Industry 4.0 and Food Safety

Guidance Document

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SSAFE

Table of Contents

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Executive Summary

Goal of this document:

To help determine what Industry 4.0 means in the context of food safety and suggest good practices, through case studies, on how Industry 4.0 may best be deployed by the food sector to strengthen food safety.

Definition:

The Fourth Industrial revolution is ***"characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres"***. Industry 4.0 relies on a group of disruptive technologies including but not limited to internet of Things (IoT), Big Data, blockchain, advanced analytics, machine learning, artificial intelligence (AI), simulation, virtual reality (VR) and augmented reality (AR), and advanced robotics and automation.

Target audience

- ✔ Food companies of all sizes, across the supply chain, frontrunners and newcomers to Industry 4.0
- ✔ Food safety and quality departments to better understand the Industry 4.0 benefits
- ✔ Top management, supply chain / procurement, digital / IT departments to understand the benefits of integrating food safety in the digital strategy from the start
- ✔ HR departments to get a sense of which employees will be impacted
- ✔ Suppliers of the food industry to develop digital solutions matching the interest of their customers
- ✔ Intergovernmental and governmental agencies
- ✔ Certification / auditing organizations

Potential food safety benefits of Industry 4.0

- Strengthening traceability and transparency capabilities
- Providing process assurance through repeatable processes delivering products with consistent and predictable quality and food safety
- Allowing parametric release of products
- Bolstering predictive capabilities to enhance the resiliency of products and process
- Supporting the continuous improvement of food quality and safety

These benefits are enabled by real-time monitoring of product and processes, connected data, risk-based modeling connected across the value chain, automation as well as the right mindset and right behavior.

Industry 4.0 adoption by the food industry in still in its infancy

Digitization

- Shifting from paper and manual based processes to digital process
- Allows to detect incident, take corrective actions and understand what happened quicker.
- Level of adoption: low to medium

Digitalization

- Integrating systems and data flows from the various data sources
- Enable to predict when and where an incident might occur in the future.
- Level of adoption: low

Automation

- Prevent the incident through automatic adaptation of critical parameters
- Level of adoption: very low

Culture

- Change the business culture and models from reactive, to preventive, to proactive and finally predictive
- Level of adoption: very low

Call to action for a cross-industry initiative

- Need for harmonizing standards to allow interoperability at the company level and across the supply chain
- Need for data ownership and business models to incentivize data sharing by food companies with health agencies and the entire food sector

Industry 4.0 in the context of food safety

Adoption level

Low → High

Core principles	Digitalize data and automate data collection		
Farming	**Automated farm management systems** to record practices	**Precision agriculture:** Uwe of remote sensing technologies and sensors to : • Detect crop and water contamination • Manage pest that might result in food outbreak	
R&D and Procurement	**Electronic certificate of analysis** to validate ingredients from suppliers	**IoT (location, temperature)** to prevent break in the cold chain and food fraud	
Processing and Manufacturing	**Real-time inline measurement** to detect issues more rapidly, control 100% of the production (e.g. temperature, humidity, gas presence, water quality, pesticides residues, air quality monitoring, material wear, usage time for machinery, etc.)	**Error-proof workflow through digital and interactive SOPs** which ensure operators have up-to-date information, prompt operators to take preventive or corrective actions and make them accountable by asking them to log these actions	**Augmented reality** (for new operators training, external contractors for maintenance and audits) to limit exposure of persons and products to unnecessary risks
Distribution, Logistics and Retail	**Digitalized management of stocks and expiration date of products**	**IoT sensors** to help prevent break in the cold chain and fraud QR codes, (EAS) tags and RFID tags for traceability **Smart labels** to detect food spoilage Smartphone-based **biosensors** for on-site rapid pre-screening of food quality and safety parameters	
Restaurants and Catering		**Smart kitchen equipment** monitoring time and temperature processes	**Error-proof workflow through digital and interactive SOPs** **AI and predictive analytics applied to managerial controls**
Regulators, Certification Bodie s and Auditors	**Paperless trade** (electronic SPS)		**Augmented reality** (for new operators training, external contractors for maintenance and audits) to limit exposure of persons and products to unnecessary risks
Food sector as a whole	**End-to-End traceability** to allow fast root cause analysis and selective recall as well as prevention of food fraud (through technologies such as RFID, Blockchain, etc.)		
	Utilization of shopper cards in case of recalls		

Industry 4.0 in the context of food safety

Adoption level

Low → High

Core principles	Leverage data to speed up and enhance root cause analysis, contain incidents to a small scale	Predict higher risks to better allocate resources	Automate processes to increase repeatability and limit human errors
Farming		Anticipate which farming commodities are at higher risk of contamination	Rate controllers to limit inappropriate use of chemicals
R&D and Procurement	Dashboard to effectively filter by ingredient type, supplier, locations, year to enable analysis and identify patterns	Predict which ingredients / suppliers are at risk using data from supplier performance, external data on emerging threats, consumer Silico models for safety-by-design	Automatic prevention of receiving the ingredient if not compliant
Processing and Manufacturing		AI-powered predictive maintenance Sanitation effectiveness monitoring Ingredient sorting AI-powered predictive diagnostics Connected pest control Digital twin (emerging technology)	Automation (robots/ cobots) to reduce the risk of exposing the product stream to foreign materials and increase process repeatability
Distribution, Logistics and Retail	Smart sensors to measure environmental factors influencing the quality of food products to detect food spoilage	Identify the teams, plants or sites that require additional program/ training/auditing to improve their hygiene and food safety practices	Digital sensor food labels that enable the shift from static to dynamic shelf life
Restaurants and Catering		Customer feedback monitoring through social media to identify and predict potential food safety issues	Automation to reduce exposure to human handling
Regulators, Certification Bodies and Auditors		Moving from preventative audits scheduled regularly to predictive audits scheduled when needed based Predictive analytics based on social media and historical data from inspection bodies to allocate their resources to inspect higher risk organizations	
Food sector as a whole		Data sharing platforms using anonymized data from food safety incidents	

Recommendations to effectively apply industry 4.0 in the context of food safety

1

Define a unique Industry 4.0 company-wide strategy with a multidisciplinary team, including food safety

Common pitfall: *lack of digital strategy or multiple approaches in parallel limiting holistic analytics, leading to competitive outcomes, and useless investment*

- Advocate for a change of mindset **from food safety being a cost to food safety being an investment** for continuous improvement
- Have the food safety function involved in the Industry 4.0 strategy to increase adoption in food safety, provide context on what exist, demonstrate their needs, and **ensure the safety of new Industry 4.0 technologies**

2

Invest in skills and talents

Common pitfall: *thinking that digitalization means less employees*

- Define **the skill needs and gaps** in your strategic roadmap including data analytics and statistics
- Make **budget available to upskill and train the current workforce** (food safety and quality professionals including line and lab operators) on the benefits for them and food safety
- Shifting to a digital mindset is a must
- Make sure employees read data provided by equipment properly and take the right corrective actions in response to an alert

3

Define critical pain points and associated use-cases and POC

Common pitfall: *generating data and testing technologies without knowing how to use it and what it means*

- **Pain points must be specific with a clear** quantified business value and impact
- Prioritized technologies must address multiple pain points (risk mitigation, cost, productivity, talent retention and industry attractivity, etc.) to increase ROI

4

Think about scaling up early at the pilot/ design phase

Common pitfall: *one-time isolated project that doesn't advance beyond the pilot stage*

- **Ensure data quality and anticipate data integration** (data governance) to allow interoperability from different systems at the company level
- Be mindful of the **quality of the communication network** for new technology deployment
- Favor **modular design**

5

Collaborate outside of your organization

Common pitfall: *underestimating the complexity and time to achieve ambitious results when facing the prolific offer of "miracle" solutions on the market*

- Carefully select your **providers** by looking for partners that:
  - Offer **collaborative solutions and a POC** tailored to your specific problem.
  - Can **adapt to the existing digital infrastructure** (i.e. interoperability)
  - Can **customize** the functionality of digital applications
  - Have a **global coverage** to enable standardized data across different locations
  - Have **expertise in their field to help with data analysis**
- Engage **external stakeholders** (typically suppliers from whom you need data) early on
- Proactively reach out to your **B-to-B customers** to know how you can support their industry 4.0 strategy corrective actions in response to an alert

6

Implement a cybersecurity culture and data ownership culture

Common pitfall: *lack of cybersecurity culture in F&B companies*

- Invest in a **data management solution that secures the access rights to data** and prevents unauthorized personnel and organizations to access and modify data
- Invest in **traceability to mitigate cybersecurity risk** to enable fast root-cause analysis and selective recalls

1

Purpose of this document

The goal of this publication is to help determine what Industry 4.0 means in the context of food safety and suggest good practices, through case studies, on how Industry 4.0 may best be deployed by the food sector to strengthen food safety.

This paper is envisioned as a tool for food companies of all sizes, across the entire supply chain, anywhere in the world, whether they are newcomers, movers or challengers in Industry 4.0. This document can be used by:

- Food Safety and Quality departments to better understand how Industry 4.0 can be used within the organization and what potential benefits it can deliver
- Top management, supply chain/procurement and digital/IT departments to understand the benefits of integrating food safety in the digital strategy of the organization
- Human resource departments to get a sense of which employees could be impacted and how

This paper can also be of benefit to suppliers to the food industry to develop digital solutions that match the interest of their customers, government agencies and certification/auditing organizations.

2

Background to Industry 4.0

After mechanization (steam engine), industrialization (introduction of electricity and production lines), and automation (electronics and robotics), the World Economic Forum defined the Fourth Industrial Revolution as being "characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres". Industry 4.0, initially applied to the manufacturing industry, relies on a group of disruptive technologies including but not limited to:

- **Connectivity, data, and computational power:** cloud-based systems, Internet of Things (IoT), Big Data, blockchain
- **Analytics and intelligence:** advanced analytics, machine learning, artificial intelligence, simulation
- **Human–machine interaction:** virtual reality (VR) and augmented reality (AR), advanced robotics and automation
- **Advanced engineering:** additive manufacturing

However, the Fourth Industrial Revolution is about more than just technology-driven change. It is an opportunity to help everyone, including leaders, policymakers and people from all income groups and nations, to harness converging technologies in order to create an inclusive, human-centered future.[1]

1. Fourth Industrial Revolution | World Economic Forum (weforum.org)

3

Current challenges in food safety

The food industry faces many challenges such as:

- Supply chain disruptions caused by inflation, geopolitical uncertainty, the impact of climate change, pandemics, labor shortages, etc.
- Transparency and traceability requirements from consumers, customers, suppliers and regulatory bodies to have access to information quickly and readily. To protect public safety, governments have intensified their regulatory scrutiny, leading to higher costs for companies. Regulators are looking for more transparency, more food traceability and real time data during inspections. Industry desires to have real time data to make immediate decisions related to food safety and quality. Consumers trust in the food and beverage industry has declined since 2019 and restoring trust requires breaking through the information barrier and building trust across the full food ecosystem.[2]
- The food sector is a highly competitive industry with low margins which requires cost effective processes. [3]

In the meantime, food and beverage manufacturers must ensure that all ingredients in products are listed accurately, and that the food is not compromised by contaminants, either physical (e.g. metals or plastics), chemical or biological (e.g. harmful microorganisms).

- Undeclared allergens are a serious safety issue for consumers impacted by food allergies. One of the main causes of undeclared ingredients is a discrepancy between the recipe and what happens on the production line. Paper-based work instructions without automatic validation can lead to supply chain failures and manufacturing errors to go unnoticed (error on weighing and dispensing ingredients, labels out of sync with ingredient/recipe change, cross contamination/cross-contact, etc.). Often, the root cause of labelling errors remains unknown.

2. Edelman's 2022 Trust Barometer. https://www.edelman.com/trust/2022-trust-barometer/food-beverage
3. Standard operating procedure

- Metal contaminants are typically linked to machine failures. Traditionally, machine data is only collected at the end of the production day, rather than in real-time, resulting in a lag and potential release of compromised batches.[4]

- Preventing bacterial growth of biological hazards (such as Listeria, E. Coli, and Salmonella) often means maintaining environmental parameters (temperature, humidity) to tight tolerances not only during manufacturing but also during storage and transportation. Variability in raw materials, new recipes, change of transporters, power or machine failures all present risks and require monitoring and analysis of these variables.

- Chemical hazards cover agricultural residues such as pesticides, environmental contaminants (e.g. heavy metals), veterinary medicines, toxins, banned food ingredients and process contaminants. Precision agriculture to limit the use of pesticides along with monitoring and predicting failures (especially along the entire supply chain) are key to reduce the risk of chemical hazards.

Food safety is a 24/7/365 challenge, requiring constant monitoring of the multiple inputs, human factors, and other food safety risks across the company. However, it is facing many hurdles such as:

- manual processes to monitor and identify food safety risks
- data from multiple sources
- unstructured data shared through different formats
- manual logging of external data, which can be prone to errors
- limited testing of products and processes
- human handling, which can increase food safety risks

Therefore, a key challenge for the food industry to solve is how to deliver safe food over a reasonable time at an optimal cost through highly effective and trustworthy processes that ensure 100% of products are safe.

4. Fabio Tiviti. Maintenance 4.0 — Minimising Food Recalls, And Maximising Trust. https://www.apfoodonline.com/industry/maintenance-4-0-minimising-food-recalls-and-maximising-trust/

4

Potential benefits of Industry 4.0

Industry 4.0 can help food and beverage businesses address this challenge by:

- **Strengthening traceability and transparency capabilities.**
  In a context of evolving transparency, food and beverage companies must be able to provide information quickly and readily to consumers, suppliers and regulatory bodies - especially for high-risk products. In the "New Era of Smarter Food Safety: FDA's Blueprint for the Future" [5], the U.S Food and Drug Administration (FDA) emphasizes the importance of adopting digital tools for food and beverage manufacturers to survive a recall. The modernization of the food safety system is intimately linked to the Industry 4.0 journey, which can provide the needed tools.

- **Providing process assurance.** Delivering products with consistent and predictable quality and food safety through capable, repeatable processes.

- **Allowing parametric release of food products.** Put food products on the market without waiting for the results of analysis while being certain that the products are safe.

- **Bolstering predictive capabilities of food safety issues and enhancing the resilience of food products/processes.** Taking preventive and corrective action early on reduces the cost of investigation, avoids putting production on hold, reduces product loss, and limits/avoids additional costs of recalls and market withdrawals.

- **Supporting continuous improvement of quality and food safety.**

Industry 4.0's benefits go beyond producing safer food and include improved cost-effectiveness, better efficiencies, and increased sustainability thanks to a more effective use of resources and reduction of waste.

These benefits are enabled by real-time monitoring of product and processes, connected data, risk-based modeling connected across the value chain, automation, and a mindset that results in the right behaviors of people.

5. US regulatory authority overseeing approximately 80% of food products including production and manufacturing, packing, distribution and service to consumers.

5

Adoption of Industry 4.0 by the food industry

The adoption of Industry 4.0 technologies across the food industry is in its infancy. Despite a lot of news in 2019 the adoption of Industry 4.0 technologies was between 20% to 40% for the food and beverage industry while sectors such as oil and gas had an uptake over 80% and automotive of 45 to 60%[6].Therefore, there is an opportunity for the food sector to learn from these industries' experience to transition more quickly towards Industry 4.0 technologies.

There are four maturity levels in the implementation of Industry 4.0 to achieve better food safety:

Digitization (shifting from paper and manual processes to automating data collection and digital processes) which allows businesses to detect incidents, take corrective actions to contain anomalies, keep disruptions to a small scale and understand what happened quicker (root cause analysis).

Digitalization (integrating systems and data flows from the various data sources) which will enable to predict when and where an incident might occur in the future. Predicting high-risk sites/suppliers/ingredients is key to better allocation of resources for oversight, testing, auditing, and maintenance.

Automation which increases repeatability, limits human error and ultimately prevents incidents through automatic adaptation of critical parameters.

Culture which changes the business mindset and models from being reactive to being preventive, proactive and ultimately predictive.

Currently, the food industry is embracing digitization. Predictive analytics is still in its infancy and is struggling with data integration, limiting the ability for food businesses to truly leverage its full potential. Automation to prevent incidents is applied only in a very localized way and rarely deployed to leverage data as an additional source of revenue.

6 Pearly Neo. Flexibility, food safety and productivity: Three proven benefits of Industry 4.0 for the food and beverage industry – Foodnavigator-asia.com

6

Industry 4.0 along the food supply chain

6.1 Farming

The problem:

Crops are at risk of getting contaminated due to:

- biological factors such as viruses, bacteria, and parasites, which can pose great food safety risks. Such food can cause various negative health conditions, especially when it is consumed raw.
- chemical residues such as those found in the edible plants, when MRLs are exceeded.
- fungal toxins that arise form crop diseases that have not been adequately dealt with in the field.

How it can be solved through Industry 4.0:

Precision agriculture to detect contamination and reduce the use of inputs

Precision agriculture relies, among other things, on the use of drones and onboard GPS systems, smart sensors (soil, livestock) and various connected objects (agricultural robots, smart agriculture for greenhouse lighting). Precision agriculture can help to improve food safety by:

- **Avoiding inappropriate application of chemicals** which reduces the level of residues found on food crops. For example, rate controllers are meticulously designed to curb the presence of chemical elements such as fertilizers and pesticides in liquid or granular form. Their function is to keep a check on the speed of sprayers used across the field. These tools also monitor the rate and pressure of liquid chemicals and make real time adjustments during the time of application.
- **Knowing that water used to grow the crop is safe thanks to real-time sensor monitoring** which is part of the FDA's objectives in the New Era of Smarter Food Safety Blueprint. As a first step, the FDA's Agricultural Water Assessment Builder[7] is a user-friendly tool designed to guide farms for a pre-harvest agricultural water assessment specific to their unique conditions in an interactive format.
- **Using remote sensing technologies and satellites to detect crop contamination.** For example, the US Department of Agriculture applied remote sensing technology and spatial information to detect food contamination.[8]
- **Using sensors and lasers for pest management.** For example, to identify the presence of wild boar which might have been at the origin of E. Coli outbreaks.

7. FDA. Agricultural Water Assessment Builder. https://www.fda.gov/food/food-safety-modernization-act-fsma/agricultural-water-assessment-builder
8. Heuvel, Wouter Hoenderdaal, Hans J.P. Marvin, Big Data in food safety- A review, Current Opinion in Food Science, Volume 36, 2020, Pages 24-32, ISSN 2214-7993, https://doi.org/10.1016/j.cofs.2020.11.006
https://portal.nifa.usda.gov/web/crisprojectpages/1023313-remote-sensing-applications-in-crop-and-animal-agriculture.html

Automated farm management systems for end-to-end food traceability

Transparent records of farm management practices thanks to precision agriculture technologies (maps of material applications, bar-coded or RFID-tagged produce, online entries into record-keeping programs, etc.) can support an end-to-end food traceability system.

Predictive analytics to prevent contamination

Predictive analytics is used by companies to anticipate which farming commodities are at higher risk of chemical contamination or to anticipate water contamination (by pesticides or heavy metals) based on historic data.
Predictive analytics will also play a critical role in the near future to model the impact of climate change on agriculture by answering questions such as:

- Can we link weather, soil, price and agricultural practices to model, forecast and predict contamination in crops (e.g. mycotoxins, heavy metals)?
- Can we link prolonged rainfall and animals being wet to risk of increased STEC shedding due to animal stress?

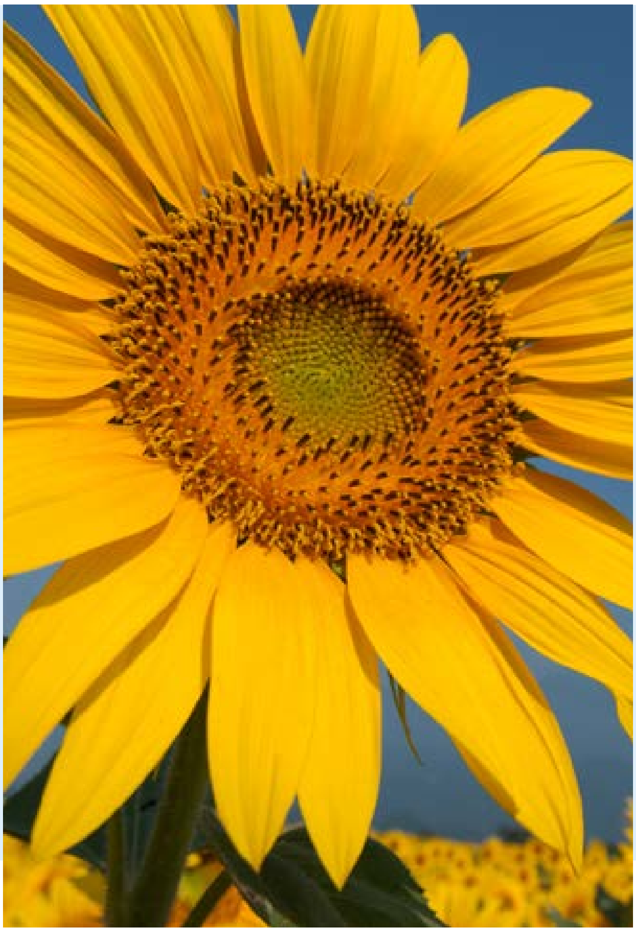
Case study

The FDA and NASA have developed the Geographical Information Systems (GIS) risk program to assess environmental risks (heavy rains, temperature, soil available water storage, landscape features, etc.) and for microbial contamination of crops (E. coli, Salmonella, L. monocytogenes) prior to harvest. Farmers can predict when and in which part of the farms microbial contamination is more likely to occur and intervene early to minimize cross-contamination. The FDA has also used machine learning to establish a predictive model for the survival of E. coli in soil where untreated animal manure is applied.

6.2 R&D and Procurement

The problem:

Raw materials and procurement are the first steps in food manufacturing and therefore impact the safety of food products, especially in the context of a globalized supply chain. Traditionally, food businesses adhere to codes, guidelines and standards and perform audits and inspections to ensure their ingredients meet the relevant food safety requirements. Limited resources do not allow food companies further up the supply chain to inspect every single batch coming from their suppliers. Furthermore, paper-based documentation and/or unstructured data (e.g. in spreadsheets or PDF documents) limit the ability for data sharing and trend analysis.



How it can be solved through Industry 4.0:

Automating data collection

As a first step, automating data collection enables the ability to demonstrate that raw materials meet specifications and possibly allow suppliers to share alerts quicker with food companies. It also enables food companies to switch from results in spreadsheets to dashboards where information can quickly and effectively be filtered by ingredient type, supplier, location, year, etc. which in turn enables rapid analysis and identification of patterns.

Internet of Things (IoT) can help to proactively track temperature-sensitive and perishable food ingredients and products in real-time as they move throughout the supply chain thanks to IoT temperature sensors and GPS tracking.

Electronic Certificate of Analysis (COA) systems allow food companies to receive COAs from suppliers and, through interaction with the food company's own system, help the food company avoid receiving products that do not meet specifications and/or critical parameters for food safety.

Predict which ingredients/suppliers are at risk

Once data collection is automated, companies can leverage data on supplier performance as well as external data (emerging risks and hazards through recalls, supplier news, scientific publications, etc.) to assess where safety risks exist in the supply chain and prevent incidents from occurring by focusing time and effort on higher-risk ingredients and suppliers.

They can also leverage AI and machine learning to assess consumers perception of these food safety risks through social media scanning. These practices offer advantages to both suppliers and manufacturers/brand owners because it enhancing mutual trust and fosters collaboration. They facilitate the adjustment of processes and joint problem-solving efforts, leading to reduced costs associated with rework or product rejection, even before COAs are provided.

Safety-by-design

Beyond suppliers, predictive modelling can be applied to ensure "safety-by-design". A digital twin is a digital representation of a real-world product, system, or process. Below are two examples:

- A food research company uses predictive modelling to ensure product safety. Initial microbial risk assessments are conducted in silico to identify microbes of concern and make informed decisions on preventative measures and product preservation strategies. The model looks at processing conditions, the intrinsic properties of the product and the intended storage and consumption conditions.
- A technology provider offers digital twinning software to predict migration and permeation through packaging materials which can affect food safety. The digital twin can help to develop innovative packaging that complies with food regulations in a faster, more resource effective way.

6.3 Processing/manufacturing

Industry Survey

According to a 2019 survey on Quality 4.0, survey participants consider predictive quality, machine vision quality control, and digital standard operating procedures (SOPs) to be the most important examples in manufacturing.9 In addition to the top three examples selected by participants, other significant manufacturing applications included automatic root cause analysis, machine-to-machine communication to enable self-adjustment of parameters, and real-time process simulations.

Automated record keeping and inline measurement

The problem:

Traditionally, the food industry relies on manual processes (periodic manual record keeping, spreadsheets, finished product testing, etc.) to monitor and identify food safety hazards and risks. Data has is collected from multiple sources (microbiological, chemical testing, and physical testing of ingredients and finished product) and then shared through different formats depending on the source. Manual logging of these external data is prone to error. Furthermore, for some metrics only a limited number of products and processes can be tested, product release be delayed for several days while waiting for the test results to come back, or the product is released based only on the basis of process controls.

9. BCG. Quality 4.0 Takes More Than Technology. 2019 survey of executives and quality managers from 221 companies representing 18 producing industries in major sectors: consumer goods, industrial goods, and medical technology and pharmaceuticals. https://www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology

How it can be solved through Industry 4.0:

Automated record keeping

Automated record keeping leads to more standardization, saving both time and money on compliance and facilitate root cause analysis when issues arise. Steps can be small like simply adding sensors and data logging solutions, but they deliver many of the benefits of Industry 4.0 without the need to replace existing equipment.

Case study

A major global retailer uses Bluetooth-enabled handheld devices to measure the temperature of their rotisserie chicken. Prior to deploying these devices these checks had to be logged manually on paper or a computer but now all the information is automatically uploaded to a web-based recordkeeping system. In one month, government health inspectors visited their stores to check the temperature of their rotisserie chickens 10 times. In that same period, the retailer also worked with a private inspection firm to check their rotisserie chickens in stores about 100 times. Through the new system, they were able to record 1.4 million internal cooking temperatures of rotisserie chickens. The large amount of data enables the retailer to rapidly detect undercooked chicken.

Inline environmental monitoring and testing increases food safety and hygiene thanks to IoT, alert systems and smart industrial robots endowed with cameras and inspection systems. In-line and at-line IoT sensors help detect safety issues in food processing more rapidly than traditional methods and react before the contamination spreads. Robots and automatic systems can control 100% of the production instead of just a few samples. Sensors incorporated in machinery and equipment collect data regarding temperature, material wear, moisture level, usage time, etc. IoT in food safety still appears to be in its early development though.

Below are some examples of how metrics and technologies can be used for in-line monitoring:

- **Temperature, humidity and location** are the most measured variables.[10] Other examples of commonly measured variables include Brix, pH, CO2, conductivity, etc.

- **Machine vision quality control technologies** (x-ray, thermal imaging, MRI, etc.) can provide a variety of real-time data on the shape, color, biological characteristics, presence of foreign bodies as small as 1.5 x 1.5 mm, packaging integrity, label inspection, empty and filled bottle inspection, and more. Compared with manual inspection processes, machine vision technologies are less expensive to use and more effectively verify quality or detect quality issues at early stages of the production process.

10. Yamine Bouzembrak, Marcel Klüche, Anand Gavai, Hans J.P. Marvin, Internet of Things in food safety: Literature review and a bibliometric analysis, Trends in Food Science & Technology, Volume 94, 2019, Pages 54-64, ISSN 0924-2244, https://doi.org/10.1016/j.tifs.2019.11.002.

- **Pathogen environmental monitoring technologies** can monitor water quality for bacterial contamination through Rapid Microbiological Methods (RMMs). For example, a commercial online microbial-testing system can be used to measure presence/absence of E. coli, thermotolerant coliforms (fecal coliforms) and total coliforms in drinking water supplied to the food industry. Inline miniaturized testing for pathogens is still in its infancy but will be quite advanced in ten years, and its implementation will probably be complete within twenty-five years.

- **Real time data-generating testing technologies** such as torque tester, Titrators, net content, PET material distribution, air quality monitoring, etc.

- **IoT-based solutions to detect pesticides residues** especially in fruits and vegetables are under development by researchers.

Error-proof workflow through digital interactive SOPs

The problem:

Multiple human factors can influence operator compliance with food safety requirements such as limited knowledge, inadequate training, carelessness, lack of accountability, and insufficient resources. Traditionally, training of operators is done through paper processes or hands on demonstration and standard operating procedures (SOPs) are typically paper based, which does not ensure that the appropriate food safety actions will be taken by operators (e.g. testing). Similarly, alerts generated by automated alert systems or text/phone calls from testing laboratories do not guarantee that the relevant corrective actions are implemented. Also, if employee turnover is high there is also the risk of losing past knowledge.

How it can be solved through Industry 4.0:

The goal is not to replace operators but to help them do their job better and strengthen food safety. Digital and interactive SOPs prompt operators to take preventive or corrective actions and make them accountable by asking them to log their actions. It helps operators perform daily tasks and complex processes, ensures that workers have the most up-to-date instructions to keep up with recipe changes, and allows them to act quicker when food safety incidents may occur. Digital systems asking operators to provide inputs can help pass the information to new operators and provide better visibility to the food safety team because they can consult the logs. For example, automatic validation applied to weighing scales can limit discrepancies between the recipe and the actual weighing of ingredients, which can lead to mislabeling and product recalls. These interactive systems are also applicable to audit/quality inspections and preventative maintenance, mapping locations to investigate, logging observations and providing corrective actions. Currently mostly available on mobile platforms such as phones or tablets, these interactive systems will be soon embedded in augmented reality devices.

Prediction of food safety issues in manufacturing

The problem:
Real-time data and interactive SOPs enable manufacturers to spot anomalies and disruptions before they become major issues, minimizing the impact and cost of the incident. However, the ultimate goal will be to anticipate the incident and prevent it from occurring.

How it can be solved through Industry 4.0:
Analytics can transform the connected environmental monitoring data to inform when, for example, conditions arise that can compromise food safety. A major aspect of the FDA's plan (The New Era of Smarter Food Safety Blueprint) is to use predictive analytics to help find root causes of problems and avoid identified risks. Digital twinning to predict the behavior of a machine under changing conditions or the spread of pathogens in a facility are currently mainly at a research stage and will therefore not be further described in this document.[11] Below are some applications of sensors (potentially combined with AI) to improve the safety of food processing.

11. The UC Berkeley Center for Next Generation Food Systems. Digital Twin and Machine-Learning for Optimized Pathogen Contact-tracing, Sanitation and Decontamination. https://food-manufacturing.berkeley.edu/pathogen-contact-tracing-sanitation-and-decontamination/

Application 1: Predictive Maintenance

- Beyond preventative maintenance that can be enhanced by the digitalization of data, predictive maintenance can also enable the comprehensive assessment of the condition of equipment and predict why and/or when it may fail. This can be done using sensors that are ideally connected to an asset management system through IoT and analyzed through artificial intelligence and machine learning.

- The most common predictive maintenance technologies in food manufacturing include:
  oil analysis instruments for hydraulic systems, compressors, conveyor belts, and refrigeration systems to detect oil build-up or leakages

- temperature sensors for electronic equipment to detect overheating or imminent fusing

- vibration analysis sensors for early detection of potential malfunction combined to computerized maintenance management systems (CMMS)

- It is important for food safety because equipment failure, misalignment or vibration can lead to metal or plastic contamination. Predictive maintenance software can also help identify the appropriate cleaning intervals to minimize contamination.

- Improved operation and maintenance of HVAC systems and their filters, pressures, etc. through real-time information on their performance helps minimize food safety risks.[12]

Case study

A food maintenance service company was able to predict specific equipment issues and down time with a near 100% success rate, enabling them to replace fixed maintenance intervals partially with data-based predictions obtained from sensors measuring temperature and vibration profiles. The standard annual preventive maintenance practice can be scheduled for when it is needed rather than when it is timed. Beyond operational efficiency, it limits the risk of contamination caused by machine failures and hygiene issues due to the volume and frequency of external contractors on-site.

Application 2: Sanitation Effectiveness Monitoring

- Imaging and sensing devices can be used to identify food residue on equipment that has the potential to contaminate an entire product line such as commercial equipment that uses ultrasonic sensing and optical fluorescence imaging assessed by AI algorithms to detect the presence of food residues and microorganisms inside food processing equipment.

- As of today, cleaning in place has already reached a high level of incident prevention through automatic adaptation of critical parameters such as the concentration of cleaning chemicals or the duration of cleaning processes. It can also be applied to wash water for the cleaning of sensitive products (e.g. tomatoes, lettuce) to adjust chemical concentrations in real-time.

12. Heating, ventilation, and air conditioning systems

Application 3: Ingredient Sorting

- A food company used to rely on manual/visual detection and inspection of their raw ingredients which was a considerable workload. Machine vision by itself was not practical in terms of precision or cost as it meant setting sorting definitions for every ingredient. For example, the color of potatoes can vary in ways that have nothing to do with safety or freshness. A company has successfully completed a pilot with AI-enabled inspection on diced potatoes used in baby food. The key benefit is to get safer ingredients faster than ever to boost production that used to be limited by raw ingredients inspections.
- Data science companies are also working on leveraging microbiological biomes to predict the appearance of pathogens in raw materials and processed foods.
- Artificial biomimetic technology (E-noses, E-tongue, and computer vision) are intelligent methods based on changes in smell, taste and appearance that are under investigation to detect real-time food spoilage. Chemical sensors can accurately distinguish various food odors supported by an AI algorithm with access to a database of potentially dangerous odors.

Application 4: Predictive Diagnostics

- A prototype using deep learning neural networks and high-definition cameras to detect dangerous bacteria and harmful particles in water has been developed by a technology company. Drinking water can be seen at a microscopic level with real-time detection.
- Data science can be applied to the enormous amount of data generated by new molecular technologies (Whole Genome Sequencing, metagenomics, etc.) to identify the root cause of contamination and design customized diagnostic kits and sanitation practices to enable proactive prevention. For example, sequencing can identify the presence of disinfection tolerance genes, and this information can be used to design effective sanitation strategies. Metagenomics can be used to look for specific risk factors by mapping microflora throughout a facility, in various hygienic zones, at various times, and during various seasons. Although reviewing and trending data from environmental monitoring pathogens is not new, data science makes it easier, faster and more thorough.[13]

Application 5: Connected Pest Control

- Rodent and insect pests are known to be vectors of foodborne illness pathogens. A hygiene company has designed continuous remote pest monitoring devices allowing to track the activity of pests and connected rodent traps. When the pest management provider recognizes rising rodent pressure in specific locations (and cross-reference risk factors to help determine root cause, whether structural, seasonal, etc.), they can immediately activate prescriptive service to mitigate pest risks — before the rodent issues create a food safety incident that harms consumers or damages the business' reputation. This connected trap strategy has been shown to improve pest findings by 300% and helped drive an 80% reduction in overall pest activity.

13. Wendy Bedale. Environmental Controls: Emerging Technologies and Predictive Analytics to Address Complex Sanitation Challenges. https://www.foodprotection.org/files/food-protection-trends/jul-aug-22-bedale.pdf

Automation and Augmented Reality (AR)

The problem:

A large contributor to foodborne illnesses is poor hygienic practices.[14] The more the product is exposed to human handling, the higher the food safety risk. This safety risk might be increased by high staff turnover in a context where it can be difficult for companies to hire due to a lack of skilled labor.

How it can be solved through Industry 4.0:

Robots and automation favor a reduction in manual work and an increase in supervision and coordination activities. The use of robots and automation in the riskiest processes such as carcass cutting increases employee safety and reduces the risk of human error. Collaborative robots, or cobots, are a new generation of robots made to work alongside humans, under limited supervision[15]. Cobots/robots reduce the risk of exposing the product stream to foreign materials such as animal hair, lint and perspiration, which are not fully removed by donning a gown and cap. As individuals handle products less, the risks of human-borne pathogens like norovirus or Hepatitis A are also reduced. Automatic calibration also helps to reduce food safety incidents.

Several groups can be targeted by Augmented Reality (AR) to reduce contamination risks.

- New operators can be provided with an immersive training program using AR, bringing them close to the activity that they will be undertaking without risking contamination during the learning process.

- External contractors that may not be fully familiar with food processing hygiene good practices can, with the help of AR, be directed remotely to fault-find/maintain/repair a significant majority of the equipment failures that would be experienced.

- Audits can also be (partially) performed remotely as seen during the Covid-19 pandemic and is likely to continue as a hybrid format combined with automated collection of data during inspections and predictive analytics to define and prioritize when and where audits should be performed.

14. Diana Bennett, Tim Noone and Sam Tinsley. Factory of the Future – Industry 4.0 and Hygienic Design. Food Safety Magazine. https://www.food-safety.com/articles/1748-factory-of-the-future-industry-40-and-hygienic-design
15. FAO. Thinking about the future of food safety. https://www.fao.org/3/cb8667en/cb8667en.pdf

6.4 Distribution, logistics and retail

Logistics and shelf life

The problem:

Many things can happen to the product (exposure to light, inappropriate handling, cold chain breakage, food fraud, etc.) that can impact the safety of the product or change its shelf life.

How it can be solved through Industry 4.0:

As a first step, **automating data collection and IoT sensors** (temperature and light sensors along with GPS tracking) can inform on potential incidents likely to impact product safety.
At the product level, QR codes, EAS (Electronic Article Surveillance) tags or RFID tags can track products as they move through the supply chain, confirm that products have not been tampered with, and allow quick identification of products in a supply chain in case of contamination. **Smart sensors** are being included in food packaging to measure environmental factors influencing the quality of food products (temperature, humidity, gas concentrations including C2H4, O2 and CO2, pH) to detect food spoilage in sensitive products such as meat, fruits, etc.

Startups are developing and trialing **digital sensor food labels that enable the shift from static to dynamic shelf life**. These solutions that could be commercialized within three years would allow sending consumers reminders of how much shelf life is left in their packaged food and indicate whether it is still safe to eat the product. Food manufacturers could also use the shelf-life data to choose the best shipping routes to optimize freshness. In addition, if a product is spoiling faster than it should or if the packaging has been tampered with, the manufacturer can immediately identify and fix the problem.

Smartphone-based biosensors could also help to simplify on-site rapid pre-screening of food quality and safety parameters as well as wireless data transfer to servers of relevant stakeholders as explored by the FoodSmartPhone ETN European project.[16] It could even allow consumers to become part of food safety testing, as demonstrated by OrganaDx of MyDX which is already available for consumers to screen for pesticides in fruits and vegetables.

16. Smartphone analyzers for on-site testing of food quality and safety

Customer feedback monitoring

Customer feedback monitoring through social media to identify and predict potential food safety issues is still in its infancy but several companies are looking at it. The main limitation appears to be the difficulty of correctly interpreting natural/casual language inputs.

Case study

A global food retailer continually monitors and analyses more than 67 million pieces of customer feedback a week. When identifying customer feedback that mentions a food safety concern, their system immediately classifies it as a signal of a potentially serious safety issue. Once the company identifies the product that may be unsafe, they immediately remove it from sale while they investigate. The retailer also uses customer feedback to train predictive systems that proactively assure safety for their customers. Through their machine learning tools, they calculate the relative distance between products they sell and those that have received a safety-related concern. Where a positive correlation exists, the retailer predicts the severity of the potential issue and likelihood of a similar occurrence.

6.5 Restaurants and Catering

The problem:

According to the Centers for Disease Control and Prevention (CDC), restaurants and other retail establishments remain the most common nexus of foodborne illness outbreaks[17]. One of the biggest risks is linked to thermal processing of raw proteins (cooking or freezing/cooling temperatures not being respected).

How it can be solved through Industry 4.0:

Food service companies might be in a better position to invest in Industry 4.0 technologies, thanks to their higher margins compared to food manufacturing. Like food processing businesses, restaurants and food service companies can leverage **digitalized management of their stocks and the expiration date** of their products, environment inline monitoring (e.g. smart kitchen equipment capable of automatically monitoring time and temperature processes[18]), and **automation and customer feedback monitoring on social media**.

Another key aspect is **managerial controls**. Primarily, this can take the form of error-proof workflow through digital interactive SOPs (as detailed previously). Food businesses can analyze, manually or in real time through IoT and AI, adoption patterns and compliance percentages, and correlate the data with recalls and nonconformances. The results can help to identify the teams, production facilities or sites that require additional educational programs or training to improve their hygiene and food safety practices. Most often, monitored food safety practices include handwashing, temperature checks and wearing of appropriate personal protective equipment (hats, masks, etc.). The aggregation of audits results from the company, regulators and third-party certification bodies can also be leveraged. Beyond simple managerial controls, predictive analytics can be applied to

17. FDA. New Era of Smarter Food Safety. https://www.fda.gov/food/new-era-smarter-food-safety
18. FDA. New Era of Smarter Food Safety. https://www.fda.gov/food/new-era-smarter-food-safety

the entire company data to prioritize the internal audits and focus the audits and limited resources on higher-risk sites. Instead of preventive audits scheduled regularly, predictive audits are scheduled when needed based on key indicators (not only food safety indicators, but also purchasing indicators such as the number of pest control products bought or human resources data where a high turnover can represent a higher risk).

Case study

A Shanghai municipal health agency uses cameras and AI technology to ensure that restaurants comply with local food safety laws, in particular wearing hats and masks. After analyzing the images, the software detects any violation of the specified food safety laws and extracts screen images, with violation details, that the health agency can then review.

https://www.prnewswire.com/news-releases/remark-holdings-announces-seven-figure-artificial-intelligence-contract-for-facial-and-object-recognition-technology-to-ensure-food-safety-in-shanghai-china-300526557.html

6.6 Benefits for the food sector as a whole

End-to-end traceability

The problem:

The negative publicity of a food recall and food fraud not only impacts the trust in the company that is directly involved but in the entire food sector. Traceability is essential when a product needs to be recalled. The records involved in moving food through the supply chain are still (in part) paper-based. This, along with insufficient data identifying the product along the supply chain, creates an inability to rapidly track and trace food[19]. There is a need to demonstrate to the consumer and regulators that the private sector has control over the food system. The FDA is asking companies to focus on digitizing data and industry will be expected to transfer data within 24 hours, in the event of a recall of certain food products.[20]

How it can be solved through Industry 4.0:

Advanced traceability can be achieved thanks to the use of QR codes, RFID chips, smart packaging (See 6.4.1 \), geo-traceability (See 6.3 \), sensors (6.1.1 \), blockchain, etc. Effective traceability requires structured data acquisition, with accessible and searchable data that can be used across different companies along the supply chain (i.e. is interoperable). Even for food retailers working with hundreds of thousands of suppliers, tracking information using blockchain becomes a matter of seconds or minutes instead of days or weeks using previous methods. This will help reduce response time when contaminated foods are discovered as well as make it possible to perform selective and targeted recalls.

Companies usually start by applying these technologies to products intended for a sensitive population (e.g. new-born babies, people with allergens) or expensive and food safety sensitive products (fresh meat, seafoods, fruits and vegetables, etc.). Finally, consumers with known allergens can benefit significantly from QR Codes etc. to help them quickly identify potential allergens in packaged foods.

19. FDA. New Era of Smarter Food Safety. https://www.fda.gov/food/new-era-smarter-food-safety
20. GFSI. Advancing supply chain visibility to reach new levels of food safety. https://mygfsi.com/blog/advancing-supply-chain-visibility-to-reach-new-levels-of-food-safety/

Several companies and service providers are already testing or offering RFID based solutions. RFID seems to be the direction taken by the U.S food industry to improve traceability. For example, for meat, farmers can attach an RFID tag to each animal's ear or hoof. From there, farm workers use readers to track the vaccination records, general health, and movement of all livestock. In the slaughterhouse, staff can add information such as the name of the slaughterhouse, name of the butcher, time of the animal entering the house, and final weight. After the animal is processed, they'll be put into a small package on which there is a 1D or 2D barcode consistent with that of animal's ear tag. Handheld readers then enable workers to monitor meat as it travels along the production line, helping monitor the hygiene of a processing facility, recording the grade of meat, levels of impurities, temperature levels, and other information pertaining to quality control. This information is stored in a database where every package of meat is associated with the exact farm and animal from which it came. If a food quality or food safety problem does arise, this data allows for a targeted recall of compromised products only, which can be removed from the supply chain immediately. Meat can not only be traced back to its source, but it can also be tracked to every restaurant or supermarket where it may be sold. RFID traceability system has been applied to meat, dairy, vegetables (tomatoes, lettuce) bakery products, beverages, sushi, pasta and coffee based on our literature review.

There are currently only a few blockchain-based pilot applications in the food industry, several of them applied to seafood. As the product moves through the supply chain, origin, custody, and conditions data is selectively shared among consortium partners. The entire chain can collaborate in real-time with agility and certainty. Food companies can also give access to some of this information to the consumer to increase transparency and trust. This might become a requirement to supply leading food and retail companies in the future.

However, it raises the question of the compatibility with other blockchain-based tracking systems. A consortium with major food suppliers has been set up to apply blockchain technology to the food supply chain to improve food safety and transparency and to detect sources of contamination quickly. Over 300 authorized suppliers and buyers have joined the network, accounting for millions of packed food products. In addition, data integrity is key: poor and/or incomplete data (See 7.4 \) is not compatible with blockchain.

Case study

A chain of restaurants has faced several food safety issues with thousands of people sickened, lost sales and a multi-million government fine. The company is testing radio-frequency identification technology (RFID) at one of its distribution centers and 200 restaurants to improve its traceability and inventory systems. The RFID labels will be used on meat, dairy and avocados from five suppliers. Ingredients being tested will have RFID-enabled case labels that are scanned with RFID readers, which complement existing scanners in restaurants. Some systems can send alerts on products nearing expiration.

Case study

A food retailer has been tracing 500 items (fruits and vegetables, meat, dairy, and baby products) thanks to blockchain, artificial intelligence (AI) and IoT technology, using sensors and RFID tags to enable the recording of real-time data as food items travel through the supply chain. The solution helps trace not only the final product but also the ingredients. Working with numerous suppliers, the retailer now requires blockchain implementation from many of them.

Case study

A food safety traceability platform, ChinaTrace, has been developed by the Chinese government mainly for national food manufacturing companies to enable traceability, anti-counterfeiting, and oversight. ChinaTrace is used by governments, enterprises, consumers, and third-party institutions. ChinaTrace collects food traceability data from 31 provincial platforms, integrates the data and relies on barcode traceability.

The utilization of shopper card data to improve response to outbreaks is also envisioned by the industry. For example, the FDA is exploring strategies for how we can better utilize available shopper card information during outbreak and recall events to better target contaminated food and speed up the recall process to prevent additional foodborne illnesses.

Data sharing platforms to increase predictive analytics and root-case analysis.

The problem:

Big Data is generated by precision agriculture, connected factories/logistics/restaurants, social media, public health databases, e-commerce tools, etc. Big Data is therefore a prerequisite to move from lagging indicators (number of food safety incidents, product compliance, certification results, consumer complaints) to leading indicators (social media ratings, product design, audit compliance, etc.) to reduce food safety risks significantly. Predictive analytics using machine learning requires training on large datasets. The larger the dataset, the better the predictability. However, despite the enormous potential, the use of Big Data remains challenging due to data ownership, interoperability and accessibility[21] .

How it can be solved through Industry 4.0:

- **By creating public-private "data trust"**, banks of large volumes of data generated by industry that can be accessed for analytical work by health agencies, regulators, trade associations, Non-Governmental Organizations (NGOs) and others to further strengthen preventive approaches and develop outreach programs for the industry. The FDA wants to start such an initiative by working with stakeholders to create a "leafy greens data trust[22]."

- **By having data sharing platforms** compiling safety incidents including food counterfeiting from several companies in an anonymous way to identify issues early on with a given ingredient, act faster by increasing testing and vigilance in the entire food value chain, and speed up root cause analysis.

21. Donaghy JA, Danyluk MD, Ross T, Krishna B, Farber J. Big Data Impacting Dynamic Food Safety Risk Management in the Food Chain. Front Microbiol. 2021 May 21;12:668196. doi: 10.3389/fmicb.2021.668196.
22. FDA. New Era of Smarter Food Safety. https://www.fda.gov/food/new-era-smarter-food-safety

Current limitations and call-to-action at the industry level

Like the health industry, to date each food company tends to develop its own data system, isolated from the supply chain. In the best-case scenario, they integrate the data from their suppliers and diagnostic/audit companies and data sharing goes up to the consumer. Despite the opportunities of continuous improvement, experiments of data connectivity between regulators and the private sector are rare and success stories remain to be written.

The first limitation is interoperability. Datasets are coded differently even though interoperability will be critical to make sense of the data generated by Industry 4.0 tools. For example, it means that you still need manual entry to transfer data from one system to another, resulting in an important time lag and potential errors. In the absence standardization and harmonization, the food industry is many years away from interoperability. Therefore, there is a strong need for harmonized standards to make data comparable and transferable.

Another limitation is how to interpret data that isn't generated by a food company itself and how reliable the outcome will be. GS1 standards, in particular Electronic Product Code Information Services (EPCIS), structures collected data and enables interoperability between traceability systems, so the data is meaningful to all trading partners[23]. However, complete and accurate data feeds from all stakeholders is a key requirement for the success of such initiatives.

For data sharing, using a shared platform with regulators and competitors comes with a serious question for companies: how much access to data should be provided to external partners and oversight bodies? The fear of penalties that may come from sharing data with regulatory bodies is real and remains a concern that needs to be addressed.

Finally, the investment barrier is significant and might prevent smaller businesses from implementing these technologies even though their data is key for the rest of the supply chain. Therefore, identifying the bottom line value of data and/or the potential for data as an additional revenue source for the food industry might also help lift the investment barrier.

23. GFSI. Advancing supply chain visibility to reach new levels of food safety. https://mygfsi.com/blog/advancing-supply-chain-visibility-to-reach-new-levels-of-food-safety/

6.7 Regulators, Certification Bodies and Auditors

The problem:
With limited resources, it is impossible for regulators and inspection bodies to control every single organization or shipment. The exchange of regulatory documents and certificates is crucial in international trade transactions, but governments and industry partners are actively seeking solutions to move goods across borders more quickly and efficiently.

How it can be solved through Industry 4.0:
Predictive analytics based on social media or historical data from inspection bodies can be used by regulators to allocate their resources on higher risks food companies or shipments. Several projects at different levels (cities, states, national) have demonstrated that predictive analytics increases the likelihood of identifying food safety issues by 25%-30% and speeds up the identification of these issues (see case study). It also allows to speed up the review of lower risk organizations[24].

Sanitary and Phytosanitary (SPS) certificates ensure compliance with tolerance limits for residues, restricted use of substances, labelling requirements related to food safety, hygienic requirements, and quarantine requirements[25]. **Paperless trade through electronic SPS** can lower trade transaction costs (up to 33% in the Asia-Pacific region), generate export gains, reduce export time (by up to 44% in the Asia-Pacific region), improve food security against contamination, decreases fraudulent certificates and increases transparency.

24. Canadian Institute of Food Safety. New Data Technology to Identify Food Safety Risks in Real Time https://www.foodsafety.ca/news/new-technology-uses-data-identify-food-safety-risks-real-time
25. STDF. Facilitating safe trade: going paperless with SPS e-certification. https://standardsfacility.org/sites/default/files/e_Cert_Briefing_note_EN.pdf

7 Recommendations

The maturity, product mix, business complexity and technological know-how of a food business will greatly impact on where to start the Industry 4.0 Food Safety journey. Frontrunners might be challenged by challenges related to technology and data: outdated systems, fragmentation, or data integrity and quality. Business newer to Industry 4.0 will likely first need to deal with the lack of a digital strategy, quality culture, and outdated systems[26].

Smaller businesses tend to be more flexible and open to change and implementation of Industry 4.0 food safety technologies and systems in part because the necessary investments are smaller (even though the overall cost barrier remains high). Larger food businesses might have more financial resources and technical know-how, but the required investment tends to be much larger due to the scale of the business and can be slowed down by internal bureaucracy.

There is no unique business profile to successfully implement Industry 4.0 and there are several good practices to make sure food businesses' investments are optimized, no matter the size or maturity level of the business.

26. BCG. Quality 4.0 Takes More Than Technology. 2019 survey of executives and quality managers from 221 companies representing 18 producing industries in major sectors: consumer goods, industrial goods, and medical technology and pharmaceuticals. https://www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology

7.1 Define a unique Industry 4.0 strategy with a multidisciplinary team

Even if Industry 4.0 is a great opportunity for each function of the organization, there should be only one Industry 4.0 strategy. Having separate approaches of digitalization per function carries the risk of:

A lack of data alignment.

Taking advantage of the full potential of Industry 4.0 requires a complete change of mindset. Industry 4.0 can enable the identification of unsuspected root causes of food safety issues on the condition that data is fully integrated. This requires true interconnectivity of data across different functions (food safety and quality, production, maintenance, HR, finance, supply chain, procurement, etc.). However, be prepared: fundamental process standardization gaps between functions cannot be resolved only through digitalization.

Reduced competitiveness.

Making sure that all key business functions are part of the Industry 4.0 strategic development process reduces the speed of decision making and can result in conflicting outcomes between operational efficiency and food safety.

Ineffective investments.

A multidisciplinary team is needed to maximize the investment in new technologies because digitalization has the potential to inform investments in a holistic manner. For example, should the food business invest in a single, faster production line or two slower lines of production? The first option might be less costly upfront (CapEx) but in the long run food safety incidents could make it more expensive than the second option (OpEx). Furthermore, it is easier to start with new production lines rather than retrofitting existing ones, but this is not necessarily more cost effective. Hence designing for the future, taking into account the long-term use of a new production line and in turn aligning this to the long-term financial and operational objectives of the business is fundamental. Hence the need for multidisciplinary teams in the Industry 4.0 strategy.

Food safety should not be considered as a cost but as an investment, and therefore should have a seat at the Industry 4.0 strategy development table!

The strategy needs to be adjusted over time as technologies, data and supply chains continue to evolve rapidly. Having the food safety function as part of the cross-functional team overseeing Industry 4.0 projects, even if these projects do not directly address food safety, is key.

- Even if the pilot is not food safety centered it might spark thinking about what is possible, especially when it comes to leveraging data in new ways.

- When a food safety pilot is envisioned, the food safety function is key to provide context to design outcomes that they can leverage and take advantage of.
- New Industry 4.0 technologies (especially automated cooking, production and service equipment) might not always be designed with food safety in mind. As a result these new technologies can introduce new risks to the business. Therefore it is important to evaluate them from a food safety perspective too.

7.2 Invest in skills and human talent

Shortage of digital skills and talent is one of the greatest challenges for companies trying to implement Industry 4.0 across all sectors. Developing a strategic roadmap should allow companies to define the required skills and assess the skills gap. For Industry 4.0, skills in data analytics and statistics are fundamental to enable the correct interpretation of generated data.

Beyond recruiting new digital talents, it is also key to upskill and train the current workforce and shift to a digital mindset. It is crucial to educate food safety and quality professionals, including line operators and laboratory staff, and make sure they focus on the data generated by Industry 4.0 technologies to help identify hazards and risks, predict emerging issues, and act fast to avoid any food safety or quality issues from happening in the first place. A digital mindset refers to a way of thinking that embraces and leverages digital technologies to solve problems, to innovate, and to adapt to the fast-paced changes in today's world. This mindset values continuous learning, experimentation, collaboration, and openness to change. It involves understanding the potential of digital tools, being aware of emerging trends and opportunities, and using data-driven decision-making. People with a digital mindset are typically comfortable taking calculated risks and seek ways to improve processes or products with the support of technology.

Digitalization does not mean headcount reduction. Having the right technology with the right controls is not enough. Training must ensure that operators and food safety professionals are able to read data provided by the equipment properly and take corrective actions accordingly. Industry 4.0 technology should be seen as a solution that helps food safety professionals and operators do their job better rather than replace them. It is an opportunity to demonstrate how attractive the food industry can be to work in and drive talent retention, especially in the current context of labor shortages in North America and Europe.

To achieve this companies must make budget available for training. Not all employees need to be digital experts, but the training must ensure that all staff, and in this context food safety professionals specifically, have a good understanding of the potential benefits that Industry 4.0 technologies can offer. The extent of the resources needed should not be underestimated. According to a BCG survey, best-in-class companies dedicate 10% to 20% of their quality management FTEs to Quality 4.0 initiatives[27].

27. BCG. Quality 4.0 Takes More Than Technology. 2019 survey of executives and quality managers from 221 companies representing 18 producing industries in major sectors: consumer goods, industrial goods, and medical technology and pharmaceuticals. https://www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology

7.3 Define critical pain points and conduct pilots

One of the most common pitfalls is generating data and testing technologies without knowing how to analyze or use the results. Installing sensors everywhere is not a silver bullet, the provided data must be useful and usable.

Identify safety-related pain points in operations that can be addressed using Industry 4.0 technologies

- Start with mapping what exists, what the key food safety drivers are, and define the associated metrices, controls and reporting needs. Stopgap measures to prevent simple mistakes from happening early in the process are especially relevant.

- Survey the entire supply chain (both up and down, beyond 1-up and 1-down, and especially with B2B customers) to understand what their expectations are now and in the future regarding the implementation of and compliance with Industry 4.0 technologies.

- The pain point must be as specific as possible to help narrow the scope. As an example, reducing foodborne illness is not specific enough. Validating high risk items in transit is more specific and enables more targeted action and investment.

- Describe how pain points threaten the business and prioritize them. Being able to quantify the business value and impact is key. Top priorities should be technologies that address multiple pain points (risk mitigation, return on investment, productivity, talent retention, brand protection, etc.) to maximize the value generated by Industry 4.0 technologies.

Identify solutions resolve the prioritized pain points and conduct proof-of-concept pilots

- In each pilot, a multidisciplinary team should use agile methods to quickly develop a minimum viable solution and improve it through rapid iterations. Solutions successfully tested and adjusted in pilots can then be rolled out across the business where appropriate.

- Measure the effectiveness over time and adjust where appropriate, while keeping an eye on other new, emerging technologies that become available or more affordable.

7.4 Scale up

The timeframe for implementation of an Industry 4.0 strategy can range from a couple of years to several decades depending on how the strategy is integrated in the overall digital strategy. It is important to align with multiple stakeholder groups and set expectations regarding the depth, breadth, and speed of the implementation goals. Industry 4.0 is not a project but a long-term journey.

One of the biggest challenges to execute Industry 4.0 strategies is “pilot purgatory”. Many companies tend to execute a one-time improvement in a specific part of the organization using industry 4.0 technologies and then struggle to scale the opportunities across the business. Pilots must be aligned with the overall strategy to ensure long term value generation and success.

- Define what resources are needed to achieve the goals (budget, skills, timing, etc.)
- Ensure data quality: most of the effort goes into preparing the data (getting the data out of the process control systems or databases, understanding what the data means, making sure valuable information is not lost or compromised, etc.)
- Identifying potential issues in the company’s data architecture and IoT infrastructure that could block the possibility of scaling up by making sure that all technologies that are brought in will provide data that can be interconnected and standardized to use across the entire business
- Use data from HR (e.g. training records, staff turnover, incentive programs) or purchasing departments to identify potential risks and truly leverage the potential of predictive analytics
- Data connectivity across the company requires an efficient governance of data and investment in technologies and processes
- Assess if the envisioned technologies can be deployed at their point of use (not all sites might have connection to share data in real time)
- Favor modular design that enables future adaptation in a cost-efficient manner
- Standardize data models (e.g. use ontologies for the domain as a whole and for specific subdomains) internally and externally to enable interoperability
- Support and encourage industry-wide standardization by sharing positive experiences and outcomes from implementing Industry 4.0 technologies to improve food safety

7.5 Collaborate with others

Currently, there is a dramatic increase in technology solutions promising extraordinary results but Industry 4.0 is a journey that will take time. Carefully select providers by looking for partners that:

- Offer a collaborative project and a proof-of-concept that is tailored to address a specific problem
- Can adapt to the digital infrastructure that is already in place, or at least provides long term open access and interoperability
- Can customize the functionality of digital applications to the existing digital infrastructure - buying sophisticated solutions and trying to make them fit with internal processes is often more costly than investing in a generic solution and customizing it
- Provide global coverage for those who need to have standardized data across different regions of the world
- Have the right expertise in their field

When new technology is purchased, it is important to ensure the business understands how it works and what the generated data means. Larger companies need to have a digital team that understands what is behind the technology (concept) and how it can benefit the business. Also, engage external stakeholders from whom information is needed but that the business does not control directly. For example, monitoring of temperature control incoming ingredients.

7.6 Implement a cybersecurity and data ownership culture

Farms and food manufacturers are experiencing ransomware attacks that can result in multimillion dollar losses. These attacks can also negatively impact consumer safety by causing major issues to both sanitation and traceability within manufacturing plants. The University of Minnesota's Food Protection and Defense Institute says food companies need to strengthen their security and IT systems. Food businesses should extend their food safety and food defense culture to include a cybersecurity culture, and consider the implementation of internationally recognized standards (e.g. ISO 27001 series) for IT and cyber security.

The first step in protecting data is data ownership. Data solutions should respect data ownership by managing access rights to data and preventing unauthorized persons and organizations to access or modify data. Suppliers, regulators, and customers might need access to certain data sets but only in a restricted way.

Traceability also helps to mitigate cybersecurity risks by enabling fast root cause analysis and selective recall once the source of a breach has been identified.

Finally, data ownership might be even more crucial in countries where data protection laws are not as well developed.

8

Conclusions

The food industry needs to deliver safe food over a reasonable time at an optimal cost through highly effective, efficient, and trustworthy processes that ensure 100% of the products are safe. Food safety is facing many hurdles including manual processes and unstructured data from multiple sources. Food businesses can address these challenges by better leveraging Industry 4.0 technologies that help strengthen the repeatability, monitoring, traceability and predictive capabilities of their food safety activities.

These benefits are enabled by real-time monitoring of products and processes, connected data, risk-based modeling connected across the value chain, automation as well as the right mindset, behaviors and training.

Adoption of Industry 4.0 technologies (especially predictive analytics) is still in its infancy in the food industry and would benefit greatly from harmonizing standards that enable interoperability at the company level and across supply chain, as well as data ownership and business models that incentivize data sharing by food companies with suppliers, regulators and customers across the entire food supply chain.

In summary, to maximize the benefits of Industry 4.0 in strengthening food safety, companies should:

- Define a unique Industry 4.0 company-wide strategy with a multidisciplinary team that includes food safety
- Fully appreciate the human dimension, especially by providing training to the current workforce and by promoting a shift to a digital culture across the entire business
- Define critical pain points and conduct targeted pilots with clearly identified objectives to test Industry 4.0 technologies
- Scale up early, especially in terms of data integration
- Seek out equipment that is modular by design to allow flexibility for future developments
- Implement a cybersecurity and data ownership culture

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