Artificial Intelligence Opportunities to Improve Food Safety at Retail

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SUMMARY

Food retailers drive food safety programs throughout the supply chain, within their stores, and across e-commerce platforms to mitigate the risk of foodborne illness for consumers. Delivery of food safety from the producer through retail requires strong food safety culture, reliable data, robust database management, and technical expertise. Artificial intelligence (AI) has been proposed for its potential to advance and transform food safety practices and outcomes. This article aims to introduce AI terminology and definitions to a food safety audience and to outline the opportunities, challenges, and ethical considerations when adopting AI-based technologies at retail. For food safety at retail, the applications of AI presented here are categorized as vision, text, interactive, analytical, or functional-based solutions. As AI capabilities continue to develop, food safety professionals will have a role in shaping the tools and algorithms that are adopted across the food industry, including at the retail sector. AI can strengthen food safety but, to be successful, will require strategic collaborations across the supply chain, including with technology providers, regulators, and academics.

OVERVIEW

The retail food industry employs more than 6 million people and contributes $800 billion USD to the U.S. economy *(8)*. Retailers are responsible for the food safety of all products sold in their facilities. This responsibility includes sourcing food from suppliers with validated food safety practices, developing strong food safety programs within retail facilities, and providing consumers with fundamental food safety information to reduce their likelihood of foodborne illness. In the United States, 93% of shoppers trust food retailers to sell safe food and remove specific products when recalls and outbreaks are announced *(7, 9)*. Single-store independent operators, traditional brick-and-mortar grocery stores, multinational supermarket chains, e-commerce delivery platforms, and producers all provide consumers with abundant food choices but must evolve the methods employed to prevent, predict, and, when necessary, respond to harmful food safety events. It is strategic for retailers to understand how new technology and research can be used to improve food safety programs and response time, in addition to promoting diverse employment opportunities and expanding leadership capacities.

The 2019 International Association for Food Protection (IAFP) Annual Meeting in Louisville, Kentucky, convened two symposia on the topic of artificial intelligence (AI) within the food industry, titled "Impact of Robotics and Artificial Intelligence on Food Safety" and "Artificial Intelligence and Machine Learning: What They are and Their Potential Applications for Food Safety." Both symposia introduced how these technologies could be considered to improve food safety outcomes for different segments of the food industry. This article builds upon one presentation from the conference focused on surveying emerging AI technology relevant to retail food safety issues and analyzing the role food safety professionals should play in development and implementation of new food safety tools involving AI.

Leveraging AI-based technology to create a safer food supply will require food safety professionals from retail to collaborate with strategic partners. For example, in some areas of the industry, data needed to identify and prevent contamination may be lacking or unavailable for retailers. Other areas may be so data rich that retailers alone are unable to process it in a meaningful way to prevent product contamination or proliferation of an outbreak. Food safety should be considered in the design and integration of AI and robotic solutions, especially as the solutions for food retail progress from individual tasks to broader capabilities. Therefore, the goal of this article is to facilitate communication between the food and technology industries on where and how AI tools can be applied to gain experience and/or learn about managing food safety risks at retail.

BACKGROUND

Within the past decade, growing global interest in AI and business automation, due in part to increased access to and generation of data and advances in computing power, has sparked new research, investment, and applications across many industrial and service sectors, including the food industry. Whereas AI scientists are proficient in problem solving, food safety subject matter expertise and access to quality data are the underpinnings of AI tools that will provide meaningful solutions to retail food safety challenges.

A review of some basic definitions and methods associated with AI will lay the groundwork for a discussion of next generation food safety systems:

- **Intelligence:** the mechanism(s) related to the ability to acquire and apply knowledge, reason deductively, and exhibit creativity to achieve goals *(13, 23)*.
- **AI:** the science and engineering of making intelligent machines, especially intelligent computer programs to sense, reason, engage, and learn. AI systems display intelligence by analyzing a given environment and taking actions, with some degree of autonomy, to accomplish specific goals *(4, 13)*. AI systems require data to define and improve their behavior and goal-seeking performance. AI-based systems may be purely software based or can be embedded in hardware devices.
- **Data:** more or less structured and standardized information that can be processed by computers, usually in the form of text and numbers *(5)*. Data are an important asset used as input to the algorithms at the core of AI applications.
- **Big data:** data collected in massive volumes (e.g., via the internet and smartphones), with increasing variety and pace, such that they are too large or complex for traditional data processing. Characteristics of big data are commonly summarized by four Vs: volume, velocity, variety, and veracity *(11)*.
- **Data mining:** application of a combination of machine learning, statistics, and database system methods to discover patterns in large data sets.
- **Algorithm:** an unambiguous set of rules, written by humans and followed by a computer, that translate input data into outputs for solving a class of problems *(5)*. Algorithms can perform calculations, data processing, and logic tasks.
- **Machine learning (ML):** the science of constructing computer programs (or algorithms), drawing from many fields, including statistics, philosophy, biology, and information theory, that automatically improve with experience or data by establishing patterns and rules that can be applied to new, subsequent data *(6, 14)*. At a minimum, application of ML requires a learning task and a performance metric. There are three groups of ML methods:
  - **Supervised learning:** learning a function that maps an input to an output based on labeled input–output data pairs (training data).
  - **Unsupervised learning:** learning patterns in unlabeled input data.
  - **Reinforcement learning:** learning behavior based on trial-and-error interactions within a dynamic environment, balancing between exploration of the unknown and evaluation of current knowledge *(12)*.
- **Deep learning:** more advanced ML involving layers of algorithms and decision networks that progressively extract higher-level features from raw input, typically based on millions of data points.
- **Internet of Things (IoT):** a global infrastructure enabling the connection of interrelated physical and virtual objects (e.g., computing devices, mechanical and digital machines) to transfer data without requiring human-to-human or human-to-computer interaction.
- **Predictive analytics:** a variety of statistical, data mining, and ML techniques to analyze current data and historical facts to make predictions about future or otherwise unknown events *(17)*.
- **Robotics:** an interdisciplinary branch of engineering and science that deals with the design, construction, operation, and use of robots (as well as computer systems for their control, sensory feedback, and information processing) to perform tasks either alone or with human direction *(15)*.
- **Virtual reality (VR):** a simulated experience, similar or completely different from the real world, in a space that allows for human sensory interaction and overcomes spatial and physical limitations of the real world *(3)*.
- **Augmented reality (AR):** an interactive experience of a real-world environment where objects in the real world are enhanced by computer-generated information, including images, sounds, textures, and scents.

At a high level, AI does not refer to "one thing" but rather is an umbrella term for a variety of current technological developments and processes *(6)*. Where ML is focused on the ability to learn and make predictions, AI encompasses the ability to sense, reason, engage, and learn. Use of an algorithm or predictive model does not always warrant the label AI or ML; the utility of AI depends on algorithms as capable as people at solving problems. The broad purpose of AI could be considered as eliminating repetitive and laborious tasks with automation and automated decision-making, but the specific branches of AI present different solutions depending on the business problem. There are myriad ways to identify branches of AI and their related computational methods or mathematical logic, but for this article aimed at the food retail industry, applications of AI tools may be categorized as (i) vision, (ii) text, (iii) interactive, (iv) analytical, or (v) functional solutions *(2) (Fig. 1)*.

Visual AI tools encompassing image recognition, computer and machine vision, and AR offer new technology for tasks related to product scanning and employee training. Text-facing AI tools recognize text or speech for the purpose of text-to-speech and speech-to-text conversion. Interactive AI tools often utilize expert systems and natural language processing for capabilities of extracting information from customers to provide troubleshooting and customer service. Analytical AI tools, heavily based on ML, provide predictive and actionable information useful in risk assessments,

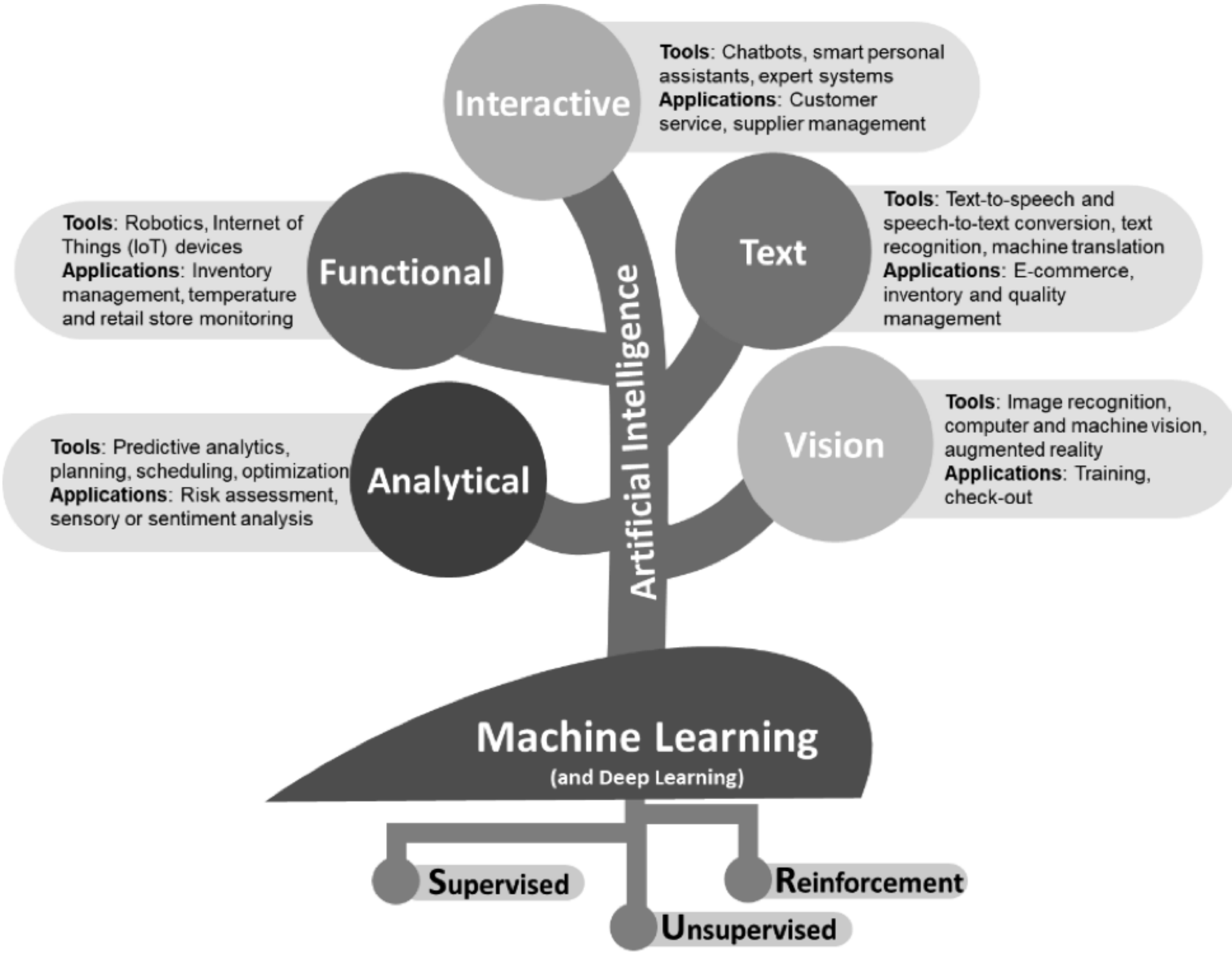

FIGURE 1. Branches of artificial intelligence tools and their applications for the retail food industry (adapted with permission from *(2)*). Specific branches of artificial intelligence (AI) present different solutions depending on the business problem. For purposes of this article aimed at the food retail industry, AI tools may be categorized as (i) vision, (ii) text, (iii) interactive, (iv) functional, or (v) analytical solutions. Algorithms of machine learning (ML)—and more advanced deep learning—programs provide the foundation for the success and dissemination of AI. ML methods are classified into supervised, unsupervised and reinforcement learning.

scheduling and optimization tasks, and sensory or sentiment analysis. Finally, functional AI includes hardware devices such as robotics and IoT applications to automate tasks and react to conditions.

AI OPPORTUNITIES FOR RETAIL FOOD SAFETY

For the evolving food retail sector, with an increasing proportion of sales being conducted online *(7, 16)*, there may be short- or long-term opportunities for transformative technologies to improve business and supply chain efficiency. While drone delivery, robot-empowered sanitation programs, automated online order fulfillment, automated check-out, and product shelf-life algorithms are some examples of AI tools being deployed by early adopters in a variety of retail segments, opportunities remain for AI to address unsolvable or repetitive food safety challenges and tasks. Specific opportunities, rather than products and services, for different branches of AI to improve retail food safety preventive and response systems are presented next.

Vision AI: food safety training

Fostering food safety culture is vital to earn consumer trust and reduce the likelihood of product contamination. Reliable food safety cultures are built upon food safety training programs that focus on fundamental food safety education concepts. Traditional retail food safety training programs take place in classrooms or online. Vision AI technologies, such as VR and AR, can advance retail food safety training for employees and consumers. Using simulation-based training modules allows employees to visualize and practice crucial safety steps. Specifically, VR and AR technologies can improve delivery of retail food safety training on the following:

- Handwashing,
- Assembly of raw or ready-to-eat products using protective gloves,
- Reporting an illness to a manager or person in charge,
- Reporting employee illnesses to local health departments,
- Prevention of cross-contamination and cross contact within a facility,
- Cleaning and sanitation procedures for each department and piece of equipment in a facility (i.e., deli slicer, produce bins, bathrooms, etc.),
- Calibration and sanitization of food thermometers,
- Refrigerated or frozen storage of raw poultry, raw meat, and ready-to-eat foods,
- Avoiding temperature abuse during preparation, cold-holding, and hot-holding activities,
- Reviewing traffic and product flows (purchase, delivery, receiving and storage, preparation, display, and sale) to ensure food safety,
- Responding to a diarrheal or vomitus event within a facility,
- Separating raw, ready-to-eat, and chemical supply items in a shopper's grocery bag, and
- Conducting a mock recall.

Text AI: informational and operational consistency

Retailers are investing in new information technology and database management systems to collect, store, and share food safety information. Consistency of food safety information and practices between physical and digital platforms allows retailers to meet shoppers' ever-increasing personalized needs and participate in multistate recall and outbreak response. Text AI services can improve omnichannel consistency by powering internal or industry-wide databases in various ways:

- Preventing recalled products being sold to consumers in online and brick-and-mortar marketplaces
- Predicting food recalls based on online reviews of the product
- Reducing allergen misbranding and ensuring correct labeling of bakery products
- Categorizing and/or responding to consumer complaints
- Translating food safety information and food labels from international suppliers
- Facilitating visual quality assurance inspections, and
- Digitizing traceability of fresh produce using key data elements and critical tracking events from pallet labels to bills of lading or advance shipment notices.

Interactive AI: personal food safety assistants

Customers are increasingly using voice assistant devices and chatbots to help them with their grocery or food service shopping needs, as well as in their home kitchens to access information and set reminders *(19)*. Similarly, retailers can improve their in-store food safety operations by leveraging interactive AI tools as personal food safety assistants to reach their employees, suppliers, and consumers in various ways:

- Determining items included in a food recall
- Identifying products that contain major allergens
- Suggesting appropriate corrective actions for food safety deviations in retail food preparation and storage areas
- Conducting audits of suppliers or soliciting food safety information regarding a lot (or lots) of product
- Promoting safe food handling for consumers (in multiple languages) when following or building a recipe, and
- Interacting with consumers reporting symptoms of foodborne illness to improve the detection of outbreaks and public health efforts.

Analytical AI: predictive analytics

Analytical AI tools can function to create and assemble data sets or to provide insights from existing data sources for retail food safety issues. Whether retailers use these tools for ensuring the safety of their products or cooperating with outbreak response, retailers need actionable data throughout the entire supply chain to make risk-based decisions. Predictive analytics may enhance retail food safety and decision-making when used in these ways:

- To design environmental monitoring programs based on the likelihood of environmental contamination within retail delicatessens and fresh preparation areas *(22, 24)*,
- To minimize the size and scope of foodborne outbreaks with "machine-learned epidemiology" capabilities (e.g., ML algorithms that use public and private data sources to facilitate the identification of contaminated food sources *(10, 20)*), and
- To execute more strategic procurement with improved supplier risk assessment and supply chain reliability, transparency, and responsiveness (e.g., to prevent high-risk imports from entering U.S. commerce markets; and to forecast heightened risk of certain commodities, such as leafy greens, based on environmental and industry conditions).

Functional AI: robotics and IoT

Functional AI tools, such as robotics and IoT, connect data analytics with hardware to turn data into actions, particularly repetitive, labor-intensive, and/or error-prone tasks. At retail, robotics and IoT solutions are being explored to do the following:

- Monitor the retail environment for unsanitary surfaces, incorrect or damaged items on shelves, and potentially temperature-abused foods
- Reduce the risk of norovirus transmission and *Listeria monocytogenes* harborage by automating routine cleaning and sanitizing environmental areas suspected of contamination

- Strengthen preharvest risk assessments, in partnership with growers and shippers, using drones to monitor and report produce field conditions, such as pest infestation or water mismanagement, and
- Collect and transmit continuous temperature data from transportation fleet refrigerator, freezer, or hot-holding units during transit (e.g., international, interstate, or last-mile).

CHALLENGES AND ETHICAL CONSIDERATIONS

Although the opportunities to improve retail food safety exist, widespread adoption of AI and ML at retail, and along the food supply chain, will be incremental. There are several challenges and ethical considerations that the food and technology industries and regulators must work to define and address as AI's impacts on society, policy, and business matters evolve.

Data quality and bias

The quality of AI and ML algorithms depends on high-quality input data. Incomplete, biased, or inaccurate data may lead to harmful decision-making and outcomes. For example, in applications of AI for deploying public health resources and food establishment inspections based on consumer-sourced big data, a concern lies in how individual consumer bias may be propagated through the food industry and influence enforcement of food safety and consumer-purchasing habits. Altenburger and Ho *(1)* showed that predictive analytics using consumer complaints to target food safety enforcement disproportionately targeted Asian-owned establishments. This study concluded that crowd-sourced information for a single establishment had lower predictive power than prior inspection history and that these reviews did not significantly improve predictions of food safety violations when existing restaurant data and inspection history was available *(1)*. Thus, data quality will benefit from continued investments in digital data accessibility, connectivity, and infrastructure.

Vetting data prior to use in algorithms is increasingly critical. Methods to characterize and control bias in data and algorithms are being explored (i.e., statistical debiasing solutions), but greater transparency and reproducibility in AI and ML applications are needed if they are to be more widely adopted. Food safety scientists should play a greater role in providing the practical and scientific context around the available data and assumptions, especially when making food safety decisions based on predictions.

Security of information

AI and ML capabilities are anticipated to become more powerful, widespread, and vulnerable to malicious attacks or uses. Maintaining security of the information used and contained within these systems is a critical and significant task. The volume of new data sources, tools, frameworks, and people involved brings many unknowns to internal security and privacy systems. Furthermore, the obscure boundaries, ownership, and origin of data and algorithms complicate regulation and governance. This is particularly relevant as AI systems find application in new and more global business models around food retail, delivery, and consumer interaction.

Two broad parts to the security of AI and ML applications include data security and/or privacy and the security of the internal algorithm(s). As with securing other company assets, securing AI tools should include evaluation of (i) potential breaches in the confidentiality, integrity, or availability of the data and algorithms; (ii) the impact of types of breaches; and (iii) the design of protections against such breaches. Traditional policies and encryptions for data security and privacy should be reevaluated for new contexts of data access and sharing. Securing algorithms against adversarial exploits will require new internal teams and talent for food companies to ensure AI tools perform and learn as intended despite the presence of misinformation and adversaries.

Impact on business matters and relationships

As data become a new form of currency and we rely more on data for decision-making, it is inevitable that business dealings and relationships will evolve. The expansion of emerging data systems technology (including IoT, big data, cloud computing, AI, ML, and blockchain) are changing how our society lives and works, in terms of hyperautomation and hyperconnectivity *(21)*. Most notably, the rise of AI is fundamentally changing the meaning of collaboration, competition, and innovation *(18)*. Three main themes arise as companies expand the reach of AI beyond their internal tasks to encompass mutual supply chain and business ecosystem challenges: (i) trust, transparency, and accessibility; (ii) data use and ownership, and (iii) availability of required resources within organizations.

Although AI has the potential to transform food safety practices, development of common and shared approaches to data collection and access will be a central challenge facing industry-wide efforts. Information sharing, data security, and the reasons for sharing information will be important conversations with industry stakeholders. As mentioned previously, data power the algorithms that drive AI and ML, yet some data are difficult to collect or obtain due to perceived risk, time-constraints, rarity of events, confidential business information, or resource limitations. In the food industry, many stakeholders worldwide still lack the necessary digital data infrastructure to generate meaningful banks of food safety information and intelligence. For example, the transition to digital food safety data collection and recordkeeping is ongoing for growers and producers who must share the information prior to business transactions. A potential solution may lie in the creation of large aggregate data pools and practices at local, national, and international levels for shared use in the design and adoption of risk-based food safety programs. Another alternative to circumvent large-scale data collection is to use machines and computers to generate synthetic, but validated, data sets for use in decision-making and risk-setting exercises. Regardless, initiatives and partnerships around shared technology and data may become increasingly incorporated or embedded into business relationships to facilitate real-time access to food safety information.

FUTURE DIRECTIONS

Retailer partnerships with regulatory officials, consumers, academic experts, and food industry stakeholders will advance AI opportunities within food safety programs. Continued discussions and showcases at subsequent IAFP meetings on AI tools for food safety will further refine the potential adoption and benefits of application at retail. While the industry invests in data collection infrastructure, foresight should be given to turning data into actionable information. As the food industry gains access to more information, the way food safety professionals manage risks and make decisions will evolve. New operational risks may arise, particularly around business interruption, perceived liability, and data transactions. Early-adopting companies will pave the way for assessing the feasibility and return on investment for implementing these tools. Several shared campaigns across the industry may be (i) keeping jobs in the food sector by investing in food scientists and employees to be well-versed in data technology, (ii) defining how AI and ML algorithms are used in regulatory processes, and (iii) building inclusive partnerships with strategic technology stakeholders to strengthen overall food safety programs.

CONCLUSION

The retail food industry should prepare for a highly automated future. Capitalizing on opportunities to develop AI solutions that focus on strengthening food safety may result in finding new applications from existing algorithms, but food safety professionals will play an important role in developing novel algorithms for specific food safety problems. Retailers should be open to working alongside AI tools that provide actionable information to leverage experience and resources for managing food safety risks. These technologies should not replace humans involved in food safety but should help existing food safety practices work more effectively. Perceived liability, data quality, and accessibility remain the main barriers to widespread AI adoption. Moving forward, the impact of AI in the food industry will be enabled by increasing industry-wide adoption of software and solutions that provide connectivity and transparency of food safety data throughout the supply chain.

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In Memory

Alonzo Gabriel

IAFP extends our deepest sympathy to the family of Dr. Alonzo Gabriel, who recently passed away. Dr. Gabriel was a Professor in the Department of Food Science and Nutrition at the College of Home Economics at the University of the Philippines – Diliman Campus in Quezon City. He was Treasurer of the IAFP Affiliate, the Southeast Asia Association for Food Protection, and received the IAFP Travel Award for a Food Safety Professional in a Country with a Developing Economy in 2017.

IAFP will always have sincere gratitude for Dr. Gabriel's contribution to the Association and the profession.