteria for food safety and other desired outcomes including sustainable production methods, and worker and animal welfare. The harmonized standards provide savings to producers as they no longer need to undergo multiple annual audits against different criteria. The system spread throughout Europe and beyond in the face of food system globalization. EUREPGAP became GLOBALG.A.P. in 2007 and is now the world's leading farm assurance program to translate consumer requirements for food safety and other characteristics into Good Agricultural Practice in more than 100 countries. An extensive network of more than 140 GLOBALG.A.P.-certification bodies around the world ensures that standards are adapted and applied consistently on every GLOBALG.A.P.-certified farm. The GLOBALG.A.P. Secretariat function to support the system is provided by FoodPLUS GmbH, a nonprofit company based in Cologne, Germany, creating a single management platform for GLOBALG.A.P. It provides agricultural producers access to three separate sets of 16 standards—for crops, livestock, and aquaculture. Buyers can obtain source-certified products that meet the baseline requirements for food safety and hygiene, thereby reducing exposure to product safety risk for food retailers.

GLOBALG.A.P.'s traceability system allows buyers to monitor producers and validate their certificates through a database of unique 13 digit numbers which identify each certified producer, as well as review producers' certification audits. Consumer demands for safe and sustainable food production drive improvement and development efforts for the GLOBALG.A.P. standards [8]. This unique system involves retailers and producers working together to create the standards to which all producers adhere. It recognizes that food safety must begin at the point of production and continue throughout the supply chain so that retailers may deliver the level of food safety consumers expect.

There are also sanitary and phytosanitary (SPS) provisions in most international trade agreements, designed to prevent trade of contaminated products which may lead to food safety issues. Individual country trade agreements may provide for inspection by the importing country representatives of processors and handlers of food exports in the country of origin. In most cases, the point of entry to the importing country is where the inspections to identify contaminated food products which must be removed from the food supply chain are carried out. The challenge in that case is to have enough resources devoted to inspection to head off the riskiest food products.

Nonetheless, the prevalence of personal devices, shipment tracking practices, and consumer purchase trails from the retail sector generate big data which makes possible improved traceability from producer through to consumers. This may allow for rapid and accessible recalls of foods suspected in safety outbreaks which will continue to occur. By establishing analytics to digest information, companies will be able to develop shortcuts to decisions and follow-up actions that reach purchasers of the foods [6].

One important element of the US preventive approach to food safety is the implementation of the 2011 FDA Food Safety Modernization Act, specifically implementation of Proposed Rules on Sanitary Transportation of Human and Animal Food. The goal is to prevent practices likely to create food safety risks, including "failure to properly refrigerate food, inadequate cleaning of vehicles between loads, and failure to properly protect food during transportation". Requirements would establish measures such as maintaining adequate temperature controls, procedures to exchange information about temperature control between shipper carrier and receiver, and maintaining the procedures and records related to temperature control as well as other factors which could contaminate food during transportation. Importers will be required to ensure that imported food is as safe as that produced in the United States. Further, a program would be established to accredit third-party auditors or certification bodies to audit food safety practices of foreign facilities' exporting human and animal food to the United States [9]. In response, food producers and transporters are adopting sensor-based technologies and analytics which will incorporate big data to monitor their supply chains, providing potential to trace any contaminated shipment to the farm source [10].

3. Data Challenges

Risk assessments are important for identifying vulnerabilities or weak links in the food supply chain beginning at the farm level and continuing through to retail food stores and restaurants, and even in the home. Informatics plays a key role in providing the analytic framework and procedures at the multiple levels needed to successfully assess and control the risks involved as food is tracked through the supply chain. For example, temperatures are now being monitored in real time as perishable foods move throughout the supply chain, including during cross-country transportation. Considered across a substantial number of products and locations, this type of tracking produces large quantities of data requiring timely analyses in order to make intelligent decisions about determining critical points in the supply chain which should be monitored most closely and for which to develop preventive practices.

With huge amounts of monitoring data being generated from the farm level and food supply chain, informatics has emerged as a key player in agricultural food safety programs. Gary Nowacki, CEO of TraceGains, Inc. argues that big data provides a framework for companies to better organize critical information—often scattered across numerous documents related to product quality and safety—into a reportable, searchable, and actionable central data base. This enables companies to report, search and use food safety and quality data to enhance proactive as well as reactive strategies. Food companies can then risk profile their suppliers to proactively identify the riskiest points in their supply chain; and for reactive needs, the company can receive instant notification if an incoming raw material fails to meet its specifications for quality and safety [11]. This example illustrates the kinds of efforts underway in the US food system to harness big data that is already being generated by creating usable formats for analysis to better protect quality and safety of food products. Given the importance of maintaining product integrity to a company's reputation and survival, demand for these types of database development and analytic algorithms to support decision making throughout the food supply chain will continue to increase at a rapid pace.

Further, extensive sharing of big data that affects food safety in international as well as domestic contexts is expected to increase. At this time, data are generally insufficient to effectively assess risk at each level in the supply chain. In Asia, a number of governments are looking to liberalize open data policy to allow more data to be publicly available for use in development of analytics to create more efficiencies in various sectors, according to Bob Chua, CEO of Pulse Group plc, Asia's leading big data and marketing analytics agency [12]. Certainly food safety is a prime candidate for such open sharing of data to facilitate domestic food safety as well as to be a trusted partner in the global food supply chains.

For example, one concern in handling grain is to keep deadly aflatoxins out of the food supply. This may become an increasingly important control issue as climate change results in more frequent hot and dry growing conditions for grains. Extensive testing can prevent contaminated grains, especially maize, from entering the food supply, but rapid testing at delivery of the crop is necessary to pinpoint dangerous levels of aflatoxins. High-risk periods due to extreme heat are expected to highlight the importance of environmental informatics approaches and systems to developing effective control measures based on well-coordinated data gathering, recording, and tracking efforts [13].

Even better is the potential to identify dangerous levels of aflatoxins in the farm field. That possibility is now feasible with the digital information systems being used by farmers in their agronomic practices. The data gathered can include identification of areas within a field which are subject to aflatoxin contamination because of particular crop conditions. Further, the use of drones to scan fields provides an additional opportunity to identify aflatoxin-affected areas within a field. However, more research is required to make that a reality in the near future. Combining data generated by the farmer during the course of conducting agronomic practices with that gathered by drones offers a potentially powerful tool to keep aflatoxin-infested grain from even reaching the first point-of-sale for food use. Such fields may be harvested for industrial uses not affecting aflatoxin's effects on human food as well as animal feed. This is just one example of how earlier intervention may increase the safety of the food supply starting at the farm level. Other pathogens likely to occur in crops could also be kept out of the food supply chain starting at the farm level.

Seed, fertilizer, and equipment companies have worked with farmers to monitor and collect data at the farm level. When properly analyzed and correctly interpreted, the information can be valuable to both the farmer and the company. The company analyzing the data generally charges the farmer for the analysis, even though it is using the farmer's data. The company gains by strengthening its predictive analytic capabilities, improving its strategic benchmarking prowess, and building its marketing advantages. The farmer who is already using precision technologies may gain productivity from providing the data and then buying the company's analytic report, but there is no guarantee of an overall farm output increase. So the farmer must evaluate whether the benefits of providing the data outweigh the possibility that the data would be released or misused by others. At least that is a major concern among a number of US farmers currently [14].

At the other end of the food supply chain, retailers including grocery stores and restaurants are extremely concerned about food safety issues to protect their customers from foodborne illnesses. Their reputation, and even survival as a viable business, demands that they pay close attention to this issue in an increasingly global context. The possibilities for foodborne illness outbreaks are multiplied by international travel and the potential for invasive pathogens, as well as from endemic pathogens already prevalent in the US food supply chain. Big data and the associated analytics provide the opportunity for retail establishments to implement stronger food safety protocols to protect their customers and their brand. For example, The Cheesecake Factory is a US-based restaurant chain which is using IBM big data analytics to quickly alert their restaurants to remove ingredients that do not meet safety standards. Like many restaurant chains, The Cheesecake Factory generates a variety of data from its complex global food supply chain. Large volumes of data provide information about everything from transportation of food at the appropriate temperature to shelf life of food items and withdrawals of products by manufacturers. The magnitude of this data makes it difficult for large restaurant chains to get a quick insight and then manage appropriately. This is where IBM's advanced analytics, in conjunction with IBM's business partner N2N, provide solutions which allow The Cheesecake Factory to quickly withdraw any ingredient failing to meet its standards for quality and consistency [15]. Other restaurant chains will undoubtedly demand such services to assure that they are as equally protected from food safety risks.

An example of an international collaboration to improve food safety is found in ComBase, which is a combined database for predictive microbiology. It is managed by a consortium of the Institute of Food Research in the United Kingdom, the Agricultural Research Service of the United States Department of Agriculture, and the University of Tasmania Food Safety Center in Australia. ComBase is the most recognized free, web-based resource for quantitative and predictive food microbiology. It provides a systematically formatted database of quantified microbial responses to the food environment, with more than 50,000 records. The database contains thousands of microbial growth and survival curves collated in research establishments and from publications. It further provides predictive models which are a collection of software tools utilizing the ComBase data, designed to predict the growth or inactivation of microorganisms in food. Together the database and predictive models allow researchers worldwide to predict and improve microbiological safety and quality of food; allow companies to develop new food products and technologies, and store foods economically; and facilitate assessing microbiological risk in foods and setting up the government regulatory or industry voluntary guidelines, as appropriate. A user of the ComBase Internet interface defines relevant criteria for their query, including: the type or species of organism, the type or class of food, temperature, and specific food conditions, as well as more technical conditions [16]. The ComBase consortium provides training in the use of its product by hosting workshops throughout the world.

4. Looking ahead

Who owns and controls the data generated by the technology at the farm field level is an issue which must be resolved between producers and companies selling the digital information systems incorporated into farm machinery. This digital technology allows site specific decisions about fertilizer and pesticide applications, crop irrigation needs, and other agronomic practices; as well as provides information about yield variation within fields, disease problems and product quality characteristics. The data generated is transmitted back to the system vendors, as well as being available to the farmer. The big data generated at the farm level makes it a challenge for farmers to fully utilize the results. Recent developments aggregating data from various sources to create huge data files, which have value at the farm level but also when aggregated across farms, provides data vendors an opportunity to repackage the data and sell it for substantial sums, perhaps totaling in the billions of dollars. This has raised privacy concerns, as well as a desire by farmers to have access to more of the value added by these technologies. Currently there is a mix of arrangements between the technology providers and the producers using it, but these agreements are rapidly evolving. Prior to big data becoming such an important component of decision-making, the contracts between the technology providers and farmers using it were relatively straightforward. After raising serious concerns, US farmers appear to have obtained some control over details about their crop and growing conditions on their own land. However, most data sellers who are the providers of the digital information systems retain the ultimate say over how they can use the information. For example, Deere & Company and Monsanto’s Climate Corp. continue to claim an absolute right to the data collected by the combines, tractors and other equipment working the fields [17].

One strategy being tried by farmers is to form cooperatives to collect the data and develop analytics to create value from it, which they would then retain among the cooperative members. The American Farm Bureau Federation, the largest US farm organization, is giving serious consideration to establishing a data warehouse and analytics system for its members who contribute data to it. It is likely that these actions are in part responsible for the gains farmers have achieved thus far. Whether private sector actions such as this, collaboration between farmers and digital information systems purveyors, or public policy created through government action will resolve the issues involved remains to be seen. Clearly some of the data gathered at the farm level and aggregated across farms holds potential value for food safety throughout the supply chain. How the privacy and access to data issues get resolved will therefore impact food safety.

ISOBlue is an innovative approach organized by engineers at Purdue University and cosponsored by FarmLogs—a Michigan-based company backed by Silicon Valley money which sells software and data analytics that lets farmers fully control the information collected—to provide an alternative to farmers. ISOBlue teaches farmers how to capture and store their own data rather than needing to rely on the analytics from the equipment providers. Many pieces of modern farming equipment “share a standardized communications bus, known as ISO11783 bus, or ISOBUS. It is a standard CAN communications bus operating at 250 kbps. The ISO11783 protocol specifies application layer-packet structures which are sent via the CAN link and Physical layers.” Due to the proprietary data collection systems from tractor manufacturers, most farmers, researchers and interpreters cannot easily access massive amounts of mineable data generated by tractors and related sensors. The goal of ISOBlue is to free the data by forwarding it directly from the bus wirelessly over Bluetooth to devices capable of doing things with it. By getting precision agriculture data into the cloud, this project provides access to those trying to leverage advanced information technologies to produce more food efficiently and safely [18].

Demand for public access to monitoring data for foodborne illnesses will likely increase as people become increasingly aware of safety concerns surrounding food production domestically as well as from ever more prevalent imported supplies. The latter is of particular concern as global trade agreements have increased the flow of many food products, including processed foods that may come from countries with less stringent food safety processes in place than those to which developed countries are accustomed. Private sector approaches to providing access to information about foodborne illnesses and safety risks are likely to increase to satisfy this demand. Public-private collaboration to establish and maintain open access to information resources will undoubtedly play an important role in addressing this demand. Certification of inspection results for food safety conditions, as generally provided by third parties who have been certified by government agencies, will likely continue to be important to the selection and integration of key data that drive private sector management decisions and public policy.

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