Prevent food allergy alerts: an incentive-based approach

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Contents

List of figures

List of tables

How to read this report

This report presents the key findings and outcomes of the FoodPro project (FS301087) funded by the Food Standards Agency (FSA). The project is motivated by the problem of the rising number of food allergy alerts in the UK.

The project explores ways to tackle the problem. In particular, it aims to prototype a digital platform designed to prevent food allergy alerts.

To prevent food allergy alerts, we need first to understand (a) the causes of these alerts and (b) the behavioural characteristics of Food Business Operators (FBOs). These are outlined in Section 2 and Section 3.

Our investigations indicated that the nature of FBO's incentives has an important role in the prevention of food allergy alerts. The case is explained in Section 4.

The understanding of these incentives provided a basis for integrating them into the design of a digital platform for food traceability. This development is explained in Section 5.

This novel approach presents various stakeholders, including the FSA, local authorities, FBOs, with ways to prevent food allergy alerts by working collaboratively. These opportunities are pointed out in Section 6.

The details of scientific methods for developing the incentive-based approach are described in the article 'Improving food allergen management in food manufacturing: An incentive-based approach', published in Food Control.

Supporting materials for this report may be found in a separate document.

In this report, the standardised Food Product Information Form (FPIF) and the prototype of digital platform are not fully disclosed due to the need to protect intellectual property rights.

Glossary

Behavioural incentive

In this report, this term refers to any incentive that motivates behaviour changes in an individual or organisation toward desirable outcomes.

For example, an employee of an FBO has a behavioural incentive to minimise operational errors in production to demonstrate a good performance; and an FBO has behavioural incentive to improve food allergen management to avoid any damage to their brand value.

Systems approach

In this report, this term refers to the consideration of all the relevant elements (including FBOs, employees of FBOs, customers/consumers, auditors, regulators, data, operations and food traceability technology) and their interactions in the design of a solution to preventing food allergy alerts.

Systems approaches have been used increasingly to tackle complex challenges in the real world: its flexibility enables the consideration of multiple elements and their interactions in order to achieve a certain purpose (Arnold and Wade, 2015).

Incentive-based approach

The term refers to a systems approach that addresses behavioural incentive as a mechanism to drive coordination among all the relevant elements to achieve more desirable outcomes (here, the prevention of food allergy alerts).

Food allergy incidents can be caused by either deliberate or unintentional behaviours. The deliberate behaviours leading to undeclared food allergens, such as food fraud, require a distinct approach. This report, therefore, focuses only on the incidents caused by unintentional operations. Food fraud is outside the scope of this report.

The incentive-based approach highlights the gap between the desirable and the actual outcomes and seeks to minimise the gap.

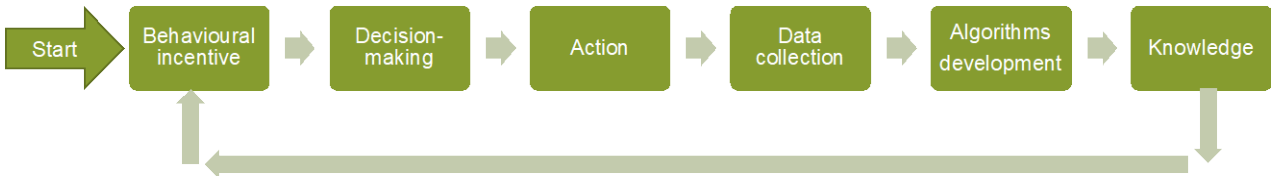
Executive Summary

This project embeds behavioural incentives of Food Business Operators (FBOs) into the design of food traceability technology. Such an incentive-based approach provides a new channel for the prevention of food allergy alerts.

Our key findings are as follows:

1. About 92% of food allergy alerts are caused by operational errors internal to FBOs. This fact indicates great potential to prevent food allergy alerts by improving food allergen management.
2. Food traceability technologies can improve food allergen management only when FBOs have the incentive to use them. Hence, behavioural incentive constitutes the starting point of using intelligent food system to prevent food allergy alerts. The essential steps of food traceability is illustrated in Figure 1.

Figure 1: Essential steps of food traceability



The key outcomes of this report are:

1. An incentive-based approach that embeds behavioural incentives of FBOs into the design of food traceability technology.
2. The principles for designing incentive-based food traceability technology for prevention of food allergy alerts.
3. A standardised food product information form providing a shared questionnaire and data infrastructure for all FBOs.
4. The design of a user-friendly digital platform for automating data exchange between different FBOs in order to improve efficiency and accuracy of food data verifications, thereby preventing food allergy alerts.

Recommendations: a summary

Our recommendations concern (a) behavioural incentives, (a) trust in food data, and (b) opportunities relating to food traceability technology and the use of algorithms.

1. The level of behavioural incentives to improve food allergen management varies between FBOs. This cannot be ignored in preventing food allergy alerts. As a consequence, we recommend that behavioural incentives should be embedded in the design of food traceability technology.
2. Food data trust is a dynamic, rather than static, phenomenon. We recommend that it should be enhanced by (a) raising various benefits (for example, increasing brand value and reducing food waste) and (b) eliminating various constraints (for example, improving knowledge and skills) of food data sharing for all the relevant stakeholders.
3. Information sharing should follow 6 principles to motivate food data trust: incentive-based, accurate, secure, efficient, intelligent and collaborative.
4. The automation of data exchange should be facilitated by the adoption of a standardised food product information form for FBOs in the UK. This could benefit Small and Medium Enterprises (SMEs) especially.
5. Data interoperability between local authorities and the Food Standards Agency (FSA) should be improved by means of an incentive-based approach. For example, developing a standardised food audit form using semantic web standards and Linked Data principles could improve data sharing and interoperability between the FSA and local authorities.
6. Interoperability between FBOs along the global supply chain should be improved by means of integration of a standardised food product information form into global standards, such as GS1 EPCIS 2.0.
7. Collaborative food safety management involving FBOs, local authorities and regulators should be supported by the use of explainable (that is, ‘clear-box’), rather than unexplainable (‘black-box’), artificial intelligence algorithms.

1 Introduction

The increasing number of food allergy alerts in the UK has raised the concern of the Food Standards Agency. This project is motivated by this problem and seeks to develop a novel solution to address this challenge.

In the UK, the food anaphylaxis admissions have increased from 1.23 to 4.04 per 100,000 population per year between 1998 and 2018 (Conrado et al., 2021). Among them, the largest increase of hospital admissions was children under 15 years, where the incidence jumped from 2.1 to 9.2 per 100,000 population per year (Conrado et al., 2021). To date, there is no cure for food allergies and the only way to prevent allergic reactions is to avoid trigger allergens (Begen et al., 2017; Hattersley et al., 2014).

To ensure a safe food environment, food business operators should provide full ingredient and food allergen information on the product label. With the introduction of Natasha's law on 1 October 2021, all the prepacked for direct sale and non-prepacked food products are required to declare the 14 food allergens: celery, cereals containing gluten, crustaceans, eggs, fish, lupin, milk, molluscs, mustard, peanuts, sesame, soybeans, sulphur dioxide and sulphites (if they are at a concentration of more than ten parts per million) and tree nuts.

With the increasing demand for safe food environment to consumers with food allergies, it remains unknown how Food Business Operators (FBOs) could prevent food allergy alerts. This report confronts this challenge by answering the following questions:

- What are the causes of food allergy alerts?
- How can FBOs be motivated to improve food allergen management?
- What kind of food traceability technology is required to prevent food allergy alerts?
- What opportunities exist for the FSA to prevent food allergy alerts?

2 Causes of food allergy alerts

2.1 Review of literature

We conducted a scoping literature review on the causes of food allergy alerts. We started with 26,628 citations from our initial searches, 26,592 citations for screening of titles and abstracts, and 464 citations for full-text screening. Following full-text screening, we selected 192 citations to be included in the review. Further, we identified five additional articles and one report that need to be included through the search of citations and organisations. In total, we have 198 citations.

An illustration of the scoping literature review process is provided in a separate document named ‘Supporting materials’.

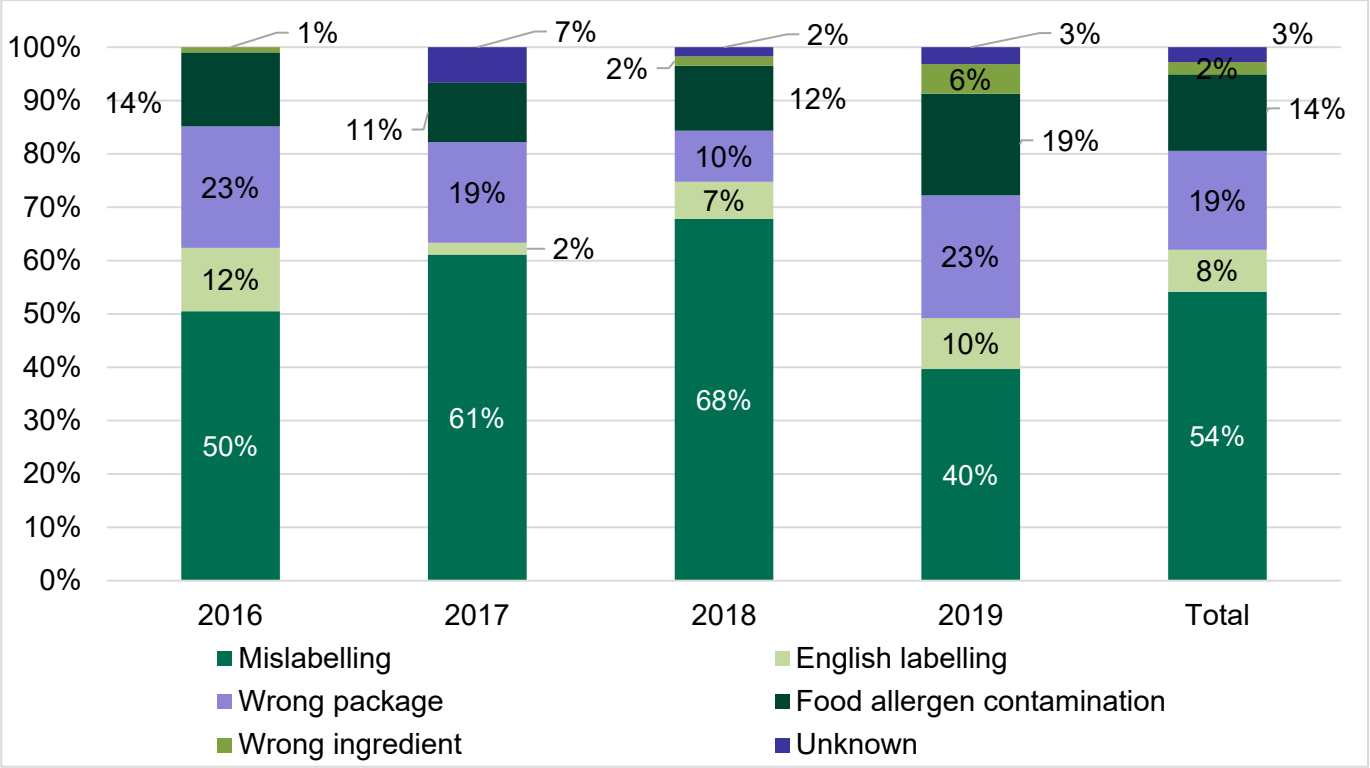
2.2 Review of industrial practices

The review of industrial practices includes both food allergy alerts and root cause analysis conducted by FBOs. The food allergy alerts include all the allergy alerts from the Food Standards Agency (2018–2019) for England, Wales and Northern Ireland, and Food Standards Scotland (2016-2019) and National Archives websites (2016-2017), making 435 food allergy alerts in total after duplicates were removed.

Figure 2 reveals the causes of food allergy alerts in the UK for the period 2016-19. Mislabelling was the biggest cause. Forms of mislabelling include ‘not indicated on label’, ‘wrong allergen advice’, ‘wrong label’, ‘unintended presence’, ‘labelling error’ and ‘unauthorised or undeclared sulphites’. Mislabelling accounted for 54% of the total food allergy alerts.

Wrong packaging was the second cause, accounting for 19% of the total. Food allergen contamination was the third cause, accounting for 14% of the total.

Figure 2: Causes of food allergy alerts in the UK (2016–2019)



Source: Jia and Evans (2021)

Data source: Food Standards Agency (2018-2019), Food Standards Scotland (2016-2019) and National Archives websites (2016-2017).

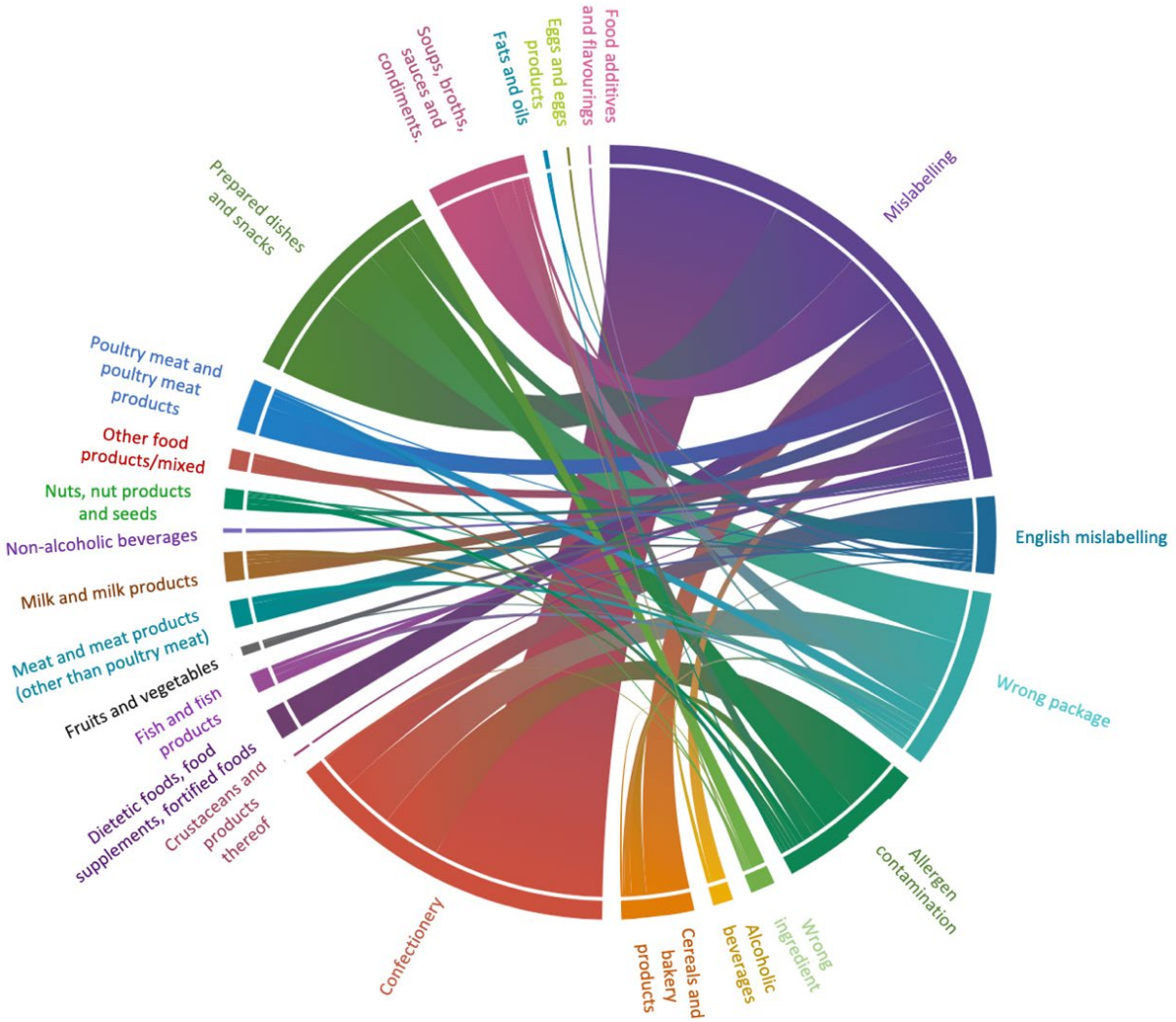
The relationship between (a) the causes of food allergy alerts and (b) Rapid Alert System for Food and Feed (RASFF) food groups are in Figure 3.

Though the allergy alert incidents vary from one food group to another, the likelihood of mislabelling incidents is the highest among all the potential risks in each food group. This indicates that mislabelling constitutes the biggest challenge for reducing food allergy alerts, especially for confectionery, prepared dishes and snacks and soups, broths, sauces and condiments products.

Wrong package represents the second biggest challenge, especially for prepared dishes and snacks and confectionery.

Food allergen contamination was also a major cause for food allergy alerts. The top 3 food groups associated with it were confectionery, prepared dishes and snacks, and cereals and bakery products. The picture looks quite different for wrong ingredient and English mislabelling where food allergy alerts occurred primarily in prepared dishes and snacks and confectionary respectively.

Figure 3: Food categories and allergy alert causes (RASFF,2016-2019)

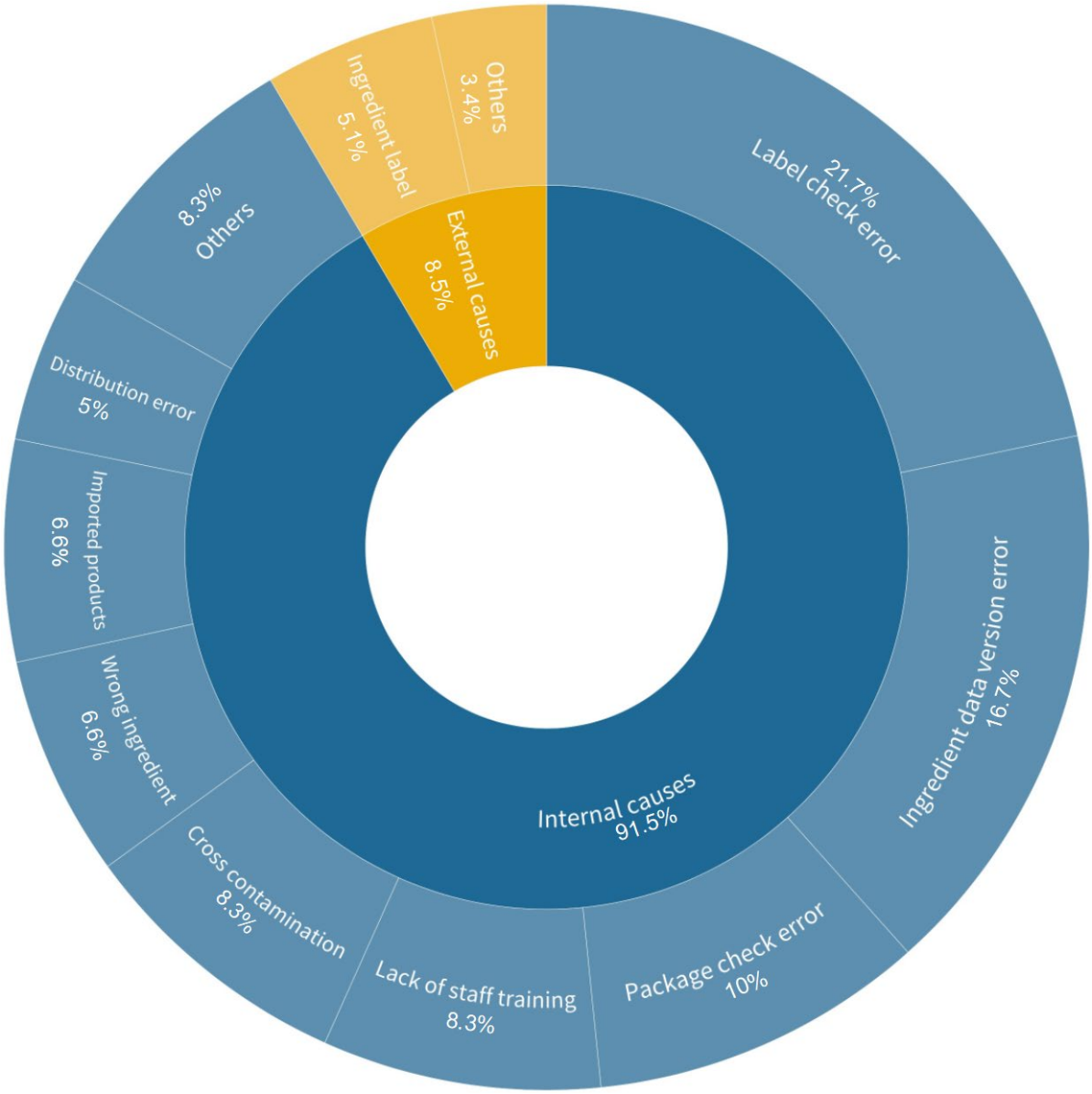


Drawing on 60 root cause analyses from the FSA during 2018 and 2019 (there were 75 case analyses in total and 15 cases were dropped due to unknown root causes), we found 12 different operational errors internal to food manufacturers. These operations are displayed in Figure 4.

The top three operational errors were label check error (accounting for about 21.7% of food allergy alerts), ingredient data version error (accounting for about 16.7%) and package check error (accounting for 10%). The data also revealed that the English mislabelling problems announced in food allergy alerts were associated with distribution errors (accounting for 5%).

Meanwhile, food manufacturers experienced five ‘external’ types of error, comprising errors related to ingredient labels accounting for 5.1% and other errors (label or package supplier error and food safety consultant failure) accounting for 3.4%. In total, the food allergy alerts caused by internal factors (91.5%) amount to more than ten times of those caused by external factors (8.5%).

Figure 4: Operations related to food allergy alerts in 2018-19



Source: Jia and Evans (2021)

2.3 Synthesis of causes

Based on the causes of food allergy alerts ascertained from the review of both literature and industrial practices, we identified 24 operational errors directly associated with food

allergy alerts. Indirect causes, such as lack of staff training and communication, will be discussed separately in Section 4 and so are not included here.

A number of food standards that provide comprehensive guidance on food safety, such as HACCP, British Retail Consortium (BRC) and International Organization for Standardization (ISO). We don't aim to duplicate effort by providing a list of good practices here. In this report, we focus on the operations that food manufacturers particularly need to improve in food allergen management based on current practices.

This list provides only a starting point and will be modified progressively as more operational error data becomes available.

To ensure this list is generally applicable to all food manufacturers, we avoided manufacturer-specific errors. For example, we identify 'mistakes in cleaning production line and other facilities' as an operational error, but do not specify the method of cleaning production lines and the facilities to be cleaned since different food manufacturers may choose different cleaning methods.

A full list of operational errors is presented in Table 1. This list could be used by FBOs to screen their practices and identify their own errors.

Table 1: Operational errors in food allergen management

Source: Jia and Evans (2021)

Number	Operational errors
1	Product recipe/ development/reformulation errors
2	Personal hygiene problem
3	Hygienic design errors of facilities, equipment and procedures related to allergens
4	Failed production separation
5	Database update failures
6	Verification failure in distribution
7	Verification failure in label & package
8	Verification failure in ingredient information (for example, imported ingredients)

Number	Operational errors
9	Verification failure in ingredient specification
10	Verification failure in data validity
11	Verification failure in raw materials input
12	Documentation/records mistakes
13	Data storage and version errors
14	Mistakes in cleaning production line and other facilities
15	Missing data approval system
16	Delayed notification of food incident
17	Label design and terminology check errors
18	Delayed food information sharing and update
19	Failed to control movement
20	Mistakes in allergen tests
21	Failures to avoid airborne/cross- contamination
22	Packaging and post-production control errors
23	Misleading guidance from food safety consultants
24	Failures to obtain timely information on food allergen risks from suppliers

3 Behavioural characteristics of Food Business Operators

Before analysing the behavioural incentives of FBOs, we first outline the three most important behavioural characteristics of FBOs in food allergen management. These behavioural characteristics provide fundamental context for analysing food allergen management of FBOs.

3.1 Economic incentives

The current food safety assurance systems rely heavily on audits. More restrictive regulations are often regarded as a common recommendation for improving food allergen management (Hobbs, 2010; Carreño & Vergano, 2014). The economic incentive for food manufacturers to improve food allergen management is rarely discussed.

In fact, food manufacturers have an economic incentive to improve mandatory food allergen management and avoid the risks of food allergy incidents. A food product contains multiple values demanded by consumers (Lancaster, 1966). A correct declaration of food allergens provides the value of information transparency in a food product. Information transparency is an important value demanded by consumers with food allergies (Poulos et al., 2007) and others. For example, chefs need transparency to their customers; parents need it to help their children avoid food allergies; and retailers need it to develop proper strategies for promoting food products in their shops.

FBOs can only obtain their profit by providing the value that their customers need (Jia & Petrick, 2013; Aidt et al., 2017; Smith, 1776). In this manner, FBOs do have an economic incentive to ensure that they declare food allergens in order to increase their profits.

When failing to deliver the value of declaring mandatory food allergens, food manufacturers have to recall food products and thus incur significant economic losses. For example, the Grocery Manufacturers Association (GMA, 2011) in the US estimated that 52% of their member food manufacturers incurred losses of $9 million or more (including sales losses and direct recall costs, etc.) when they recalled a food product. Many food companies even purchase insurance to mitigate the cost caused by potential food recall risks (GMA, 2011).

A study conducted by Byun et al. (2020) shows that 38% (of 1919) of regular customers never purchase the recalled food products again; and it would take 59 days on average

for customers who ‘stayed’ to repurchase a food product with a recall record. Another survey with SME food manufacturers (Dora et al., 2013) indicated that customer loyalty was the biggest driver for them to improve food product quality. Such economic incentive to improve food allergen management should not be overlooked.

3.2 Gaps between intention and action

Merely having the intention to avoid the risks of food allergy alerts (Griffith et al., 2010), however, does not assure the adoption of good practices among FBOs. This is because there are gaps between a person’s intention and actions (Jia & van der Linden, 2020; Ajzen, 1991).

FBOs may face various constraints (or barriers), such as limited information or insufficient knowledge and skills, to prevent them from implementing good practices (Ajzen, 1991; Simon, 1957). For example, an operator might not have sufficient time to check whether there was packaging leftover from previous food products on the production line.

An FBO, as an aggregation of its employees, hence also encounters significant gaps between intentions and actions due to the constraints (or barriers). This means that an FBO’s intention to prevent food allergy alerts may not be sufficient to ensure good practices implemented in daily operations. It is important to understand their constraints (or barriers) in order to motivate them to improve food allergen management.

3.3 Collaboration

Food allergen management is a complex process that requires multiple stakeholders along the food supply chain to adopt good practices in a collaborative manner (Ball et al., 2009). The stakeholders of food allergen management include both internal and external stakeholders.

For the internal stakeholders, every employee needs to make sure that all food allergens are managed according to good practices (De Boeck et al., 2016; Wright & Leach, 2013); management teams need to have every team member’s commitment (Ball et al., 2009; De Boeck et al., 2016); all relevant employees need to maintain good communication (Ball et al., 2009; De Boeck et al., 2016; Wright & Leach, 2013); and supervisors and managers need to ensure that their teams are equipped with sufficient resources, technologies, knowledge and skills (Jespersen et al., 2017; Ball et al., 2009; De Boeck et

al., 2016; Denison, 1997; Jespersen et al., 2016; Taylor et al., 2015; Wright & Leach, 2013; Jespersen et al., 2014) for food allergen management.

For the external stakeholders, food manufacturers need to work closely with the ingredient suppliers, label and package suppliers, food safety consultants, inspectors and other relevant stakeholders closely to ensure that all the products and services provided by the suppliers meet their requirements concerning food allergen management.

4 Motivating Food Business Operators to improve food allergen management

Behavioural incentives of food allergen management may vary from one FBO to another. In the following, we outline how to identify and enhance these incentives.

4.1 Behavioural benefits of food allergen management

An individual's behavioural benefits here refer to the values derived from her or his activities (Jia et al., 2019). According to Steg et al. (2014), they are comprised of an individual's personal hedonic goals (for example, avoiding effort, gaining pleasure), gain goals (for example, money and social status); and normative goals (doing what is right, normative, or appropriate)'.

An FBO is the aggregation of its employees: thus its behavioural benefits are the aggregation of its employees' behavioural benefits to the FBO. This is different from the aggregation of every employee's behavioural benefits to themselves, since an employee's behavioural benefits do not necessarily increase the FBO's behavioural benefits. For example, if an operator verified food packages and corrected the wrong packages immediately, they thereby contribute to the FBO's behavioural benefits through preventing a potential food allergy alert. If the operator did not verify the food packages, they may obtain behavioural benefits from reducing personal workload in food allergen management but would increase the FBO's risk of food allergy alerts. In this way, employees' behavioural benefits reduce the food manufacturer's behavioural benefits.

Behavioural benefits are not limited to economic benefits. It has been found that food allergen management has economic (for example, cost reduction and raising customer loyalty) (Dora et al., 2013); social (for example, reducing foodborne diseases) (Loh & Tang, 2018); and environmental (for example, reducing food waste) (Zhong et al., 2017; Bocken et al., 2013) benefits to FBOs.

4.2 Behavioural costs of food allergen management

Behavioural costs here refer to all the materialised and non-materialised resources required (Jia et al., 2019) for food allergen management, such as equipment, labour,

time, knowledge and skills. An FBO's behavioural costs are not unlimited and its adoption of good practices is constrained by its available behavioural costs (the constraint of behavioural costs is represented by the triangle in Figure 5: each edge represents one type of cost constraint and the three edges represent social, environmental and economic costs respectively).

Behavioural costs include both internal and external behavioural costs related to an FBO's food allergen management. FBOs commonly consider internal behavioural costs in making decisions, while the external behavioural costs are often overlooked or underestimated. For example, an FBO may intend to save time and resources on food allergen management leading to a reduction of internal behavioural cost; this, however, may raise the risks of food allergy incidents leading to a higher external behavioural cost.

Sometimes, the external behavioural cost (such as reputation damange, loss of customer loyalty and legal charges) of managing food allergens could amount to much more than the internal one. This means that FBOs need to consider both internal and external behavioural costs in managing food allergens and prevent any potential risks of food incidents.

Similar to behavioural benefits, behavioural costs too have three dimensions, namely social, economic and environmental costs. For example, a food allergy incident could result in economic cost from recalling food products and sales decreases (GMA, 2011), social cost from consumer hospitalisation due to allergic reactions (Poulos et al., 2007) and environmental cost from disposing the recalled food products to landfill (Helmer, 2019).

Sometimes, increasing one behavioural cost could eliminate the constraint of another, for example, investing in staff training to improve their knowledge and skills in food allergen management.

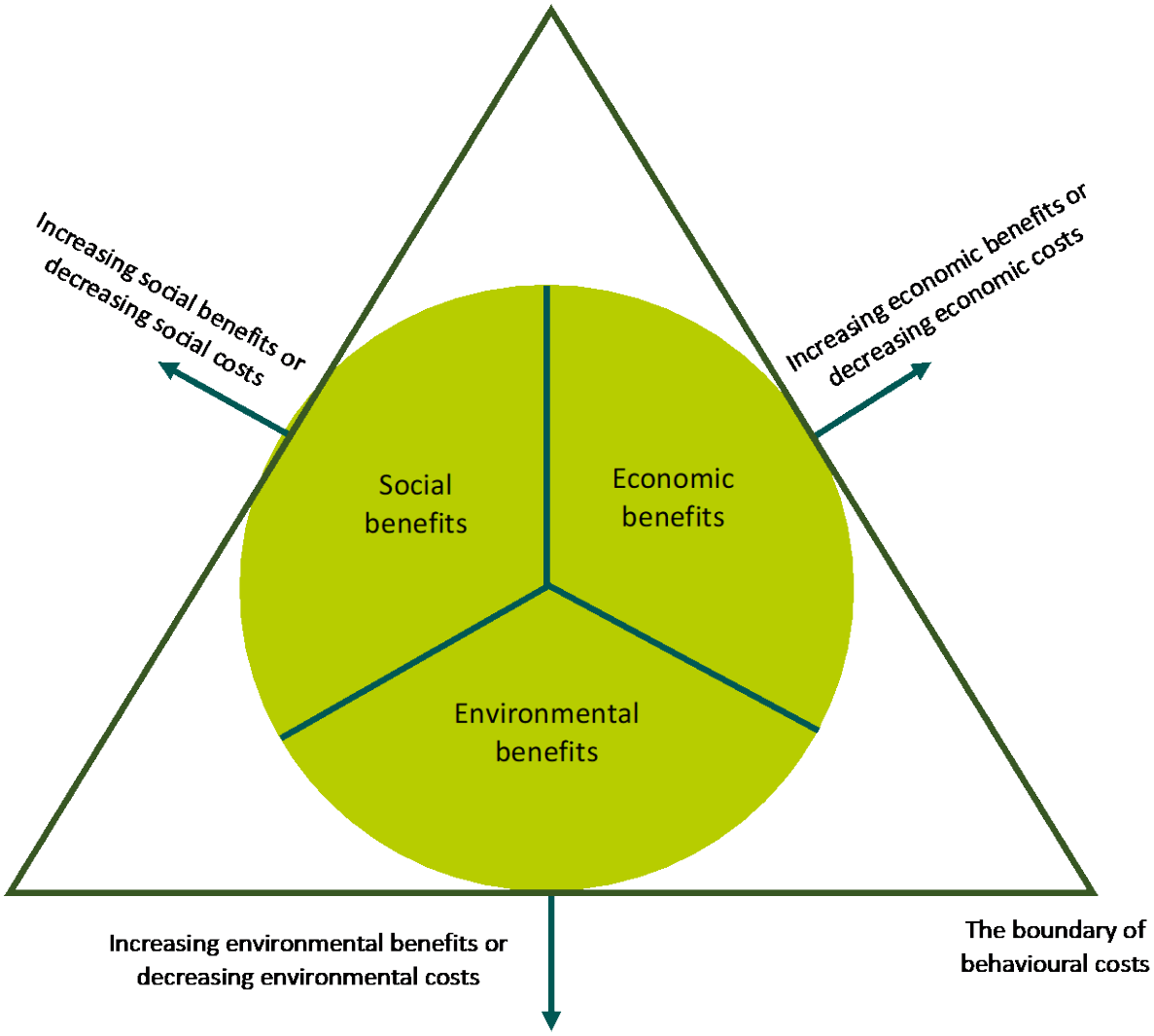
This type of compensation, however, may not be always achieved. For example, a negative social image due to a food allergy alert cannot easily be eliminated simply by increasing the marketing budget (Byun et al., 2020).

4.3 Behavioural incentives

Following a behavioural cost–benefit analysis (Jia et al., 2019), a food manufacturer can aim to optimise its behavioural benefits of food allergen management within the

constraints of its behavioural costs (as shown Figure 5). This means that an FBO can be motivated to improve food allergen management both by increasing its behavioural benefits and reducing its behavioural costs. The process is illustrated in Figure 5.

Figure 5: Behavioural cost–benefit model of food allergen management for an FBO



Source: Jia and Evans (2021)

4.3.1 Increasing behavioural benefits

The behavioural benefits of food allergen management can be increased in many ways. For example, improving leadership in an FBO is critical to promoting the social benefits of food allergen management (Yiannas, 2009; De Boeck et al., 2016). Good leadership can create a vision of food allergen management, align operators' interests with the expectations of food allergen management and attract operators to follow. Under such leadership, operators will be recognised for their good practices in food allergen

management, which can motivate them to commit to food allergen management (Ball et al., 2009; De Boeck et al., 2016; Yiannas, 2009).

Communication contributes to the gains in both social and economic benefits of food allergen management. It can enable successful collaborations among all the relevant stakeholders within an FBO (Griffith et al., 2010; Yiannas, 2009) and along the food supply chain.

For example, if good practices of food allergen management are well communicated with operators, it can help operators develop shared values and collaborate more efficiently (De Boeck et al., 2016; Wright & Leach, 2013) to prevent food allergy incidents. If employees in an FBO are unable to communicate operational errors properly, it may discourage staff from preventing mistakes at an early stage or taking responsibility for their mistakes, thus raising the risk of food allergy incidents.

Sometimes, even a small change can increase the behavioural benefit of food allergen management. For example, colour-coded labels on production machines can make it easier and quicker for operators to identify the production lines dedicated to a specific allergen profile (FoodDrinkEurope, 2013).

4.3.2 Reducing behavioural costs

The improvement of food allergen management can also be motivated by reducing its behavioural costs (in Figure 5, this would move the boundary of behavioural costs outward). For example, resource constraints have been regarded as one of the top barriers for food companies to manage food allergens properly (McAdams et al., 2018). Due to limited resources available, food manufacturers may have difficulty adopting good practices (Tomašević et al., 2013; Chaoniruthisai et al., 2018; McAdams et al., 2018). When a sufficient budget is not allocated to food allergen tests, it is impossible to ensure that the required frequency of tests can be conducted. If a specific allergen profile does not have dedicated production facilities (for example, production line, scoops, utensils, and containers, etc.), it will raise the risk of food allergen contamination (FoodDrinkEurope, 2013). It is critical to remove the resource constraint for food allergen management and prioritise its resource availability.

While the management of food allergens requires good knowledge and skills, lack of sufficient knowledge and skills becomes a constraint for food allergen management. A good understanding of food allergen management can prevent potential risks from the

design phase. If the facilities are set to avoid the crossover of open production lines (such as conveyor belts), this can prevent food allergen contamination from spillage and reduce the risk of food allergen contamination (FoodDrinkEurope, 2013).

Without a sound knowledge of adequate space between production lines and around equipment, operators will have difficulty mitigating the risks of food allergen cross-contact and avoiding airborne cross-contamination.

A survey in Ireland has shown that only 13% of food operators could list the 14 allergens identified in the EU Regulation No.1169/2011 and 28% of these food operators did not receive any food safety training in Ireland (Gruenfeldova et al., 2019). More than 50% of the workers surveyed did not know that celery, peanuts, mustard, sulphites, sesame seeds, lupin and molluscs are food allergens (Gruenfeldova et al., 2019). The root cause analyses in Figure 4 also reported that lack of staff training is the cause of 8.3% of food allergy alerts.

4.3.3 Incentive and the natural environment

The environmental cost and benefit of food allergen management are often overlooked. A labelling error may result in a disposal of labels or packages or even food products; all the natural resources that went into these labels, packages and food products are thus wasted (Helmer, 2019; Bocken et al., 2013).

FBOs have increasing interest in raising their environmental benefit and reducing their environmental cost (Zhong et al., 2017), such as cutting food waste and CO_2 emissions. From this perspective, all the improvements that can prevent these incidents of packaging and food waste contribute to either the increase of environmental benefit (for example, possession of a good reputation for clean production and champion of food waste reduction) or the reduction of environmental cost (for example, water usage, CO_2 emissions, and food waste disposal). The key to distinguishing environmental benefit and cost is whether an FBO takes proactive actions to reduce their negative environmental impacts (such as leading the industry in food waste reduction) or meet environmental compliance (such as obtaining an environmental permit). The former is associated with environmental benefit, while the latter is associated with environmental cost.

4.3.4 Incentives and external stakeholders

Some constraints (or barriers) may stem from the legal context in which food manufacturers are embedded (part of the social cost boundary in Figure 5). For example, the inconsistent food allergen labelling regulations across countries have created difficulties in food allergen management. There are eight food allergens that are mandatory to declare for international trade (Codex Alimentarius Committee, 2013). In the U.S., there are also eight food allergens, yet they include wheat rather than different cereal sources of gluten like in Codex and EU. The EU Regulation No. 1169/2011 Annex II stated 14 food allergens that it is mandatory to label (EU, 2011).

The different labelling regulations for imported ingredients or materials may cause confusion to operators and result in undeclared food allergens. A strategy such as more consistent regulation or a better food traceability system that can eliminate the confusions would assist FBOs to manage food allergen more effectively.

An FBO's food allergen management is also constrained by its suppliers (part of the economic cost boundary in Figure 5), such as food ingredient suppliers, label and package suppliers and food safety consultants. For example, when the ingredient suppliers fail to label all the food allergens or use a confusing label, it will make it impossible or difficult for the FBO to declare all the food allergens correctly. If FBOs choose suppliers carefully, it will help them lower the risks of food alerts.

Every FBO may have distinct behavioural costs and benefits, hence its strategy to motivate food allergen management may differ from that of other FBOs. Figure 5 can function as a tool for FBOs to identify their own incentives through analysing behavioural costs and benefits.

5 An incentive-based approach to preventing food allergy alerts

Improving food allergen management is a dynamic process to enable FBOs to address emerging issues and minimise risks of food allergy alerts. In this manner, the behavioural incentives of FBOs should also be upgraded to motivate the improvement of food allergen management progressively.

We have, therefore, established an incentive-based approach to preventing food allergy alerts. It contains (a) an incentive-based food traceability system which provides a coherent framework for embedding behavioural incentive into the design of food traceability technology; (b) a standardised food product information form; and (c) a prototype of digital platform. These are outlined in turn below.

5.1 Incentive-based food traceability system

The employees involved in food allergen management within an FBO (such as operators, managers and supervisors) are at the centre of an incentive-based food traceability system.

They may start by examining their current practices in food allergen management and identify practices for improvement. For example, the operational errors listed in Table 1 could be used for screening their practices, although their operational errors may not be limited to this list and additional practices for improvement may need to be added.

Then, they could use the behavioural cost–benefit model in Figure 5 to identify their behavioural benefits and costs of improving food allergen management, and develop and implement their strategies accordingly. They need to document their operational, control, management and strategic changes. This will allow them to evaluate their performance and harness value to the business (such as food and material wastes reduction) accordingly.

Once an FBO obtains more economic, social and environmental value from improving food allergen management, they will be motivated to continue the virtuous circle (as shown on the left of Figure 6).

The data collected from the above steps will allow analysis of the pattern of behaviour changes and tailor more efficient incentives to FBOs with Artificial Intelligence (AI)

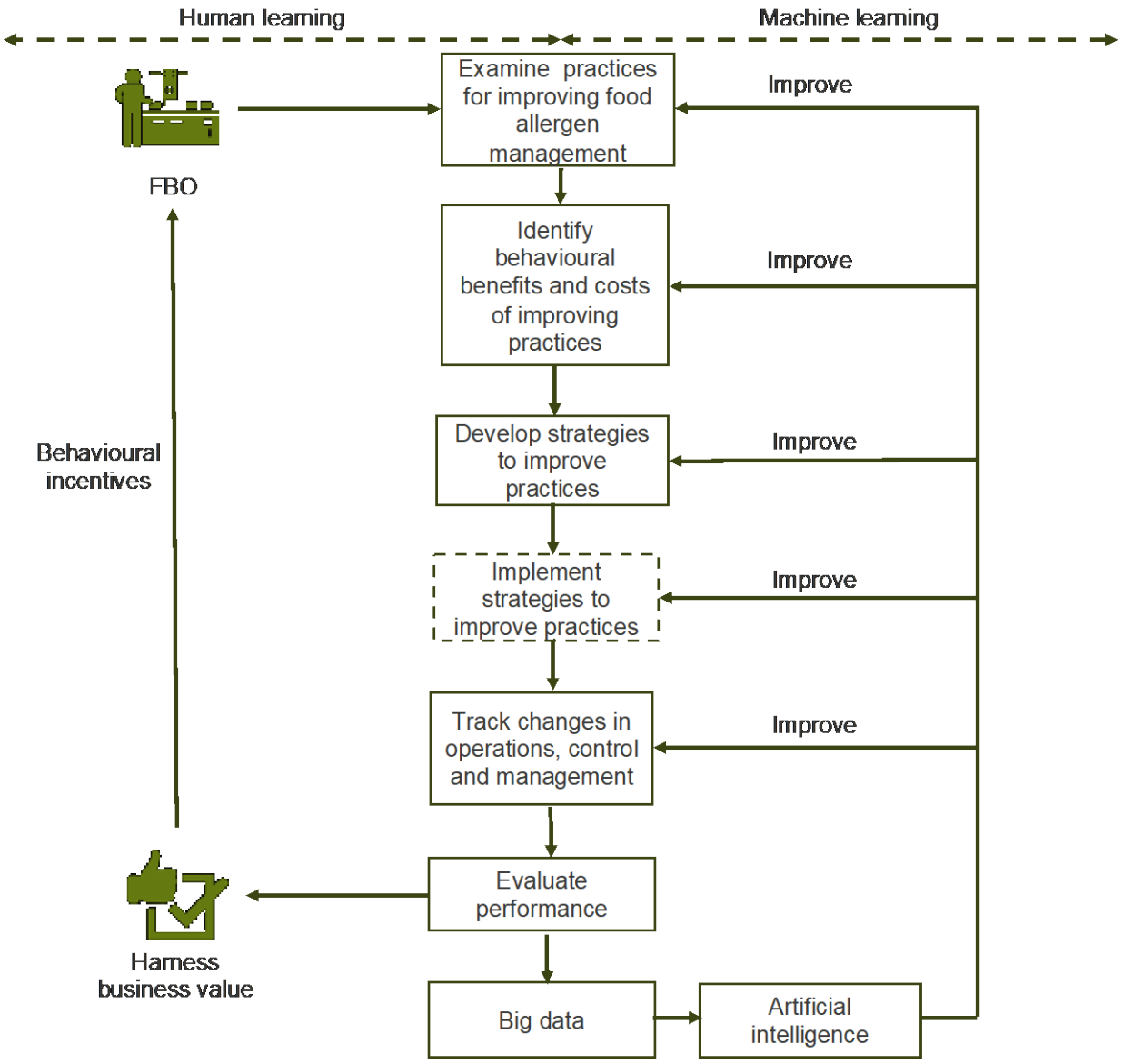
algorithms (as shown on the right-hand side in Figure 6). This differs the use of machine learning in conventional automation and food traceability technologies (Badia-Melis et al., 2015) where machine learning is used independently, with the aim to replace human beings. Here, in contrast, we consider machine learning acts as a prediction tool to provide information to users, rather than making decisions for them (Agrawal et al., 2018).

By assisting human learning with machine learning iteratively, food allergen management may be improved and motivated sustainably. The process is illustrated in Figure 6.

This system can motivate food allergen management by:

1) Increasing awareness of potential risks in food allergen management. As we discussed in Section 4, many food allergy alerts are caused by operational errors. When some common errors are unknown to a food manufacturer, they may make the same mistakes that others made before due to low awareness. The proposed system allows food manufacturers to examine their practices against the common errors. It hence raises awareness of their poor practices and encourages them to take actions to improve their performance before the outbreak of any food allergy incident.
2) Raising intention to improve food allergen management. This system provides a tool to analyse the behavioural benefits and costs for improving food allergen management systematically. Such an analysis will help FBOs understand the true value of improving food allergen management – to society, to themselves and to the natural environment –thereby triggering greater intention to take actions.
3) Facilitating collaboration on improving food allergen management. Without clear communication, the value of improving food allergen management is often invisible or obscure to FBOs and their stakeholders. This system provides a shareable framework to all the relevant stakeholders and improves their communication. This will contribute to collaboration on improving food allergen management along the supply chain.

Figure 6: Incentive-based food traceability system for improving food allergen management



Source: Jia and Evans (2021)

5.2 Standardising food product information form

At the moment, different FBOs are using various Food Product Information Forms (FPIFs) to exchange food data. For example, PepsiCo, ABP Food Group and 2 Sisters all have different FPIFs for their suppliers. FBOs often need to provide the same data to many different customers, Sainsbury's, Co-op and Tesco, by filling in different forms manually or input food data from different suppliers manually into their own system.

Without a standardised FPIF, it is difficult to automate the data exchange process. It is time consuming to exchange and verify data across different FBOs. This increases the likelihood of errors.

We have developed a standardised FPIF to overcome this challenge. It is drawn on 24 FPIFs from different FBOs in the UK, strategies to mitigate common operational errors in food allergen management (in Section 2.3), and PIF 6.0 (2021) in Australia and New Zealand. A test with real FBO users indicates that it includes 80%-90% of food product information required by any FBO in the UK.

5.3 A prototype of digital platform

In the recent report 'Food Data Trust: A framework for information sharing' (Pearson et al., 2021), seven principles have been developed for sharing food data. Drawing on this report and our research through this project, we propose that the principles for an incentive-based food traceability technology include:

1. **Incentive-based**: Behavioural incentive of adopting best practices should be optimised in information sharing.
2. **Accurate**: Information shared should be accurate and verified by data owning organisations.
3. **Secure**: Data security should be ensured to the owning organisation by providing necessary options to manage and control data distribution.
4. **Efficient**: It should optimise the value of data and avoid duplication of effort for all relevant stakeholders through automating data exchange.
5. **Intelligent**: Artificial intelligence should be used as a tool to improve decision-makings for users rather than make decisions for them.
6. **Collaborative**: It should involve all the relevant stakeholders and facilitate progressive collaboration through information sharing.

Based on the standardised FPIF, we designed a user-friendly prototype of digital platform with Axure RP 10. The prototype contains the following features:

- a standardised FPIF (Principle 1);

- users can tailor their own form based on the standardised FPIF for each product (Principle 1, 4 and 6);
- data owners can choose what data to be shared at which scale, such as within company and customers (Principle 1, 3 and 4);
- self-reporting system in which food data needs to be verified and approved before being sent to customers (Principle 2);
- a multi-user platform. Users include but are not limited to operators, licence administrators, data approvers, suppliers, manufacturers, customers, auditors and inspectors etc. (Principle 4 and 6);
- different levels of food data accessibility for all the relevant data users can be defined by administrators of data owner company (Principle 1 and 3);
- previous FPIFs, except for the information specific to the batch of product (for example, frequency of ingredient data verification), can be reused (Principle 4 and 5);
- questions related common operational errors in food allergen management are embedded in the prototype and optional for FBOs to share with external stakeholders (Principle 5 and 6).

6 Opportunities for preventing food allergy alerts

Preventing food allergy alerts is critical to maintaining a safe food environment for consumers with food allergies. This report confronts this challenge by developing a systems approach – an incentive-based approach to reducing food allergy alerts. This approach brings new opportunities for preventing food allergy alerts, as follows:

- FBOs can be motivated to improve food allergen management by increasing behavioural benefits and decreasing behavioural costs of food allergen managements. This means that unlocking behavioural incentives of FBOs has a great potential for reducing food allergy alerts.
- Providing a standardised FPIF to FBOs in the UK could facilitate the automation of data exchange among them, which will especially benefit Small and Medium Enterprises (SMEs). For example, if the existing food traceability technology companies could adopt the standardised FPIF, they will be able to automate data exchange with their customers and suppliers.
- The incentive-based approach developed during the project can also be applied to improving interoperability between local authorities and the FSA. For example, developing a standardised food audit form and semantic web standards (for example, Web Ontology Language (OWL)) could help the FSA automate data exchange with local authorities.
- Integrating a standardised food product information form into global standards, such as GS1 EPCIS 2.0, could improve interoperability between FBOs along the global supply chain.
- Establishing explainable (that is, ‘clear-box’) rather than unexplainable (‘black-box’) Artificial Intelligence (AI) algorithms will allow machine learning to support FBOs, local authorities and regulators to improve food safety management collaboratively and effectively. Research on ‘clear-box’ AI algorithms form improving food allergen management is scarce, due to insufficient data and research funding. There is a great opportunity to reduce food allergy alerts with ‘clear-box’ AI algorithms if the FSA, local authorities and FBOs could work together with researchers to tackle this challenge collaboratively.

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