Utilisation of Internet of Things to Improve Resource Efficiency of Food Supply Chains

Sandeep Jagtap[1] and Shahin Rahimifard[1]

[1]Centre for Sustainable Manufacturing & Recycling Technologies (SMART), Loughborough University, Loughborough LE11 3TU, United Kingdom, e-mail: S.Jagtap@lboro.ac.uk and S.Rahimifard@lboro.ac.uk

Abstract. The food sector is increasingly facing significant challenges throughout the supply chain to become more resource efficient. In this context, three critical areas of focus are the reduction of food waste, energy, and water consumption. One of the key factors identified as an obstacle to improving resource efficiency is the lack of suitable capabilities to collect, exchange and share real-time data among various stakeholders. Having such capabilities would provide improved awareness and visibility of resource use and help make better decisions that drive overall productivity of the supply chain. The principle concept of the 'Internet of Things' (IoT) has been used in several applications to improve overall monitoring, planning, and management of supply chain activities. This paper explores the feasibility of adopting such IoT concepts to improve the resource efficiency of food supply chains. An IoT-based framework is proposed to support the incorporation of relevant data into supply chain decision-making models for the reduction of food waste, energy and water consumption.

Keywords: Internet of Things, Food Supply Chain, Resource Efficiency.

1 Introduction

The complexity of global Food Supply Chains (FSCs) is the result of consumer demand for fresh, quality and low priced food products (Rahimifard et al., 2017). Also, changes in consumption patterns and population growth are increasing global food demand which is estimated to rise between 50-70% by 2050 (European Commission, 2011). On top of that, FSCs are more and more exposed to other challenges such as resource scarcity, food wastages, inconsistent productivity and from time to time lack of resilience (Parfitt et al., 2010). These problems are forcing FSCs to be more resource efficient which means making the best use of resources and reducing the negative environmental impact on food systems.

Sustainable food production needs to consider all stages of FSCs and should focus on food losses and food waste management, sustainability standards and environmentally friendly actions and techniques to reduce resource consumption

(FAO, 2015). Some researchers deduced that FSCs suffer from resource inefficiency due to a lack of awareness of resource usage and food losses and wastage which could be avoided by using novel monitoring technologies (Jedermann et al., 2014). The benefits of implementing monitoring technologies include financial savings, adhering to environmental regulations set by governments and fulfilling consumer demand for sustainable food products through sustainable production (Haight & Park, 2015).

Access to real-time resource consumption data offers the new prospect of making the FSCs truly resource efficient. The advent of the IoT paradigm, which has the capability of collecting real-time data to monitor behaviour patterns in resource consumption, could play a crucial role. Its ability to communicate and interact with various things almost 24/7 in real-time could be exploited to reduce the food loss and waste, water and energy consumption (Combaneyre, 2015).

This paper aims to consider the merits and challenges of adopting the latest advancements in IoT concepts to support and improve the resource efficiency of FSCs. The first sections of this paper provide an overview of IoT-based resource efficiency management and benefits of IoT implementation. The following sections focus on describing the typical IoT architecture needed for resource efficiency and a framework developed for incorporating the resource consumption data in FSCs decisions. The framework is expected to facilitate an improvement in supply chain practices by minimising water and energy use as well as a reduction in food wastage. But, due to the significant range and type of activities, actors and stakeholder within FSCs, the precise scope of research reported in this paper is confined to post farm-gate to retailer's shelf, as depicted in Fig 1 (highlighted in yellow). As an example, an IoT-based energy monitoring system is designed.

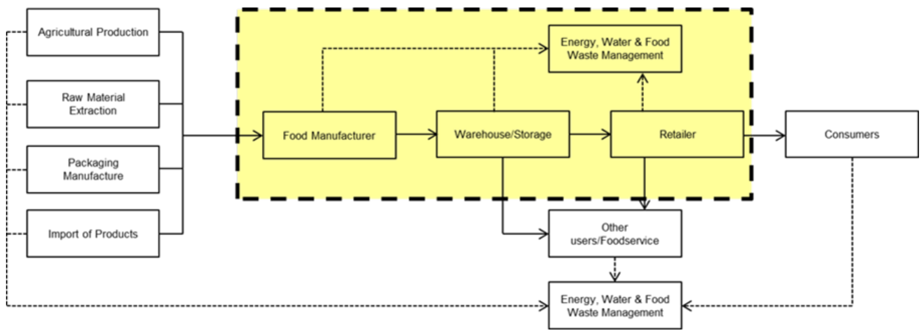

Figure 1 Research Scope

2 Resource Efficiency in FSCs

Current supply chain practices within FSCs are unsustainable, particularly the continuous and uninterrupted demand for vital resources such as ingredients, energy and water. Hence, researchers and practitioners are attempting to develop a sustainable FSCs with resource efficiency capability in an environmentally friendly manner without affecting overall supply chain productivity (Sheffield University, 2015). Managing resource consumption in FSCs is difficult due to the complexity which stems from the range of resources used across numerous processes with each process having unique resource consumption features. There are significant prospects for better sustainable production through the improvement of communication between producers, retailers, and consumers (Henningsson et al., 2004). But the lack of robust and readily available data is highlighted as one of the main barriers to attaining a high level of resource efficiency in FSCs (Lee et al., 2013). Another issue is that the food industry is not fully aware of the resources it uses, e.g. they are aware of total water intake and water discharge in the form of effluent, but are generally unaware of water usage at individual process level (Webb, 2016) which is also applicable to energy consumption (Thollander & Ottosson, 2010).

In order to reduce or eliminate waste and inefficiencies, it is vital to get meaningful, accurate and on-time data (Shahrokni et al., 2014) with regards to the energy and water consumption as well as food waste generated by various processes and equipment. Hence, to make supply chains resource efficient, the first step is to be resource aware (Matopoulos et al., 2015) and real-time data is essential for optimising resource efficiency (Pitarch et al., 2017). The traditional methods of collecting data using pen and paper are inefficient, tedious and laborious. In this respect, IoT-based applications for improving resource efficiency with regards to water and energy consumption and reducing food waste can be very beneficial. For example, IoT-based smart water meters are of particular importance to water users as they can provide real-time data on consumption, leakages and quality of water, and in some cases, could make water efficient decisions by learning from their surrounding environment (Iotsens, 2017).

3 Overview of Internet of Things (IoT)

The concept of the IoT is garnering a lot of attention these days and is successfully implemented in the logistics, manufacturing, retailing and healthcare sectors. The IoT consists of a network of sensors and actuators that can exchange information across platforms through an integrated framework, and can perform various functions such as ubiquitous sensing, data analytics, and cloud computing to develop a seamless operation for enabling state-of-the-art applications (Gubbi et al., 2013). The IoT has the capability to continuously collect information and send it to cloud-based software tools to store, visualise and analyse data in real-time and help make better decisions. The IoT relies on Radio Frequency Identification (RFID) and Wireless Sensor Networks (WSN) technology to gather real-time data from various hotspots within the supply chain (Verdouw et al., 2016). There is continuous data collection about machine availability, stock levels, traceability of products and also resource consumption through various sensors and smart meters. RFID tags are extensively employed in logistics, pharmaceuticals, retailing, and supply chain management for identifying, tracking and monitoring products and things (Amendola et al., 2014). WSN technology uses interconnected intelligent sensors to sense and track, and finds wide applications in the area of environmental conditions, health-care and industrial monitoring (Akkas, 2016). Table 1 shows IoT technologies implementation in FSCs which has been investigated and adopted by companies to improve resource efficiency.

Companies	Resource Monitoring	Parameters being checked for	Benefits of IoT adoption (resource efficiency –related)	Practices enabled by IoT which lead to those benefits
Rova	Energy	Operation efficiency	Optimising truck routes and bin collection times	Provides vehicle location, traffic congestion and bin volumes
Siemens	Energy	Production and maintenance effectiveness	Increasing productivity	Provides alerts and schedules about machine maintenance to avoid future breakdowns.
Martec	Water	Cleaning process	Maintaining hygiene standards	Avoids over-cleaning and microbial contamination
2 Sisters	Water	Washing raw material	Water consumption, reduction in effluent	Control system to deliver exact quantity needed
MyFresh	Water	Washing raw produce	Water consumption, Reduced effluents	Reduced incoming water pressure, Installation of efficient pumps
LeanPath	Food	Food waste	Reduction in food waste	Reasons for food waste, changing production process
Winnow Solutions	Food	Food waste	Reduction in food waste	Reasons for food waste, recipe change, production planning

Table 1 IoT adoption by companies and its benefits

The implementation of the IoT concept for monitoring resource consumption in FSCs is still at an early stage compared to the other manufacturing sectors (Verdouw et al., 2016). However, several actors within FSCs from food manufacturers to food retailers have deployed such systems for monitoring the energy and water consumption and food waste management at equipment level as described in Table 1 above.

The implementation of the IoT in FSCs has generated some benefits which have been identified as follows:

1. It permits comparison of the amount of resources wasted to resources consumed to achieve a specific production output. If there is no

correspondence, it alerts stakeholders to search for the waste source and act to eliminate it.

2. It considers the resources consumed by various FSCs activities (e.g. peeling, washing, cooling) and then strives to make the underperforming processes better.
3. It supports resource-aware supply chain planning by incorporating resource consumption data into IT planning systems. It allows selection of resource efficient job routeing to select production lines with the best configuration, minimising idle time, and also considers various parameters (abnormal deviations from set food quality standards, start time, finish time, labour availability) (Pang et al., 2012).
4. It can predict maintenance issues before they occur, thus saving time, money and resources (Satyavolu et al., 2014).
5. It helps in managing and tracking resource inventories (current stocks, expired stocks, quarantined stocks, and safety stocks) (Satyavolu, et al., 2014).
6. It can help in improving environmental standards by measuring and reducing the CO_2 emissions of supply chain activities by suggesting the best optimum solution (optimised vehicle routeing, maintaining freezer temperatures).
7. It helps in the continuous improvement of FSCs activities by decentralisation of decision-making process through the generation of resource oriented key performance indicators.
8. Availability of resource consumption patterns 24/7 and in real-time allows stakeholders to plan and prioritise the efficient use of resources (first use of stock with less shelf life) (Pang et al., 2012).

4 Developing an IoT Architecture for Resource Efficiency in FSCs

The implementation of the IoT for resource efficiency is based on an architecture consisting of four layers: sensing layer, network layer, service layer, and application layer (Ray, 2016) as shown in Fig 2. The IoT architecture is designed in such a way that it can meet the needs of FSCs to minimise energy and water consumption and reduce food waste. A typical IoT architecture for driving resource efficiency in FSCs could consist of a series of sensors, electronic devices (WSN, RFID readers/tags, etc.), a storage and linkage system (databases, servers, and distributed computer networks, etc.); and a number of wired and wireless communication infrastructures (WiFi, cellular, satellite, power line, Ethernet, etc.) (Gubbi et al., 2013). Due to its pervasive nature, all sensors and devices generate a vast amount of data which is processed to extract meaningful information to support decision-making (Zaslavsky et al., 2013).

The functionalities of the four layers are as follows:

- Sensing layer – It is aimed at gathering data with regards to energy, water and food waste using various sensing technologies such as load cells, smart-meters, sensors, cameras, and RFID tags (Akyildiz et al., 2002). For measuring energy and water consumption, respective smart-meters are needed (Hancke et al., 2012) whereas solid food waste could be measured using load cells and image processing technology. Liquid food waste could be measured using the corresponding smart-meter.

- Network layer - It is a medium for transferring the data gathered in the sensing layer and making it available to service layer for further analysis and storage, using a variety of modern technologies such as WiFi, Bluetooth, and other electronics devices or hardware (Arduino, Raspberry Pi, etc.) (Akyildiz et al., 2002).
- Service layer - It stores all the data collected in a cloud or on the local server (Akyildiz et al., 2002). This information can be analysed by food manufacturing experts in cooperation with IoT developers by extracting meaningful information to develop applications which would help in decision-making. Resource key performance indicators (KPI's), behavioural patterns and other activities which influence resource efficiency can also be formulated in the form of graphs or charts. This layer can have self-learning capabilities and make decisions without human input.
- Application layer - It provides user-friendly services to stakeholders or users (Akyildiz et al., 2002) with accurate data to manage long term projects on minimising resource consumption or waste such as the restructuring of a factory layout, relocation of specific supply chain activities, or launching of new products.

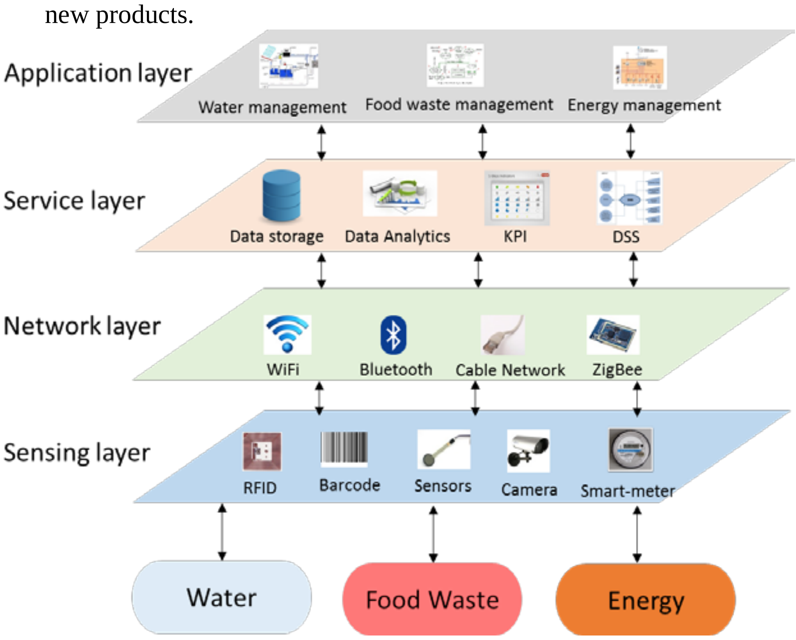

Figure 2 IoT Architecture for Resource Efficiency in FSCs

5 Methodology for IoT-based resource management in FSCs

The literature review has highlighted the urgent need for an IoT based framework to be adopted in FSCs. A four stage IoT-based framework for resource efficiency in FSCs is presented in Fig 3. The four stages are as follows:

1. Establishing impactful resources - In the first stage, it is important to determine impactful resources. The literature review has highlighted three key resources to be addressed which are the generation of food waste, and consumption of energy and water. The other essential criteria are to assess and understand the resource impact on the environmental sustainability of FSCs and the strategies deployed by various actors in FSCs toward resources.
2. Supply chain process - In this stage, it will be crucial to understand how resources flow within different actors of the supply chain. For example, if we consider resource flow at the factory level, it will be essential to understanding resource flow within various departments of the company, which may be further narrowed down to the machine level. These would help in understanding the consumption behaviours and wastage of resources at various levels.
3. IoT Modelling – The third stage will be to build an IoT model. In this stage, it is essential to identify what kind of hardware, sensors, electronics, software or technology is needed to collect resource consumption or wastage data. Also, it is necessary to know from where within the supply chain network the data can be extracted and how this data will be filtered to get meaningful information to support the supply chain decisions concerning resource efficiency.
4. Generate recommendation or solution – In this stage, the valuable information generated through the IoT concepts will be used to produce reports for better planning of resources in FSCs and the improvement of supply chain activities.

Figure 3 IoT Framework for resource efficiency in FSCs

By integrating the four stages of the framework as shown in Fig 3 above, the resource efficiency of FSCs could be improved by minimising energy and water consumption and reducing food waste. The real-time data produced using IoT concepts with the aid of smart-meters, sensors and cameras will be used to increase the resource consumption awareness of each FSCs activity and will create a set of new standards. Taking into consideration the energy and water use and food waste during planning activities will lead to improvement and optimisation of resources, flexibility in production planning and control, appropriate communication and better decision making at all actor levels. The three key issues which are the minimisation of water and energy consumption and reduction in food waste could be achieved through step by step implementation of the IoT framework as shown in Fig 3. Establishing which information needs to be gathered regarding these resources is described below.

- Water – For example, water used in food manufacturing can be classified into two categories, namely production water, and non-production water. Production water is the water used directly by food production processes, and non-production water is the water used by facilities or infrastructures which support activities such as heating, sanitation, etc. Hence, separate smart-meters are required to record these two types of water. Production water is further divided into two categories namely, process water and system water. Process water is needed to transform the raw material or ingredients into finished products, while system water is water which is used to sustain the production machines, utensils, and environment (Sachidananda, 2016). Therefore, to get accurate data on water consumption, two further smart-meters need to be installed.
- Energy – Energy can be characterised into two groups: direct and indirect energy. The direct energy is the energy used by different processes within FSCs to make a finished food product available at retailer's shelf (e.g. cleaning, washing, chopping, packing, chilling, transporting, etc.). Whereas the indirect energy is the energy utilised by activities to sustain the environment in which the food production processes are carried out, or food is stored and transported (e.g. lighting, ventilation, heating). It is essential for decision-makers to install energy smart-meters which distinguish both types of energies (Seow, 2011).
- Food Waste – Food waste can be divided into three categories: avoidable, unavoidable and possibly avoidable waste. Avoidable waste is the waste which at some point was edible before it was disposed of (e.g. bread loaves, meat, cheese, etc.). Whereas unavoidable waste is that which is not edible (e.g. bones, banana skins, egg shells, etc.). While possibly avoidable waste is the waste which may be consumed by some people (e.g. bread crumbs), or that can be consumed when food is prepared in a certain way (e.g. potato skins). Measuring food waste is a complicated process since it can be a mix of avoidable, unavoidable or possibly avoidable waste; to counter these issues, food waste smart-meters with minimal human input can be employed

to track and measure various types of food wastes accurately (Garcia-Garcia, 2017).

The data which is collected by smart meters in real-time is stored in a cloud or storage database and analysed to filter useful information. Data analytics or data mining can be employed to understand the consumption pattern and behaviour of energy and water as well as the generation of food waste. In the next step, the useful information generated can be incorporated into FSCs management systems and into the tools that aid resource efficiencies improvement efforts, such as decision support system (DSS), Key performance indicators (KPI) and real-time consumption dashboards. The information obtained from the data analysis layer would help higher-level decisions with regards to the strategic, operational and control decisions that can be made in FSCs management systems.

In future, IoT applications and on time data will play a crucial part in creating production plans, updating production line status, tracking the present state of resource consumption and wastage during each activity and monitoring the production activities throughout the FSCs. The IoT can integrate IT planning systems with real-time data on stock levels, stock movements, machine and labour availability, etc. so that an effective decision can be made by stakeholders (Satyavolu et al., 2014).

6 IoT-based Energy Monitoring System for FSCs

An IoT architecture for energy monitoring in FSCs is illustrated in Fig. 4. At the bottom layer of this architecture are production lines, equipment, machinery and components installed with smart meters and sensors collecting the energy data across the FSCs (food manufacturer, warehouse, distribution and retailer). These smart meters and sensors are continuously transmitting the data on energy consumption and other parameters (idle periods, max/min peak voltage) through wired or wireless networks (Piti et al., 2017). The network connectivity of smart meters or sensors allows greater flexibility in monitoring and analysing energy usage data. Smart meters or sensors can be installed throughout the whole production line or just in an individual machine or components.

At the middle layer, the collected energy data is sent to the local server or cloud storage via various options (Power Line Carrier, Broadband over Power Lines, Cellular, Bluetooth, General Packet Radio Service, Internet, Zigbee). Wireless networks are more preferred for sensors or smart meters due to their non-intrusive nature and greater flexibility while installing them throughout the FSCs. In this layer, stored data can be filtered to extract meaningful data using cloud analytics. The data is also analysed for whether it is a direct energy or indirect energy. Direct energy is the energy consumed by various food processes (washing of food, storage of ingredients in a freezer, food processing machinery) to produce finished food products. Indirect energy is the energy used by activities which do not contribute to food production (heating, office, lighting), but are necessary to sustain the food production environment. Various user-friendly applications can be created using Software as a Service (SaaS) to reduce and efficiently manage energy consumption.

In the top layer, the data can be further integrated into the other planning systems such as Manufacturing Resource Planning (MRP), Enterprise Resource Planning (ERP), and Advanced Production and Scheduling (APS) to achieve energy efficiency in FSCs.

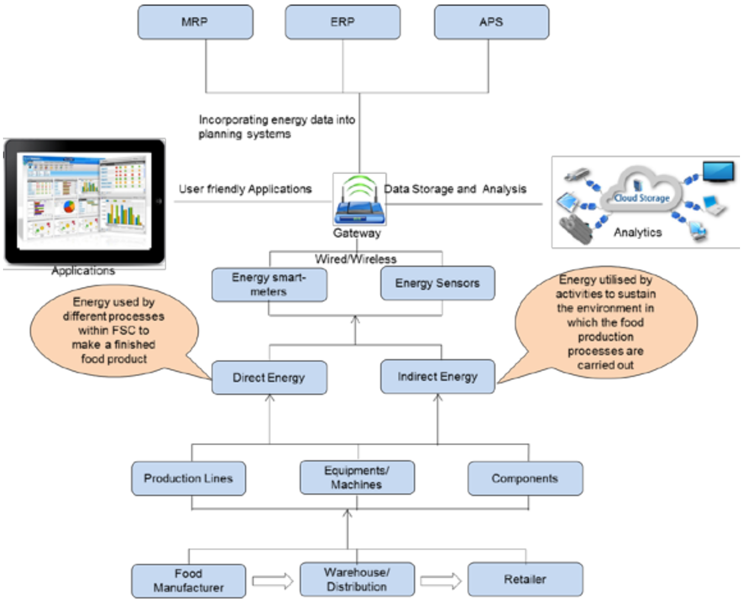

Figure 4 IoT Architecture for Energy Monitoring in FSCs

7 Conclusions

Implementing the IoT in FSCs would enable the provision of a high level of information and awareness on resource consumption at all actor levels. This new-found knowledge may lead to discovering new opportunities to save and reduce consumption of resources. Also, the IoT concept may address or find better solutions to monitoring and managing inventory, and tracking and visibility of food products and labour movement throughout the FSCs. These actions will lead to improved efficiency of food production activities and consequently reduce energy and water consumption and food waste. Incorporating the real-time data into supply chain planning systems such as SAP, APS, MRP, and ERP could help stakeholders with better decision making on optimising resource consumptions and reducing wastage. More research is needed to develop IoT concepts for improving the resource efficiency of FSCs and embedding them in supply chain planning and control to enhance decision- making processes.

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