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Are You AI-Ready? A Framework for Evaluating Artificial Intelligence Applications in Food Safety Programs

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SUMMARY

The rapid advancement of artificial intelligence (AI) and machine learning technologies presents significant opportunities for enhancing food safety programs. Successful implementation requires careful assessment of both technological capabilities and organizational readiness. The Food Systems Assessment Framework for Evaluating AI (FoodSAFE-AI) is a comprehensive tool designed to evaluate organizational preparedness for implementing AI automation in food safety applications. The framework assesses readiness across three business areas: (1) organizational buy-in and business problem definition, (2) information technology infrastructure and data management capabilities, and (3) food safety program maturity and agility. It evaluates these areas against four stages of automation: information acquisition, information analysis, decision selection, and action implementation. The framework was implemented as a freely available Excel-based tool containing 32 assessment statements scored on a 4-point scale. Three case studies demonstrate the framework's application, showcasing AI solutions for automated sampling and interventions, automated record review, and supply chain optimization through horizon scanning. Results indicate that organizations must achieve high maturity across all three business areas to successfully implement each progressive stage of automation. FoodSAFE-AI equips food safety professionals to drive collaboration on designing smarter food safety programs that both incorporate AI and align with their organizational capabilities and business objectives.

OVERVIEW

Continuous advances in artificial intelligence and machine learning (referred to as AI throughout this article) are creating new opportunities for enhancing food safety programs through automation. Precision food safety has been used to describe systems that leverage numerous data streams and AI to enable more dynamic risk management and real-time notifications and adjustments of food safety and quality deviations *(5)*. Food companies are beginning to recognize the potential to modernize food safety management. In fact, in a Food and Agriculture Organization of the United Nations foresight exercise, it was predicted that within the next 5 years, digitalization and data-based technologies, including AI, Big Data, internet of things, and digital twins, will have an impact on food safety programs and metrics *(9)*. However, effectively implementing AI requires careful consideration of both technological capabilities and organizational readiness, especially where the vision is to be people-led and technology-enabled *(14)*. Premature technology adoption may lead to failed implementations and missed opportunities for realizing smarter food safety and improved food safety outcomes.

How can organizations design future food safety systems with human-centered automation that upholds reliability and food safety culture? Across business sectors, the top challenges in starting and scaling AI-based projects have been proving business value, obtaining necessary data, managing risks, and implementing the right technology *(2)*. Surveys continue to find that business value creation from AI is not instantaneous, nor realized at the pace of technological advancements, but rather requires significant organizational leadership and transformation *(3)*. For food safety in particular, where there is great interest in using technology to help solve complex problems, it is strongly advised to anticipate the delivery, maintenance, and evaluation over time of AI tools that are critical for ensuring food safety standards are maintained *(12, 15)*. This article introduces and demonstrates a comprehensive framework that: (1) assesses organizational readiness across three business areas and four automation stages; (2) provides actionable recommendations for addressing capability gaps; and (3) guides food safety professionals in making informed decisions about AI adoption aligned with their organizational maturity and business objectives.

The framework is demonstrated through several case studies of evaluating AI solutions for emerging food safety risks, showing how companies can systematically evaluate their preparedness for implementing AI across the automation spectrum. By carefully considering both the stage(s) of automation needed and organizational readiness factors, food companies can make more informed decisions about AI adoption while avoiding investments in solutions that may be premature for their current capabilities. While this framework could theoretically be applied to evaluate any automated food safety system, its primary intent is to assess organizational readiness for AI applications aimed in particular at decision-making and implementation where the greatest opportunities and challenges currently exist.

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Examples evaluated here include automated sampling and interventions with a machine learning algorithm, automated record review using natural language processing and AI agents, and automated supply chain optimization using an AI-based horizon scanning platform.

FRAMEWORK

The "Food Systems Assessment Framework for Evaluating AI" (FoodSAFE-AI) was first introduced during the 2024 IAFP Marketplace at the Annual Meeting in Long Beach, CA to support dialogue around evaluating the utility of AI for food safety. This structured framework considers both the stages of automation that could be applied and an organization's maturity level for implementation to determine readiness. It builds upon established models of human-automation interaction, particularly one that classifies automation into four fundamental stages: information acquisition, information analysis, decision selection, and action implementation *(11)* *(see Appendix 1)*. This influential model provided a systematic way to understand the varying degrees to which automation can support, replace, and change human functions across different cognitive functions. Rather than viewing automation as an all-or-none approach, the Parasuraman et al. *(11)* model conceptualized it as existing along a continuum from fully manual to fully automated for each stage. In food safety applications, these automation stages could range from automated pathogen detection systems (acquisition) to predictive analytics for identifying emerging risks (analysis), to AI-assisted HACCP plan development (decision making), to automated control interventions (action) *(Fig. A.1)*. When assessing AI implementation, beginning with this four-stage framework allows organizations to strategically determine which specific aspects of food safety processes would benefit most from automation, while considering the appropriate level of human involvement needed at each stage to maintain oversight, situational awareness, and the ability to intervene when necessary.

The focus of FoodSAFE-AI was on the initial steps of the Parasuraman et al. *(11)* automated system design model to help food organizations primarily define what should be automated in their food safety systems, understand the different stages of automation, and evaluate their readiness for implementation *(Fig. 1)*. Based on the common barriers to effectively deploying AI-based systems - proving business value, obtaining necessary data, managing risks, and implementing the right technology *(2, 3)* - FoodSAFE-AI determines readiness, an organization's ability to execute and create value from AI-based food safety projects, based on high maturity in three key business areas: 1) organizational buy-in and clear definition of the business problem to be solved, 2) information technology (IT) infrastructure, support, and data management capabilities, and 3) food safety program investment, maturity, and agility *(Fig. 2)*. This three-dimensional assessment helps companies gauge whether they have the necessary foundation to successfully implement AI in a food safety program and highlights potential consequences of premature implementation.

Organizational buy-in and business problem

To implement and integrate AI, you need a strategy and a problem. At present, the cost and expertise needed to achieve these kinds of precise systems is difficult to estimate. Careful consideration and design are needed to evaluate how AI solutions will interact with users and the business environment to automate workflows, facilitate real-time decision-making, and enhance overall food safety strategy. And integration of these tools into software and hardware systems, as well as business functions, requires significant time and financial commitments before benefits and performance improvements can affect measurable changes in key problems. Finally, as with all food safety initiatives, having leadership support and the organizational food safety culture to act or not based on data and model outputs is essential. Without Organizational Buy-in and Business Problem, AI solutions are likely to be fleeting, or short-lived, due to changing priorities and business objectives *(Fig. 2)*.

The FoodSAFE-AI includes assessment of the Organizational Buy-in and Business Problem related to the AI use case. A likely starting point for many is to identify the core business challenge that may benefit from AI and determine the support for and acceptance of algorithmic decision-making and task automation. It is recommended to evaluate if the problem is well-defined and critical enough to necessitate data science solutions. Because, "…without the presence of a problem, there is no need for the application of data … Problem solutions require carefully framed questions, and a rigorous, replicable, and repeatable process..." *(8)*. In addition to well-framed questions fit for data science, the problem should be high priority, supported by business leaders, and difficult to otherwise solve to justify the long-term investment needed.

IT support and data acumen

Data acumen, also referred to as data literacy, is defined as the "ability to make good judgements about the use of data to support problem solutions" *(8)*. Organizations with data literate decision-makers and dedicated IT teams are well-positioned to initiate projects that leverage datasets, integrate models with other technologies and workflows, and mitigate business/security risks. The main consequence of implementing AI solutions without having solid data acumen and IT support is the introduction of disparate solutions that the organization will struggle to maintain over time *(Fig. 2)*. This is because only a small fraction of the production AI system consists of computer code for learning and prediction; rather, the majority is data collection and preparation, plus establishing the required surrounding

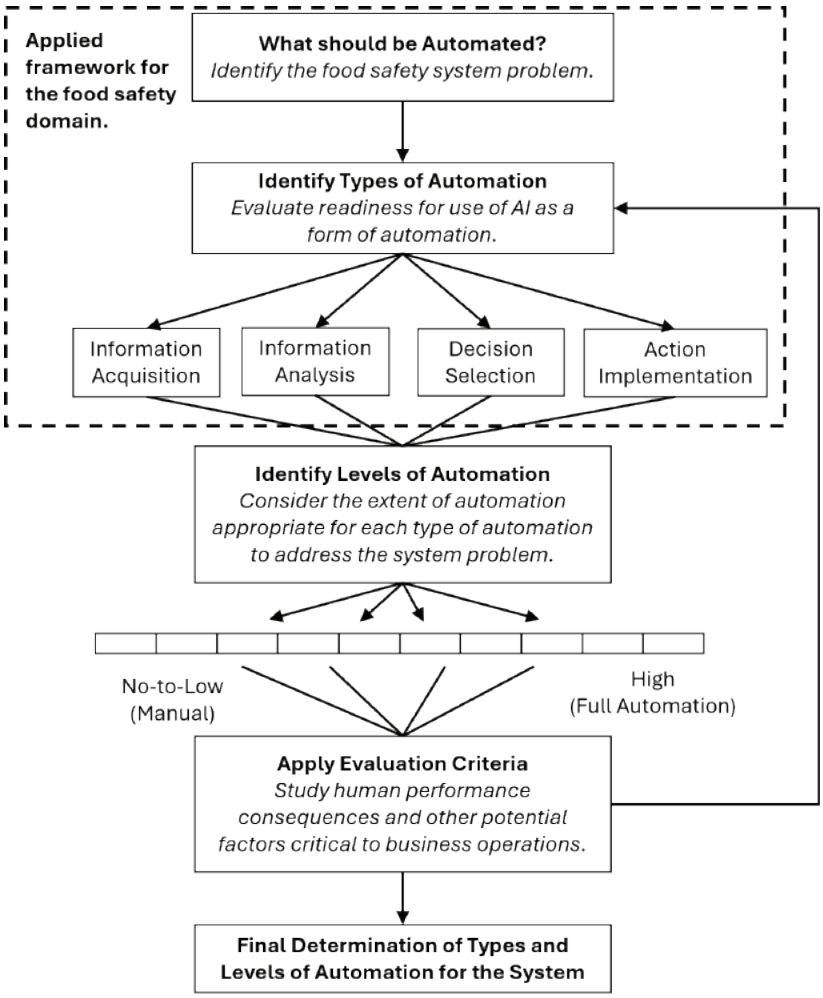

Figure 1. Illustration of FoodSAFE-AI as part of a broader approach to designing human-centered automation (adapted with permission from Dr. Wickens *(11)*). The flowchart provides a previously published model for iterative design of automated systems, including identification of appropriate types and levels of automation, as well as evaluative criteria for human interaction with automation. The dashed box highlights where the applied framework for the food safety domain fits into the overall model to facilitate exploration of AI/ML-based automation in food safety systems.

infrastructure to deploy and maintain the model *(12)*. This is particularly important for organizations and enterprises that rely on integration of many tools, systems, services, and partners to operate their business, including the food safety program. For example, there is growing interest in data sharing across the food chain for use in modeling efforts. However, without requirements for data annotations and definitions, the resulting data ecosystem actually becomes too diverse, less integrated, and more time-consuming for both human and machine interpretation *(16)*.

The FoodSAFE-AI includes assessment of the IT Support and Data Acumen by examining if a cloud-based infrastructure is in place, along with a dedicated IT team or role. A starting point is to evaluate the reliability, standardization, and accessibility of the data relevant to the AI use case. It is also recommended to consider how various disparate systems in place might affect the automation of food safety tasks.

Food Safety Maturity and Agility

If AI implementation is successful, it should result in a clear action plan. According to Stanford Professor of Operations, Information, and Technology, Kuang Xu, "AI and data science are supposed to help you drive better decisions. Always. If there's no way for you to change your operation or decision-making, then having more information doesn't help you" *(6)*. While it is recognized that businesses should keep up with new technologies, AI for food safety may not be productive or essential for all businesses and likely depends on the maturity of their food safety program. For example,

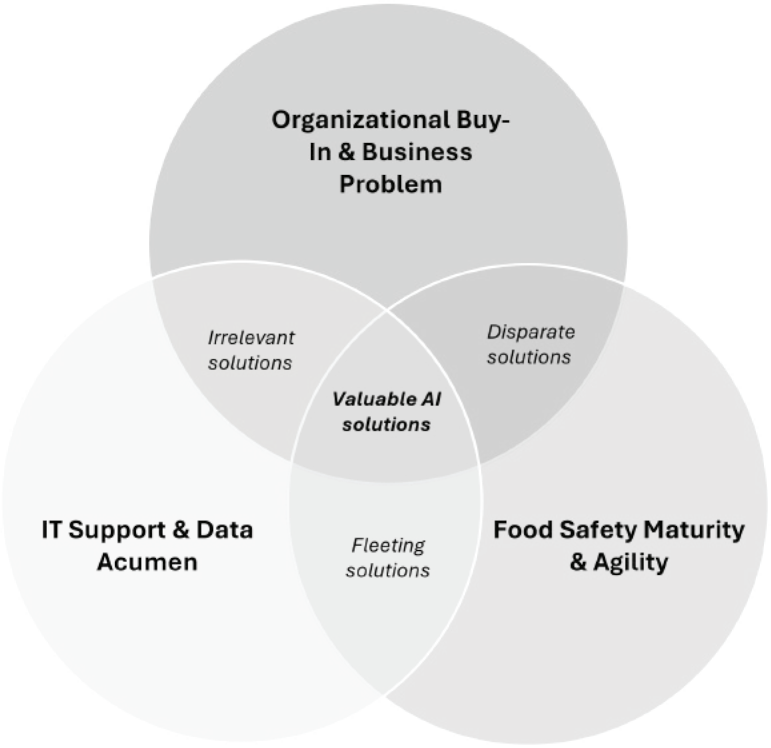

Figure 2. Three business areas are necessary to support valuable AI solutions that solve food safety problems. Development, deployment and utilization of production AI systems that are valuable to food safety problems requires (1) organizational buy-in and a business problem, (2) information technology (IT) support and data acumen, and (3) food safety maturity and agility. The consequences of missing one or more of these foundational areas is lost investments spent on developing solutions that are inevitably fleeting, disparate, or irrelevant, respectively.

there are existing models for measuring food safety culture as a progression and/or the propensity for preventive actions and investments *(7, 18)* and studies showing that mature food safety culture is linked to higher food safety and quality program outcomes *(13, 17)*. There may be other barriers to taking or changing actions beyond food safety culture to consider for a particular use case as well, such as regulatory and market conditions that slow or prohibit certain decisions.

The FoodSAFE-AI assesses both Food Safety Maturity and Agility to determine whether the organization's food safety program is further in its progression and enables continuous improvement to evaluate supply chain, economic, or regulatory risks. Without Food Safety Maturity and Agility, AI solutions are likely to be irrelevant, or inapplicable, due to the inability to change current practices easily or in a timely manner *(Fig. 2)*.

Spreadsheet tool

FoodSAFE-AI was implemented in a freely available macro-enabled Excel spreadsheet for users to fill in responses and view results and recommendations (https://docs.google.com/spreadsheets/d/1847rfg6RY_9KujxfxHjfSN-_r17bg-Fg3/edit?usp=sharing&ouid=114716334408598358237&rtpof=true&sd=true). The FoodSAFE-AI consists of 32 statements across the business areas and task automation stages that a user must evaluate on a 4-point scale (e.g., strongly oppose, somewhat oppose, somewhat agree, strongly agree) to provide a quantification of maturity (low, medium, high). The 4-point rating scale was specifically used to force respondents to choose a viewpoint (i.e., not remain neutral). The final scores are presented for each stage/area category and are color-coded to indicate strengths and weaknesses. An overall recommendation is suggested for the readiness in the progressively advancing task automation stages as well as how to improve maturity in each business area. The full list of statements is provided in *Appendix 2*.

APPLICATION OF FOODSAFE-AI IN EXAMPLE CASE STUDIES

The following hypothetical case studies represent opportunities for AI applications in food safety that may not yet currently exist or may be under exploration by more mature and cutting-edge companies. These case studies are presented to help the reader understand how to approach and use the FoodSAFE-AI spreadsheet.

Case #1: Immature company + automated sampling and interventions

Company A is a national fresh produce company specializing in growing, packing, and processing fresh fruits and vegetables for the fresh and ready-to-eat foods market. With a high-risk product category and increasingly challenging production environments, Company A is looking to leverage innovative technologies to better prepare for and manage food safety risks in growing and processing. They are working on digitization and IT initiatives, as well as assessing budgetary needs.

Company A is concerned that continued outbreaks and recalls associated with their industry sector suggest that current pre harvest and harvest sampling programs need more validation to ensure potential changes in microbial risks are detected prior to harvest and shipment. While their current programs are based on industry guidance and best practices, they would like to use historical data to support and inform a sampling program that adapts sampling activities to current conditions while maintaining cost and food safety commitments.

To address this problem, Company A will leverage their historical pathogen and indicator sampling data to predict the likelihood of contamination of harvest equipment and products and implement targeted product and equipment sampling. Company A is evaluating the use of an AI-based algorithm that integrates user inputs with multiple (automated and manual) data streams, analyzes contamination risks, and provides a recommendation on targeted sampling and sanitation or other interventions in relation to harvest decisions.

Company A scored high across the Information Acquisition stage and within the Food Safety area *(Fig. 3A)*. The summarized results explain how Company A's responses influence their maturity level *(Fig. 3C)*. Across the Information Analysis stage, the business accepts data automation, has a well-defined problem and a low frequency of food safety incidents due to proactive food safety management practices. However, continued investment and IT support are needed to develop interoperable systems for food safety processes and controls to automate stages beyond information acquisition. For Decision Selection, the identified problem and potential information derived from the AI solution may not be economically rational for Company A to mitigate or act upon, which limits appetite for further investment in automating decision-making processes. Lastly, the business is still skeptical about eliminating human supervision from critical stages of their operation and has therefore not yet considered any evaluation criteria or performance metrics and consequences from automation, which limit readiness in Action Implementation.

The framework recommends that Company A is ready for automation in Information Acquisition only *(Fig. 3B)*, indicating they should focus on optimizing their data capture systems before advancing to more complex automation stages. Given their current maturity profile, with strengths in electronic data capture but limitations in interoperable systems and automation readiness, Company A should concentrate on building a solid foundation in Information Acquisition while preparing for future advancement.

Recommended next steps for maximizing their current stage of automation readiness include:

1. Expand and enhance their electronic data capture systems across additional food safety and operational areas, ensuring comprehensive coverage of critical control points and environmental monitoring data.
2. Continue investment in cloud-based architecture and data standardization to ensure data reliability, accuracy, and accessibility for future analytical applications.
3. Develop data governance structures to address potential biases and ethical considerations in their data sources and analytical methods.

Specific milestones that would help Company A advance toward Information Analysis readiness include:

- Solidify the availability of dedicated IT resources and ensure they are effectively utilized for data management and standardization.
- Create and fill a dedicated role responsible for data standardization and management across locations and departments.
- Define a clear IT roadmap that outlines the technical requirements and timeline for implementing analytical capabilities.
- Establish a cross-functional data governance group with defined objectives and allocated resources.
- Develop training programs to increase organizational understanding of data analysis techniques relevant to food safety.
- Build organizational trust in AI by organizing educational sessions on how machine learning models are built and evaluated, potentially through invited speakers, conferences, or vendor demonstrations.
- Conduct a gap analysis to identify specific data streams that need to be integrated to enable effective predictive analytics.

Case #2: Maturing company + automated record review

Company B is a growing national grocery retail chain with over 300 locations across the United States. They carry a diverse product range including fresh produce, prepared foods, and shelf-stable items sourced from hundreds of suppliers. With increasing consumer demand for transparency and food safety assurances, Company B is looking to strengthen their supplier management program while managing costs and maintaining efficiency. They have a culture of innovation and leadership in adopting new technology and have supply chain partnerships to support introducing new processes.

A

Your Scores

	Organizational Buy-In & Business Problem	IT Support & Data Acumen	Food Safety Maturity & Agility	Total
Information Acquisition	10	12	7	29
Information Analysis	6	7	7	20
Decision Selection	8	3	7	18
Action Implementation	4	1	9	14
Total	28	23	30	

B

OVERALL RECOMMENDATION

Information Acquisition	Ready
Information Analysis	Not Ready
Decision Selection	Not Ready
Action Implementation	Not Ready

C

AREA	TASK STAGE	MATURITY LEVEL	RESULTS SUMMARY
Organizational Buy-In & Business Problem	Information Acquisition	High	The business fully accepts automation with minimal reliance on manual processes. A problem is well-framed, clearly understood, and prioritized as critical to solve. The business not currently managing a crisis, which allows resource allocation for comprehensive strategic planning and decision-making.
	Information Analysis	High	The business accepts fully automated information analysis. A food safety problem is apparent and the business has already explored other solutions, resulting in a need for new approaches and technologies.
	Decision Selection	Medium	The business accepts automated decision selection but still require human supervision. The business somewhat agrees on the value of AI/ML in accelerating advancements in food safety and other areas. It is clear what kind of decision needs to be made regarding the specific food safety problem, and solving the problem has some level of cross-functional unit support, indicating a moderate priority.
	Action Implementation	Low	The business opposes potentially automating critical activities even with human supervision. Additionally, the business is either not aware or only somewhat aware of the evaluation criteria and potential human performance consequences from automation.
IT Support & Data Acumen	Information Acquisition	High	The business completely captures critical operational and food safety data electronically and fully utilizes cloud-based architecture for data storage and access. There is excellent access to accurate, reliable, and relevant data, and the business is completely aware of any biases or ethical considerations in their data sources and analytical methods.
	Information Analysis	Medium	The business has some dedicated IT resources available for the project and have a somewhat acknowledged dedicated role or individual for data standardization and management across locations and departments. The business is moderately aware of the specific types of data analyses needed to inform decisions.
	Decision Selection	Low	The business does not have existing interoperable systems for food safety processes and controls to enable efficient decision making. Additionally, there is no or limited acknowledgment of a dedicated role or individual in the business serving as a bridge between the food safety and data science disciplines/teams.
	Action Implementation	Low	There is no way that model results can be integrated with existing systems and data platforms.
Food Safety Maturity & Agility	Information Acquisition	High	The business experiences a low frequency of food safety incidents due to proactive Food Safety Management Systems and use of AI/ML fits within their legal/regulatory compliance standards.
	Information Analysis	High	The business is aware of food safety control challenges and familiar with AI/ML capabilities that could improve food safety. They strongly value continuous improvement and routinely review their business practices and procedures.
	Decision Selection	High	The business uses research and data to update SOPs and implement additional risk-based monitoring and corrective action programs in critical areas. They have a history of investing in infrastructure and using indicators to get early warnings that food safety risks may change and/or events may occur.
	Action Implementation	Medium	The business is somewhat comfortable taking action based on predictive indicators and has established relationships within the supply chain to collaborate externally on problems when needed. They can somewhat identify what they would do differently based on the results of implementing an AI/ML solution. The food safety problem identified and potential information derived from AI/ML solutions may be economically rational to mitigate.

Figure 3. Results from FoodSAFE-AI for Case #1 on a low maturity company seeking to automate product and environmental sampling plans with an AI-based algorithm. Based on responses to the framework statements, Company A raw scores are presented by business area and automation stage (A), resulting in an overall recommendation for automation readiness (B). A summary table (C) provides details of how their responses impact their current maturity progress in each business area and automation stage.

Company B's current supplier onboarding and monitoring processes are manual and resource-intensive, requiring food safety specialists to review hundreds of pages of documentation for each supplier and then conduct on-site inspections as needed. This process limits the ability to make quick sourcing decisions to satisfy customer and market needs. To scale, they need to streamline their manual supplier documentation review and incident response capabilities through assisted analysis of supplier certifications, audit reports, testing records, and corrective action documentation.

Company B is evaluating an AI-based document analysis system that can extract critical information from supplier documentation (PDFs, images, spreadsheets) to:

1. Automatically evaluate supplier compliance with Company B's standards
2. Flag high-risk findings from third-party audits
3. Successfully identify relevant information during food safety incidents
4. Create standardized supplier scorecards
5. Generate summaries of lengthy documents for quick review by food safety personnel

Company B scored high across both Information Acquisition and Information Analysis stages and within the Food Safety area *(Fig. 4A)*. The company demonstrated high maturity across all three business areas for Information Acquisition and Analysis, having acceptance of automation, dedicated IT resources for data standardization, and a strong food safety culture that values continuous improvement. The results summary *(Fig. 4C)* further elaborates that existing systems effectively capture and store supplier documentation



A

Your Scores

	Organizational Buy-In & Business Problem	IT Support & Data Acumen	Food Safety Maturity & Agility	Total
Information Acquisition	11	14	7	32
Information Analysis	7	9	8	24
Decision Selection	9	5	6	20
Action Implementation	6	2	11	19
Total	33	30	32	

B

OVERALL RECOMMENDATION

Information Acquisition	Ready
Information Analysis	Ready
Decision Selection	Not Ready
Action Implementation	Not Ready

C

AREA	TASK STAGE	MATURITY LEVEL	RESULTS SUMMARY
Organizational Buy-In & Business Problem	Information Acquisition	High	The business fully accepts automation with minimal reliance on manual processes. A problem is well-framed, clearly understood, and prioritized as critical to solve. The business not currently managing a crisis, which allows resource allocation for comprehensive strategic planning and decision-making.
	Information Analysis	High	The business accepts fully automated information analysis. A food safety problem is apparent and the business has already explored other solutions, resulting in a need for new approaches and technologies.
	Decision Selection	Medium	The business accepts automated decision selection but still require human supervision. The business somewhat agrees on the value of AI/ML in accelerating advancements in food safety and other areas. It is clear what kind of decision needs to be made regarding the specific food safety problem, and solving the problem has some level of cross-functional unit support, indicating a moderate priority.
	Action Implementation	Medium	The business slightly supports potentially automating critical activities and accepts full automation of action implementation with human supervision. The business is moderately aware of the evaluation criteria and potential human performance consequences from automation.
IT Support & Data Acumen	Information Acquisition	High	The business completely captures critical operational and food safety data electronically and fully utilizes cloud-based architecture for data storage and access. There is excellent access to accurate, reliable, and relevant data, and the business is completely aware of any biases or ethical considerations in their data sources and analytical methods.
	Information Analysis	High	The business has dedicated IT resources available for the project. There is a dedicated role or individual for standardization and management of data across locations and departments. The business is completely aware of the specific types of data analyses (e.g., predictive, diagnostic) needed to inform decisions.
	Decision Selection	Medium	The business has some extent of interoperable systems integrating food safety process and control data to enable efficient decision making. They also somewhat agree that there is a dedicated role or individual serving as a bridge between the food safety and data science disciplines/teams.
	Action Implementation	Medium	Model results can be somewhat integrated with existing systems and/or data platforms.
Food Safety Maturity & Agility	Information Acquisition	High	The business experiences a low frequency of food safety incidents due to proactive Food Safety Management Systems and use of AI/ML fits within their legal/regulatory compliance standards.
	Information Analysis	High	The business is aware of food safety control challenges and familiar with AI/ML capabilities that could improve food safety. They strongly value continuous improvement and routinely review their business practices and procedures.
	Decision Selection	High	The business uses research and data to update SOPs and implement additional risk-based monitoring and corrective action programs in critical areas. They have a history of investing in infrastructure and using indicators to get early warnings that food safety risks may change and/or events may occur.
	Action Implementation	Medium	The business is somewhat comfortable taking action based on predictive indicators and has established relationships within the supply chain to collaborate externally on problems when needed. They can somewhat identify what they would do differently based on the results of implementing an AI/ML solution. The food safety problem identified and potential information derived from AI/ML solutions may be economically rational to mitigate.

Figure 4. Results from FoodSAFE-AI for Case #2 on a maturing company seeking to automate review of food safety documents and records. Based on responses to the framework statements, Company B raw scores are presented by business area and automation stage (A), resulting in an overall recommendation for automation readiness (B). A summary table (C) provides details of how their responses impact their current maturity progress in each business area and automation stage.

electronically, established roles for data management exist, and a proactive food safety management system is effective at addressing food safety incidents. However, they still face challenges in the later stages of automation due to limited integration capabilities for model outputs with existing systems.

The framework recommends that Company B is ready for automation in both Information Acquisition and Information Analysis *(Fig. 4B)*, indicating they should proceed with implementing their AI-based document analysis system for supplier documentation while preparing for more advanced stages of Decision Selection and Action Implementation. To maximize the value of their current readiness level, they should focus on optimizing their existing data systems and analytical capabilities while building foundations for Decision Selection readiness.

Recommended next steps for advancing to the Decision Selection stage of automation include:

1. Establish clear criteria for when AI-driven insights should trigger specific actions in supplier management processes. This includes defining thresholds for risk indicators and creating decision trees for common supplier documentation issues.
2. Develop a governance structure for AI-assisted supplier decisions, including roles and responsibilities for oversight and exception handling. This should include representatives from food safety, procurement, and IT departments.

3. Create a phased implementation plan that gradually increases automation of decision processes while maintaining appropriate human supervision.

Specific milestones that would advance Company B toward Decision Selection maturity include:

- Design and implement a pilot program applying the AI solution to a subset of suppliers (perhaps 20%) to demonstrate value and refine processes.
- Develop standardized protocols for handling AI-flagged supplier documentation issues.
- Create and test integration points between the AI system and existing supplier management platforms.
- Establish metrics to measure the accuracy and effectiveness of AI-suggested decisions and work with subject matter experts and the solution provider to update model weights based on these validation processes.
- Conduct training sessions on interacting with the AI system, including basic prompting skills and strategies for reviewing AI-generated summaries efficiently.
- Organize educational sessions about large language models with vendors or academic experts to build organizational trust in the underlying technology.

Case #3: Mature company + horizon scanning for supply chain optimization

Company C is a leading multinational food company specializing in sourcing and supplying raw agricultural commodities and food ingredients from around the world. With a well-developed IT infrastructure and dedicated budget resources, Company C is committed to leveraging innovative technologies to enhance food safety and regulatory compliance, particularly by enabling advanced indication of potentially unknown food safety hazards and regulatory risks.

Global pandemic impacts on complex interconnected international supply chains led to production bottlenecks, food shortages, food waste, and ultimately workforce reductions. To ensure the highest standards of food safety and quality for its global operations, Company C has begun to compile data, research, and expertise to get ahead of future potential supply chain disruptions. Currently, the time and human resources available for compiling, analyzing and reacting to the volume of traditional (e.g., scientific literature, historical incidents) and non-traditional (e.g., social media, economic indicators) data sources are not sufficient for achieving continuous risk assessment and decision selection.

Company C is developing an AI-powered horizon scanning solution to visualize indicators of global food safety hazards and regulatory compliance risks and provide actionable advice. This includes a comprehensive data integration platform to collate information from diverse data sources, ML to quantify risk patterns and correlations, forecasting models to predict potential food safety hazards and regulatory risks, real-time data monitoring and alerting to capture emerging threats and changes in the regulatory landscape, and an AI agent to interpret the risk assessments and suggest mitigation strategies to address identified threats.

Company C scored high across Information Acquisition, Information Analysis, and Decision Selection stages, as well as within the Food Safety and IT Support business areas *(Fig. 5A)*. The resulting scores and overall recommendation indicated room for improvement in the Action Implementation stage in the Organizational Buy-In business area *(Fig. 5A and B)*. The summary table further elaborates on how the business is ready for automation and has identified a high-priority use case; their dedicated IT team and data owner have set a strong data foundation for building data products and adding value; and, they have a highly mature food safety program and culture of continuous improvement and investment in food safety *(Fig. 5C)*. For the desired AI-powered horizon scanning solution, Company C is ready to automatically ingest and analyze information, as well as select actions to take in response to predicted risks. Where they can continue developing is in business alignment around complete action implementation automation and development of evaluation criteria to prevent increased business risks.

The framework recommends that Company C is ready for automation in Information Acquisition, Information Analysis, and Decision Selection *(Fig. 5B)*, meaning they could proceed with implementing their AI-powered horizon scanning solution for predicting food safety hazards and regulatory compliance risks. The company's strong technological foundation and organizational support make them well-positioned to execute a sophisticated AI implementation across these three stages.

Recommended next steps for advancing to full readiness in the final stage of automation, Action Implementation, include:

1. Develop a comprehensive strategy for integrating AI-generated recommendations into existing operational workflows, focusing on creating seamless handoffs between the horizon scanning system and frontline teams responsible for implementing actions.
2. Create clear protocols for escalation and human oversight when AI recommendations trigger significant business changes, including decision matrices for different risk levels and impact scenarios.
3. Establish feedback mechanisms to measure the effectiveness of actions taken based on AI recommendations, enabling continuous improvement of the system.

Specific milestones that would help Company C advance toward Action Implementation maturity include:

- Define specific KPIs to measure the business impact of actions taken based on AI-generated insights.
- Develop a change management program to build broader organizational comfort with AI-driven action recommendations.

A

Your Scores

	Organizational Buy-In & Business Problem	IT Support & Data Acumen	Food Safety Maturity & Agility	Total
Information Acquisition	9	14	6	29
Information Analysis	7	10	8	25
Decision Selection	12	6	8	26
Action Implementation	6	3	13	22
Total	34	33	35	

B

OVERALL RECOMMENDATION

Information Acquisition	Ready
Information Analysis	Ready
Decision Selection	Ready
Action Implementation	Not Ready

C

AREA	TASK STAGE	MATURITY LEVEL	RESULTS SUMMARY
Organizational Buy-In & Business Problem	Information Acquisition	High	The business fully accepts automation with minimal reliance on manual processes. A problem is well-framed, clearly understood, and prioritized as critical to solve. The business not currently managing a crisis, which allows resource allocation for comprehensive strategic planning and decision-making.
	Information Analysis	High	The business accepts fully automated information analysis. A food safety problem is apparent and the business has already explored other solutions, resulting in a need for new approaches and technologies.
	Decision Selection	High	The business fully accepts automated decision selection and strongly agrees that AI/ML is a valuable technology that can accelerate advancements in food safety and other areas. It is very clear what kind of decision needs to be made regarding the specific food safety problem, and solving the problem is a high priority with strong cross-functional unit support.
	Action Implementation	Medium	The business slightly supports potentially automating critical activities and accepts full automation of action implementation with human supervision. The business is moderately aware of the evaluation criteria and potential human performance consequences from automation.
IT Support & Data Acumen	Information Acquisition	High	The business completely captures critical operational and food safety data electronically and fully utilizes cloud-based architecture for data storage and access. There is excellent access to accurate, reliable, and relevant data, and the business is completely aware of any biases or ethical considerations in their data sources and analytical methods.
	Information Analysis	High	The business has dedicated IT resources available for the project. There is a dedicated role or individual for standardization and management of data across locations and departments. The business is completely aware of the specific types of data analyses (e.g., predictive, diagnostic) needed to inform decisions.
	Decision Selection	High	The business has existing interoperable systems integrating food safety process and control data to enable efficient decision making. There is a dedicated role or individual serving as a bridge between the food safety and data science disciplines/teams.
	Action Implementation	Medium	Model results can be somewhat integrated with existing systems and/or data platforms.
Food Safety Maturity & Agility	Information Acquisition	High	The business experiences a low frequency of food safety incidents due to proactive Food Safety Management Systems and use of AI/ML fits within their legal/regulatory compliance standards.
	Information Analysis	High	The business is aware of food safety control challenges and familiar with AI/ML capabilities that could improve food safety. They strongly value continuous improvement and routinely review their business practices and procedures.
	Decision Selection	High	The business uses research and data to update SOPs and implement additional risk-based monitoring and corrective action programs in critical areas. They have a history of investing in infrastructure and using indicators to get early warnings that food safety risks may change and/or events may occur.
	Action Implementation	High	The business is comfortable taking action based on predictive indicators and has strong relationships within the supply chain to partner and collaborate externally on problems when needed. They have identified what they would do differently based on the results of implementing an AI/ML solution. The food safety problem and potential AI/ML solution are economically rational to mitigate in terms of cost-effectiveness and compliance with regulatory standards.

Figure 5. Results from FoodSAFE-AI for Case #3 on a mature company seeking to automate supply chain decisions based on results of an AI-based horizon scanning data platform. Based on responses to the framework statements, Company C raw scores are presented by business area and automation stage (A), resulting in an overall recommendation for automation readiness (B). A summary table (C) provides details of how their responses impact their current maturity progress in each business area and automation stage.

- Create detailed implementation playbooks for common risk scenarios identified by the horizon scanning system.
- Establish cross-functional rapid response teams trained to act on AI-identified emerging risks.
- Implement a phased rollout of automated actions, beginning with lower-risk scenarios to build organizational confidence.
- Design and implement regular simulation exercises to test the organization's ability to respond to AI-identified threats.

DISCUSSION

FoodSAFE-AI is intended to be applicable across business maturity levels and food safety problems and for use as a general compass along with broader business strategy activities and tools. Industry surveys reveal that organizations with successful AI deployments have made strategic investments in three key areas: technical infrastructure and strategy, talent development and workforce pipelines, and data management. However, despite these investments, "accessing the right data proved to be the biggest bottleneck," and most organizations expect to spend the next 1–2 years continuing to address implementation challenges (*3*). Therefore, it is generally prudent to first identify an AI vision and then develop and execute upon a 1–2-year roadmap based on an evaluation of readiness. A common alternative is to throw resources and ideas out there, engage in proof-of-concepts and pilots, and see what comes from rapid experimentation and prototyping. In either approach, the framework can evaluate both domain and technology

readiness to facilitate prioritization of projects and ensure alignment to business goals.

These featured case studies are a small subset of business situations and food safety problems based on our on-going interactions with food safety and technology leaders. The case studies illustrate AI readiness as a progression towards effective problem solving, dissected by the three business areas and the four stages of task automation. In Case #1 and Case #2, the problem was narrowly scoped to improving efficiency of information analysis while the business organization was either scaling or maturing digital and preventive food safety initiatives. These were operational applications aimed at putting more information in the hands of "boots-on-the-ground" employees to improve either the time to react/respond or the consistency of response according to standard operating procedures. Case #3 demonstrated a broader, more strategic application of AI for mid- to long-term decisions around allocation of resources or hazard identification and risk assessment. Through these case studies, readers can envision both what an AI-enabled system might look like and how FoodSAFE-AI can be used to get started.

The results of the framework across all the case studies showed that all three organizations had the highest maturity in the Food Safety Maturity and Agility area, which was somewhat expected based on the general state of the industry, but is not necessarily required for achieving readiness across the automation stages. That said, the remaining gaps were intentionally different across the three scenarios. Case #1 was limited by poor technical definition of the ML analysis required to provide a reliable and actionable output for adapting product and environmental sampling and was impacted by Company A's concern around the potential economic disincentives of generating and storing more precise contamination data. Recommendations for achieving readiness in Information Analysis in Case #1 included data standardization and governance to increase organizational definition of the desired analysis and food safety outcomes and minimize unintended business risks. Case #2 demonstrated how alignment between organizational priorities and technical capabilities resulted in readiness for addressing the identified business challenge with automating Information Analysis. Recommendations were for continued working towards the next stage, automating Decision Selection, such as investing in cross-functional teams with data acumen and streamlining supplier evaluation criteria. Case #3 was an example of an organization farther along in maturity and therefore ready for the stage of automation identified for the business problem, Decision Selection. Remaining gaps to fill for readiness in the final automation stage, Action Implementation, were business support for automation in action implementation and integrating systems to enable that. FoodSAFE-AI could also apply to other food safety and/or business problems related to ingredient quality, sanitation verification, label review, HACCP/SOP development, employee training, or any other food-safety application where data collection and analysis can be automated.

Based on their collective experience working with companies across the food supply chain, FoodSAFE-AI was developed by the authors to get food safety teams and their organizations thinking about AI applications for common goals and initiatives. The framework was tested on participants of the IAFP 2024 Marketplace. We learned through the Marketplace discussions that this tool might be incorporated into an organization's annual self-assessment for strategic planning. Knowing what questions to ask during a performance evaluation is critical to identify strengths, weaknesses, and areas for improvement to inform future business strategies. While research from other sectors provided a basis for the framework and approach, the statements and scoring methodology may require more validation to be widely applicable. In particular, readiness in an automation stage was based on having "high" maturity in all the business areas. The point thresholds for "low", "medium", and "high" maturity in each business area were based on the sum of statement scores (based on the 4-point rating scale where 4 is "high") but were different across organization buy-in and IT support, for example, due to the different number of available responses (see Appendix 2). In other words, the statements included in the framework may not be entirely comprehensive across all stage/area combinations but do provide sufficient overview for the purposes of the evaluation.

Another limitation of the proposed framework is its relatively narrow scope compared to the Parasuraman et. al. *(11)* model *(Fig. 1)* and omission of other considerations that impact the design of human-centered automated systems. The case study results demonstrated how the framework simply provides a determination of readiness for applying the four stages of automation to a food safety problem; in other words, can you begin to automate food safety tasks. The next steps in the Parasuraman model are to determine the level of automation desired/required in each stage and define and apply evaluation criteria, which would involve additional assessment within an organization; in other words, how and/or should you automate food safety tasks.

Automating food safety processes with AI faces several key barriers that may influence how an organization decides to approach it. First, building human trust in automated systems remains challenging, particularly when these systems make critical decisions or take actions based on complex data analysis that operators do not fully understand. This trust gap will require significant cultural shifts at both organizational and industry levels as companies study benefits and consequences of fully delegating food safety decisions to AI systems. Second, the legal and regulatory framework for AIis still developing. Current food safety regulations mandate

validation and verification of preventive controls and critical control points. Companies must therefore consider how to validate and continuously verify any AI system involved in making food safety decisions. This becomes particularly complex with "black box" systems like deep learning neural networks that process multiple data streams and offer little visibility into their decision-making logic. For instance, if Company C's horizon scanning AI makes an automated decision that leads to consumer illness or injury, the company could face severe consequences from brand damage to legal liability to public health impacts *(10)*. Or, Company C could discover new, previously unknown, food safety risks that could require additional management and have adverse economic impacts on its business in the short or long term (such as triggering the need for a product recall), and therefore may be disincentivized to use this technology altogether out of fear of legal, regulatory, or reputational risks *(1)*. Alexander et al. *(1)* argues that adjustments to regulations and liability costs should be considered to incentivize companies to adopt AI where it has the potential to reduce harm to society. Food safety is anecdotally non-competitive and collaborative, so as companies start to adopt automation to reduce costs and increase efficiency in food safety, others will feel compelled to follow suit. Organizations with mature food safety cultures that view automation as a strategic evolution of their business are more likely to succeed. In contrast, companies that rush to adopt these technologies without proper foundation and planning may face worse outcomes if the systems fail or produce unintended consequences.

CONCLUSIONS

Rapid developments in AI technology have increased the pressure for companies to keep up with the competition and ensure efficiency, but industry surveys continue to show that adoption is moving at the pace of organizational innovation. We encourage the food industry to get started and have developed an easy-to-use framework to help organizations drive alignment and readiness across three foundational business areas. FoodSAFE-AI is intended to be used as a self-assessment tool to drive strategic AI-automation projects in the area of food safety. The example applications for various organization types and food safety problems presented here demonstrate the mechanics of the tool and interpretation of its results, as well as provide some depiction of what future food safety systems may look like with human-centered automation. Food safety professionals should bring FoodSAFE-AI to their cross-functional business teams and provide us feedback on how it supports new technology initiatives aimed at improving food safety. Future exploration of evaluation criteria such as "human performance consequences," reliability, and cost in the automation of food safety applications should be pursued. Additionally, the legal and regulatory implications of food safety system AI automation warrant multidisciplinary research and discussion.

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APPENDIX 1

Design of human-centered automated food safety systems

The distinction between traditional automation and AI-based automation is important to clarify, as automation has been present in food manufacturing for decades through machine execution of functions—particularly those that humans cannot perform as reliably, accurately, or safely. Traditional automation, whether full or partial replacement of a function previously carried out by a human operator, includes sensors, controls, and software systems that have long supported food safety operations through automated data collection, such as continuous temperature monitoring, pH measurements, and basic environmental controls. However, AI-based automation represents a significant evolution from these established systems.

The food industry's growing interest in AI represents a progression from traditional rule-based expert systems toward predictive and prevention-based approaches. While automated information acquisition through sensors and monitoring devices has been commonplace for decades, it is the enhanced ability to analyze complex datasets and generate potentially predictive insights that has driven recent enthusiasm for AI/ML applications. This shift from reactive to predictive food safety management, supported by the emerging analytical capabilities of modern AI systems, offers the potential to identify emerging risks before they manifest, optimize intervention strategies, and enable more dynamic risk management approaches *(4)*. However, successful implementation of such systems requires that they be built upon the foundation of strong Food Safety Management Systems (FSMS), as technological sophistication cannot compensate for fundamental gaps in food safety infrastructure and culture.

Parasuraman, et al. *(11)* describe four levels of automation in their foundational research. We have contextualized these levels relative to their food safety applications and provide examples of information acquisition, information analysis, decision selection, and action implementation *(Fig. A.1)*. These food safety related levels may be useful to the user of the FoodSAFE-AI when deciding on the appropriate response selection using the spreadsheet tool.

Information acquisition

Information acquisition represents the first stage in the automation spectrum and serves as the foundation for all subsequent automation functions within food safety management systems. This initial process involves the sensing, collection, and organization of data critical for hazard detection and verification of control measures. Traditional food safety programs have historically relied on manual information gathering through visual inspections, temperature checks, and laboratory testing. While effective, these approaches face inherent limitations including sampling constraints, time delays between collection and results, inconsistency between operators, and potential human errors that can compromise food safety outcomes.

The application of automation technology to information acquisition processes seeks to address these challenges by enhancing the scope, frequency, reliability, and objectivity of data collection. Automation in this domain exists along a continuum from low to high levels, with varying degrees of human involvement. At lower levels of automation, technology primarily assists human operators while still requiring significant involvement for data collection and verification. Examples include digital temperature logging systems that replace paper records but still require manual probe placement by operators, barcode scanning for ingredient traceability where workers manually scan incoming materials, basic environmental sampling programs with automated tracking of sample locations, and simple vision systems requiring human review of captured images. In these scenarios, technology primarily supports documentation and organization of information, while humans remain responsible for most physical data collection activities and initial quality verification.

In contrast, high-level automation systems independently acquire information with minimal human intervention. Such systems, while still largely conceptual, could include continuous inline monitoring that automatically measures critical control parameters in real-time throughout production, advanced vision systems with AI capabilities that inspect complete product flows for defects or foreign materials, electronic noses and hyperspectral imaging that detect volatile compounds or spectral signatures associated with spoilage, automated environmental monitoring using

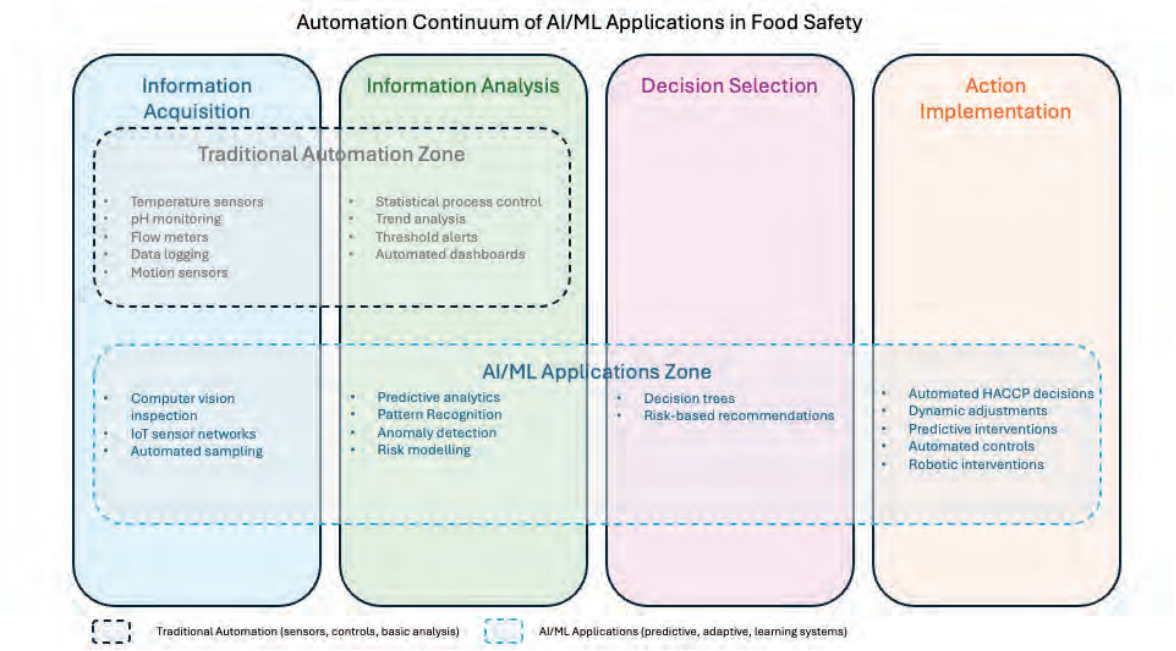

Figure A.1. Mapping traditional and AI-based food safety automation to the stages of task automation. The four stages of task automation – Information Acquisition, Information Analysis, Decision Selection, and Action Implementation – are applicable to both traditional (e.g., sensory controls, basic analysis) and AI-based (e.g., predictive, adaptive, learning systems) automated systems. Examples of traditional and AI-based applications for food safety related tasks and problems are categorized accordingly.

robotics for sample collection and processing, and IoT sensor networks throughout the supply chain that continuously monitor storage and transportation conditions. These advanced systems transform the human role from data collector to system monitor, gathering more comprehensive information while performing preliminary filtering to highlight relevant patterns.

Implementation of automated information acquisition systems requires careful consideration of several factors to ensure effectiveness. Organizations must validate automated methods against traditional approaches to ensure equivalent or superior detection capabilities, particularly for regulatory compliance. Integration with existing data management infrastructure is essential for integrated information transfer between acquisition systems and analysis tools. Ongoing calibration and maintenance protocols must be established to prevent sensor drift or equipment malfunctions that could compromise data integrity. Additionally, appropriate human oversight mechanisms should be incorporated to allow verification of system functionality and intervention when necessary, especially for high-risk processes.

The shift toward automated information acquisition carries important implications for human performance within food safety management systems. Automation affects how personnel interact with processes and information. Benefits include reduced physical workload for routine monitoring activities, freeing quality assurance personnel to focus on higher-value verification tasks, and improved detection consistency by reducing variations between different operators or shifts. However, potential challenges include attention shifts from direct observation to system monitoring, which may alter how personnel understand production dynamics, and risk of complacency if over-reliance on automated systems reduces active engagement with the production environment. Effective implementation requires balancing these factors through appropriate training programs that emphasize the complementary relationship between automated data collection and human expertise in interpreting contextual factors that may not be captured by sensors.

Information analysis

Information analysis is the second stage in the automation spectrum for food safety management systems, building upon the data collected during the information acquisition phase. This stage involves processing, interpreting, and deriving meaning from raw food safety data to identify patterns, trends, and potential hazards. In food safety contexts, effective information analysis transforms discrete data points into actionable information that support risk assessment and management decisions.

Traditional food safety programs have typically relied on manual analysis methods performed by trained personnel. Quality assurance professionals review monitoring records, laboratory reports, and inspection findings to identify deviations, evaluate trends, and assess compliance with established standards. While this approach relies on valuable human expertise and contextual understanding, it faces limitations including inconsistent interpretation, cognitive biases, limited capacity for handling large datasets, and difficulties detecting subtle patterns that emerge over time or across multiple processes.

Automation of information analysis enhances these capabilities through analytical approaches that can process larger volumes of data with greater consistency and reveal patterns that might escape human detection. Like information acquisition, information analysis automation can exist along a continuum from lower to higher levels of technological sophistication and human involvement.

At lower levels of information analysis automation, technology primarily augments human analytical capabilities while leaving significant interpretive responsibilities to trained personnel. Examples include basic statistical process control systems that calculate means and standard deviations for critical parameters but require operators to interpret the significance of trends or outliers; simple dashboard visualizations that organize monitoring data by location or time but rely on humans to identify concerning patterns; threshold-based alert systems that flag individual measurements outside preset limits but depend on human judgment for contextual evaluation; and basic trending tools that graph historical data for parameters like sanitation effectiveness or temperature control, but require personnel to draw conclusions about systemic issues. These systems organize and process information in ways that make human analysis more efficient but preserve the central role of human expertise in interpretation.

High-level information analysis automation, by contrast, applies computational methods to independently process, integrate, and interpret food safety data with minimal human involvement. While still largely conceptual, advanced examples could include multivariate analysis systems that automatically identify correlations between process parameters and finished product testing results; predictive analytics algorithms that forecast potential control failures before they occur based on early warning signals across multiple data streams; automated pattern recognition that identifies emerging clusters of consumer complaints; machine learning systems that continuously adapt their detection thresholds based on historical outcomes; and integrated systems that automatically cross-reference environmental testing data with production records to identify potential contamination routes. These types of sophisticated systems could not only process information but also provide interpretations and prioritize findings based on their potential significance.

The implementation of automated information analysis requires careful consideration of analytical validity and practical utility. Similar to non-automated systems, food safety professionals must evaluate whether automated analysis methods have been properly validated for the specific food matrices, processing environments, and hazard profiles relevant to their operations. Integration capabilities with existing data management systems are required for ensuring complete datasets are available for analysis. Transparency in analytical methodologies becomes increasingly important as complexity increases, ensuring that quality assurance teams understand the basis for automated interpretations and can verify their appropriateness. Additionally, food safety professionals must consider how automated analysis interacts with existing hazard analysis and critical control point (HACCP) systems, preventive controls, and other regulatory requirements.

Automation of information analysis carries significant implications for human performance and organizational capabilities in food safety management. Benefits include enhanced ability to analyze much larger datasets than would be feasible manually; improved consistency in applying analytical criteria; the ability to detect subtle patterns across time, products, or facilities; and the potential to shift from reactive to predictive food safety management. However, challenges include potential overreliance on automated interpretations without appropriate critical evaluation; skill degradation if food safety professionals become less practiced in analytical thinking; difficulties in translating computational findings into practical interventions; and the risk of "automation bias" where human operators give excessive weight to computer-generated interpretations even when contradicted by direct observations.

Effective implementation of information analysis automation will require balancing technological capabilities with human expertise. Food safety management systems benefit most when automated analysis serves as a complement to, rather than replacement for, human judgment. Training programs should emphasize how to critically evaluate automated findings, when to question system interpretations, and how to integrate computational insights with contextual knowledge that may not be captured in datasets. Information visualization plays a particularly important role in effective human-automation interaction, transforming complex analytical outputs into formats that facilitate human understanding and decision-making.

Decision selection

Decision selection represents the third stage in Parasuraman's automation spectrum for food safety management systems, building upon the information acquisition and analysis phases. This stage involves selecting from among decision alternatives based on analyzed food safety data.

Traditional food safety programs have relied on human decision-makers who apply their expertise, regulatory knowledge, and contextual understanding to select appropriate actions when deviations occur. While valuable, this approach can be limited by inconsistent selection decisions between personnel, cognitive biases that affect risk perception, decision fatigue during complex incidents, and delays when specialized expertise is required.

Automation of decision selection exists along a continuum from low to high levels. Lower-level decision selection automation could support human decision-makers while preserving their authority, including systems that present regulatory compliance options during deviations, provide decision matrices for common corrective actions, generate risk-ranked recommendations for addressing environmental testing positives, and offer procedural guidance during product hold situations. These systems can enhance human decision selection without replacing judgment.

Higher-level decision selection automation could independently select responses with minimal human involvement, such as expert systems that apply decision trees to determine product disposition, AI algorithms that develop customized corrective action plans, autonomous systems that select interventions when critical limits are exceeded, predictive algorithms that select preventive measures before failures occur, and integrated systems that select appropriate process parameter adjustments based on multivariable inputs. Based on this framework, such systems could transform the human role from active decision-maker to approval authority or monitor.

Implementing decision selection automation requires careful consideration of regulatory compliance, decision transparency, appropriate authorization levels, and mechanisms for human override. The shift toward automated decision selection carries significant implications for human performance, including benefits like improved consistency and faster response times, alongside challenges such as skill degradation, overreliance, and potential loss of situational awareness. AI based decision selection systems - especially higher-level decision automation - could also carry legal and liability risks that need careful consideration.

Action implementation

This stage involves the actual execution of selected actions or interventions to control food safety hazards. Traditional food safety programs typically rely on human execution of corrective actions, preventive measures, and process adjustments. Quality assurance and food safety personnel, production supervisors, and maintenance technicians manually implement interventions such as product holds, equipment sanitization, process adjustments, and verification activities. While this human-centered approach provides flexibility and adaptability, it faces challenges including execution inconsistency, physical limitations, dependence on staff availability, and potential delays between decision and implementation.

Automation of action implementation can exist along a continuum from low to high levels, where lower-level action automation primarily assists human operators while preserving their control over execution. Examples could include semi-automated cleaning systems requiring operator initiation and monitoring, assisted product diversion mechanisms that redirect non-conforming items for additional human operator review, and partial automation of documentation that generates records of completed actions. These systems reduce physical workload while preserving human oversight of critical operations.

Higher-level action implementation automation could independently execute interventions with minimal human involvement, such as fully automated clean-in-place systems that implement sanitization procedures without operator intervention, robotic systems that physically segregate or dispose of rejected materials, integrated process control systems that automatically adjust critical parameters to maintain food safety limits, automated allergen control measures that implement changeover procedures, and self-correcting environments that maintain temperature, humidity and other parameters within specified ranges. Such systems can transform the human role from action performer to process supervisor.

Implementing action automation requires consideration of mechanical reliability, fail-safe mechanisms, appropriate override capabilities, and integration with verification systems. The shift toward automated action implementation carries implications for human performance, including reduced physical workload and fatigue, improved execution consistency, and faster response times, alongside challenges such as potential loss of hands-on process knowledge, reduced situational awareness, and the risk of over-reliance on automated systems.

APPENDIX 2

Framework statements by business area and automation stage

Key: IQ = Information Acquisition, IA = Information Analysis, DS = Decision Selection, AT = Action Implementation

Business area: organizational buy-in

1. The business supports potentially automating critical activities. (AT)
2. To what extent does the business accept automation of information acquisition. (IQ)
3. To what extent does the business accept automation of information analysis. (IA)
4. To what extent does the business accept automation of decision selection. (DS)
5. To what extent does the business accept automation of action implementation. (AT)

6. The business is aware of evaluation criteria and potential human performance consequences from automation. (AT)
7. The business sees AI/ML as a valuable new technology that can accelerate advancements in food safety and other areas of the business. (DS)

Business area: business problem characteristics

8. The business has identified a well-framed problem fit for data science. (IQ)
9. It is clear what kind of decision needs to be made regarding the specific food safety problem identified. (DS)
10. Solving the problem is high-priority and has cross-functional unit support because the business has experienced the consequences of not addressing the problem. (DS)
11. The business has explored other solutions and acknowledges the need for new approaches and technologies. (IA)
12. The business is not in a crisis mode, and there is an interim solution available while AI/ML development occurs. (IQ)

Business area: IT support

13. The business is capturing critical operational and food safety data electronically. (IQ)
14. The business information is stored in and accessed with cloud-based architecture. (IQ)
15. The business has dedicated IT resources available for the project. (IA)
16. There are existing interoperable systems that integrate data regarding food safety processes and controls to enable efficient decision making. (DS)
17. Model results can be integrated with existing systems and data platforms. (AT)

Business area: data acumen

18. For the problem identified above, there is accurate, reliable, and relevant data available. (IQ)
19. There is a dedicated role or individual in the business that owns standardization and management of data across locations and departments. (IA)
20. There is a dedicated role or individual in the business that can serve as a bridge between the food safety and data science disciplines/teams. (DS)
21. The business is aware of the specific types of data analyses (e.g., predictive, diagnostic) needed to inform decisions. (IA)
22. The business is aware of any bias or ethical considerations from the identified data sources and/or methods of analysis. (IQ)

Business area: food safety maturity

23. The business has developed proactive Food Safety Management Systems. (IQ)
24. The business is aware of food safety control challenges and is familiar with AI/ML capabilities that potentially improve food safety. (IA)
25. The business uses research and data to update SOPs and implement additional risk-based monitoring and corrective action programs in critical areas. (DS)
26. The business invests in infrastructure and uses indicators to get early warning that food safety risks may change and/or events may occur. (DS)
27. The business is comfortable taking action based on predictive indicators. (AT)
28. The business has strong relationships within the supply chain to partner/collaborate externally on problems when needed. (AT)

Business area: food safety agility

29. The business values continuous improvement and the routine review of business practices and procedures. (IA)
30. The business can identify what they would do differently based on the results of implementing an AI/ML solution. (AT)
31. Use of AI/ML fits within the business' legal/regulatory compliance standards. (IQ)
32. The problem identified and potential information derived from an AI/ML solution relate to an area of the business that is economically rational to mitigate (e.g., actions taken based on the AI/ML solution are cost-effective or do not create additional regulatory risk). (AT)