Artificial Intelligence and the food sector: a golden opportunity for growth.

PORTSMOUTH, Bryony, SHENFIELD, Alex <http://orcid.org/0000-0002-2931-8077>, ZHANG, Hongwei <http://orcid.org/0000-0002-7718-021X>, JOHNSTON, Amanda and LIMB, Jessica

Artificial Intelligence and the food sector – a golden opportunity for growth

Experts from the Advanced Food Innovation Centre at Sheffield Hallam University discuss food sector research and innovation through the lens of AI.

The Advanced Food Innovation Centre (AFIC) is a National Centre of Excellence based on Sheffield Hallam University's Health Innovation Campus. It is dedicated to driving sustainable innovations in the global food system. Four research themes - digital connectivity, food system sustainability, healthier lives, and feeding a growing population - enable problem-led, collaborative solutions for the food sector.

Through pilot-scale production facilities, laboratories, and workshops, the AFIC serves as a collaborative hub for research and innovation between industry and academia. £15m in research income has enabled advancements in food processing and manufacturing solutions, new processes technology, energy efficient systems and novel techniques to meet the demand for healthy foods.

Alex Shenfield is Professor of Machine Learning in the School of Engineering and Built Environment at Sheffield Hallam University. He has worked in UK higher education for more than 15 years across a range of engineering and computer science disciplines. Alex has extensive experience in applying AI technologies to solve real-world problems in collaboration with industrial partners and is the expert adviser for the 'Digital Connectivity and Technology' research theme at the AFIC - his research drives the adoption of digitalisation and intelligent processes within food and drink manufacturing.

Asking Alex - Why AI is a hot topic in the food sector

Food and drink is the largest UK manufacturing sector – accounting for around 19% of UK manufacturing output and directly contributing £33bn to the UK economy.

The **Sheffield City Region** surrounding Hallam, generates as much GVA from food and drink manufacturing as the whole of the North-East and there are 360 food manufacturers registered in the region.

Despite these incredible statistics, adoption of **digital and intelligent manufacturing** in the food and drink sector has been slow due to a range of factors:

- Lack of technical skills
- Complexity of food and drink manufacturing processes
- Food safety issues
- Cost

Hassoun, A., Marvin, H.J et al 2023. Digital transformation in the agri-food industry: Recent applications and the role of the COVID-19 pandemic. (1)

Running alongside these, there are future sector challenges including; climate change, a growing world-wide population, political instability and the potential of future pandemics. *https://www.newfoodmagazine.com/news/147964/climate-change-threatens-one-third-of-food-producing-regions/ (2)*

The recurring theme in the press and the literature is that, given things may well become more challenging, the food and drink industry is going to inevitably have to do more with less - droughts, storage challenges, and import/export complexities will diminish stocks of raw ingredients.

These problems are compounded by low quality food processing, inefficient manufacturing and rising costs – that is where AI comes in, applied effectively, it has the potential to greatly reduce waste and therefore slow the diminishing of resources, while cutting down costs.

These realities have significantly influenced the decision to apply Alex's expertise and knowledge toward sustainable innovations in the food sector.

A great example has been the opportunity to work with **Koolmill** on using AI and image processing for controlling the quality of food product outputs.

Rice feeds **nearly half the world**'s population but traditional rice milling is both **wasteful** and **power hungry**. The team has developed a digitalised rice mill that is **more efficient**, **less wasteful**, and uses AI and automation to ensure **high quality output**.

The collaboration has been so successful that it recently secured an Innovate UK AI feasibility study grant – this will use AI to rigorously assess the quality of milled rice, working out the amount of broken rice in order to change how the milling is done. The AI can inform variables such as the speed of belt and optimum chamber dimensions to find the sweet spot for ensuring minimum brokens – it can adjust milling parameters in real time.

8000 years of rice milling has worked on an open loop – set it going and repeat – this technology will offer closed loop control to improve output quality and minimise wastage.
Early trials suggest it will enable a machine that reduces breakage by 80%.
https://www.shu.ac.uk/national-centre-of-excellence-for-food-engineering/our-impact/all-projects/koolmill)

Additionally, AFIC have also developed AI-based rice classification and fraud detection methods and an AI-based surrogate model or 'digital twin' of the milling chamber.

This is just one example. Together with collaborations involving partners like Faraday Scientific and Rakusen's, these experiences have led Alex to the following conclusions:

- Intelligent manufacturing starts and ends with data
- Food and drink manufacturers are still catching up with Industry 4.0 technologies – they are not prepared for Industry 5.0!
- There is a significant skills shortage across the sector
- There are a number of competing strategic priorities, yet all can be satisfied with the adoption of the right AI solutions - improved quality, cost reduction, more agile manufacturing processes

A real positive for the sector though, is the emerging talent from institutions such as Sheffield Hallam. Alex highlights that, while there may be less time available for hands-on coding, he now has the privilege of mentoring the next generation of researchers across a range of disciplines.

The passion and enthusiasm for research applications in the food sector is growing and the AFIC is determined to develop a buzz around AI and sustainability through its research themes.

Case Study: Sustainable Baking

Early Career Researcher, Jess Limb, talks to us about her career to date and involvement the Innovate UK 'Sustainable Smart Factory' project with heritage bakers Rakusen's: *Smart and Sustainable Manufacturing for the Bakery Industry.*

Introducing Jess

Jess studied Food Science and nutrition at the University of Nottingham, including a year in industry with PepsiCo. She then joined the team at 'SHU Food' as a KTP Associate exploring bakery reformulation for reduced sugar, fat and salt with a South Yorkshire bakery, before joining the IUK project team.

The project

Academics from the AFIC and the University of Bradford are working alongside Rakusen's to transform production methods to support the business to optimise the baking process of their crackers – aiming to reduce emissions, produce less material waste and **deliver over 60% reduction in energy consumption**.

The project is also supporting the 100-year-old business, that produces flame-baked water crackers and biscuits in the UK, to meet demand for growth in international markets and help it to meet net zero targets, whilst maintaining its unique heritage.

The aim is to transform Rakusen's through digital technologies and food science to minimise the company's carbon footprint and maximise capacity - all without altering existing machinery.

Jess has joined the project at the mid-point, as a process engineering researcher – she is looking to implement the learnings from earlier trials in the project and transfer this knowledge into the business.

Currently Jess is leading the running of trials on the new oven and comparing the finished product to the existing line. The team is also exploring different mixing methods which give the same viscoelastic properties as the current methods but aiming to reduce the water content of the mixes - energy consumption is improved if the team are baking off less moisture. These standardised recipes create the baseline markers for the AI, which can then give real-time feedback and adjust heat and bake settings accordingly.

This is an excellent opportunity for Jess to provide food science support to deliver the project, alongside the installation of the digital transformation platform.

Highlights of the project

The concept of enabling the delivery of a quality product using AI is fascinating. The software uses previous images from within the line to adapt the baking process. The ability of AI and the impact of the digital transformation for this food business integration are quite eye opening – the modelling forecasting and adapting in-line is far quicker than any human can do, and it frees staff up for other aspects of production.

Jess has also greatly appreciated the collaboration with project partners and IUK's funding advisors, who provide support and insights to keep the project on track and help achieve its goals.

Business outcomes achieved

The business currently uses legacy equipment, which provides limited manufacturing control and restricts the introduction of new product lines. The future of the business requires it to address these challenges and invest in innovation which is sympathetic to its heritage-based offering.

The project will also have a positive impact on the workforce, by upskilling staff through training and introducing culture change, as well as having an impact regionally as most ingredients are supplied locally.

Being part of a collaborative bid has opened up Rakusen's opportunities to other funding and they are currently identifying other areas they might collaborate. There are other areas for business improvement such as waste valorisation.

Members of the team have fedback that they have had their eyes opened to the benefits new technology can bring, such as helping them stay competitive while retaining their identity, heritage and legacy values.

Implications for the wider sector and challenges for adoption

Jess notes that AI adoption remains slow in the sector, partly due to common challenges related to skills, recruitment, efficiency, and optimising operations. However, AI improvement offers potential for reduction of wasted product, achievement of sustainability goals, mitigating the skills shortage and improving energy cost effectiveness.

Regarding challenges to adoption, Jess highlights that legacy equipment, which has been used for years, can present challenges in terms of installation and capacity for adapting to different production conditions. The changes can seem overwhelming and scary – no matter how rigorous the tech is, it is still a leap into the 'unknown' for a business and there is understandable fear around the seeming costs and the investment of time in change.

The beauty of an AI solution is that once fully integrated, it can perform the repetitive and mundane and much like 'The Terminator', it will not stop. Once the recipe has been formulated and the parameters set, it will continuously update – there is no risk of fatigue or concentration loss.

This can free up staff to engage in New Product Development instead, utilising their creativity for fine tuning. It provides potential for time away from the line to develop inputs for the AI to regulate quality and consistent products – it frees up much needed capacity.

Dr Hongwei Zhang, Co-Director (Academic) at the AFIC, is a Chartered Engineer with over 20 years of academic and industrial experience and holds dual PhDs in Control Engineering and Aerospace Engineering. Hongwei's mission is to advance knowledge and practice of food engineering and process control while fostering collaboration and innovation between academia and industry.

Dr Zhang on academic interest in food system research and AI's role in enhancing the food sector

Dr Zhang is a firm believer in the transformative potential of AI in the food industry and is currently engaged in several groundbreaking projects that are utilising AI-driven digital transformation. He emphasises the massive benefits to the food industry, addressing key issues such as efficiency, sustainability and cost-effectiveness.

Despite these advantages, the adoption of AI within the food industry lags behind other manufacturing sectors, not only in the UK but on a global scale. This slow uptake is partly due to misconceptions about AI and uncertainty about where to begin from a food business perspective.

He led a workshop to highlight the potential of AI at the 2024 Conference of Food Engineering in the USA, prompting reflection on how these opportunities are articulated. Participating in a plenary session panel discussion with industry experts on 'Information Technology in the Food Industry' further reinforced the critical importance of knowledge exchange and collaborative idea-sharing.

Key AI & machine learning techniques used in the food industry

Technique	Application
Fuzzy Logic (FL)	• Sensory evaluation - used in wine tasting, cheese ripening. • Process control - optimises cooking processes, fermentation control in brewing. • Quality control - ensures consistent product quality under variable conditions
Expert Systems (ES)	• Food safety and quality control - ensures compliance with food safety standards, HACCP implementation. • Process optimisation - diagnoses and optimises production processes; optimises energy use during food processing.
Artificial Neural Networks (ANN)	• Food quality control - predicting shelf life, spoilage detection.
Convolutional Neural Networks (CNN)	• Defect detection - automated inspection in fruits and vegetables, identifying anomalies in packaging.
Recurrent Neural Networks (RNN)	• Supply chain forecasting - predicting demand and managing inventory by analysing historical data and trends. • Process control - monitoring and optimising continuous food processing operations, such as temperature regulation during baking or fermentation. • Consumer behaviour analysis - analysing sequences of consumer interactions to personalise recommendations and improve marketing strategies.
Long Short-Term Memory Networks (LSTM)	• Predictive maintenance - analysing time-series sensor data to predict equipment failures in food processing plants. • Quality control in time-dependent processes - monitoring and predicting the quality of products during processes like fermentation or ageing. • Demand forecasting - improving inventory management and supply chain optimisation by accurately forecasting consumer demand over time.
Support Vector Machines (SVM)	• Used in classification - used in sorting and grading agricultural products.
Radial Basis Function (RBF) Networks	• Used in shelf life prediction - of processed foods like cheese and meat products.

AI-driven systems, across all types, are systems where AI is the core technology that enables automation, learning, and autonomous operations, often in a complex and dynamic environment. **They bring huge areas of benefit** - enhancing efficiency, food quality control, process control and optimisation, predictive maintenance, supply chain management, product development, personalised nutrition.

Case examples

At the AFIC, a range of these techniques have been applied to some very impactful projects. In addition to the previously mentioned collaboration with Koolmill, these are two examples of AFIC's current innovations:

With OHM-E, there is an ongoing collaboration on an AI-driven system for sustainable food production, with a focus on process control, optimisation and enhancing food safety and quality. Through funding from IUK, an industrial collaboration with Premier Foods is developing an AI-driven, model predictive control system for a 'Continuous Flow Ohmic Heater'. This system aims to achieve uniform heating, precise temperature control, adaptability to product conductivity variations, enhanced quality control, improved product consistency and increased energy efficiency. https://www.shu.ac.uk/national-centre-of-excellence-for-food-engineering/our-impact/all-projects/ohmic-heating)

The AFIC's team of experts have also turned their modelling and predictive technological know-how to mixed-culture beer fermentation dynamics, using autoregressive recurrent neural networks and a deep learning-powered model predictive control. (CASE STUDY LINK? https://www.shu.ac.uk/national-centre-of-excellence-for-food-engineering/our-impact/all-projects/beer)

These approaches also lend themselves to agricultural and horticultural settings - the AFIC's teams are developing an automated root vegetable trimming system with computer vision and artificial intelligence as well as an automated flower bouquet making system!

In conclusion, AI-driven systems are transforming the food industry by enhancing efficiency, quality, and sustainability. A variety of AI/ML techniques, such as Fuzzy Logic, ANN, CNN, RNN, and LSTM, have impactful applications across the food sector.

The key is to start small, implementing AI solutions in small-scale projects to understand practical challenges. From here, businesses can iterate and improve, using feedback from initial implementations to refine models and improve results.

Practical implementation of AI in food process engineering involves understanding the basics, using appropriate tools, and applying these technologies to solve industry-specific challenges.

Continued integration of AI-driven systems will lead to smarter, more sustainable food production and processing methods.

Collaborating with the Advanced Food Innovation Centre

Amanda Johnston serves as Co-Director (Innovation) at the AFIC. With a career spanning over three decades, she has been driving research and innovation in food production at Sheffield Hallam University for the past 10 years. Amanda discusses the exciting opportunities within the food system and the pivotal role of AFIC in this dynamic landscape.

The importance of the food system

Food is an essential part of our lives, and the food system offers a wide array of career pathways, allowing individuals to start from entry-level positions and develop their skills over time. Moreover, there is immense potential for improvement through research and innovation. However, aside from the global players, many businesses lack the research and development infrastructure necessary to support significant advancements.

The business models for numerous suppliers of the food we buy from our supermarkets often result in low margins and short-term planning. This reactive nature of the food sector contrasts sharply with industries like automotive, where manufacturers benefit from predictable orders and longer product life cycles.

Recognising the food and drink sector's impact on the UK Economy

Food manufacturing is the UK's largest manufacturing sector, playing a critical role in the national economy. According to the Food and Drink Federation (FDF), the sector contributes over £29 billion annually to the UK's economy and employs around 500,000 people across the country. Representing 20% of the total manufacturing output, it dwarfs other key sectors like automotive and aerospace. Additionally, UK food and drink exports were valued at £23.6 billion in 2022, reflecting the global demand for British products. The sector's importance extends beyond its economic contribution, as it is fundamental in ensuring food security, driving innovation and addressing critical challenges such as sustainability and public health.

Despite this, it is often overlooked in economic development strategies that tend to prioritise high-tech industries. This sector requires more recognition and investment to address its challenges and realise its full potential.

The Advanced Food Innovation Centre: A hub for UK food sector innovation

Established in 2014, Sheffield Hallam University's AFIC- formerly known as the National Centre for Excellence in Food Engineering (NCEFE) - moved to its state-of-the-art facility at the Olympic Legacy Park in Attercliffe, Sheffield in October 2019. AFIC is positioned as a hub for problem-led, collaborative Research, Innovation, and Knowledge Exchange (RIKE) focused on the food and drink system.

The AFIC is designed to encompass a broad range of academic research and expertise. It features pilot-scale production facilities, laboratories, workshops, and teaching spaces. AFIC's open innovation space operates on a 'living lab' model, facilitating accelerated knowledge exchange. Experts collaborate closely with food producers and manufacturers to implement process improvement techniques and they also provide consulting services. The AFIC teams collaborate with colleagues across the wider University, in areas such as packaging design, diet and health outcomes, supply chains, SME growth, and product development.
By bringing together world-class researchers, industry and food system experts and students, the centre has become a hub for cutting-edge technological advancements in food production, from

improving efficiency in manufacturing processes to developing sustainable solutions that reduce waste, improve nutritional quality and reduce energy consumption.

Solutions businesses can expect from AFIC

AFIC offers a comprehensive range of solutions designed to support food sector businesses in driving innovation and growth. Through collaborative research and development, AFIC partners with industry giants like Nestlé as well as SMEs such as Koolmill, to tackle challenges such as energy reduction and healthier food production. SMEs benefit from AFIC's consultancy services, supported by regional funding, which helps them adopt new technologies and improve operational efficiency. Businesses can also access AFIC's experts and state-of-the-art facilities for process development and testing. (https://www.shu.ac.uk/national-centre-of-excellence-for-food-engineering/our-impact/all-projects/hendersons)

Additionally, AFIC and Sheffield Hallam University offers a pipeline of talent through its skills offer, which includes degree apprenticeships, placement opportunities for students, and graduate recruitment initiatives. This combination of research, consultancy, skills development, and access to advanced resources makes AFIC a crucial partner for food businesses looking to innovate and grow.

Successes of the Centre

It has been a great source of satisfaction that many of the projects funded by research councils have the potential to drive meaningful change in highly processed food. For instance, AFIC teams of experts have partnered with Nestlé on energy reduction initiatives and employed micro-encapsulation technology to lower salt and fat content in baked cheese products in collaboration with Greencore. One of the most impactful collaborations has been with Koolmill, a machinery manufacturer specialising in rice production. Our decade-long partnership has yielded remarkable results and significant advancements in the field.

Future perspectives for AFIC

AFIC continues to expand its projects portfolio, increasing PhD student intake, and the capacity for external engagement and profiling. Now, ten years into their journey, AFIC's teams of experts are setting ambitious plans for the future, aiming to solidify AFIC's position as a leading force in food innovation. The focus remains on driving advancements that enhance sustainability, improve nutrition, and create a positive impact on the food system as a whole.

https://www.shu.ac.uk/national-centre-of-excellence-for-food-engineering/staff