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The digitisation of food manufacturing to reduce waste – Case study of a ready meal factory

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ABSTRACT

Generation of food waste (FW) continues to be a global challenge and high on the political agenda. One of the main reasons for its generation is the absence of detailed data on the amount, timing and reasons for created waste. This paper discusses the design, the application and investigates the Internet of Things (IoT) based FW monitoring system to capture waste data during manufacturing in real-time and make it available to all the stakeholders in a food supply chain (FSC). A case study of ready-meal factory comprises of design and architecture for tracking FW including both hardware and software, its implementation in the factory and the positive data-driven results achieved. The case study demonstrates the benefits of digital FW tracking system including the FW reduction of 60.7%, better real-time visibility of the FW hotspots, reasons for waste generations, reliable data, operational improvements and employee behavioural transformation. Although the system replaced the paper-based manual system of tracking FW in the factory, it still needed human input to confirm the waste and was prone to human errors. Overall, the implementation of an IoT-based FW tracking system resulted in a reduction of FW and created a positive environmental and financial impact.

1. Introduction

In the UK, roughly 1.7 Mt per year of Food Waste (FW) arose in 2016 during the manufacturing phase in the food sector at an estimated cost of around £1.2 billion per annum (WRAP, 2017). Although a significant amount of such waste is edible food, this is often disposed of as animal feed or for energy recovery via anaerobic digestion due to economic considerations (Kibler et al., 2018; Dorward, 2012; Gustavsson et al., 2011; Stuart, 2009). Refraining from these practices could have saved 870,000 tonnes a year of avoidable FW (WRAP, 2017). Hence, in an extremely resource-constrained world, the reduction of FW is crucial for achieving global food security by reducing dependency on vital resources and enhancing the greening of the supply chain (Corrado and Sala, 2018; Shafiee-Jood and Cai, 2016; European European Commission, 2013). The stakeholders' benefits by implementing the FW reduction programme including improved corporate image, edge over their competitors, higher profits, and societal approval for morality (Ionescu-Somers and Steger, 2008; Hyde et al., 2001). The key actors within Food Supply Chains (FSC) such as food manufacturers, distributors and retailers are putting lots of efforts into reducing FW (Evans et al., 2012). But the lack of efficient FW monitoring practices has resulted in considerable costs for disposal of waste (Derqui et al., 2016; Göbel et al., 2015). Even if these actors have any FW management system, it is more reactive in nature than proactive (Darlington and Rahimifard, 2007). Garcia-Garcia et al. (2017) provided a nine-stage categorisation of FW generated and how to manage it in a more sustainable manner to reduce its environmental impacts. However, this approach does not allow much flexibility for actors to look into the reasons behind the generation of FW which leaves little scope to reduce it (WWF, 2017). Furthermore, stakeholders are facing laggard levels of information and automation, dependence on artificial values (Ju et al., 2017) which leads to insufficient data, slower response and more resources used (OECD, 2017; Gunasekaran, 2009). The FSCs, therefore, need to implement FW prevention techniques such as waste tracking, line optimisation and inventory management (Aung and Chang, 2014).

In order to minimise the FW from post farm gate to retailer's shelf, novel techniques such as the Internet of Things (IoT) could play a more significant role (Sandle, 2017; Dittmer et al., 2012). The IoT is a concept where objects communicate and exchange data through wired or wireless networks and provide intelligent solutions to stakeholders which allow better decision-making (Rose et al., 2015). The recent developments in the IoT sector with

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regards to mobile network communication and sensors equipped with WiFi and Bluetooth has garnered a lot of research interest (del Rosario et al., 2015). And it has led to the capability of sensing, actuating, collecting, storing and processing the data by linking objects to the Internet (Ibarra-Esquer et al., 2017). Some of these IoT applications have also found their way into FSCs and are currently deployed for quality monitoring of food, traceability and tracking and logistics management (Xiaorong et al., 2015; Pang, 2013). Due to the benefits offered by IoT services and its potential use in monitoring FW is a subject worthy of study by researchers, industry and government. However, currently, there appears to be no useful IoT application available for addressing this issue.

This paper proposes an IoT-based digital FW monitoring system consisting of hardware and software which play a significant role in collecting information on FW and analysing it to extract meaningful data. Through, IoT-based digital monitoring system, FW can be efficiently recorded with minimum input from humans and provides both economic and environmental data of waste thrown away. The rest of the paper describes motivation and architecture for creating an IoT-based digital FW tracking system. Furthermore, it shows how IoT-based digital FW monitoring system implemented in a ready meal food factory brought some positive outcomes such as staff engagement and awareness to reduce FW by almost 60.7%.

2. Brief overview of the role of IoT in the food sector

The term IoT was coined by Kevin Ashton, director of the Auto-ID Center at MIT in 1999. The first step in the field of IoT was Radio Frequency Identification (RFID) technology which was employed for identification, tracking and storing limited information (Ashton, 2009). However, IoT is still regarded as an emerging technology and its applications are more focussed on developing smart homes, smart cars, smart cities and smart meters (Talari et al., 2017).

Within, the food sector, the utilisation of IoT-based applications for improving FSC activities has been extensively reviewed in recent years. Prater et al. (2005) have discussed the RFID technology adoption in the grocery supply chain and its use in the real-time visibility of stocks and automated proof of delivery. Kärkkäinen (2003) demonstrated how RFID technology increased the efficiency in logistics of short shelf life products of the UK grocer Sainsbury's. Using RFID to improve the visibility of the food movement in the supply chain is being implemented by the food industry to comply with legal laws and to enhance the public image of their products (Musa et al., 2014). Ruiz-Garcia et al. (2009) have reviewed Wireless Sensor Networks (WSN) and RFID technologies in the Agri-Food sector and its applications for environmental monitoring, precision agriculture and livestock, and cold chain monitoring and traceability. Amador et al. (2009) presented the use of RFID for temperature monitoring in a shipping container of pineapples while Barge et al. (2014) showed its usage in cheese production process to record cheese-wheel movement during the production, handling, warehouse, delivery, packing and selling phases. Hong et al. (2014) showed how FW management efficiency could improve by implementing IoT-based Smart Garbage System. Also, Wen et al. (2018) demonstrated how an IoT enabled system allowed data-driven management of restaurant FW resulting in a net positive impact. As FSCs are getting longer and complicated, there are more things that can go wrong (Roth et al., 2008), therefore, it is important to adopt IoT technology to collect, analyse and transmit the correct information.

The above reviews of related work have highlighted that there has been significant progress in the development of IoT applications with regards to environmental monitoring which has led to improved and speedy decision-making with regards to environmental control and management. The reviews also demonstrated that apart from tracking and tracing (transport and logistics), the IoT can have greatest impact on activities such as monitoring, waste management and behavioural changes (Talari et al., 2017). Therefore, this paper presents the innovative digital FW tracking system which supports the decision making in real-time to combat and reduce the FW issues in food manufacturing. This research has demonstrated that the IoT-based FW tracking system can monitor the FW generated in the factory, its reasons and how that information can be used to bring behavioural changes in the staff thereby reducing the overall FW. This system, when implemented in the ready meal factory achieved a significant reduction in FW and had potential to be replicated within the whole factory and other factories within the group or connected to the other actors of the FSC in an IoT environment. FW tracking system dependency on human input was the only drawback of the system and recommendation such as image processing of waste had been provided to increase its effectivity.

3. A methodology of an IoT-based FW tracking system

The case company with the support from the authors developed an IoT-based FW tracking system to establish the exact reasons for waste generation through monitoring and recording of the FW. The details of the system are described below.

3.1. Requirements for developing IoT-based FW tracking system

The case company procedure for collecting and recording the FW was very traditional, i.e. to measure or approximate the quantity of FW generated over a given period of time (Hanson et al., 2016). For example, during the production of ready-meals, the waste generated was collected in the bin bags and measured during or at the end of the production run. The measuring process involved a staff individually weighing each bag and recording it on the daily production sheets which were a slow process and likely to contain errors.

Developing an IoT-based FW tracking system has its own challenges and need to address the following fundamental research questions:

(1) What information regarding food waste needs to be collected?
(2) What is the most efficient method to collect this information?
(3) How does this information need to be recorded and communicated to key decision makers? and
(4) How can this information be analysed and utilised to eliminate and/or reduce the food waste?

Based on the above research questions, the IoT-based FW tracking system required features such as identifying the type of waste, reasons for its generation and real-time monitoring of the FW amount. Therefore, to address the research questions, implementation of an IoT-based system architecture comprising of four layers (namely the sensing, network, service and application layers) was developed (Jagtap and Rahimifard, 2017). This real-time digitised system resulted in FW reduction through behavioural changes among staff as they had detailed information on FW generated.

3.2. Designing of a digital FW monitoring and tracking system based on IoT architecture

Designing of a digital food waste monitoring and tracking system includes the identification of suitable hardware solutions which possibly minimises human intervention to collect data as well as a software application to store, analyse and communicate the collected data to key decision makers, an overview of which is shown in Fig. 1. This digitised FW tracking system consists of six steps which are as follows:

- FW generated on a production line.
- Load cell enabled intelligent scale measures the weight of FW when waste is disposed of by the staff.
- Reasons for FW generated is entered by the staff using a software application available on the touchscreen fitted above the scale.
- FW details are verified and confirmed by the staff and submitted to the cloud or local server.
- All the data related to FW generation is received and stored.
- The FW data is analysed and presented to the management/staffs in user-friendly dashboards.

This digitised FW tracking system utilises an intelligent scale first to measure the weight of the food waste and feed this into a specially designed software application. The next step is to identify and categorise the waste type. The distinct method proposes the use of a human interface to verify the details of food waste. This data is then stored in a database using a cloud computing facility (see Fig. 1), and further analysed using the waste tracker system to provide the real-time status of food waste generated to key decision makers via a user-friendly food waste tracker dashboard.

3.2.1. IoT architecture for digitised food waste system

The reference architecture of the FW system from this case study is shown in Fig. 2, which comprises of four layers: Sensing layer, Network layer, Service layer and Application layer (Jagtap and Rahimifard, 2017). The sensing layer relies on load-cell technology to determine the weight and a software application operated via touchscreen to enter the reason for FW. In the network layer, the data is then transferred to Service layer via Bluetooth technology using hardware such as Arduino UNO, HM-10 BLE Breakout and Linkit ONE. In the Service layer, the data collected and stored locally or on the cloud and analysed further to extract meaningful information. In the Application layer, the data is presented to the stakeholders in the user-friendly form as FW tracker dashboard.

3.2.2. Hardware Design: Intelligent scale

This includes an intelligent mass scale (see Fig. 3) to collect the most relevant food waste data, 24/7 in real-time which is then recorded on a server and analysed through food waste tracker to generate a set of post interrogated information to aid with a long-term strategic planning for the reduction and if possible elimination of food waste.

Fig. 3 illustrates the visual representation of the FW monitoring system and its hardware in detail. The hardware is a combination of the Load cell, Bluetooth adapter and touchscreen. The FW bin rests on a platform installed with a load cell. It detects and captures the weight of FW and connects it to the touchscreen.

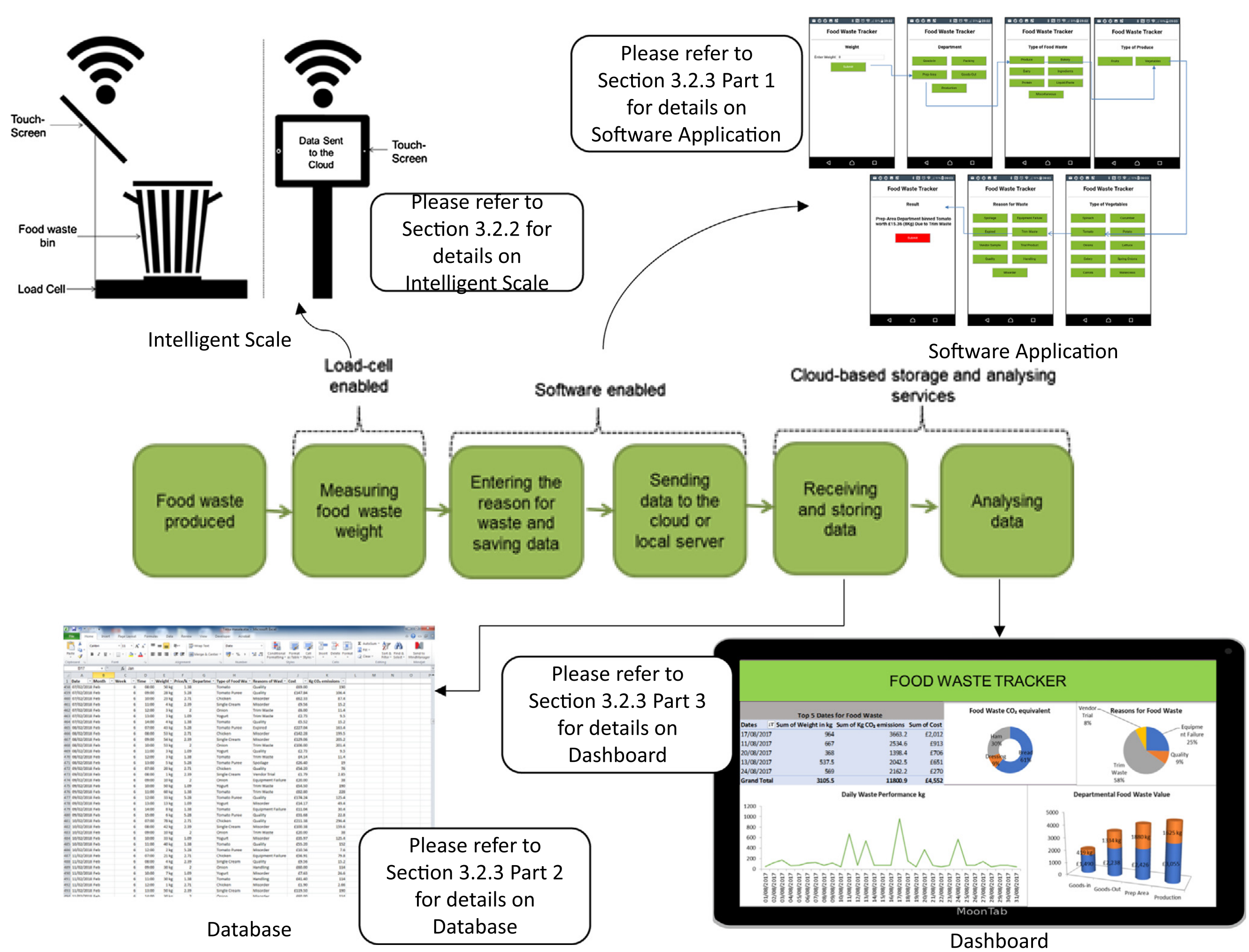


Fig. 1. Design of IoT-based FW tracking system.

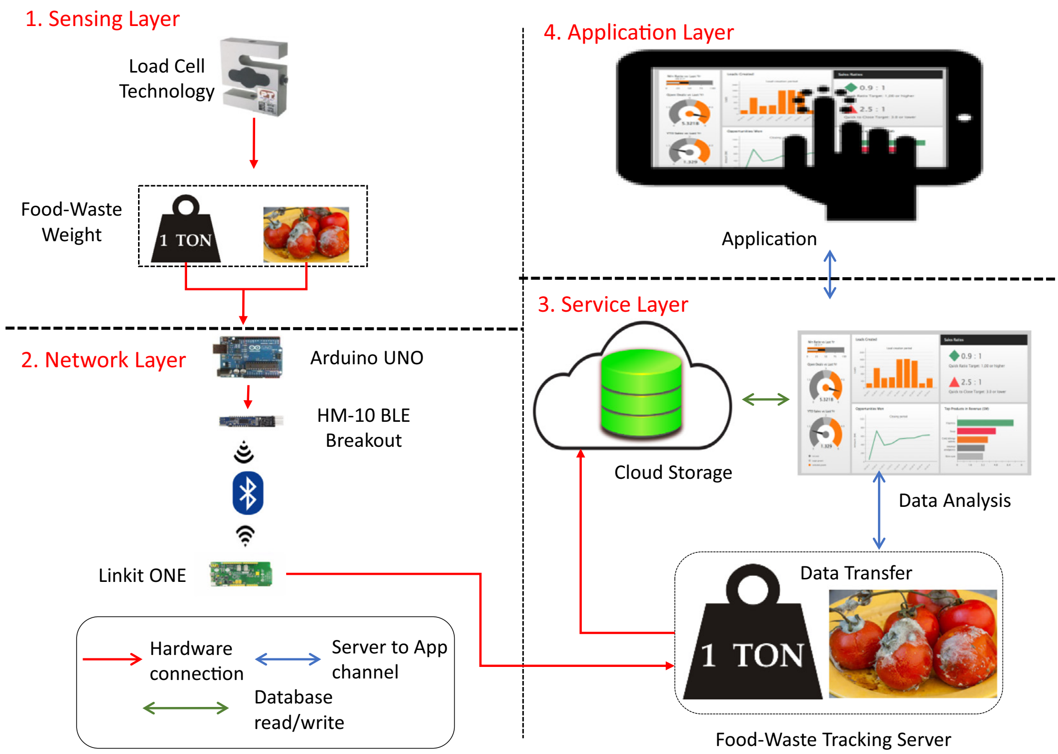


Fig. 2. Reference architecture.

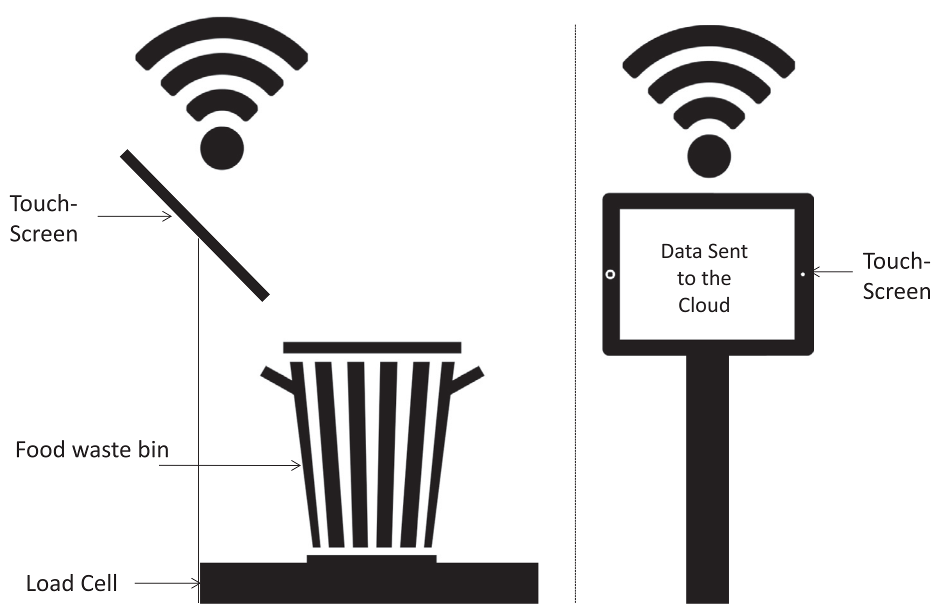


Fig. 3. IoT based FW monitoring intelligent scales.

Communication between the load cell and the touchscreen is handled by Bluetooth technology. The touchscreen has an application as shown in Fig. 4 where employee follows step by step to enter and confirm details on FW. This valuable information on FW is transferred to FW tracking server which consists of cloud storage and analytics.

3.2.3. Software design

It provides an easy interface to the stakeholders to see the state of FW and also offers analytics to view FW history over a certain period of time. The strategic features of the software design for monitoring FW are explained as follows:

(1) FW tracker application – Fig. 4 shows the visual user interface of FW tracker application. Employees need to follow the simple step by step process until they reach the result page where they verify the details and confirm it by sending the data to the local server or in the cloud. In the below example, as soon as the staff bins the tomato FW the load cell below the bin gets activated and sends the weigh data information to the software application on the touchscreen. The example shows that 8 kg of waste is binned in the prep-area which was worth £15.86 due to trim waste. The date and time are added in the background once the whole information displayed on the Result page is submitted by the

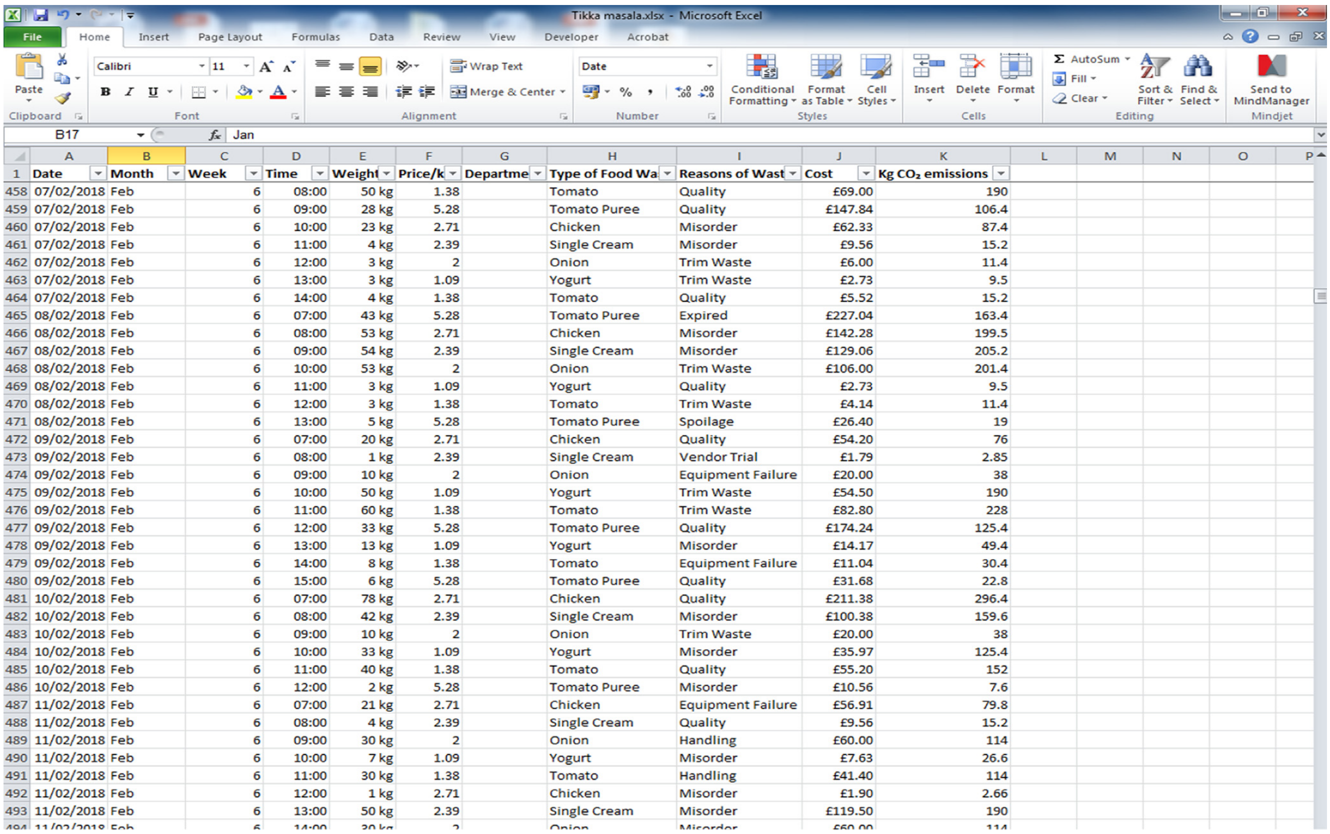
Fig. 4. Visual User Interface of FW Tracker.

staff. The blue arrows represent the steps followed by the staff for confirming the waste. While making this application, only the FW's generated by the Chicken Tikka line of the case company was considered.

(2) Data collection – Over the period all the FW data is collected and stored in the cloud or local server from where it can be retrieved in an excel format as shown in Fig. 5. It presents an excel sheet which has all the details on food waste such as date and time, location, type, cost, weight and reason for FW. The weight is measured in kilograms while the price/kg is pulled up from the Material Resource Planner (MRP) tool and it represents the retail price which company is paying it to their suppliers. The cost column is simply the multiplication of Weight and Price/kg and kg CO_2 emissions is obtained by multiplying the weight of FW with a common factor of 3.8 (on an average 1 kg of FW produces emissions of 3.8 kg CO_2 equivalent) (Zero Waste Scotland, 2011). The data is available on local server or database, and only the desired information required by the stakeholders is made available in the form of a user-friendly dashboard or excel format.

(3) Real-time FW tracker dashboard – The dashboard application is generated from the information collected in the excel format. The application delivers a real-time view of FW on the production floor. All the processes involved in creating FW are monitored, and the FW information is accessed on all the monitor screens within the factory or remotely by logging in with the correct User-ID and password. Fig. 6 represents the dashboard application. FW status for each food making processes is made available to stakeholders at fixed intervals every 30 min to 2 h. For example, in Fig. 6D, Production is the department which is creating more waste than the other departments. Fig. 6A shows the top 5 dates for the highest FW during that month. The other key performance indicators (KPIs) related to FW include the daily waste performance (Fig. 6E), CO_2 equivalent of generated FW (Fig. 6B), and the reason for waste produced (Fig. 6C). The data on FW can be generated for hourly, daily, weekly and monthly for food manufacturing processes and also alerts can be set up if there is a significant deviation in FW amounts.

(4) Real-time FW Analysis – With additional analysis, FW tracker can compare current FW status to previous historical best practice and provide reference standards to achieve the best. With all the above-discussed FW data available in real-time, it will be easy for the management to investigate the root-cause and undertake process improvement opportunities. Also, the issues which are contributing to the



1	Date	Month	Week	Time	Weight	Price/k	Departme	Type of Food Wa	Reasons of Wast	Cost	Kg CO_2 emissions
458	07/02/2018	Feb	6	08:00	50 kg	1.38		Tomato	Quality	£69.00	190
459	07/02/2018	Feb	6	09:00	28 kg	5.28		Tomato Puree	Quality	£147.84	106.4
460	07/02/2018	Feb	6	10:00	23 kg	2.71		Chicken	Misorder	£62.33	87.4
461	07/02/2018	Feb	6	11:00	4 kg	2.39		Single Cream	Misorder	£9.56	15.2
462	07/02/2018	Feb	6	12:00	3 kg	2		Onion	Trim Waste	£6.00	11.4
463	07/02/2018	Feb	6	13:00	3 kg	1.09		Yogurt	Trim Waste	£2.73	9.5
464	07/02/2018	Feb	6	14:00	4 kg	1.38		Tomato	Quality	£5.52	15.2
465	08/02/2018	Feb	6	07:00	43 kg	5.28		Tomato Puree	Expired	£227.04	163.4
466	08/02/2018	Feb	6	08:00	53 kg	2.71		Chicken	Misorder	£142.28	199.5
467	08/02/2018	Feb	6	09:00	54 kg	2.39		Single Cream	Misorder	£129.06	205.2
468	08/02/2018	Feb	6	10:00	53 kg	2		Onion	Trim Waste	£106.00	201.4
469	08/02/2018	Feb	6	11:00	3 kg	1.09		Yogurt	Quality	£2.73	9.5
470	08/02/2018	Feb	6	12:00	3 kg	1.38		Tomato	Trim Waste	£4.14	11.4
471	08/02/2018	Feb	6	13:00	5 kg	5.28		Tomato Puree	Spoilage	£26.40	19
472	09/02/2018	Feb	6	07:00	20 kg	2.71		Chicken	Quality	£54.20	76
473	09/02/2018	Feb	6	08:00	1 kg	2.39		Single Cream	Vendor Trial	£1.79	2.85
474	09/02/2018	Feb	6	09:00	10 kg	2		Onion	Equipment Failure	£20.00	38
475	09/02/2018	Feb	6	10:00	50 kg	1.09		Yogurt	Trim Waste	£54.50	190
476	09/02/2018	Feb	6	11:00	60 kg	1.38		Tomato	Trim Waste	£82.80	228
477	09/02/2018	Feb	6	12:00	33 kg	5.28		Tomato Puree	Quality	£174.24	125.4
478	09/02/2018	Feb	6	13:00	13 kg	1.09		Yogurt	Misorder	£14.17	49.4
479	09/02/2018	Feb	6	14:00	8 kg	1.38		Tomato	Equipment Failure	£11.04	30.4
480	09/02/2018	Feb	6	15:00	6 kg	5.28		Tomato Puree	Quality	£31.68	22.8
481	10/02/2018	Feb	6	07:00	78 kg	2.71		Chicken	Quality	£211.38	296.4
482	10/02/2018	Feb	6	08:00	42 kg	2.39		Single Cream	Misorder	£100.38	159.6
483	10/02/2018	Feb	6	09:00	10 kg	2		Onion	Trim Waste	£20.00	38
484	10/02/2018	Feb	6	10:00	33 kg	1.09		Yogurt	Misorder	£35.97	125.4
485	10/02/2018	Feb	6	11:00	40 kg	1.38		Tomato	Quality	£55.20	152
486	10/02/2018	Feb	6	12:00	2 kg	5.28		Tomato Puree	Misorder	£10.56	7.6
487	11/02/2018	Feb	6	07:00	21 kg	2.71		Chicken	Equipment Failure	£56.91	79.8
488	11/02/2018	Feb	6	08:00	4 kg	2.39		Single Cream	Quality	£9.56	15.2
489	11/02/2018	Feb	6	09:00	30 kg	2		Onion	Handling	£60.00	114
490	11/02/2018	Feb	6	10:00	7 kg	1.09		Yogurt	Misorder	£7.63	26.6
491	11/02/2018	Feb	6	11:00	30 kg	1.38		Tomato	Handling	£41.40	114
492	11/02/2018	Feb	6	12:00	1 kg	2.71		Chicken	Misorder	£1.90	2.66
493	11/02/2018	Feb	6	13:00	50 kg	2.39		Single Cream	Misorder	£119.50	190

Fig. 5. Data collected shown in an excel format.

generation of FW can be informed to the respective stakeholder so that they can correct the process to reduce waste. For example, in the production process where most of FW is in the form of trim waste generated due to manual handling. With this information readily available the stakeholder can adopt better handling processes to reduce FW and can integrate them as best practices in day-to-day operations to achieve better resource efficiency. The FW data can also be used to produce an annual sustainability report.

4. The case study of a ready-meals factory

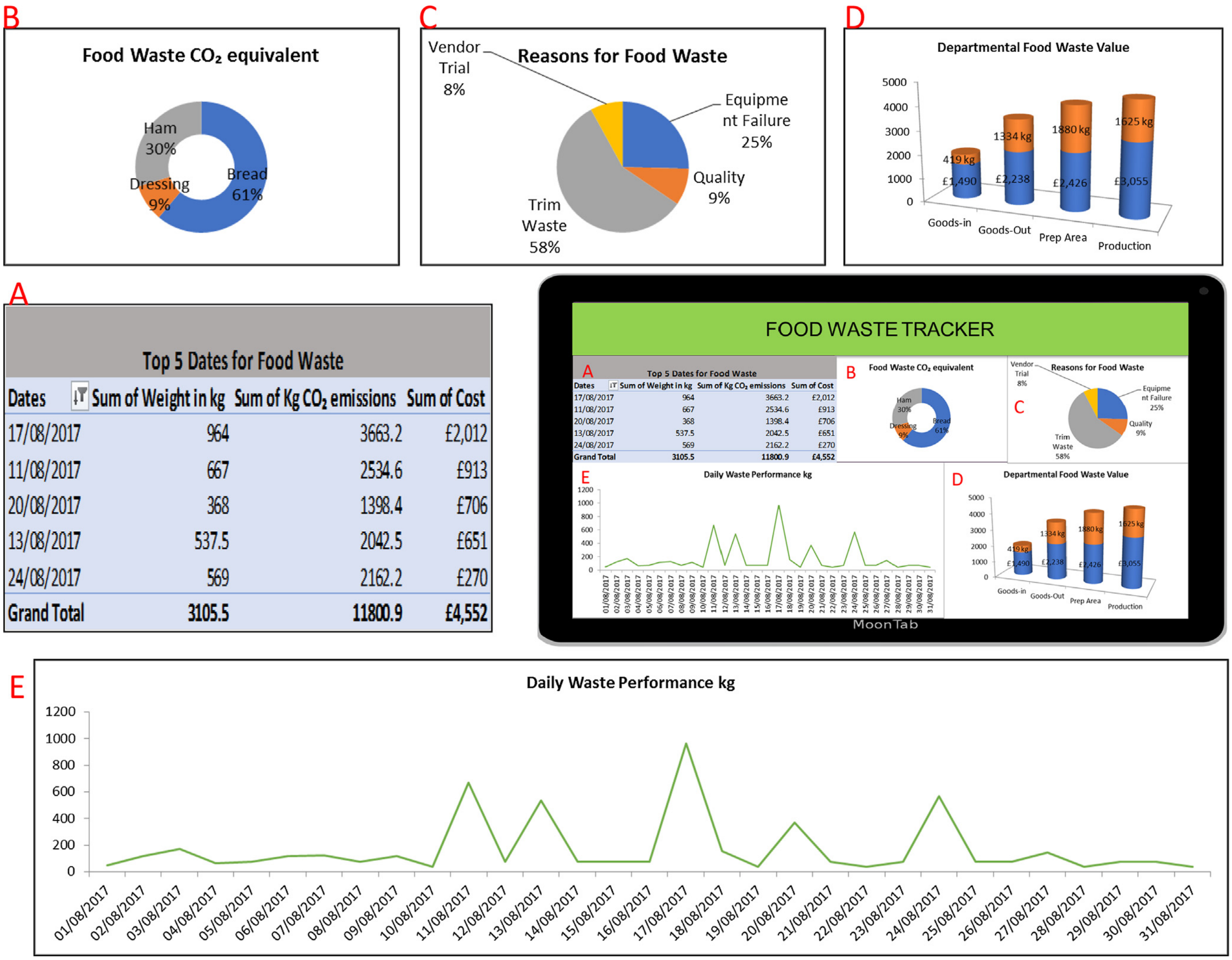
A case study of a food factory producing ready meals has been utilised to demonstrate the benefits of the proposed Digital Food Waste Monitoring and Tracking System. This factory based near London, United Kingdom produces between 100,000 and 120,000 chilled ready-meals per day of various cuisines over two shifts. The current food waste auditing is carried out using a paper-based survey every month.

4.1. Overview of production processes

The process of manufacturing ready-meals is as shown in Fig. 7 involved receiving ingredients at Goods-in department and going through various quality checks before being stored in chilled, frozen or dry ingredients (ambient) storage as per their requirements. The chilled storage is for ingredients with short shelf-life and which are received on a daily basis such as vegetables and dairy products while the frozen store is for proteins (seafood and meats) and ambient storage for long life products such as spices, flour and other canned products. The packaging materials used for packing ready meals are stored in the packaging store. Depending on the daily production orders, raw materials are pre-prepared for the cooking process which involves washing and chopping of vegetables and defrosting of proteins. The ingredients are mixed in large brat pan and cooked using steam as per the recipe. Once fully cooked the products are filled into the trays and then onto the trolleys. The trolleys are moved into blast chillers to rapidly bring the temperature of cooked products below 8 °C and then transferred into chilled storage to maintain its temperature between 5 and 8 °C. Once the temperature of products is as per the recipe standards, then it is packed into CPET (Crystalline Polyethylene Terephthalate) containers and sealed and sent to warehouse chiller, ready to be despatched to customers. This factory produces approximately 12,000 Chicken Tikka Masala (350 gm) ready meals on an average per day. Regardless of the factory strategy to reduce FW, this particular line produced around 1400 kg of production waste per week. It was primarily due to overproduction, spoilage, expiration and line waste (equipment failure, scrapings) at the start of the tracking initiative. It was a significant problem for the factory due to the financial costs and environmental impacts of FW generated from this particular line.

4.2. Challenges involved in monitoring and recording FW

The waste was generated at various locations within the factory. Most of the waste in Goods-in department was mainly due to the stringent quality and technical standards. So even though the raw material is fit for human consumption, it was rejected because of non-conformance to technical standards of the factory. The storage facility produced food waste mainly due to not following First in and First Out (FIFO) rule that is products with longer shelf being used first over the short-shelf life products. The kitchen generated the bulk of the food waste from trimmings followed by cross contamination (allergen handling). Packing lines created most of the waste in the factory due to overproduction (forecast



Top 5 Dates for Food Waste

Dates	Sum of Weight in kg	Sum of Kg CO_2 emissions	Sum of Cost
17/08/2017	964	3663.2	£2,012
11/08/2017	667	2534.6	£913
20/08/2017	368	1398.4	£706
13/08/2017	537.5	2042.5	£651
24/08/2017	569	2162.2	£270
Grand Total	3105.5	11800.9	£4,552

Fig. 6. Real-time FW monitoring dashboard.

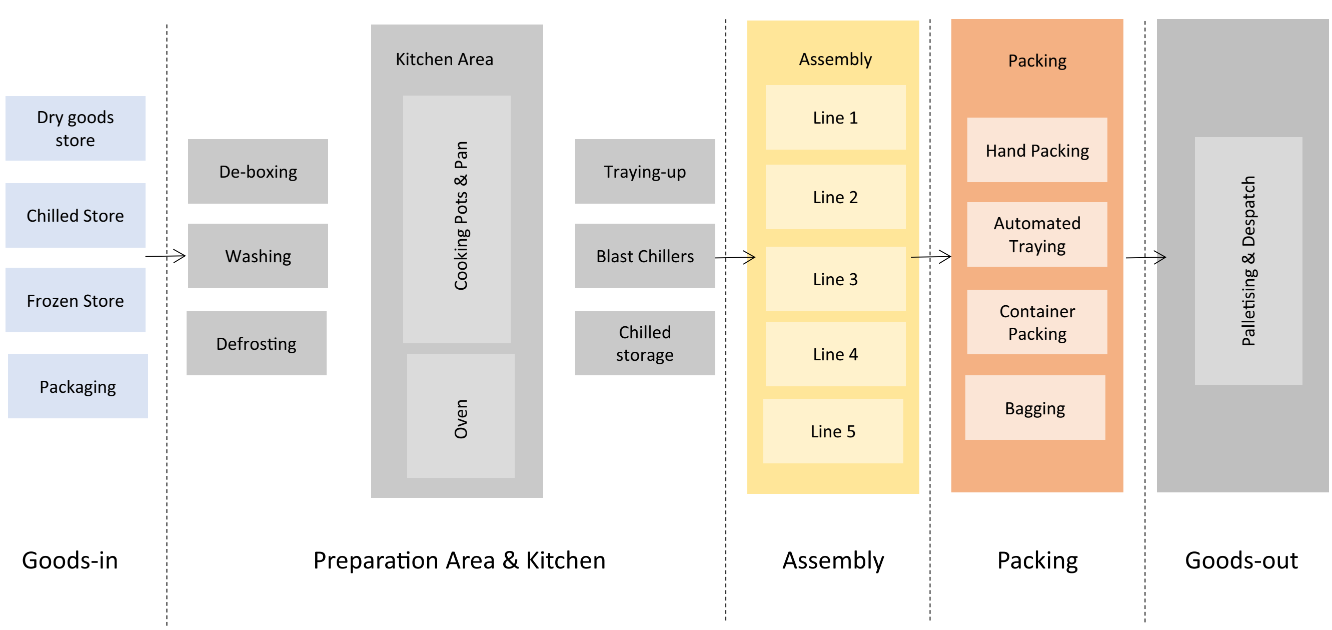


Fig. 7. An overview of ready meal processing factory.

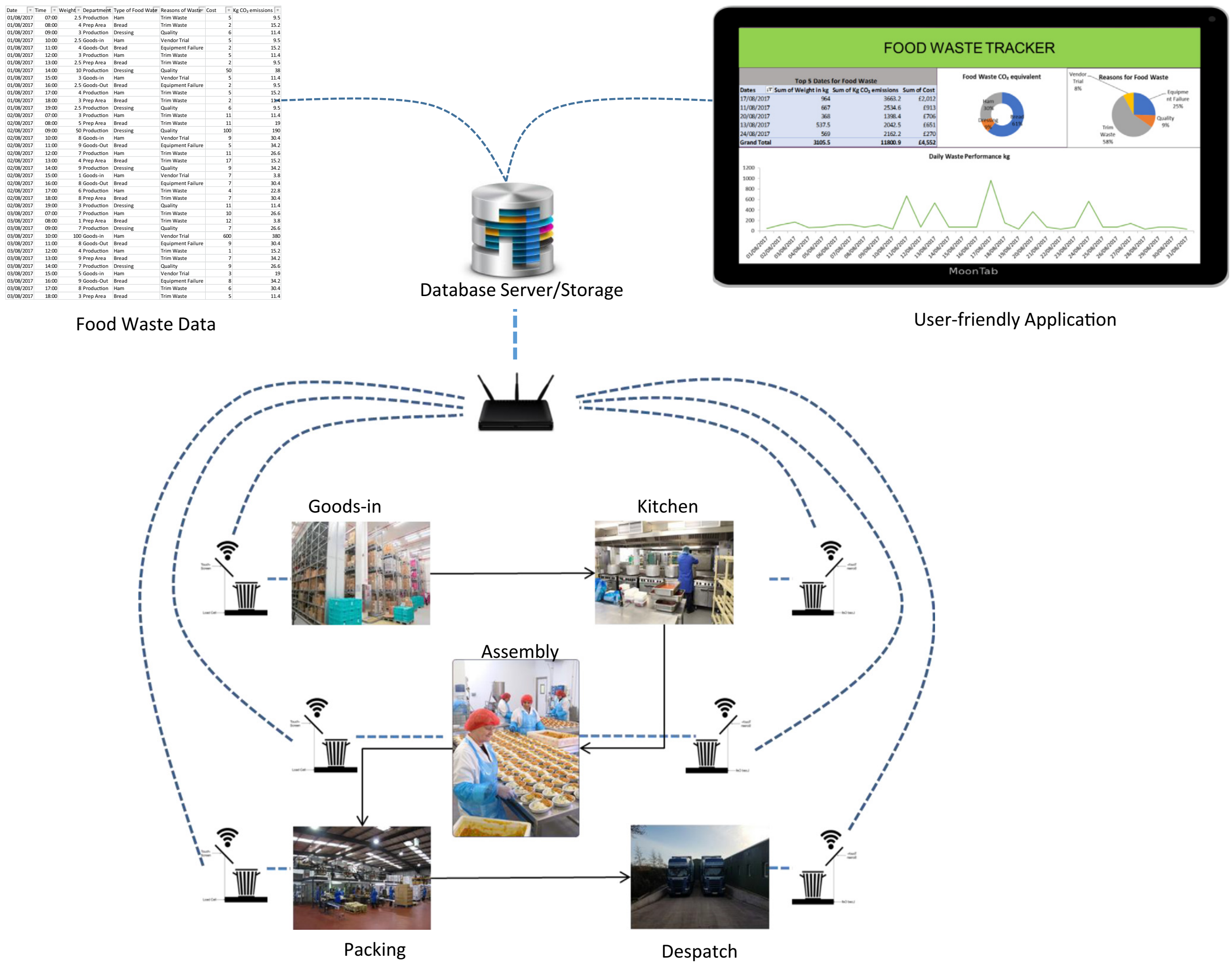


Fig. 8. Tracker data collection points.

and final orders mismatch), machine failures and handling of food processing equipment. Finally, the warehouse which stored finished goods produced minimum food waste as compared to the other departments due to products going out of life because of low demands. It was also challenging for the factory to establish 100% accurate forecast system due to the timing of order received and continuous tweaking of orders by the customer (retailer). Because of this, approximately 24% of FW was created in the factory due to overproduction or overstocking which resulted in ingredients going out of acceptable life and spoilage. The other restrictions such as allergen changeover, the labour movement, workload, standard batch sizes and order commitments made to ingredient suppliers added to the challenges.

The aim was to minimise production FW by 50% through daily FW tracking, staff training, and engagement and adopting the implementation of better waste solutions. FW monitoring was based on digitised "Food Waste Tracker" system. The belief was that "Food Waste Tracker" system information would be an important tool to categorise the various waste hotspots within the factory and the financial losses incurred due to FW.

4.3. The tracking process

FW Tracker system was placed in the production area, and all the FW related to Chicken Tikka Masala was recorded from all the departments as shown in Fig. 8. FW weights were displayed on the touch-screen and staff used it to record the type of waste and reason for its disposal. The software application automatically recorded the date, time and calculated its financial value in the background. The process of recording FW required less than 4.5 min per employee per week. The factory management did not have to employ any dedicated personnel to measure FW, and this practice of tracking may have reduced overall labour by minimising waste and overproduction.

5. Results

The FW for the Chicken Tikka Masala line was reduced by 60.7% when compared to September 2017 (2428 kg) against January 2017 (6190 kg) as shown in Fig. 9. Before implementing the IoT-based digitised FW tracking system the Chicken Tikka Masala line produced approximately 1400 kg of FW per week on an average (12,000 meals produced per day on average). It is to be noted that the FW tracking system was installed in the factory at the end of January 2017. Initially in January daily production of Chicken Tikka masala meals produced 4.7% of FW which reduced to 1.92% by the end of Sep 2017. For the month January 2017, out of the total 6190 kg of FW, approximately 51% of waste was due to Trim waste followed by Quality issue (16%) and Equipment failure (14%) and the rest as shown in Fig. 10. But, for September 2017 the total

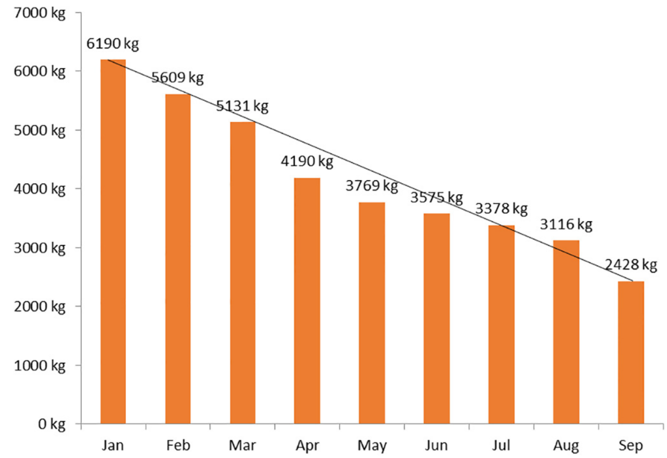


Fig. 9. FW Trend Report – Jan to Sep 2017.

FW was 2428 kg, and this was due to the digitisation and insights on FW. Since the factory did not maintain detailed data on FW from previous years, we cannot analyse how much improvement has been made. It is to be noted that factory vastly reduced their Trim waste from 3165 kg in Jan 2017 to 346 kg in Sep 2017.

Table 1 shows the FW status for Week 2 and gives the detailed breakdown of products wasted, reasons, and cost. The total amount of waste for Week 2 was 1427 kg and costed approximately £9222.

The factory took the following initiatives to reduce their FW which is described in Section 5.1.

5.1. Initiatives taken to reduce FW

The information obtained through the tracking system led to brainstorming among the staff and devised new initiatives to reduce the amount of FW as described below:

(1) **Trim waste** – It was generated from vegetables and chicken from food processing machinery. The factory was able to cut down their trim waste by 89% by using it in producing soups for the factory staff canteen.

(2) **Expired/Quality** - High-value products such as tikka sauce, chicken and dairy products (yoghurt and single cream) expired due to not having enough orders and their short shelf-life. The vegetables and ingredients were rejected due to stringent quality and technical standards but found to be entirely fit for human consumption. Attempts were made to find a user for them with other factories within the group and also collaboration was built with local restaurants and charity to sell the remaining products and thereby generate income. Buyers at the food factory negotiated with suppliers to reduce the minimum order quantity (MOQ) and lead times for the ingredients delivery which cut down over-stocking at factory and ingredients going out of life at later dates. Adopting these corrective actions led to a reduction of FW in this category by 32.5%.

(3) **Mis-order** - Most of the products which were wasted because of 'Mis-order' were due to variations in actual orders against forecast numbers. It called for greater collaboration between the factory and their customers (retailers) planning teams. Simple changes such as adopting the timing of final orders and alignment of orders and production reduced food wastages. The FW due to Mis-order increased for September (679 kg) as compared to the January (371 kg), and that was owing to promotional activities at the retailer.

(4) **Spoilage/Handling** – Spoilage occurred due to cross-contamination of products and the company's stringent allergen changeover policies whereas improper handling of equipment resulted in food wastage due to spillage. It stressed the need for periodic training of employees on basic hygiene, appropriate use of personal protective equipment (PPE), allergen usage and right use of food processing machinery and utensils. The business is heavily reliant on the weather which significantly influenced the retention of seasonal employees who were trained for food and hygiene practices. The loss of skilled labourers led to increasing in FW for the month of September (534 kg) when compared to January (185 kg).

(5) **Equipment Failure** – Equipment failure resulted in leakages, and product giveaway and the reason for that was lack of preventive maintenance and improper alignment of food machinery. The company changed its approach and focused on regular preventive maintenance and issued 'Daily Machine Start-up Check Sheets' to operators in order to monitor the state of machines and if machines are depositing the exact quantity of food components as per the recipe. This action resulted in reducing FW in this category by 80%.

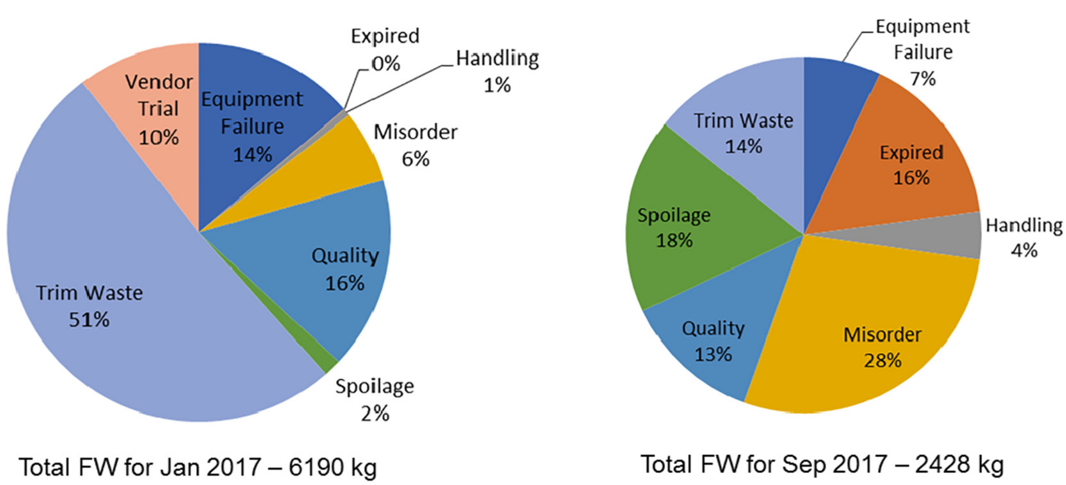


Fig. 10. Analytical data on FW.

Table 1
Weekly Ingredients wasted with reasons and cost.

Reasons for Food Waste	Equipment Failure		Quality		Trim Waste		Vendor Trial			
Week 2	Sum of Weight	Sum of Cost	Sum of Weight	Sum of Cost	Sum of Weight	Sum of Cost	Sum of Weight	Sum of Cost	Total Sum of Weight	Total Sum of Cost
Cardamon	8 kg	£317		£9	60 kg	£2376	15 kg	£594	83 kg	£3296
Chicken	3 kg	£7	41 kg	£111	13 kg	£36	4 kg	£9	60 kg	£164
Cloves	2 kg	£102			6 kg	£409	10 kg	£682	18 kg	£1194
Coriander			55 kg	£565	72 kg	£740			127 kg	£1306
Cornflour	60 kg	£180			23 kg	£69			83 kg	£249
Cumin Seeds			48 kg	£254	40 kg	£212			88 kg	£466
Garlic Puree	1 kg	£1					21 kg	£44	21 kg	£46
Ginger Puree			2 kg	£3			30 kg	£64	32 kg	£67
Green Chilli			12 kg	£115	10 kg	£102	13 kg	£130	35 kg	£347
Onion	60 kg	£120	3 kg	£6	13 kg	£25	17 kg	£34	93 kg	£186
Rapeseed Oil	1 kg	£1					1 kg	£1	2 kg	£3
Salt					105 kg	£56			105 kg	£56
Single Cream	5 kg	£12	17 kg	£41	7 kg	£16	35 kg	£84	64 kg	£152
Spice mix			7 kg	£49	20 kg	£140			27 kg	£189
Sugar	40 kg	£18			50 kg	£22			90 kg	£40
Tikka Sauce			3 kg	£6	85 kg	£159			88 kg	£165
Tomato	10 kg	£14	5 kg	£7	68 kg	£94			83 kg	£115
Tomato Puree			38 kg	£201	156 kg	£824	3 kg	£16	197 kg	£1040
Yogurt	10 kg	£11	4 kg	£4	117 kg	£127	2 kg	£2	132 kg	£144
Grand Total	199 kg	£783	234 kg	£1371	844 kg	£5406	150 kg	£1661	1427 kg	£9222

6. Conclusion

Food waste (FW) was a significant challenge for the ready meal factory, with approximately 1400 kg produced per week on Chicken Tikka Masala ready meal line. The traditional paper-based system used for recording FW was laborious, slow and often inaccurate. In order to solve these issues, a real-time digitised IoT-based FW tracking system was developed and adopted in the case company. The designing of this system included research on both hardware and software aspects. The hardware component consisted of weighing scale attached to a touchscreen to measure the weight of FW. While the software consisted of an application wherein staff can confirm the type and reason for waste. The other part of the software developed allowed real-time FW data visualisation, alerts and detailed analysis. This part of the software was responsible for better-decision making by the management with regards to FW. The whole system was developed, implemented and put into practice for nine months in the case company.

The implementation of real-time digitised FW tracking system coupled with staff training and engagement, the company managed to reduce it by 60.7%. Financially, the company saved approximately £306,873 on FW when compared to previous year results. In today's world where margins are very tight, this savings represents an enormous financial gain for the factory. By having real-time digitised data on FW status and observing the trends, timely actions were taken by the factory management to improve waste practices leading to the reduction of FW. During the tracking of FW, the waste prevention team implemented numerous best practices to be resource efficient which serve as an example for other food businesses in the war against the production of FW. However, some issues such as human input to confirm the FW details still remains unresolved and could lead to the loss of accuracy. The system may encounter problems if used for recording a complicated mix of FW such as edible, inedible, avoidable, unavoidable etc. But, with the advanced image processing technologies, the dependency on human confirmation of FW can be eliminated which will facilitate its wider replication in the food sector.

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Supplementary material

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