



**University of
Nottingham**
UK | CHINA | MALAYSIA

The future of factory cleaning

Responsible cleaning data collection and use framework

IoT Enhanced Factory Cleaning project
Smart Products Beacon/Horizon Digital Economy Research
University of Nottingham

May 2020

DOI: 10.17639/nott.7054

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1. Introduction

Ensuring a hygienic production environment is one of the biggest challenges facing food and drink manufacturers, as the industry responds to a growing demand for closer monitoring of cleaning standards and challenges from elevated allergen management, against the constant backdrop of cost pressures.

'Industry 4.0'—the next industrial revolution—promises to radically overhaul all levels of the food and drink manufacturing industry, from reducing food waste and increasing factory productivity, to reducing the impact on the environment across the entire supply chain. This is all set to be driven by enhanced sensing, data collection, and new cross-supply chain integrated digital technologies. One key area that stands to benefit from this revolution is cleaning operations within factories. Through the adoption of new technologies—including robotics, on-line in-factory sensors, and machine learning—businesses will be able to harness increased productivity and efficiency.

In conjunction with the RoboClean project at the University of Nottingham, the IoT Enhanced Factory Cleaning project has conducted interviews with SME and multinational food and drink manufacturers in the UK to understand their existing cleaning practices and perspectives of how new technologies could—or could not—change these. These projects aim to demonstrate how semi-autonomous cleaning robots could handle the task of floor cleaning and allergen-detection in the factory. In collaboration with the AI3 Science Discovery (AI3SD) and Internet of Food Things (IoFT) EPSRC Networks, we also held a workshop to discuss how digital technologies such as AI, sensors, and robotics can be used for enhanced allergen detection and factory cleaning within food production environments.

This report produced by the IoT Enhanced Factory Cleaning project introduces the future technologies that are expected to fundamentally reshape the work of cleaning food and drink factories, focusing on the possibilities for data collection and use that these technologies enable. Data serves as the core commodity that will help deliver the changes across the industry, allowing for greater fidelity and traceability across the supply chain. However, data, especially of a commercially sensitive or even personal nature, must be handled responsibly to avoid misuse or misinterpretation, which would undermine any of the benefits gleaned from enhancing data collection in the first place.

2. Cleaning today

In food and drink production, a significant amount of time can be spent cleaning processing equipment and the factory environment, depending on the nature of production. This significantly affects the overall productivity and efficiency of the manufacturing sector. The internal cleaning of processing equipment generally uses automated processes known as Clean-in-Place which are beginning to take advantage of novel technologies such as in-line sensors and machine learning-based technologies¹.

However, the cleaning of factory floors and walls, and the external surfaces of equipment is still primarily completed by human workers following strict standards including the BRC Global Standards², government regulation, and those established by customers. High care facilities may dedicate entire shifts to cleaning each day in addition to hygiene teams that work alongside production staff. Further still, many low-care facilities may spend hundreds of worker-hours cleaning each week, with much of this involving sweeping and vacuuming floors.

Why clean?

The need to clean, maintain hygienic control, and foster a culture of good hygiene is essential to businesses to ensure food and drink is safe for consumption. Facilities not only achieve this through regular cleaning but also through fostering a hygienic culture by proactively encouraging all staff to take responsibility for hygiene standards. The consequences of even been accused or linked to a contaminated product can be dire for businesses. One sandwich manufacturer which was linked to a listeriosis outbreak and deaths ultimately entered liquidation due to the fallout, despite the listeria suspected to come from elsewhere in the supply chain³. With such high repercussions, businesses must remain vigilant.

Exacerbating the challenge of maintaining a clean and contaminant-free environment for production is the growing demand for more variety and alternative formulations (e.g. vegan or gluten-free). Given the typical batch production operation of facilities, each product change

¹ Escrig, J., Woolley, E., Simeone, A., Watson, N. J. (2020). Monitoring the cleaning of food fouling in pipes using ultrasonic measurements and machine learning. Food Control. DOI: 10.1016/j.foodcont.2020.107309

² BRC Global Standards. (2018). Global Standard Food Safety - Issue 8. Retrieved from <https://www.brcgsbookshop.com/bookshop/food-safety/c-24/c-70> on 9th December 2019.

³ Food Standards Agency. (2019). Update on investigation into food supply chain linked to listeria. Retrieved from <https://www.food.gov.uk/news-alerts/news/update-on-investigation-into-food-supply-chain-linked-to-listeria?navref=search-news-alerts-news-3> on 9th December 2019.

involves downtime⁴ as equipment is cleaned and each changeover adds to the overall production costs. Furthermore, each new formulation introduces greater risk for cross-contamination including allergens. These new risks and challenges demand new innovations to minimise cross-contamination. New technologies will enable quicker detection and more accurate reporting of factory hygiene for both SMEs and multinational manufacturers.

⁴ Hygienic Pigging Systems Ltd. (2018). Retrieved from <https://www.hps-pigging.com/minimising-production-downtime-in-food-and-drink-manufacture/> on 27th January 2020.

3. The new enabling technologies

New enabling technologies will bring smarter, quicker, more reliable, sustainable and cost-efficient cleaning.

Technology	How it will help
Smart sensors (physical, chemical, and biochemical)	<ul style="list-style-type: none"> • New sensors will give real-time detection of pathogens and allergens, allowing for near immediate response time for cleaning • Data can be collected throughout production; from the moment it enters to the moment it leaves facilities • Enhanced data granularity can be used to validate cleaning for facilities to support auditing activities
Industrial Internet of Things (IIoT) to connect production across entire supply chains	<ul style="list-style-type: none"> • New devices, integrated with new sensors, connected to cloud-connected platforms will allow for a revolution in SME food and drink manufacturers to benefit from technologies previously only affordable to multinational businesses • Suppliers and manufacturers can integrate their system to present comprehensive a real-time overview of the product supply chain to the end customer
Robots and co-bots that work with operators during production	<ul style="list-style-type: none"> • New robots will be responsive to the factory environment introducing elements of self-management • New collaborative robots (so-called co-bots) will be able to work alongside, rather than supplant, human operators in factories • New digital technologies will allow continuous sensing and data analysis during production

<p>Machine Learning (ML) and smart algorithms that will process and analyse data continuously, avoiding the need for workers to interpret raw data</p>	<ul style="list-style-type: none"> • New digital data will feed into new ML-driven cyber-physical systems to proactively improve safety by identifying risks and suitable actions for workers to avoid production-impacting and safety events unfolding • ML models will also be able to detect potential optimisations through integration with other elements of Industry 4.0, including the Internet-connected supply chain and smart sensors
<p>Virtual/Augmented Reality devices such as headsets that could be worn by operators to either present simulations of the factory environment or augment the factory with a digital overlay</p>	<ul style="list-style-type: none"> • VR and AR techniques will allow for smarter training of employees by allowing factory operators to be trained and tested on cleaning efficacy in non-production or virtual environments • Readouts from sensors can be mapped to digital schematics or environments to inform "catch-up" training of factory operators

Monitoring hygiene in real-time

Strict industry standards and regulation already ensure that factories are clean environments with procedures in place to reduce contamination. At the moment, however, detection of any contamination can take considerable time in the industry (e.g. 24+ hours), by which time the product has been shipped to stores or even sold to consumers. Introducing in-factory sensing promises to provide near-instantaneous oversight of the cleanliness of worksites by providing results from the detection of unexpected allergens or pathogens inside the factory. This will allow businesses to respond quickly to the potential contamination of produce before it leaves the factory premises.

Through the realisation of digital cleaning, both businesses and consumers can form greater trust in the reliability of cleaning and food safety. Food and drink manufacturers can also benefit in terms of lower risk and consequence of food safety events—many of which result in costly product recalls after product reach store shelves.

Moreover, rapid responses to potential cross-contamination will lead to less contaminated product being produced and shipped out of facilities, contributing to overall industry aims to reduce food and packaging waste. Quick response times will allow facilities to halt production

and address problems, reducing waste, and potentially even the need for a product recall. In turn, this also minimises future businesses exposure and the likelihood of issuing food safety incident alerts, allowing consumers to be confident that their food and drink are manufactured in clean and safe environments sustainably.

4. The industrial data challenge

While Industry 4.0 promises big changes and benefits, it also introduces new legal, ethical, and social challenges. Crucially, many such challenges are aligned with both the collection of data and its use throughout the food chain.

Increased inter-connected technologies and sensing equipment offer manufacturers greater insight into the processes of food production, delivering greater traceability from farm or factory to fork, and leading to opportunities for greater data transparency and disclosures⁵. With these opportunities come new challenges, as industry, regulators, and consumers adapt to the changing landscape.

We now segment these data challenges into the various stages in the life of data, from the point where data is first captured, to where data is deleted. This report serves as a motivator to treat data responsibly rather than as an instruction manual, thus it does not offer concrete solutions. Through the presentation of the lifecycle, we will highlight the challenges—ethical and socio-technical—that lie ahead, and various points to consider in responding to them.

There are various forms and granularities of representing this data lifecycle, but here we opt for a six-stage cycle: (1) the capture of data manually and using sensing equipment, (2) the processing of this data to infer meaning, (3) the use of data to measure efficacy and enact change, (4) the sharing of data to report cleaning efficacy, (5) the archival of data for record-keeping, and (6) the deletion of data.

⁵ Internet of Food Things Network Plus. (2019). Digital collaboration in the food and drink production supply chain. DOI: 10.5281/zenodo.3368237

The data lifecycle

Data capture

Increased technology adoption in food and drink production will allow for sensing across the entirety of the factory in addition to existing data collection methods. In the case of factory cleaning, this will allow for the measurement of cleaning efficacy as well as enhanced detection of allergens and pathogens throughout the production process and factory environment.

Data processing

Increased rates of data capture offer new ways to gain insight into the work of the factory. Such data must be processed adequately to ensure it is reliable and can be transformed into actionable information for factory operators and management.

Data use

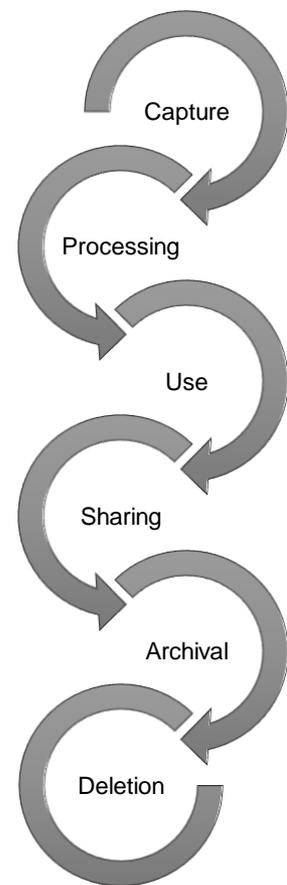
The use of data within food and drink manufacturing will radically influence all levels of the supply chain, allowing operators to respond to events quickly while providing management with a coherent overview of operations in real-time. Understanding the challenges of how to transform data will be essential to realise its true value.

Data sharing

The promise of Industry 4.0 increasing transparency within the food and drink sector introduces the challenge of who, how, and which data to share. The scope for data to be misinterpreted is great without an understanding of what the data truly represents. Controlling how data is presented to various stakeholders, from auditors, clients, and consumers will be essential to ensure the sector remains trustworthy—inaccurate understanding of data could yield tremendous damage to the industry.

Data archival

In addition to existing practices as part of supporting auditing of production facilities, greater fidelity of data will allow manufacturers to present a record of consistency to develop trust



among stakeholders. This will support the integrity of production, supporting recall of the conditions in which each product was manufactured should any food safety concerns be met.

Data deletion

Existing guidelines on data retention—based upon the shelf life of the product and any legal or customer requirements—will suffice despite the increased granularity of the data. Optionally, fine-grained data may be destroyed with summary information retained for longer periods as required.

The framework

We now frame how the expectant technologies will innovate both cleaning and the reporting of cleaning in food and drink production. This framework highlights the challenges and actions that should be taken to ensure that the associated data is collected, processed, and used responsibly. The need to retain and archive data is already covered under existing guidance and thus the last two stages of this cycle should be based upon existing guidance.

This framework represents an initial examination at the opportunities, challenges, and risks that lay ahead in terms of the management of data itself. However, there will need to be a serious and concerted effort to engage with stakeholders across the entire sector, including producers, customers, regulators, and worker representatives including trade unions, to reap the benefits ahead while mitigating risks that could negatively harm trust in the food and drink manufacturing industry.

Opportunities	Challenges and risks	Actions
<i>Capturing more data in smarter ways</i>		
<ul style="list-style-type: none"> • Online sensing throughout production equipment will alert factory operators of contamination before or during production, rather than after the fact • The ability to measure and determine unexpected allergens and pathogens throughout production will allow for greater veracity of allergen-free labelling and consumer trust • In order to ensure efficacy, robots tasked with functions such as cleaning in factories will report and measure their activity in terms of location, level, and timing of cleaning to support greater fidelity for auditing 	<ul style="list-style-type: none"> • Ensuring sensor efficiency and reliability will become a continuous activity • Overreliance on data may lead to operator blind spots and misinterpretation • Sensors for allergens or pathogens may develop faults that go unnoticed due to seemingly 'typical' results reported • The ability for robots to operate around humans safely remains an on-going challenge in robotics research • Any rapidly changing conditions in the factory will complicate the integration of smart systems, sensing, and robots should they be tied to schedules 	<ul style="list-style-type: none"> • Existing cleaning operators will need to be upskilled to maintain new technologies • Careful design and testing of new technologies will be required to calibrate workers to ensure reliable and accurate understanding of what the collected data represents • Manual inspection and testing will still be necessary to ensure sensor veracity (at reduced frequencies compared with current operations) • Potential incidents that co-bots may be required to respond should be identified, including how operators should collaborate with the systems to deviate from their scheduled programming

Opportunities	Challenges and risks	Actions
<i>Processing data for actionable information</i>		
<ul style="list-style-type: none"> • Factories will be able to statistically demonstrate the hygienic conditions under which each product/batch is produced, introducing per-item provenance • Systems will be able to guide cleaning teams (human or robot) through spaces in response to data from on-line sensing of allergens and pathogens and operator instruction • Reporting from mobile cleaning and sensing systems in facilities will identify areas most prone to pathogens or allergens, allowing for heatmaps of problem areas in the factory to support staff training • Change in detection rates over time provide oversight of the evolution of factory cleaning • Sensor data can be used to optimise cleaning processes to reduce their environmental impact 	<ul style="list-style-type: none"> • Collecting and linking real-time data with production data will require integration of multiple systems • Uncertainty challenges with large data sets will occur (e.g. data reliability and accuracy) in factory conditions— understanding the fidelity and reliability of data will be key • Existing mobile and static robots do not meet hygiene and safety requirements to operate in close proximity to food production and human operators • Indoor positioning and navigation for mobile systems will require enabling infrastructure to ensure that the data captured can be processed and assigned to particular production lines and batches 	<ul style="list-style-type: none"> • The veracity of automatically collected and processed data must be established by human operators to provide a ground truth • New systems should—by default— defer to human oversight in situations where they cannot meet goals established for the system, which will require trained operators to support new technologies • Trials will be needed with indoor positioning and details of batch production to allow data to be segmented by location and batch

Opportunities	Challenges and risks	Actions
<i>Using data to inform change</i>		
<ul style="list-style-type: none"> • Businesses will be able to proactively emphasise cleaning in particular areas in response to identified problems • Identification of pathogens or allergens at unexpected levels or times will allow for the destruction of product before dispatch—or even the avoidance of contaminated product being manufactured in the first place • Machine Learning algorithms will be able to parse the large data sets collected to spot potential hygiene and operational problems before they occur • Dashboards within facilities could present the cleaning status of the facilities in real-time • Product packaging or systems for consumers could provide confirmation to consumers of allergen-free production, raising consumer trust in production 	<ul style="list-style-type: none"> • Concise ways of representing detailed data (e.g. from detecting of pathogens) may be too detailed or not provide obvious actions for human operators to take, leading to operator confusion • Identifying mechanisms to draw only relevant operators' attention will be necessary to avoid distracting non-relevant operators (e.g. only alert hygiene teams) • Concise ways of representing data over extended periods of time should not de-emphasise issues through averaging out problems or periodical high levels in production 	<ul style="list-style-type: none"> • Systems could flag data or factory locations for further examination by human operators to ensure automated systems do not supplant management duties • Integrated control systems should present an easy-to-understand status of current factory activity, combining production and cleaning, to ensure the efficacy of cleaning • Integrating with existing workflows in the factory will be necessary such that co-bots do not distract or involve staff allocated to other duties • Alert thresholds should be set and revised periodically to avoid data from over an extended period "averaging out" issues

Opportunities	Challenges and risks	Actions
<i>Sharing data to improve transparency</i>		
<ul style="list-style-type: none"> • Within facilities, evidence of the identification and response to 'hotspots' within facilities could be used to demonstrate due diligence in ensuring sterile production facilities • End consumers may be able to obtain a self-certification of allergen-free status of a production environment • Suppliers and customers could share data as part of the connected supply chain, establishing provenance of production, from farm-to-fork 	<ul style="list-style-type: none"> • Current trends towards Internet/cloud-based interactions will introduce risk over data access, control, and storage to businesses • Growing demand for allergen-free foods creates pressures for businesses to maintain allergen-free environments • Data or analysis that is too detailed could be misinterpreted without adequate explanations, yet data that is too simplified may not add any benefit to businesses • Storing data "in house" will provide organisations with control over data access, however, this may introduce new burdens on stretched resources 	<ul style="list-style-type: none"> • Identifying reliable, secure, and cost-effective storage platforms will be key • It will be necessary to determine a suitable granularity of information made available to consumers to ensure transparency while avoiding concern over harmless data that could raise concerns

5. Conclusion

Recent advances in technology—including new sensors, Machine Learning-enhanced data processing, and cross-supply chain integration—will enhance the cleaning of food and drink factories. These technologies have the potential to benefit both consumers and producers in terms of food safety and cost-control, but also introduce new risks that the industry must rise to the challenge of dealing with.

There are also implications in terms of the 'data lifecycle'. While existing Government legislation covers data security, the sector must address the social and logistical challenges of how data is collected, analysed, presented, interpreted, and integrated into existing production processes, potentially across the entire supply chain. Additionally, while enhanced data collection will be able to demonstrate cleaning efficacy and enhance worker training, ensuring ground truth will still require vigilance from management and operators.

To realise the benefits of IoT-enhanced factory cleaning, the food and drink manufacturing industry must pre-emptively identify the ways in which the challenges and risks are mitigated to retain confidence in the sector. This will require cross-sector collaboration, between customers, producers, food safety regulators, and worker representatives such as trade unions. We hope this report serves as the starting point for this work.