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## Manufacturing resilience via inventory management for domestic food waste

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### Abstract

The ability to feed 9 billion people by 2050 will rely on processed foods being delivered through complex and dispersed international supply chains. Currently as much as a third of all food grown is lost as waste at various points along existing supply chains, with roughly half of food waste in the developed world occurring after purchase by the end consumer. For the long-term resilience of the food industry, and as holders of critical information, manufacturers need to play a part in reducing this waste. Using a novel method of food waste categorization, this research describes how the prevention of food waste for certain categories can be facilitated using a Smart Phone App that enables industrial inventory management for the domestic environment, providing the consumer with supporting information about food condition and appropriate preparation processes. Data availability issues and the benefits in terms of resource efficiency and consumer loyalty are discussed.

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### 1. Introduction

It has been estimated that as much as 50% of all food that is produced never actually enters a human mouth [1]. This amounts to a potential two billion tonnes of food waste per year, revealing a significant waste of farmland, time, energy, water and money. As the global population moves toward 9 billion people by 2050 the pressure on agriculture and the manufacturing industry to provide sufficient food for the global population will continue to increase [2]. One way of reducing this pressure is to improve the efficiency of the entire food supply chain to reduce inefficiencies in terms of food waste.

Clearly depending upon the region of the world, food waste occurs for a wide range of reasons. The IMechE categorized different reasons in their 2013 report [1] which defined three distinct types of country: Fully developed, late-stage and newly developing countries. The focus of this research is on the waste generated in the UK (as an example of a fully developed country) which has been shown to be split across the supply chain (see figure 1) with 3 million tonnes from

farms, 3.9 million tonnes from manufacturing and almost half of all food waste (7 million tonnes) occurring after food products have been purchased by the consumer [3 - 7].

The need for the reduction of food waste throughout the manufacturing supply chain is now well recognized [8] but there has been little incentive to reduce the waste generated by consumers. Industry and retailers are not incentivized as the purchase of more products equates to larger profits. However this business arrangement (overproduce, purchase and discard) not only carries significant environmental impact, but also reduces the ability of established supply chains to meet the growing global demand for food [9]. Therefore a focus on reducing consumer food waste is required in order to reduce this environmental impact and increase the long term resilience of existing supply chains.



Fig. 1. The breakdown of UK food waste. Data from [3 - 7].

Manufactures have a range of tools and techniques to help reduce the production of waste and these can be replicated across different industries. Unfortunately consumers do not act as organizations and both crowd and individual behavior patterns are difficult to predict [10]. As an additional complication, food manufacturing has many differences to other sectors including short product shelf lives and perceived low value. A key challenge therefore is to enable consumers to have similar waste prevention and management techniques to industry, thus facilitating a reduction in food waste generation. To put this into perspective, it is possible, in simple terms, to envisage a consumer as a micro manufacturer (figure 2): they buy raw materials (ingredients), which they store (in cupboards, refrigerators, freezers) and then use a wide range of processes (such as mixing, cooking) to produce a final product (meals) to meet a demand (themselves, family, etc.). However, they do not have access to the powerful tools that industry has such as inventory management or materials requirement planning (amongst many others).

In this research it is proposed that access to inventory planning type tools would improve the ability of the consumer to better manage their ingredients and stock and therefore reduce overall food wastage. On the assumption that all food prevented from waste is not additional consumption, this result would alleviate strain on, and therefore increase resilience of, the food manufacturing industry.

In this context, this paper reviews existing domestic food waste and seeks to understand which food types are most problematic, presents a novel food waste categorization process, and describes the development of, and roles of supply chain partners in supporting, a mobile application (App) that facilitates consumer inventory management. This solution is evaluated and a continuation of the work is discussed with respect to implementation.

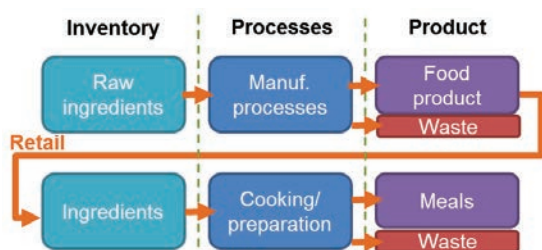


Fig. 2. Consumers as micro manufacturers

2. Current activities for food waste minimization

There are a number of ways to quantify food waste (e.g. by weight, cost, calorie content, environmental impact) but the majority of published literature refers to weight. This might be misleading because some food types are comprised largely of water and have little environmental impact (such as home-grown apples) or are expensive but have low calorie content (e.g. saffron). In this respect it is important to select appropriate metrics for evaluation to avoid unintended outcomes.

Ideally the current research would cover all developed countries but reliable data on domestic food waste could not be obtained. The focus therefore remains on the UK issue, for which a number of reports exist, but which is deemed to be largely representative of other fully-developed countries.

The UK generates about 15 million tonnes of food waste per year [4] with almost half of this attributable to the consumption stage of its life cycle. From UK households, the amount of food waste has decreased from 8.3 to 7.0 million tonnes between 2007 and 2012 [3, 7]. It is important however to understand that not all food waste is avoidable since various components are not edible (e.g. egg shells, meat bones). Various definitions of food waste exist and have been discussed [11] but for domestic waste in this research it is possible to have two main categories, unavoidable and avoidable (this latter category includes food waste which some people eat but others do not such as bread crusts and potato skins). It is estimated that 4.2 million tonnes UK domestic food waste is avoidable [12] with the cost of avoidable food waste for a family of four estimated at £720 (US\$1,100) per year.

Food waste can be further divided into types of food such as fresh fruit, ready meals and meat products (see figure 3). The aforementioned difference between weight and cost of food waste is evident, but of interest in this research is the environmental impact. Animal products typically have higher environmental footprints due to the resources required to grow their food, land and water requirements, and greenhouse gas emissions associated with livestock. Similarly, highly processed foods may require a large number of processes, have long supply chains and may have travelled thousands of miles.

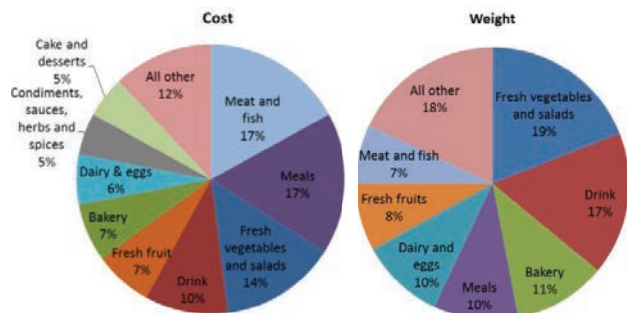


Fig. 3. Comparing UK domestic food waste in terms of cost and weight. Adapted from [13].

Key to providing a solution is to understand why various types of food waste are generated by consumers. Little work appears to have been published on this topic but it has been reported that there is some confusion by consumers over 'Use By' and 'Best Before' dates provided on products [14]. Some analysis has been provided Boyer [15] as to the recommended length of days that fruit and vegetables remain edible, but this clearly also depends on the period of time before purchase, their storage conditions and initial ripeness.

In order to influence the design of a solution for better food waste management, it is therefore necessary to better understand why certain food types (high weight, cost, environmental impact) are wasted by consumers. The remaining sections of this paper are concerned with this objective.

### 3. Research methodology

It is understood that consumers are 'responsible' for a considerable amount of food waste and therefore the supply chain would be happy to attribute the environmental impact of this waste to consumers rather than shoulder the impact themselves. However, it is not clear from the literature reviewed precisely why food waste is created by the consumer. In order to better understand this, a micro-survey was undertaken to establish the amount of waste discarded and the reasons for this.

Over the period of seven days, ten volunteers recorded a description of the food waste, its weight and the reason for discarding within their homes (figure 4). The volunteers were from a range of ages, gender, occupations and inhabited different types of residential housing. In an ideal situation, the subjects would not know that they were being studied as this might lead to an adaptation of behavior and lead to artificially enhanced levels of food waste prevention. Such a study would also contravene research ethics and so in this work, volunteers were informed of the intention of the study.

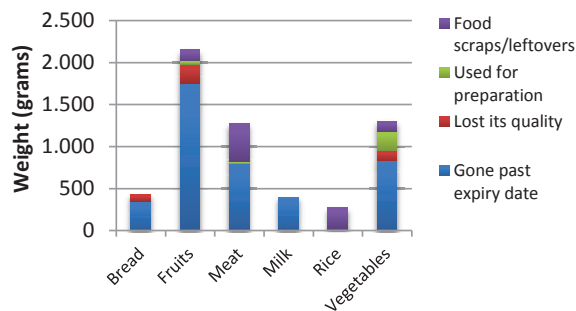


Fig. 4. The most commonly reported food wastes and reasons for their disposal.

From the survey conducted, 60% of food waste was generated due to items having gone past their expiry date, indicating that the management of food inventory is difficult in domestic environments. From figure 3 it is possible to identify that for their weight, the cost of meat and fish is relatively high, as is the environmental impact of these types

of food [16]. In addition, such food types are known to carry higher risk of food poisoning and so are unlikely to be consumed after the Use By Date, unlike other food types (e.g. fresh produce, bakery items) which are more likely to be consumed after the Use By Date.

In this respect, the case for inventory management of food products within a domestic environment is made, with an emphasis on the provision of the 'Use By Date' for quickly perishable foods. Other methods of reducing food waste might include extension of shelf life through improved processing, better packaging solutions or faster supply chains, however these improvements are outside of the scope of the current work. In order to harness the power of inventory management within the domestic environment, there needs to be a transfer of data regarding items purchased and associated Use By Dates. Such dates are available to the manufacturer (they define and print them) and are used by the retailer (e.g. for stock rotation). The consumer does not take ownership of the data regarding their purchases except on their till receipt, or increasingly, electronically from on-line shopping. However the list of items purchased does not contain information pertaining to Use By Date of products, and this is critical for the management of inventory.

In addition to the flow of information, there is a need for an inventory management tool that can be used by the consumer to audit, review and plan the use of food products, similar to the way that Enterprise Resource Planning (ERP) systems support businesses. In order for prioritization of consumption of foods (which may be approaching their Use By Date) there is a need to analyze the type of food in question. Without holding or calculating data for every food type, a more simple way of analyzing the cost, environmental impact, etc., of food is by categorization. A nine stage classification process has been developed for industrial waste management [11] of which four stages are applicable here enabling an indication of the above criteria pertaining to a potential waste. The abridged categorization process addresses four criteria; origin, complexity, animal product presence and treatment as described below.

1. Origin: Animal based or plant based – implications of environmental impact and ramifications for waste handling
2. Complexity: Single or mixed ingredient –
3. Animal product presence: Animal product, by product from animal bodies, contact with animal-based products
4. Treatment: processed or unprocessed - implications of environmental impact and ramifications for waste handling

Such categorization is useful for limiting the overall environmental impact from waste which is 'inevitably' generated and also has the potential to assist consumers with improvement of waste handling.

#### 4. Inventory management for domestic consumers

The intention of this work is to provide a food inventory management system for the domestic user. The data requirement is for the user to have clear visibility of the use-by dates for key food products and thus be able to minimize wastage of these product categories. Information therefore needs to be passed from the food manufacturer, through the retailer and to the customer in a form that is easily accessible. For the purpose of this problem, any logistics activities play a passive role, since they are not concerned with individual products but only batches of product, which have different information requirements.

In this respect, there are three main actors, defining three stages, that are of concern in any solution that could provide the required inventory management: stage 1: the manufacturer, stage 2: the retailer and stage 3: the consumer.

**Stage 1: The Manufacturer.** The primary information requirement is the Use By Date which needs to pass from the manufacturer to the product to the consumer. This is currently achieved by a lawfully printed date on each product. However the format and location (front, top, bottom, side of product) of this printed date varies hugely and so it is unlikely that an image capture system would be successful in reading this date and the point of sale (POS). Therefore a number of different options were considered as tabulated below.

Table 1. Options explored for recording Use By Date at POS.

Information system	Required reader
Standardization of expiry date stamp (e.g. next to barcode)	Optical character recognition adjacent to barcode reader
Magnetic ink	Magnetic ink character recognition adjacent to barcode scanner
Radiofrequency identification embedded into packaging	RFID reader at POS
Multi-field barcode (e.g. GS1 DataBar)	Standard barcode reader

Of the above solutions, the multi-field barcode offers the easiest solution since no additional hardware is required at POS and only minor modifications would need to be made to the product packaging. The major change would be that the barcode for the product could only be printed during the final stages of manufacture or after the product has been packaged as this barcode would contain the Use By Date data of the product (which changes daily).

**Stage 2: The Retailer.** The data that is ultimately required by the consumer is the item name, expiry date, date of purchase, origin, complexity, animal product presences and treatment. Apart from expiry date and date of purchase, all fields will remain unchanged and can therefore be referenced from a database. At the POS, it is therefore only the expiry date, date of purchase that need to be generated, which are possible following the recommendations in Stage 1.

These fields of information need to be made available to the consumer inventory management tool for which there are two options: Near field communication (NFC) onto a smart phone, or storage on a ‘loyalty card’ system and accessible via

the internet. NFC uses radio communication (13.56 MHz) by proximity (~100mm) to transfer data to a compatible device at baud rates of 100’s kbit/s. Although a suitable solution, such a technology would need to be installed at every POS, would only be suitable for consumers with particular types of smart phones and requires an additional procedure at checkout.

In contrast, a loyalty card system approach would utilize existing data infrastructure within retailers to record the purchases made by a consumer with the associated fields including expiry date. This register of information could then be made available to the consumer via secure internet link, providing the opportunity for the consumer to manage inventory via mobile or static internet device.

**Stage 3: Consumer.** Once the consumer has access to the required fields, there is a need for an inventory management programme and interface. In this work an app has been developed for use on a smart phone, but the programme is equally applicable for use on tablets or PCs. Three main functions were considered and developed:

- **Stock List** - allows users to keep inventory of their food items already purchased, including expiry dates. Modifiable to remove items already consumed, partly consumed or disposed of.
- **Expiry Tracker** - notifies the user when items are about to exceed Use By Date. Dependent on settings, alarm activates *n* days before expiry date. Once alarm triggers, four options are provided consumed, partly consumed, not consumed, wasted. Alarm can be ‘snoozed’ for *m* hours before reminder sent.
- **Recipe Recommendation** - depending upon the items highlighted by the Expiry Tracker function, a number of recipes using these ingredients and others within the Stock List can be identified via the internet and suggested to the user.

The pathway for the introduction of an inventory management tool for consumers therefore comprises of the three solutions as shown in figure 5. The development of the App is further described in section 5.

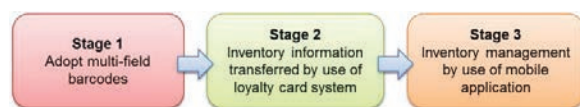


Fig. 5. Three stages of information flow for domestic inventory management of food.

#### 5. App Development

A mobile application, entitled *Pantry*, was programmed using graphical interfaced, cloud-based, MIT App Inventor 2. This programme was used to create the front-end application described in this section, but also required the use of a Backend as a Service (BaaS), in this case Parse. BaaS is a model for providing mobile apps with a way to link to backend cloud storage, which for this application would be the information recorded by the retailer regarding a customer’s purchases. An application programming interface (API) between the front end and backend service allows the provision of features such as user management, push

notifications, and integration with social networking thus opening up opportunities for retailer marketing and reward schemes.

In order to receive data regarding items which need to be kept in Pantry's inventory, the requests are required to be in JavaScript Object Notation (JSON). Table 2 describes the fields required by Pantry in order to populate the Stock List. Request for updates can be done manually by the user, or automatically at user defined intervals or from preset triggers (e.g. push request from store). Since not all food items may be bought from a store with a loyalty card system that can be accessed by an App, it is also possible manually input products into the Stock List of Pantry.

Table 2. Fields required by Pantry for Stock List.

Name	Type	Description
userId	String	userId is a string unique to the class User that identifies this object.
productId	String	An identification to the product which can be used to access additional data from the web.
productStatus	Integer	0 for inactive entries, 1 for active entries
productPrice	Decimal	The product price, without currency sign, or thousand separators.
productName	String	Product name
expiryDate	String/ date	Expiry date UTC timestamps stored in ISO 8601 format.
imgSrc	String	A string containing the image source.
productUnit	String	A string that identifies the product unit, which must exist as an object in class <i>Unit</i> .

The Stock List is then kept locally on the device with a graphical user interface that is intuitive for consumers (figure 6). At the top-level, the data shown from the database, provides an item description, categorization as defined in section 4, days left (before expiry) and a Boolean indicator for eaten/not eaten.

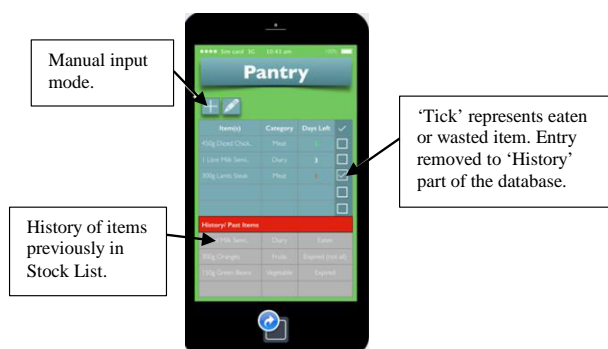


Fig. 6. Graphical user interface of Expiry Tracker.

The Expiry Tracker operates in parallel with the stock list and refers to user defined preferences to trigger alarm notifications. The user has the option of selecting eaten, partly eaten, not eaten and wasted for items reported by the Expiry Tracker as well as inputting new expiry dates (e.g. for opened or cooked meat). Once an item has been eaten or has expired, it is moved into the recent history part of the database, where it is stored and displayed for a user defined period of time.

In the current study, the Recipes Recommendation function was not incorporated into the app as no existing suitable recipe database could be found. The query information requires access to the items remaining in the Stock List, with preference given to the items with the shortest remaining life and of key categorizations (e.g. high environmental impact). Other items that exist in the stock list are used to identify a number of suitable recipes for the user. Advanced versions of the Recipe Recommendation function could link to retailer internet shopping sites for easy purchase of additional items and even be linked to a meal planner.

## 6. System testing

A number of barriers relating to data availability and limitations of the programming software used prevented extensive testing of Pantry. However, dry-process testing was carried out on a small scale to demonstrate the functionality of Pantry. This section describes the limitations and testing of the developed inventory management tool.

In terms of the Stock List, currently there is no commercial system in place that enables customer of food retailers to have access to Use By or Best Before Dates of foods purchased. In addition to this, large UK superstore websites will not currently accept requests via java script and any information held about products purchased (e.g. via on-line shopping) cannot be obtained by the current version of the app. These limitations mean that product information and expiry dates must be entered manually into Pantry for system testing.

From the perspective of the Expiry Tracker, apps created using MIT App Inventor 2 cannot run in the background as services, and this imposed a critical limit to the functionality of the current version of the app. A warning that food is about to expire could only be triggered if the user actually has the application open, which is not convenient for the majority of users. In response, bespoke alarms were set for individual food items which sounded three days before the expiry date, and repeated every 24 hours.

System testing was carried out by a small number of consumers over a week-long period, and was concerned with five types of food: meat, fruits, vegetables, milk and bakery items. Items bought and expiry dates were manually recorded and alarms set for three days prior to the expiry date. Although suggestive of reductions in food waste, results were not conclusive and would need to incorporate a comparison with a control group of consumers or significantly larger sample of participants. Despite this, for the five types of food studied over the testing period, a reduction of 34% of food discarded was recorded. Scaled-up for all food types in the UK, this would equate to savings of circa 1.5 million tonnes of food waste per annum. As stated, it is not possible to determine how much of this reduction was due to the use of the Pantry system for domestic inventory planning, and how much could be attributed to the heightened awareness of expiry dates from dedication to using the system. Perhaps it does not matter since the end result is beneficial, but the real benefit would be in sustained reductions in food waste, and for this it is suggested that an easy-to-use inventory management system (such as the Pantry app) would be better able to deliver this.

## 7. Conclusions

From the literature reviewed in the early sections of this paper it is clear that a large percentage of food waste in the developed world is generated after final purchase by the consumer. It seems misdirected therefore, that the majority of efforts to reduce food waste by industry focus on reducing internal waste production and not along the remainder of the supply chain. In this respect, this work has highlighted the opportunity for the manufacturing industry to assist consumers in reducing the amount of food they waste by developing tools prevalent in industry for the domestic environment. In this context this work has demonstrated the importance of short shelf life food types such as meat and dairy which carry larger economic value and environmental impacts.

A proposed solution is an inventory management tool suitable for consumers, to manage ingredients bought from retailers. Such a tool, which has roots in material requirements planning, can be supported by recording and transferring data regarding product Use By Dates to consumers, for which a number of mechanisms are discussed. A mobile application-based approach is described involving the key capabilities of Stock List and Expiry Tracker to enable consumers to better monitor the food items they have within their domestic environment and to consume these before the expiry date is met.

The app, which was developed in MIT App Inventor 2, is described in detail and preliminary system testing is undertaken. The implementation and benefits of the app are discussed with early results showing a reduction of 34% food waste across key food types. However collaboration with a large grocery retailer, incorporating advances in expiry date communication and testing over long periods with a greater number of participants is required for conclusive results to be drawn.

The solution of domestic inventory management proposed in this work is just one of many potential methods that the manufacturing industry can assist domestic consumers in reducing food waste.

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