The Internet of Food Things

The IT as a Utility Network
Digital Economy Challenge Area

Review of the literature on the area of Internet of Things (IoT) applied to aspects of the safety and security of the Food Network

Undertaken by the IT as a Utility Network+ on behalf of the UK Food Standards Agency for England (FSA)

Internet of Things and Food: ITaaU/FSA programme	
Project title:	IoT and Food Security Literature Review
Principal investigator (institution):	Jeremy Frey (University of Southampton)
Description	Summary of a research literature survey to capture the landscape of the role of the internet of things (IoT) in the safety and security of food
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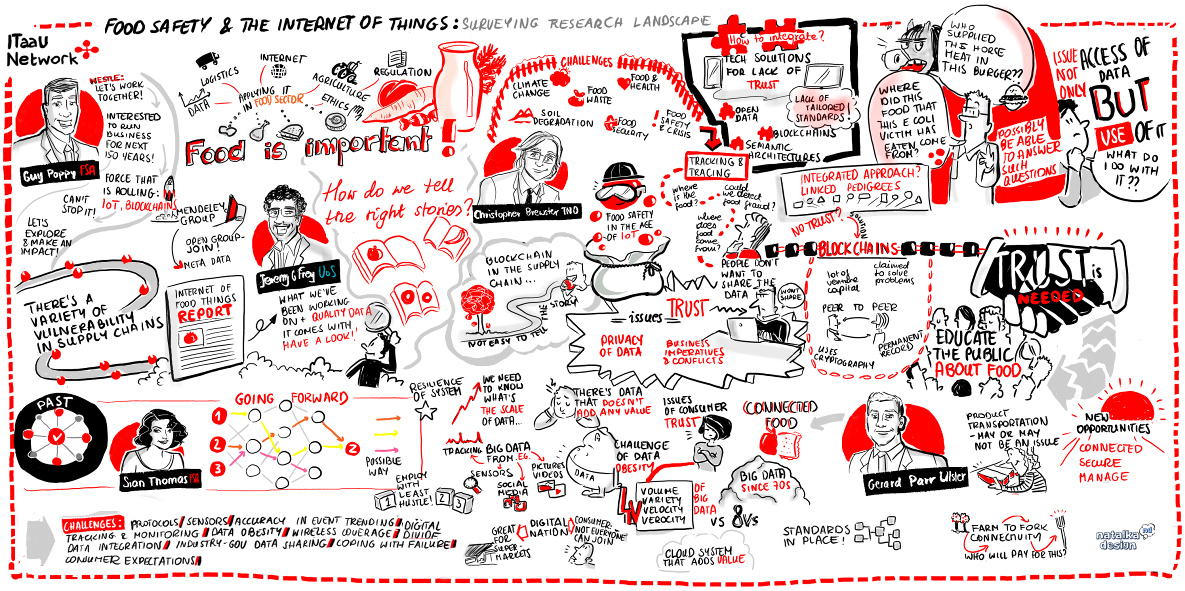
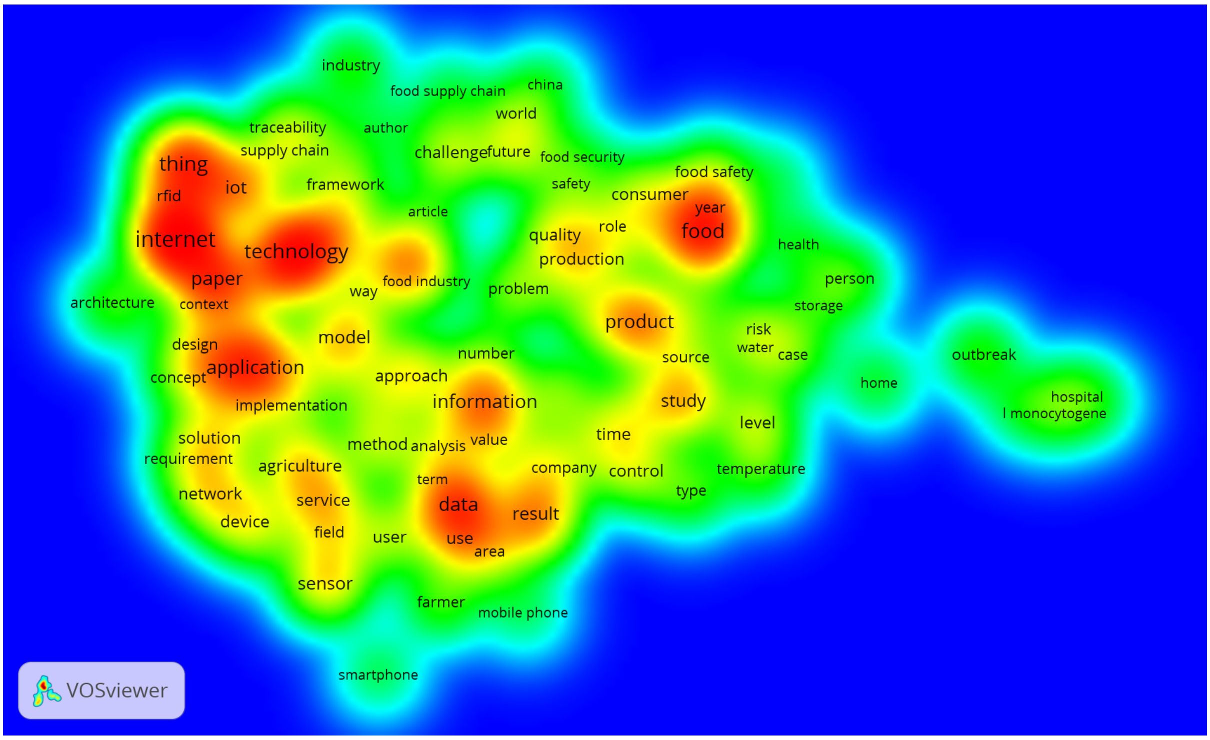


Graphical Summary of the Internet of Food Things Workshop 27 June, IT as a Utility Network, University of Southampton held at the Hilton Hotel, Chilworth, Southampton, created by Natalka Talkowska, Storyteller.

INTERNET OF FOOD THINGS



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Report by the ITaaU network for the Food Standards Agency

[1] Figure generated by VOS Viewer based on the title and abstracts of all the papers reviewed and collected in the Mendeley IoT & Food group

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1) Acknowledgements

Over the course of the winter of 2015 and spring of 2016 ITaaU undertook a collaborative venture with the Food Standards Agency (FSA). This page brings together information about the pilot projects and academic literature review together with the original claims of the collaboration and the final recommendation. A number of workshops were held over the course of this initiative and these are also reported.

The work was led by Prof. Jeremy Frey on behalf of ITaaU and Sian Thomas from the FSA.

2) Executive summary

Technology in general, and the Internet of Things (IoT) in particular, has considerable potential for assisting with food safety and, to a lesser extent, food security. A significant prospect for food safety in the capability to extend automation through “from farm to fork”, owing to the growing recognition that it is the data created and the use made of it that is significant, rather than the details of the technology deployed. However, to date the published academic evidence relates much more to architecture and design than to extensive system implementations.

The areas that receive the most attention are logistics, supply chain management and, at the production stage, precision agriculture. The emphasis is very much on tracking and traceability, including surveillance. Consumer interests are also a focus area, comprising health and nutrition topics, identifying safety issues, and supporting personal responsibility for diet decisions.

IoT studies have two facets: sensors and other devices; and the deployment of the data that they generate. Standards are emerging, but slowly, which holds back academic appraisal of the methods, impact, and quality of IoT applications. There is a clear need for deeper appreciation of the data needed and what could be achieved by understanding that data.

The literature survey on the role and potential of IoT in the area of food safety was conducted in a progressive manner, beginning with a wide-ranging search, which was subsequently refined to explore specific topics in more depth. Based on the surveys as a whole, the 43 most significant authors were identified and their work highlighted.

The surveys exposed a range of topics of interest, with tracking and tracing being the area in which the potential of IoT was most evident. However, many of the articles proposed architectures but provided little or no indication that the approach had been tested in real practice. Moreover, there were few signs of the emergence of standard good practice. One of the pilot projects used Tinytag™ data loggers to monitor the cold chain for sandwiches and highlighted significant breaches of temperature control, concluding that point measurements are inadequate and a shelf-life profile is more accurate.

Data acquired by precision agriculture applications is used to inform practices and decisions. The search results cover not only system and informatics considerations but also specific resources and produce. However, a significant proportion of the articles are primarily about communication rather than the agriculture data itself.

A significant emerging from the surveys is the deficit of knowledge about what data is needed, rather than the lack of data or ways to collect it. The transparency and provenance of the data will also be important considerations: veracity is one of the four ‘V’s associated with applications that generate “big data”.

IoT can still be regarded as an emerging technology. The technology sections of the media consistently feature stories about smart homes, featuring monitoring and control of heating, lighting, and fridges, but wide scale uptake has been limited, even for the smart meters offered by the power companies. Within the food sector, the greatest impact of IoT has been in transport and logistics: tracking and tracing. As might be expected, other distribution networks use devices to track items in transit. Evaluation of the broad-ranging role of IT in interpreting data to inform actions and mitigate consequences suggests that IoT could help not only with tracking and tracing but also in areas such as surveillance, waste management, and behavioural change. However, it is vital to collect and transfer the correct information. Food now has a very long supply chain, which is like a maze, and the longer the chain, the more things that can go wrong. For IoT to play a useful role it must be equally usable by the consumers, the small producers and marketers as well as big, global, organisations.

The opportunities for IoT to improve food monitoring, product traceability, and consumer trust are conspicuous, as revealed by the research identified during the literature surveys: Appendix F lists specific examples. However, it is important that monitoring is accurate, as shown by the Tinytag™ project. Furthermore, integrating specialist areas into an interoperable framework will require standards, which inevitably take time. Although standardisation work is ongoing, little of it currently appears in the formal academic literature. A key issue to be resolved is the differentiation of the Internet of Things from "sensor networks".

Issues that have emerged during discussions of the literature survey findings include: the lack of trust, aggravated by limited sharing of data; privacy and data protection; the influence of supermarkets and other large organisations, and network complexity, which affects connectivity. The many and varied challenges relate to all these issues, to managing consumer expectations, and – last but not least – data management.

The need for deeper appreciation of the data needed and what could be achieved has already been identified and in part 6 the report makes recommendations with respect to data, behaviour, and technology.

For realistic IoT deployment there is a need for low-cost sensors running widely agreed and interoperable standards and connected with widely available wireless coverage. To ensure consumer trust the IoT systems must be secure, must have demonstrable accuracy in event trending, tracking and monitoring, and be able to cope with failures of the devices, networks and system. The data modeling is key to the use of IoT systems, so that the ability to undertake data integration and fusion is essential while avoiding "Data Obesity ". Consumers will expect that Industry – Government data is available for sharing under appropriate secure conditions, the extent to which this can be extended to consumers highlights the need to address and bridge the "Digital Divide". Managing consumer expectations following all of the above will be essential if the valley of doom in the Gartner Hype Cycle is to be circumvented for the useful deployment of IoT in the food network.

3) Introduction and Background

a) Motivation

This document presents a survey of literature, predominantly academic, in the field of Internet of Things (IoT) and food safety. We describe the search strategy, the key findings, and provide some commentary on the search results as well as some observations on what we observe is missing. This is clearly a dynamic and fast moving field and so we present this report as a snapshot at a moment in time. We therefore propose that this becomes a living document, to be updated as new material and insight becomes available. Nevertheless, the marrying of new technologies to complex but essential strategic national interests is important and valuable. In this introduction we start by considering what we mean, or at least understand, by food safety and also by the term the Internet of Things before moving on to consider the implications, benefits and risks associated with these two important aspects of our times combined (Atzori, Iera, & Morabito, 2010; Barnaghi, Wang, Henson, & Taylor, 2012)(Gubbi, Buyya, Marusic, & Palaniswami, 2013; Karimi, 2013; Kominers, 2012; Sanchez et al., 2014).

b) Approach

We under took a wide-ranging view of IoT and Food, covering the years 2013-15 using a very broad definition of both IoT and food matters. This led to about 20 or so key categories. We then extended the search to to look specifically at Precision agriculture as this was an area in which it seemed that extensive use of IoT was at least being considered in detail. Subsequently a third survey was completed using the papers and key terms obtained from the first two surveys to search back to earlier years, using cited and cited by references, and related papers. The literature surveys were combined with the results of the ITaaU Food Workshops and the background from the FSA ITaaU IoT Food pilot projects.

c) Food in the Digital Age

Whilst this report focuses on the role of IoT in food safety, it is worth noting that in the digital age, an era of pervasive technology and unavoidable social media, how we interact with everything, food included, is inexorably changing. In addition to our senses, which we know govern how we perceive food – from appreciating pleasure to identifying danger – the richness of information provided though social media and other digital channels has an increasingly dominant influence on the food we seek out and consume. This increased influx of information may in turn lead to a demand for a more integrated approach to technology and food. Experimental solutions are being developed that enable consumers to play with the options presented by food in an environment that augments foodstuffs with further information and guidance (Maras, 2015).

d) Food Security

Food safety is inextricably linked with food security as the wider issues of sustainability, reliability, crime and malicious disruption and distortion, and natural disasters not to mention market forces all significantly contribute directly to the risk-related decisions that all stakeholders take regarding food safety.

What is food security? It is possible to present a simplistic definition of food security, however, putting forward a comprehensive explanation that encompasses all of the essential facets is significantly more challenging. Indeed, as with many other areas of the modern connected world - communication, transport and finance for example - the term security is highly loaded with political, social and technological implications.

The 2014 House of Commons report, Food Security,(McIntosh, Draw, & Fitzpatrick, 2015) uses the UN Food and Agriculture Organisation definition for food security:

> *"When all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life."*

The report goes on to add that this also implies sustainability of food production methods for future generations, and mentions the National Farmers Union's comment that we have a moral obligation to do what we can for others elsewhere in the world.

So much for the definition, key questions then arise over who has responsibility and how this should be achieved. Currently in the UK responsibilities for food security lie with multiple departments including those for Business (BIS), Energy (DECC) and the Environment (Defra), not to mention the Food Standards Agencies in England and Scotland. Indeed, the complexity of this situation is reflected in one of the key findings of the report that the UK needs a new post of Food Security Coordinator to ensure a coherent approach. That said, the focus of this report is more on the *how* than the *who*, in terms of food security.

The Government report and other documents outline the inherent challenges: these stretch from sustainability to economics, and from accessibility to availability. These challenges include a desire to shorten supply chains, a need for better long-term weather forecasting, and improved resilience to recover from events. In terms of addressing increased demand the report acknowledges the need for sustainable intensification. It's worth noting also, that the food and drink supply chain is the UK's single largest manufacturing sector and accounts for 7% of GDP, employs 3.7M people and is worth £80Bn per year (Food Matters: Towards a Strategy for the 21st Century (Cabinet Office, 2008)).

The RuSource Briefing (Spedding, 2007) on the Defra Food Security report (DEFRA, 2006, 2009)adds a further take on the conclusions, specifically around British self-sufficiency. First some history: prior to 1750 Britain, as an island, was almost completely self-sufficient. This rate dropped to a figure approaching 30% in the 1930s, and then peaked in the 1980s at around 70%. The recent drop in self-sufficiency can be attributed to various factors from taste (demand) to tariffs (supply). However, the report explains why food security cannot be the object of a single policy whether at a UK or European level. There is a clear distinction between agricultural self-sufficiency and an extensive retailer-driven food distribution network. Any matrix of risk planning has to reflect this complexity and engage with the key players across the landscape.

Food security, in all its complexity, continues to be a hot topic for debate given its prevalence, impact and intractability in terms of detection and prosecution (Temple & Evershed, 2016).

e) Food Safety

Ensuring that food is safe is costly and challenging, yet essential to our survival. This applies at an individual, family, community and national level. Therefore, ensuring this requires actions at all of these levels and therefore, to some degree integration and monitoring of actions that affect food safety in terms of handling, preparation, storage and transportation at all stages of the food chain.

Furthermore, there are multiple dimensions to the reasons by which food can become unsafe: faulty or badly maintained equipment, accidents, malicious and criminal behaviour, poor practices, traditional habits and beliefs, lack of knowledge, and misinformation. All of which can occur at any point in the food chain from the suppliers to the consumer.

How we ensure and communicate the safety of food is also important in order to tackle the complexities of emotion, tradition and belief systems that govern eating habits. The mechanisms, channels and voices for conveying the raw data of safety information both between stakeholders in the food chain as well as the end-users is equally challenging and an essential part of building trust between all parties. The speed at which messages can get propagated and responded to varies between the urgency of contamination to the different challenge of tackling broader unsafe practices that lead to obesity and heart disease.

f) The Internet of Things - background

It probably is fair to say that IoT took off around 2013. The previous four years were very much a period of proof of concept and prototyping, and - pre-2009 - research and development. The term “Internet of Things” was first coined by British entrepreneur Kevin Ashton in 1999 while working at Auto-ID Labs. There is still a something of a debate about the exact meaning of the term with some adhering to the strict belief that the technologies should be restricted to Internet Protocol devices. However, many are comfortable with using the term IoT to refer to the wider world of interconnected devices of various types.

g) The Internet of Things - timeline

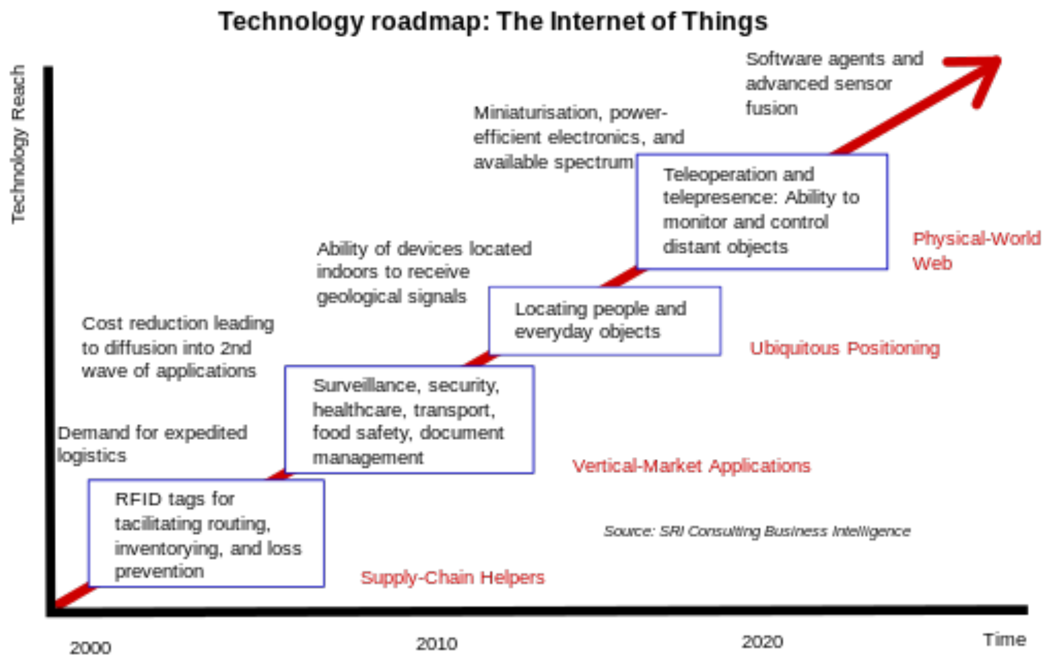
The idea of the Internet of Things has evolved from a number of different technologies that have converged into a vision of how the World Wide Web as a collection of interlinked human-readable files could evolve into a network of devices that could interact with each other. Importantly, IoT also brings together a number of clearly different academic disciplines including: embedded systems, ubiquitous computing, wireless sensor networks, control systems, automation and other areas that underpin the Internet.

The Internet as we know it today began with the implementation of Internet Protocol version 4 (IPv4) in 1983. The early history of IoT therefore covers from the early 1980s when a Coke machine at Carnegie Mellon University became the first internet-connected appliance to around 2010, phase that was characterised by ad-hoc demonstrators with things like toasters connected to the Internet, and ideological speculations about what could be achieved. In 1999 Andy Stanford-Clark and others at IBM authored the MQTT (formerly Message Queue Telemetry Transport) protocol which provided a more efficient mechanism for devices to communicate with each other over the Internet, a process commonly referred to as Machine to Machine or M2M. Other similar protocols soon followed.

Whether or not by coincidence, after the introduction of the new Internet Protocol version 6 (IPv6) in 2011, more ambitious IoT solutions start to emerge from companies rather than just academic labs. These included: LG with their fridges, Nest Labs (now owned by Google) with their thermostats and Google themselves with their Google Glass and Apple with their HealthKit and HomeKit.

IoT is now, in 2016, providing a platform for many implementations of smart cities and smart energy systems with more opportunities in the pipeline where the automated integration of devices can contribute to efficiency, safety and economic benefit. The economic benefit in particular, being a major factor behind the Chancellors pledge of £40M for IoT in the 2015 budget.

According to Gartner there will be nearly 20.8 billion devices on the Internet of Things by 2020. Perhaps the era of humans connecting to the Internet will be looked back upon as a tiny blip in the world of interconnected devices acting as an independent ecosystem? One line of thought for the future of IoT is for more intelligent devices contributing to an ambient intelligence whereby devices act autonomously dependent on local conditions and circumstances.



Technology Roadmap – the Internet of Things[2]

h) The Internet of Things and food safety

The potential for deriving benefits from the amalgamation of food safety practices with a pervasive low-cost technology like IoT is significant. Whilst economies of scale may be available in the future, a key challenge, at least in the short-term will be identifying short-term gains that are both affordable and demonstrable. Much of what is done currently to address and manage food safety is protracted due to legacy practices and manual processes. Readings are taken, either manually or through sensors, and data collated, sifted and distributed for later analysis and comparison dependent on legacy policies and loosely coupled organisational structures.

Unlike simple sensors alone, IoT technology offers the opportunity for two-way communication between devices and indeed intelligent i.e. autonomous and semi-autonomous interaction that could take remedial action to optimise management of elements of the food chain. Using IoT technology to capture, and also manage, the stages of the food chain delivery process will have benefits in terms of how the chain is controlled and directed, and also in terms of creating an audit trail for subsequent investigation when things do go wrong (“The Internet of Things and Food Safety,” n.d.).

Activity is starting to take place at a significant pace in various places around the world (Moore, 2016). As we discovered in the literature survey, China has started to become active in this field. The EU, through the Alliance for the Internet of Things Innovation (AIOTI)(AIOTI, n.d.) has now established the Smart farming and food security working group and launched a call for project proposals in this area early in 2016. Technology provider, Cisco has established a partnership with Italian pasta maker Barilla to enable consumers to track the journey of their pasta from the manufacturer to their plate (Bellin, 2015).

The utilisation of IoT technology in the field of food safety is not just an interesting diversion, regulatory compliance businesses have recognised the real economic benefits to be gained from integrating active sensors into the data capture process. Data gathering may not cease

[2] By SRI Consulting Business Intelligence/National Intelligence Council - Appendix F of Disruptive Technologies Global Trends 2025 page 1 Figure 15 (Background: The Internet of Things), Public Domain, https://commons.wikimedia.org/w/index.php?curid=10501643

to have a human dimension, but the triggering and support function will have a significant impact in saving time and money ("How the Internet of Things is Shaking Up Food Safety," 2016).

IoT also offers direct interaction possibilities for consumers, not only in terms of enabling them to ascertain the provenance of the goods. Active packaging coupled with the prevalence of smartphones enables users to scan bar and QR codes to directly engage with the significantly more data about goods than can be printed directly on the packaging materials (Wilder, 2015a).

IoT also enable closer and active scrutiny of the energy consumption of equipment involved in servicing the food chain. In particular the efficiency of refrigeration units has a major impact on the safety of the food chain. What is interesting is that the energy efficiency of such units is not just important for economic reasons, but also as in indicator of temperature fluctuations which has a direct impact on food safety. IoT has the potential to play a valuable role in tracking and addressing such temperature fluctuations and power usage issues (Roeder, 2016).

Ensuring safe boundaries for key parameters including temperature and humidity has a direct influence on the prevalence of microorganisms and mycotoxins in the food chain. Such a precise degree of monitoring enables suppliers (and regulators) to track back accurately to trace the origin of contamination outbreaks, but also to direct remedial action and alerts more precisely than was done previously (Fletcger, 2015).

Monitoring of the supply chain can go right back to monitoring the welfare of the livestock. Cattle can be monitored for respiratory disease. Ear tags have are being manufactured that can monitor bovine respiratory disease enabling farmers to isolate sick animals before disease can spread (Andrews, 2015a).

With the added contribution of artificial intelligence (AI) and machine-to-machine (M2M) communication, devices can auto-diagnose problems and deliver pre-emptive alerts enabling predictive maintenance on distributed production systems. Delivering such solutions will take time. Initially, human-managed solutions will prevail, but fully integrated enterprise-wide solutions are not far away(Brown, 2016).

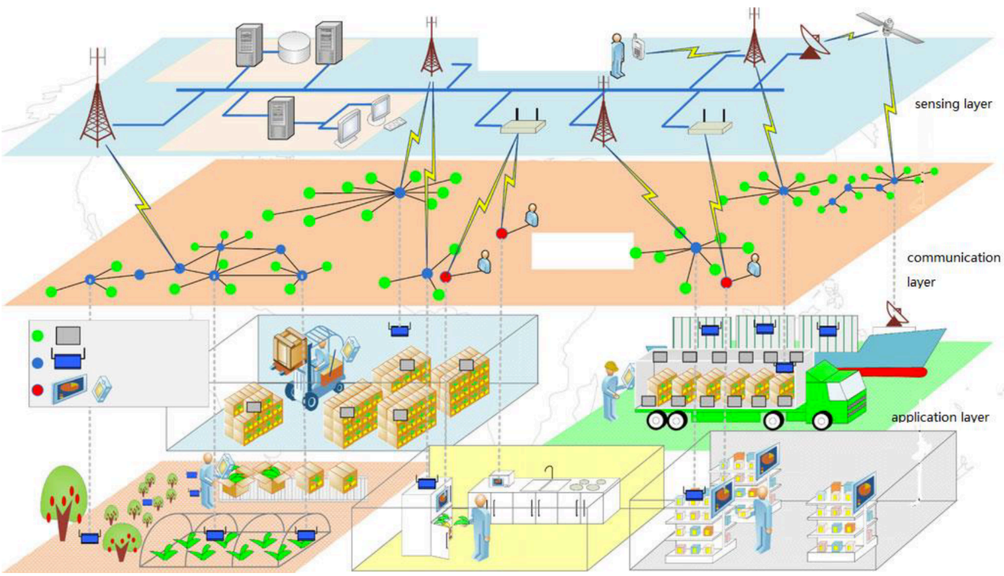


Figure. 1 A whole picture of food supply chains in the era of Internet-of-Things

Temporary graphic: to be replaced by original drawing

The key purpose of this white paper is to survey the landscape of academic literature in this area to explore the degree to which research in the fields of food safety and IoT has come together to address the challenges, risks, opportunities and progress in the field of food safety and the Internet of Things. Having done so, we make some recommendations to better understand the route forward.

i) Surveying the literature landscape for food and the Internet of Things

Having seen the ideas and opportunities inherent in the merging of IoT and food safety, a strategy was developed to examine the extent to which a cross over has been established between these two important, but disparate, fields have come together.

j) IT as a Utility Network+

This report has been written by the team behind the IT as a Utility Network+, an RCUK-funded initiative (2012-216) with the objective of cultivating an active network of researchers from the academic, policy and commercial worlds to examine the ideas surrounding utility IT in the broadest sense. Food safety has one of the key themes of this network and this report incorporates findings, ideas and insight that has arisen from various workshops, pilot projects and conferences as well as the specific research conducted for the report.

4) Overviews of searches and reviews

a) Key Players

Based on the literature survey as a whole we have highlighted the most significant authors (in terms of primary literature). The table is also available as an Excel™ spreadsheet. Viewing the Mendeley group with the Mendeley desktop or via the Web allows individual searches for people to be made.

b) Summary of search strategy

We under took a wide-ranging view of IoT and Food, covering the years 2013-15 using a very broad definition of both IoT and food matters. This led to about 20 or so key categories. We then extended the search to to look specifically at Precision agriculture as this was an area in which it seemed that extensive use of IoT was at least being considered in detail. Subsequently a third survey was completed using the papers and key terms obtained from the first two surveys to search back to earlier years, using cited and cited by references, and related papers.

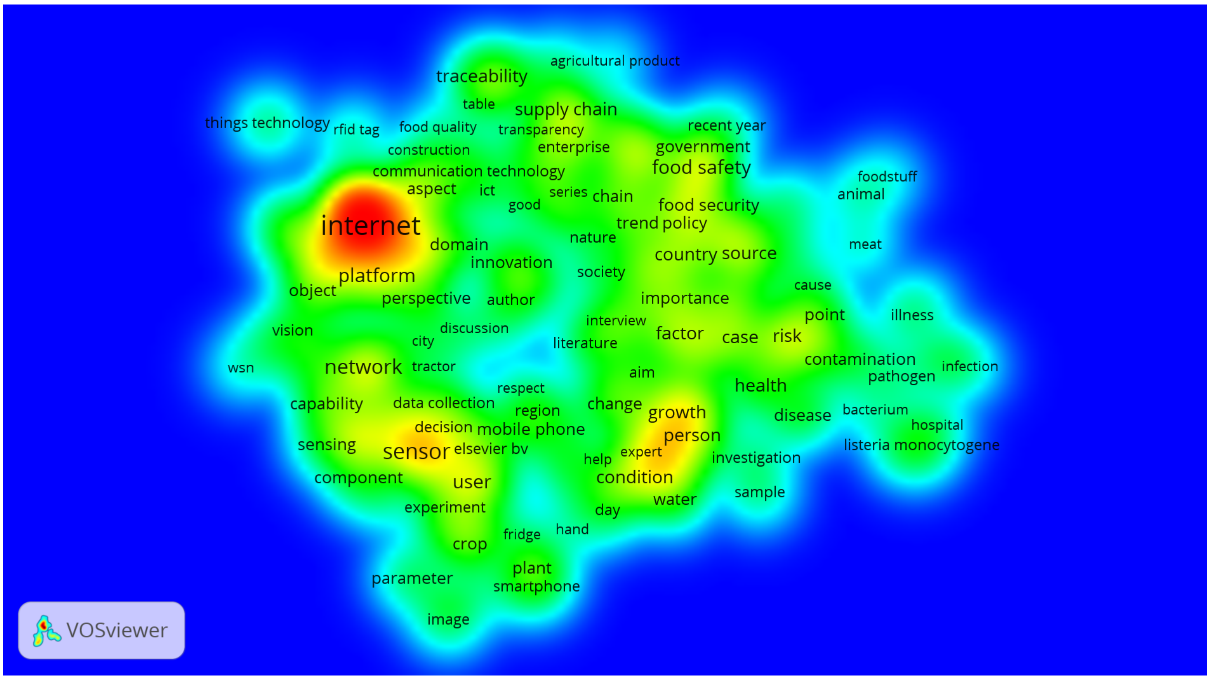


Figure Network map of key terms showing how their correlations.

c) Summary of initial search (Survey 1)

The initial search for articles relating to both IoT and Food was limited to the years 2013-2015 to obtain a current view without introducing too many topics of marginal relevance. For subsequent analysis and the compilation of the digest in Appendix B, the resulting 159 articles were sorted into categories and then further grouped into three topic areas according to their primary focus: production, distribution, or care through the lifecycle.

Rather than attempt to outline each of the categories – and thus present a digest of the digest – this summary gives an overview of the three topic areas, highlighting articles that are of specific interest.

Under the heading of Production, we analysed articles dealing with the management of resources, especially water and particularly at the farm site, together with the intelligent packaging of produce for onward distribution. The packaging category includes two reviews, one from the Netherlands and one from Belgium, of which the latter provides considerably more technical and technological detail.

With regard to Distribution, we took the view that the eight categories under this heading related to supply chain issues. The majority of the articles dealing with basics and with traceability are from China, including two of the three reviews, neither of which have full texts available. The third review, from Spain, is more wide-ranging than its abstract might suggest; it also has a long list of references. Most of the articles about traceability systems propose architectures, but it's not always easy to see how far they have gone towards implementing their ideas, although the factors that the authors take into account might be of some interest. Uncertainty about implementation applies also when specific foods are under consideration.

More detail is available for the topic of logistics, with two papers about the EU SmartAgriFood project and a review of RFID and WSN technologies for "intelligent packaging and logistics for the fresh food tracking and monitoring service".

However, less detail is accessible in the following topic areas, owing in several cases to a lack of full texts: refrigeration, intelligent shelf systems, automatic ordering, and personalised grocery services.

The two projects under in the area of connecting consumers are both funded as part of the Digital Economy programme, with articles from both the Lancaster and the Aberdeen teams.

Considering Care through the lifecycle, more than twenty of the articles deal with the benefits of IoT in food and agriculture. The review of IoT applications in animal husbandry in China indicates real implementations, but unfortunately the full text is not available. In 2015 Beecham Research produced a report that “focuses on the worldwide adoption of the Internet of Things in smart or connected farms within the agriculture industry sector.” The full report is expensive, but the Executive Summary is available and looks impressive. Otherwise the coverage of this topic area is broad and varied.

There is one review in the area of health and nutrition issues, dealing with food and non-food ontologies and how they can supplement the cloud-based lookup databases. The objective is to enable progression from the mere automated identification of food and drinks in our meals to a more useful application. The other articles in this area suggest that it attracts interest. Less detail is accessible in the areas of spoilage control and waste management.

There is a substantial range of articles relating to lifecycle monitoring. An analysis from Australia of IT requirements for “digital agriculture” is possibly the most thorough study in this section. It proposes an architecture based on the EU FP7 OpenIoT project and is well illustrated. A short but wide-ranging article in Food Safety News deals with areas of impact for IoT.

There is no shortage of architectures, models, and proposals: architecture to track and trace agriculture from the field through the supply chain and in food processing environments. Ten articles deal with the control of environmental conditions, four of them specifically address greenhouse monitoring. Two articles discuss data collection on food products over the lifecycle, one being an 11-page overview from Romania.

A few articles do not fit easily into a topic area, commonly because they describe specific applications. Unsurprisingly, some are about aspects of managing food in “smart fridges”: only the description of ‘iFridge’ provides any detail.

d) Summary of Second Search (Survey 2)

We extended the search to look specifically at Precision agriculture and the use of IoT like systems (for example sensor networks and farm information management systems) and to encompass the detailed decision making and control of farming and agriculture with a view to the provenance and quality control.

This search produced 48 articles, demonstrating a wide range of uses for precision agriculture data and, naturally, interest in the management of that data, including the potential role of ontologies in the sharing of food-related information. Three articles deal specifically with the use of precision agriculture data to inform practices and decisions. Five other articles relate to soil characteristics and usage, of which three refer to specific elements: tritium, nitrogen, and phosphorus; and one also talks about a data model for soil characterisation.

Five articles report work that relates food production to environmental issues: greenhouse gas emissions, carbon sequestration, energy consumption, climate variation, and community health.

System and informatics considerations are the subject matter of ten articles, of which four relate to knowledge exchange, informatics-based platforms, and ontologies. The other six deal with specific applications and technological approaches: user-defined data processing workflows, an agricultural information service platform, observation of pest attacks, an advisory information system, a usage study, and a tool for protecting against foodborne illnesses.

Specific resources and produce are the subject of five articles: tea crops, aquaponics, small livestock farms, soil moisture, and natural resources that could accelerate agribusiness development. There are also four larger scale studies, relating to: optimizing industrial structure in agriculture; obtaining the optimal crop mix and resources needed to maximize output; mapping and monitoring crops; and mapping the land use of local communities, which is critical to resource planning.

A significant proportion of the articles resulting from the search are primarily about communication rather than the agriculture data itself, so could be regarded as a separate area. The topics covered include the use of mobile phones for information exchange in an agricultural context, improving access to market opportunities and information, and a weather forecasting service.

e) Summary of third Search (Survey 3)

We used the papers and topics generated in the first two surveys as a basis for looking further back though the literature and uncovered many more relevant articles.

There is clear evidence of European involvement, in the form of initiatives, exercises, and projects, notably in the areas of logistics and the benefits of IoT in food and agriculture. Thus, the FP7 projects, SmartAgriFood, Ebbits, FOODIE, and FutureFarm are all represented; and two articles relate to a foresight exercise instituted by the EU Standing Committee on Agricultural Research (SCAR).

The largest three sections in the digest cover supply chain basics, logistics, and the potential of IoT in food and agriculture. Within these areas, which overlap to some extent, the emphasis is on tracking and traceability. One paper cites the definition of food traceability put forward by Bosona and Gebresenbet in 2013. A 2009 Korean paper concluded that *consumers were willing to buy more food and pay more for it when they used the traceability system*, albeit with some qualifying remarks. There is the usual crop of articles proposing architectures and models, some of which report implementation experiences. The research in such cases tends to be based on a bigger project or to relate to standards work. Several of the benefits articles adopt a technology perspective, one such being a 2014 review of the IoT future by the Government Office for Science. The potential for mobiles to be used in food supply chain and traceability systems for consumers is achieving recognition, in most cases using QR codes, although one article argues the need for a successor. Other articles discuss the use of mobile technologies for delivering information and real-time assistance to farmers. The use of mobile phones has spread rapidly in many developing countries, as they provide an enabling technology, especially for money services.

The areas of precision agriculture and farm management overlap. Some articles describe architectures and case studies; others deal with more specific aspects: fertiliser control, land resource utilisation, tractor control, and barley spraying.

Health and nutrition topics include identifying the causes of safety issues, improved surveillance and notification. A body of papers discuss the challenges of identifying what people actually eat, in several cases with the aim of monitoring diet, along with increasing consumer awareness and then recommending appropriate diets and consumption levels. Research into consumer behaviour occurs in various areas: refrigeration, connecting consumers, waste management, and traceability. Other consumer work relates to offering them a better service, in which respect it is not surprising that articles about smart fridges are in plentiful supply, with a couple being about other household devices. Mobile technology is increasingly being used to inform consumers about goods and personalising their food shopping, and apps have been developed to provide information in one form or another about food safety. Concerns about an increase in illness resulting from unsafe food handling have led to smartphones being used for direct concealed observations of food handling practices. Mobile apps are also being developed to support food security by improving access to field data and other agricultural information.

In the area of food policy, DEFRA produced reports in 2006 and 2009 concerning UK food security. RuSource, an Arthur Rank Centre project, published a briefing in 2007 saying that the decline in self-sufficiency relates to agriculture's ability to meet consumer demands, but food supplies are remarkably resilient. A more recent House of Commons report focused on food production, supply and the systems necessary to ensure food security in the future. A Danish study published this year considers five scenarios, which are under consideration in future policy planning.

5) Overview of ITaaU Food studies and workshops

a) Introduction

The IT as a Utility (ITaaU) Network+, in conjunction with the Food Standards Agency (FSA), other food-related organisations, and academics active in the field held three workshops to explore the potential for IT solutions to contribute to food safety and security.

The first workshop, held in Belfast in September 2013, was a large meeting, primarily composed of talks. It looked specifically at security and trust in the food chain, including the security of the information in this process, and was aimed at raising awareness and sharing ideas. The second in the series was an FSA-internal workshop on data exploitation and food security, which took place in London in December 2013. The third workshop was held in Southampton in May 2014 and focussed on food security issues.

The role of the ITaaU Network+ followed the usual model of bringing together a smaller number of people to discuss key issues relating to a specific field, explore possible solutions, aiming to produce concrete follow-on actions:

> “[The ITaaU Network+] brings together social and technology research for intelligent and effective innovation.” [Jeremy Frey]

Figure 2 A Wordsift view of the main items in the report on the ITaaU Food workshops

b) Food safety and security

While related concepts, the terms food safety and food security describe two different aspects of concern over the food network:

> **Food safety** is a scientific discipline describing handling, preparation, and storage of **food** in ways that prevent foodborne illness. This includes a number of routines that should be followed to avoid potentially severe health hazards.[3]
>
> **Food Security**. The World **Food** Summit of 1996 **defined food security** as existing "*when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*."[4]

c) Workshop 1, Belfast, September 2013 (Organised by Professor Gerard Parr, University of Ulster)

Collectively, the speakers brought out the significance, complexity, and the importance to the consumer of food safety and security. Responsive management and communication strategies are essential when dealing with issues that arise, and in recent years there have been several high profile events that have raised serious issues. With increasing consumer concern regarding the safety of the food supply chain in the UK as well as the rest of Europe, there is an important role for new digital technologies to improve security and trust. Technology can usefully assist in several areas, including surveillance, traceability and even supporting personal responsibility around diet decisions.

This workshop brought together scientific experts, policymakers and technology practitioners from across the spectrum of government agencies, academia and other organisations involved in the interests of food producers, government stakeholders, manufacturers, vendors, supermarkets and consumers from “field to fork”. The goal was to discuss best practice from around the UK and Ireland and identify tools and ICT systems that could be harnessed to improve food product security, traceability, nutritional benefits and consumer confidence with the social, health and economic benefits that can arise.

The workshop was also intended to explore opportunities for collaboration, joint projects and new funding. The format was a series of keynote presentations, followed by roundtable discussions and informal networking, finishing with a firm commitment to take the discussions forward.

Professor Rob Edwards[5], chief scientist, Food and Environmental Research Agency (Fera)[6] described the role and practice of Fera. It was set up to respond to national emergencies, and works on a basis of all-around surveillance, looking for new threats, often in a non-specific sense. ICT can help Fera by enabling a multiplexed approach to obtaining evidence, rather than replying on just one methodology. There is a strong move from lab decision-making towards field decision-making, and similarly so for surveillance and detection. IT has a crucial role here in facilitating transfer and interpretation of large datasets.

Professor Terry Donohoe[7], head of strategy and policy, chemical safety division of the FSA described the role and practice of the Agency. It has an early warning system highlighting

[3] Food safety. https://en.wikipedia.org/wiki/Food_safety
[4] Food security. http://www.fao.org/forestry/13128-0e6f36f27e0091055bec28ebe830f46b3.pdf
[5] http://www.ncl.ac.uk/afrd/staff/profile/robertedwards.html
[6] http://fera.co.uk
[7] https://www.linkedin.com/in/terry-donohoe-0b123626

future risks to food using information from a range of sources. They have a lot of data, which they need to use wisely to obtain the necessary intelligence, especially as much of the data is qualitative. The challenge for the agency is to use ICT to implement a system that: analyses and makes best use of the information available to it; identifies future risks to food safety, quality and integrity; takes timely action to prevent or mitigate the impact of future risks[8].

Professor Barbara Stewart-Knox[9], University of Bradford, was a partner in the EU-funded Food4Me project, an extensive investigation of direct-to-consumer personalised nutrition. The methodology was to engage with the general public and stakeholders on matters of food and health and to gain an understanding of factors affecting uptake and compliance with personalised nutrition. One outcome was that IT issues seem to be of greater concern to the public than the nutrition, especially that data might be misused.

Professor Alan Reilly[10], chief executive, Food Safety Authority of Ireland, introduced the analogy of food safety as a sleeping volcano: authorities need to monitor and remain vigilant regardless of how dormant it might appear. When the "volcano" does go bang [for example, the horsemeat scandal] there needs to be crisis management and a communication strategy. Food now has a very long supply chain, which is like a maze, and the longer the chain, the more things that can go wrong. The areas in which ICT can help are: behavioural change; traceability; improved surveillance.

Professor Tim Benton[11], 'champion' for the UK's Global Food Security Programme reaffirmed that food chains are increasingly complex and volatile. Supply needs to increase but needs to be sustainable; there is pressure to modify diets; and ICT is crucial in the food chain. We are witnessing a huge growth in global food demand, but production in not the only issue: global food losses/waste is estimated to be 1.3 billion tonnes per annum, equating to approximately one third of the edible food intended for human consumption. ICT as a crucial backbone in the food chain, and can also help in the following areas: precision agriculture; sensing systems in field and supply chain; modelling and forecasting demand and supply; tracking and analysing; smart metering of personal food intake.

A subsequent presentation from Geoff Golligher, Invest Northern Ireland[12], and Ian Scott[13], Lemma Solutions[14], described an agronomy and food traceability system that tracks food from the growers to the buyers. Professor Sean Strain, University of Ulster[15], reported on the interplay between food, nutrition and health

The subsequent roundtable discussions focussed on the following questions:

- Where might ICT assist most in the food chain…at the farm/producer source or in the supermarket facing the consumer?
- What are the main challenges in widespread adoption of technology in the food chain?
- How can we avoid the cost of introducing new technologies and monitoring systems being passed to the consumer?
- Do you think systems such as iPhone Foodscanner for reading food barcodes in supermarkets are a good idea or do they marginalise the elderly and poor in society?

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8 http://www.foodsafetymagazine.com/magazine-archive1/augustseptember-2013/the-identification-of-new-and-re-emerging-risks-a-british-perspective/
9 http://www.bradford.ac.uk/social-sciences/staff-profiles/psychology/stewart-knox-j-barbara.php
10 http://www.ucd.ie/foodandhealth/oldsite/people/academicstaff/profalanreilly/
11 http://www.fbs.leeds.ac.uk/staff/profile.php?tag=Benton_T
12 http://www.investni.com/support-for-business/finding-new-markets.html
13 https://www.linkedin.com/in/ian-scott-a799253
14 http://www.lemmasolutions.com
15 http://biomed.science.ulster.ac.uk/Strain-Sean-Professor.html

- What are the expectations of the next generation of consumers (ie today's primary school children) in terms of trust in the food chain?
- Are the current methods for gathering data from the food chain robust enough and where should they be improved?
- Where is the most vulnerable segment of the food supply chain and how might the adoption of technology make it more robust?
- What types of technical systems and standards are required going forward to assist with real-time traceability?
- How can we best demonstrate that technology can assist in reinforcing trust and security in the food chain?

d) Workshop 2, FSA, December 2013

The theme of this workshop was data exploitation, with the scene being set by Sian Thomas, joint head of the FSA's Social Science Research Unit. Sian based her presentations on the IBM “5 in 5” predictions of the innovations that will change our lives in the next five years.[16]

- Education – How might the FSA be able to understand better the links between knowledge, attitudes, and behaviour?
- Retail - How can technology help with conundrum that we do not eat all the food that we purchase? Sian also talked about tracing campylobacter contamination.
- Health – Could the FSA learn things from samples collected in areas such as chemical studies and metabiological analysis?
- Security – What might be the opportunities for obtaining data relating to food safety directly from individuals and the ethical issues? What are the ethical issues, such as informed consent, might arise?
- Access to Information – People want their personal data protected but they also want things to be open, for example, information about the provenance of their food. How do we integrate these conflicting demands for the greater good? Using the example of GM foods, Sian posed the question: could it have been handled better? The issue is partly one of risk perception: people not feeling in control, the "dread factor".

In the subsequent discussion, a number of topics were considered for more in-depth examination in the breakout groups, before narrowing them down to two areas:

i) Consumer-focused data

The group discussed developing a case study for contamination issues, combining existing knowledge with other data sources (such as social media) to give greater explanatory power. Social media might also be used to monitor campaign awareness or effectiveness and/or to compare chatter about certain products with actual sales data. Other questions arose with regard to data input, such as who is eating what in different places and at different times?

The FSA identified a need for an internal data audit: what do they already hold that they might not even know about? What other data might they be able to get easily that others know about? What are the limitations of that data? Locating gaps in data needs might help FSA to ask where the information might be located.

ii) Food chain and security / enforcement

There are limitations to the data sources and databases that currently exist, and there are also other data sources that the FSA do not exploit. Standardisation of data is also an issue, as is currency, with some data being quite old. Data that would benefit the FSA

[16] IBM, The 5 in 5. http://www.ibm.com/smarterplanet/us/en/ibm_predictions_for_future/ideas/

is information about compliance from food businesses, which could be used to determine resource allocation by the FSA and by local authorities. Questions that arose were:

- What the FSA can gather from different sources of data and how can that be used to prioritise?
- Can the FSA share systems as well as data to help other local authorities to do it in the same way?
- Can the FSA get better at predicting behaviour and where failures take place? It might be that compliance has only improved on paper and reflects a change in numbers rather than behaviour.
- Are the FSA still collecting the right information or are they telling themselves what they want to hear?

iii) Next steps: areas for the FSA to explore further

- Dataset audit
- Compile a portfolio of case studies
- Innovation in data and capture
- Dataset connections: analysis and investigation of best practices
- Capacity and capability, being an intelligent customer
- Data culture

A meeting was held subsequently, in January 2014, at the FSA to review these seven areas.

e) Workshop 3, Southampton, May 2014

This workshop was mainly about food *security*, but recognised that food *safety* was inextricably associated. The following key issues were identified at the outset:

- Economics and the power of supermarkets with regard to public health.
- Behavioural change and how that can be influenced by education.
- How food security in the UK is connected to the rest of the world.
- Socio-economics and demographics and interesting emerging data.
- Food intelligence and food security.
- How local food producers can tell a story about their products – and how technology can help them.
- Minimising waste, increasing resilience – how different kinds of knowledge in the supply chain and gathering knowledge from different stakeholders can provide effective intervention strategies.
- Investigating how the smallest farmers and food producers use technology.
- How to embed people in communities - trusted brokers – rather than parachuting in digital solutions.
- Need for more effective and efficient way for local food groups to communicate across the UK with other groups.
- Getting messages out to the public about what we're doing.
- Supermarkets and agrochemical business: what are the issues we would like to discuss with them?

Guy Poppy[17], Professor of Ecology, University of Southampton, now Chief Scientific Advisor for the FSA, explained why the global food system is so complex. The vision is for food security alongside environmental stability in the context of global climate and population change. There are issues of access, safety, and resilience/security. In the UK we are looking at a complex food web - we import from 184 different countries – and demographics are a

[17] http://www.southampton.ac.uk/biosci/about/staff/gmp.page, https://www.gov.uk/government/people/guy-poppy

factor, as we have an aging society, which contributes to public health risks. About a third of all the food on the planet is wasted before it reaches a human stomach. We could take the billion people out of hunger if that waste could be avoided; it would also be equivalent to taking 20% of the cars off the road in terms of energy and emissions. Professor Poppy highlighted waste as the area where IT could contribute most.

Gerard Parr, University of Ulster, provided background information about Workshop 1 (September 2013) and raised some possible areas for further investigation:

- Schools: reaching the next generation of consumers;
- Supply chain: traceability, tracking, tagging, and physical security;
- Privacy: ethical issues that can arise even with anonymised data;
- Resilience: how are we planning for major exceptional events, and are we resilient to them?
- Data mashing and data sharing and linking;
- Identifying patterns from noise analysis.

The three breakout groups discussed the following topics:

i) Standards, brokers and supply networks

The discussion focussed on how to create a data system, such as for chicken data. It would be a pilot that could apply to other foods. The industry would be the main source of data, with different people able to see different levels of data. The FSA could see if there had been an increase in bacteria, and could also use the data to target areas to inspect.

ii) Communication and changing behaviour

The enormous gap in people's understanding that food security is an imminent problem. Communications need to be targeted and carefully to different constituencies. The recycling message has been very successful in schools: could it be reproduced with food? Could we have food waste or composting bins that become a social norm? A governance approach is needed, aiming to create a moral economy around food security and waste.

iii) Data lifecycles

How do we move from data to information, information to knowledge and knowledge to innovation? What are the opportunities to link different sources of data? The challenges are: How to identify the useful data sources; how to collect the data; and convert data into information, knowledge, and innovation?

iv) Plenary session

Socioeconomics does not have a big influence on reported food behaviours. Demographic factors such as age have a significant effect on awareness of food safety; there is no relationship with income or educational attainment. Unfortunately, knowledge does not translate into behaviour change in people with regard to food. In fact, energy has come more up the agenda than food security. When prices go up people change their behaviour. So how for example do we incentivise the supermarkets, which have immense power, to get involved? They could be enablers or they could block ideas. Would consumer power help? A small niche organisation can change the game sometimes. The FSA though, needs and wants to be able to respond swiftly to misinformation.

v) Next steps: areas to explore further

The areas identified were: gap analysis; mapping of all the different data sources; involving supermarkets in a subsequent workshop; and obtaining examples of best practice. Much of this still remains to be attempted.

f) Emerging themes

- *IT has a crucial role in facilitating transfer and interpretation of large datasets.*
- *The challenge for the FSA is to use ICT to implement a system that analyses and makes best use of the information available to it.*
- *IT issues seem to be of greater concern to the public than the nutrition, especially that data might be misused. People want their personal data protected but they also want things to be open.*
- *Are the FSA still collecting the right information or are they telling themselves what they want to hear?*
- *Waste is the area where IT could contribute most to resolving food security issues. A governance approach is needed, aiming to create a moral economy around food security and waste.*
- *Food now has a very long supply chain, which is like a maze, and the longer the chain, the more things that can go wrong. The areas in which ICT can help are: behavioural change; traceability; improved surveillance.*

These questions informed the subsequent ITaaU Food investigations and prompted the study of the potential of Internet of Things (IoT) in the food network.

6) ITaaU – FSA IoT Pilot Projects

a) Pilot Project – Approach and Process

The call for proposals for pilot projects was announced via the ITaaU website and on the mailing list on the 7 October 2015. The closing date was the 2 November 2015. Projects had to be completed before the end of March 2016 as this was the end of the ITaaU project. Although in the end a three-month no-cost extension was permitted.

As a result of this call we received 11 applications and funded 4.

The applications were checked for formal compliance and then circulated to a five-person review panel comprising members from the FSA, the ITaaU management team and an external consultant project manager. The panel members were invited to complete a spreadsheet and apply scores against the following criteria which followed the original call criteria:

- Fit to ITaaU priority areas (5)
- Fit to FSA remit (5)
- Track Record of team (5)
- Multi-disciplinary approach (5)
- Industrial partner (5)
- User engagement (5)
- Confidence factor (5)
- Value for money (5)
- Sustainability (5)
- Potential for impact (10)

These scores were then amalgamated into a new spreadsheet and prioritised by score. We then convened a teleconference to review the results.

This matrix provided a framework against which the results were discussed. In the end the scores helped frame and guide the decision. (It is worth noting that we did not feel that the other applications lower down the list were missing out by not receiving funding from us on this particular call in their current state. In other words, they were outside the focus of this call.)

The original call documents can be accessed from the web page on the IT as a Utility webpage that originally launched the call:

- http://www.itutility.ac.uk/2015/10/07/itaau-network-plusfood-standards-agency-pilot-studies/

b) Pilot project summary reports

i) Report 1: University of Birmingham - Use of Tinytag™ data and Scoresafe hygiene software to evaluate cold chain continuity

Maintenance of the cold chain is essential to ensure the safety and quality of high risk ready to eat foods. Storage of such foods is considered a critical control point (CCP) and Food

Business Operators are required to monitor the control at CCPs. Typically Food Business Operators measure the temperature of stored foods at pre-determined times during storage but continual temperature monitoring is unusual, especially in small businesses. This project used two forms of IT to carry out real time monitoring of cold chain integrity. Sandwiches were selected for the assessment as they are high risk, ready to eat foods which had recently been the subject of a Public Health England survey. Sampling results from retail premises in Birmingham suggested that some sandwiches were being sold with high aerobic colony counts. This could be due to poor hygienic practices during manufacture and/or poor temperature control during their shelf life.

The two forms of IT used for the monitoring were:

1. Tinytag™

The Tinytag™ data loggers have been proven to be effective and accurate in logging food temperatures (rather than air temperatures) and can be programmed to record at regular intervals over a long period of time.

2. Score Safe Hygiene software

The Scoresafe hygiene software is bespoke software for use on any android device which has been designed by the UoB and ScoreSafe to monitor CCP's and automatically store the results on google cloud. This allows real time access to the data by anyone with the authority to access it.

Method:

Forty one retail sandwich premises in Birmingham were approached and invited to participate in the study. Nineteen (46%) agreed to allow Tinytags™ to be inserted into their products and nine of these agreed to also use the Scoresafe App. The Tinytags™ were activated and inserted into the sandwiches by the researcher. Recordings were carried out for 2-3 days according to shelf life, at three minute intervals. Two distributors also agreed to participate. From the recordings it was possible to calculate a time temperature profile for the products and to identify when and for how long any product was above 8^0C during its shelf life. Self-reported temperatures from the FBO's were compared with those recorded by the Tinytags™.

Results:

The Tinytag™ results demonstrate that some retailers and both distributers were able to maintain good temperature control of the products. However, while the sandwiches in ten premises (55%) were below 8^0C with only limited periods above (<10% of the shelf life), in seven retailers (39%) the products were above 8^0C for substantial periods. In two cases the sandwiches were above 8^0C for over 50% of their shelf life.

Use of the Scoresafe app was more limited but comparing the minimum and maximum temperatures recorded by the FBO and the Tinytag™ loggers shows inconsistencies between the two sets of data. Typically the FBO's are underestimating the temperature at which their products are being held.

Conclusion:

Tinytag™ data loggers were an effective way of monitoring the cold chain and highlighted significant breaches of temperature control in the sample group. Many of these were not identified by the Food Business Operators monitoring and could compromise the safety and quality of the products.

Madeleine Smith, Alaa Alazoki

University of Birmingham

ii) Report 2: University of Lincoln - Feasibility of the IoT for domestic refrigerators food safety and waste

This was a multi-disciplinary project combining the food quality expertise of the National Centre for Food Manufacturing (University of Lincoln) and the food refrigeration expertise of the Food Refrigeration and Process Engineering Research Centre (Grimsby Institute), with the knowledge of IoT systems at the Department of Control System Engineering (University of Lincoln) and the UK consumer panel of Tesco plc., the biggest food retailer in the UK.

The overall aim of this project was to establish the feasibility of using the Internet of Things (IoT) to support the safe handling and storage of foods within the domestic refrigerator.

In doing so it sought to:

a. Understand if the IoT can be used to control domestic refrigerators and identify the likely benefits.
b. Establish the potential impact on food safety and waste.
c. Carry out a benchmark study to understand the performance of refrigerators and potential to improve control.

The project was structured in three parts:

- Part One: Survey consumer understand and attitudes to refrigerators and IoT.
- Part Two: Monitor the actual performance of domestic refrigerators in the home.
- Part Three: Examine how the IoT could be used to develop truly SMART refrigerators, change consumer behaviours and effect SMARTer uses of existing refrigerators.

The study showed that relatively few consumers understand how well their refrigerator was performing and just 7% of survey respondents (n=711) measure actual temperature. In our refrigeration monitoring we showed very wide variances in temperature performance between refrigerators, and also considerable variations of temperature within an individual fridge. We used a fuzzy clustering approach to show that a group of refrigerators were poorly controlled and had measured temperatures well above the FSA guidelines of 5 degrees. IoT has the potential to identify poorly performing refrigerators and an opportunity to bring about behavioural changes which may help underpin food safety in the home. We recommend that policy changes are considered to raise awareness of the importance of refrigeration temperature, in particular it should be considered that all new refrigerators should be equipped with a digital display of the actual temperature.

Simon Pearson, Argyrios Zolotas, Jin Chu, Christian James, Graham Purnell, Stephen J. James

University of Lincoln

iii) Report 3: University of Aberdeen – Food safety assurance: combining provenance and the Internet of Things

This three-month pilot-study explored the potential of low-cost commercial wireless sensors as a means to monitor food safety compliance within a restaurant kitchen. A software infrastructure was developed (built upon existing standards including the Semantic Sensor Network and PROV ontologies) able to manage sensor data streams. Inference rules were designed to represent HACCP (Hazard Analysis and Critical Control Point) food safety protocols and these were used to generate a record of compliance/non-compliance events directly from the raw sensor data.

Peter Edwards, Milan Markovic

University of Aberdeen

iv) Report 4: University of Nottingham – Into the Garden

The “Into the Garden” project explored what value IoT might provide as a utility to local food growing communities. In the early stages of the project, we brought together project researchers and non-academic partners in two ideation workshops – one in London, and one in Nottingham – where we presented examples of existing products marketed at “connected growing”. Critique of these products gave us insights into what could rapidly be developed and deployed “in the wild” at a local test site to provoke reflection on a future generation of value-adding IoT products for allotments, community gardens and small-scale commercial growers. The project proceeded to produce the technology demonstrator - an array of outdoor environmental sensors networked via portable waterproofed cellular hotspots, pushing data to a cloud data store and on to a web-based “community” visualization – and deployed it at a local large allotment, along with “probe” packs allowing allotment tenants to check out sensors, contribute and explore the resulting data, and log their expectations of the technology. At the time of this report, the demonstrator is being used on a daily basis and we are working with the allotment association to coordinate a feedback session with tenants who have used (and avoided using) the technology. Early informal responses suggest that tenants are conducting simple communal experiments to understand how growing conditions vary across the allotment, and that the communal “equipment bank” model of temporary loans is an effective way to get technology out into the allotment.

Derek McAuley, Sarah Martindale, Ben Bedwell

University of Nottingham

7) Observations and Recommendations

a) The Internet of Things (IoT) and Food Safety & Security

IoT is still very much a buzz phrase, but the literature survey has indicated considerable potential for aiding food safety. However, there is not currently a huge body of published academic evidence for extensive system implementations to date relating to food safety. There is a significant body of recent literature from China but even this has a predominance of proposed systems rather than actual implementations. This may be motivated by the recent food contamination problems in China, the complexity of longer food distribution chains across the country, or simply a greater academic interest in the topic. There are a few key groups in Europe working on “Agriculture 4.0” which encompass the whole of the food system, for which the data potentially provided by IoT is essential.

Another factor limiting the number of specific papers focused on the topic may be that IoT is not a single traditional academic discipline. It falls into an increasingly important approach of challenge-driven research that is inherently interdisciplinary. Furthermore, the two key facets of study are the physical, the sensor and actuator devices on the one hand, and the data on the other.

In terms of the technology, IoT covers a number of specialist areas, even without the data issues. We have seen papers from the perspective of sensors, actuators, wireless transmission, machine-to-machine, weightless wireless protocols, commodity devices and bespoke engineering. All of these areas could offer solutions to particular challenges in food safety but integrating them all, heterogeneous or otherwise, into an interoperable framework would require standards, which inevitably take time to ratify and implement as working profiles. There is work being undertaken in this area, with groups such as GODAN, FAO taking the lead, however, little currently appears in the formal academic literature.

This highlights an issue for the analysis and dissemination of the methods, impact, and quality, judgements of the application of IoT. So much is going on, moving so fast, by industry that academic studies of controlled implementations are few and far between. Ethical considerations make studies of food safety difficult to undertake, compared to those applications of IoT in precision farming, and the closer to the consumer the more difficult it is to collect the data (pervasive IoT sensors in the home notwithstanding).

b) IoT paradigm shift or hype?

What makes it IoT? While there is a major debate on this subject it is clear that distinguishing features are pervasive solutions, installations at scale and inter-communication from machine to machine. One of the key issues with regard to the questions posed for the literature review (and indeed highlighted by the projects) is of IoT versus “sensor networks”.

Sensor networks offer great benefits over traditional data gathering practices based on human intervention, and arguably are part of the IoT landscape. However the significant benefits will come when more active solutions are introduced, in terms of actuators controlling services and mechanisms. Ultimately this will lead to autonomous systems where the network makes adjustments based on what the system has discovered and learnt. This will have a considerable impact on the levels of automation in the food sector, something that has been growing since the industrialisation of food production. IoT has the potential to extend this from farm to home, but it is the data created and the use made of it, that is really the significant change, not the technology itself. It is clear that this is currently only feasible for very specific and narrow parts of the food supply/consumption network. Neither scale, nor useful machine communication, is yet feasible across large parts of the system, and it is these parts focussed on the home that are where there is least knowledge.

c) The Real Problem

As we surveyed the literature it became clear that the major problem is the "Lack of knowing what data is needed", not simply the lack of data or the ways to collect it. Without fixing this aspect, simply having lots of sensors and so collecting lots of data is not going to help. What is needed is a deeper appreciation of the data needed and what could be achieved by knowing that data. Only then could actuators and other decision implementation devices be introduced into the system.

d) Where is IoT helping?

In order to speculate on where IoT might contribute to improving safety in the food chain it is worth exploring the where IoT has been used or had an impact to date. A significant area is in transport and logistics. Knowing where assets are located and being able to monitor and predict when they will arrive is driving many excellent business cases. Understanding the regulating the conditions of the materials being transported goes along side this, and again has led to greater efficiency.

Even in these cases the real problem is that the main barrier is the sharing and reporting of data rather than IoT itself, and the issue that needs to be addressed before succumbing to the IoT hype. The report focuses on IoT but it perhaps should have focussed more on "Data" as it is the Data & Analytics not "IoT" that will save time and effort and lead to greater warning / advanced intervention / more efficient deployment by the FSA

e) Lack of really useful experiments

Despite all the media stories about the smart fridge there is very little good work on IoT in environments containing smart devices. IoT for the assisted home has had more penetration. There is a fundamental difficulty in making the necessary observations in a home and even more in a work place. The ethical issues around food preparation and consumption were highlighted in the projects. This leads to many experiments being undertaken in a quite contrived manner and makes it difficult to know how the results relate to the real world. IoT may provide more appropriate data, data that is currently not available but ethical issues hamper the experiments (as highlighted by the 4 FSA/IoT projects)

f) Comparison with other sectors

Within the overall agricultural and food area (farming, food industry and shops) so far the greatest impact of information technology has been in the logistics of food distribution, online commerce, and in a more limited way to precision agriculture. Behind each of these is a wider use of the data arising from the increased use of digital systems (e.g. weather data, market data) but the direct impact of IoT (sensors, and more) has been evident at a B2B level mainly in transport and at the consumer end in online services.

Where has IoT made the most impact? While stories of the smart home (lighting, heating, monitoring and fridges) are a consistent part of the technology sections of the papers and web sites, wide scale uptake has been limited. This is true of even the smart meters offered by the power companies. Incompatible systems, lack of easily demonstrated end user advantage, the perception that this will help only the "big companies" and not the users, all leads to less than enthusiastic reception outside the "techy community".

IoT should be and needs to be about the data not the technology. It is still far from meeting this aim. Glimmers of real business cases are seen in the insurance deals given to those with in-car monitors[18].

Ease of use can be achieved more readily in a vertically integrated service-oriented provision (iCar, energy etc) but this come with a serious downside for the future of the UK economy as a whole. The vertical integration runs counter to the inclusive, horizontally integrated, idealistic vision of the WWW, in which all players, small and large are able to engage and compete.

This is particularly significant in the food industry, in which there are many small and well as large players. For IoT to play a useful role it must be equally usable by the consumers, the small producers and marketers as well as big, global, organisations.

g) Recommendations

Having conducted the literature survey of food safety and the Internet of Things, considered the results and reflected on progress to date with research in this area and potential for the future we propose the following recommendations which can be grouped into three broad areas:

i) Data:

1. Data is the most important aspect and the implications of the data and the use made of the data generated, needs to be reviewed before more sensors are placed everywhere!
2. More small-scale projects investigating the sensor deployment in the home, restaurant, shop etc. to establish what measurements are useful, what measurements are achievable.
3. Investigation of smart utensils to see if even in special cases these will help capture information on people and food in a reliable and acceptable way.

ii) Behaviour (People):

4. The roles the people play in all aspects of the food system is difficult to capture but needs to be addressed directly otherwise interpretation is too ambiguous. To this end the economic aspects of the "What's in it for me?" questions need to be addressed for all stakeholders.
5. The integration of different commercial and open systems, whilst avoidable and unnecessary in a single farm, or a unified manufacturer, is a concern in the downstream parts of the supply chain: the need for agreed standards must be addressed to facilitate scalability and interoperability.

iii) Technology:

6. Data sharing infrastructure is needed. IoT systems can provide additional data, which is often already recorded but not shared. Once that data is shared and can be integrated, it will be clearer what data an IoT system should provide.
7. Value of IoT to the logistics and farming aspects of the food network has been demonstrated in the B2B context and can be applied using commercial systems and

[18] Provision of telematics research from the Transport Research Laboratory: http://www.trl.co.uk/reports-publications/report/?reportid=7033

these should now need to be tested in an extended environment though to the customer.

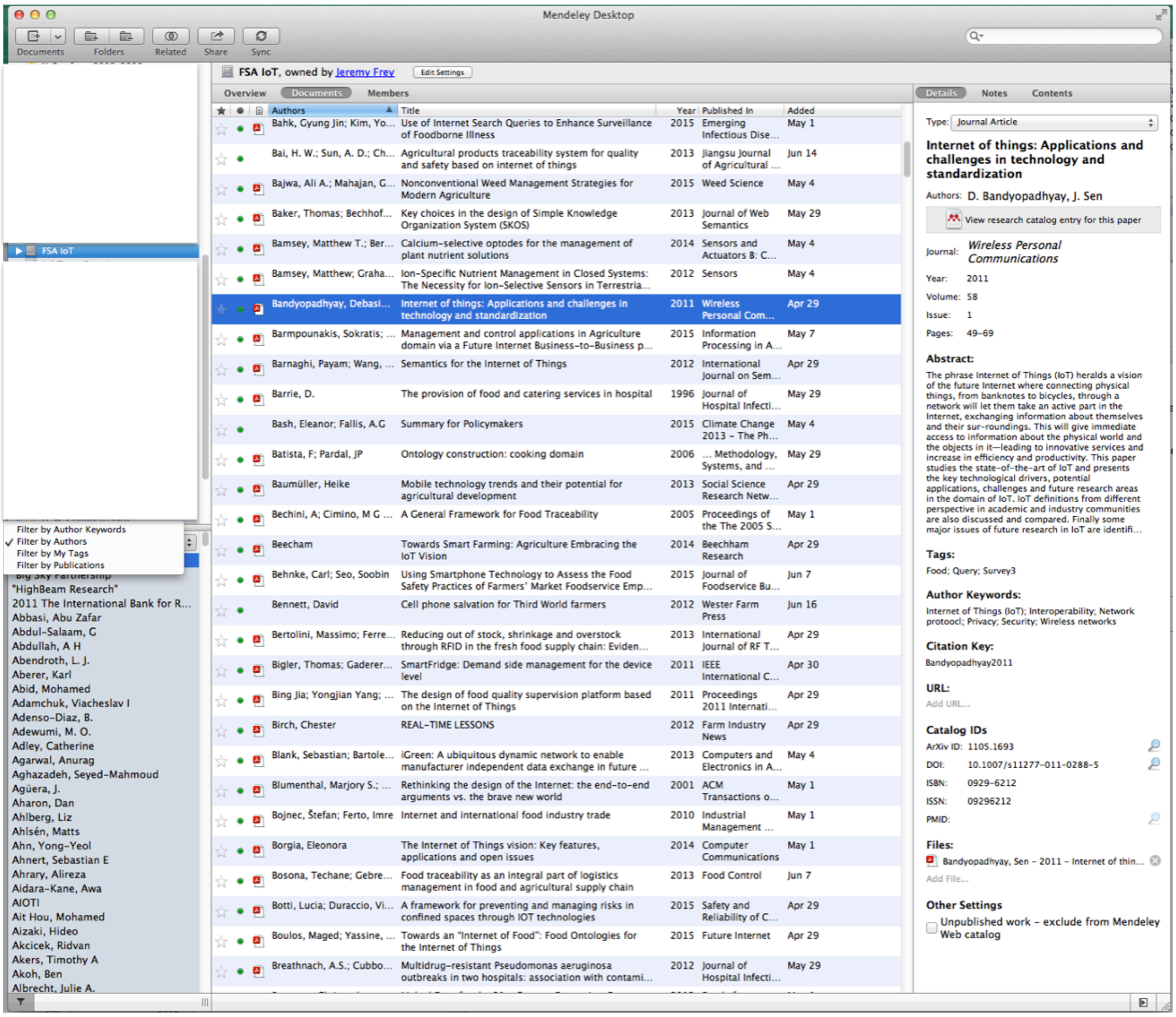
8. The food industry is a collection of large and very many small business and lots of consumers, which is ideal for a horizontal IoT integration but the vertical solution seems to be gaining ground. The issues of vertical vs. horizontal integration in this sector need to be studied and addressed and are likely to benefit from regulation.

For realistic IoT deployment there is a need for low-cost sensors running widely agreed and interoperable standards and connected with widely available wireless coverage. To ensure consumer trust the IoT systems must be secure, must have demonstrable accuracy in event trending, tracking and monitoring, and be able to cope with failures of the devices, networks and system. The data modeling is key to the use of IoT systems, so that the ability to undertake data integration and fusion is essential while avoiding “Data Obesity “. Consumers will expect that Industry – Government data is available for sharing under appropriate secure conditions, the extent to which this can be extended to consumers highlights the need to address and bridge the “Digital Divide”. Managing consumer expectations following all of the above will be essential if the valley of doom in the Gartner Hype Cycle is to be circumvented for the useful deployment of IoT in the food network.

8) Electronic Resources – Mendeley Group and Scoop.it

The full literature search resulted in over 600 items. These are all curated in a Mendeley group[19]. All the items have the citation details and an abstract, many have full text pdf files attached as well.

Currently the Mendeley group is private and shared with specific FSA staff allowing access to the full text files. We will transfer the bibliography to an open group so that the bibliographic metadata and abstracts will be available openly.

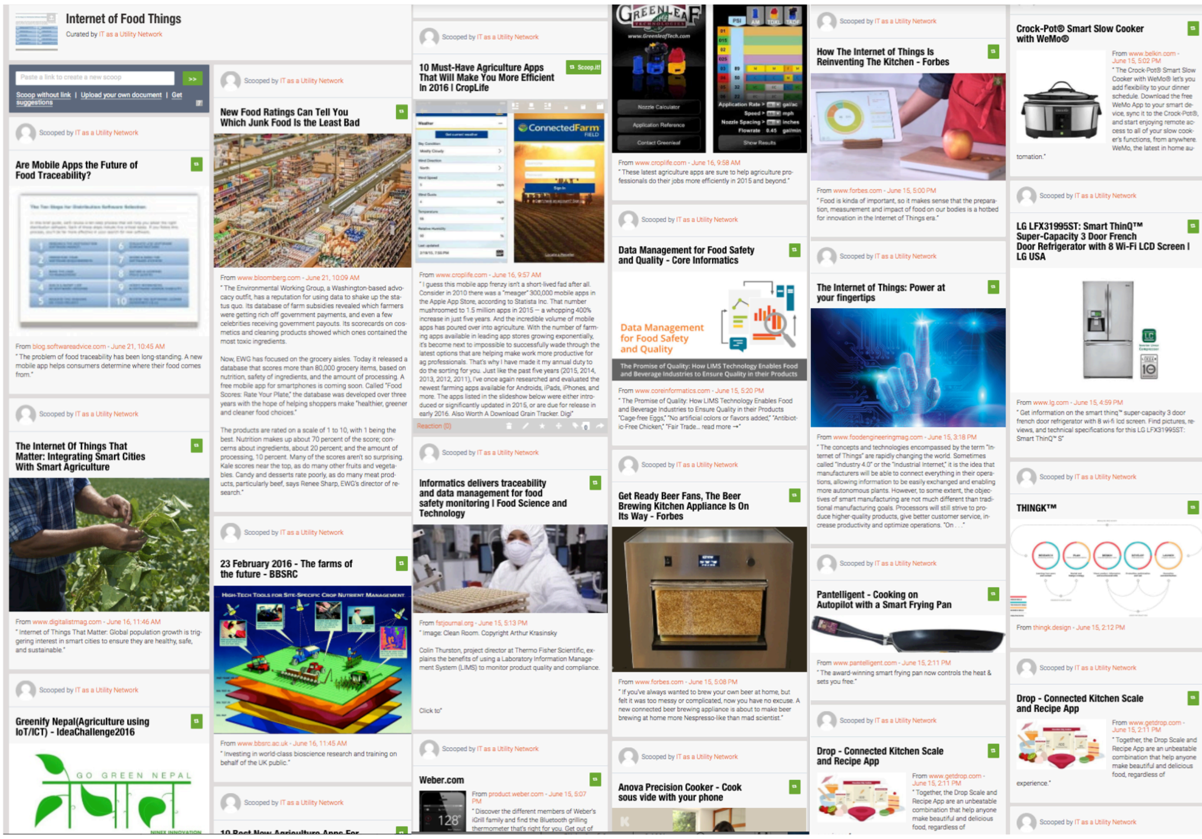


The Mendeley web and desktop allow for powerful searching of the bibliographic data (authors, titles, etc) and abstract text as well as providing an efficient way to deal with referencing in any documents. Details can be found on the Mendeley web site and help pages.

[19] http://mendeley.com

Files containing the full set of bibliographic data (in bibtex, RIS) is available from the ITaaU web site (under the IoT & Food sections). These files will facilitate transferring the literature resource to other reference management software. Similarly, the key players spreadsheet is available in the same section to facilitate searching and re-ordering of the spreadsheet

The IoT area is currently fast moving in terms of the Web, news, and more generally 'grey literature' and a formal literature review is not an ideal vehicle to keep track of this type of material. We have curated many of the web sites in a Scoop.it[20] service, and these can be viewed at the Internet of Food Things scoop[21].



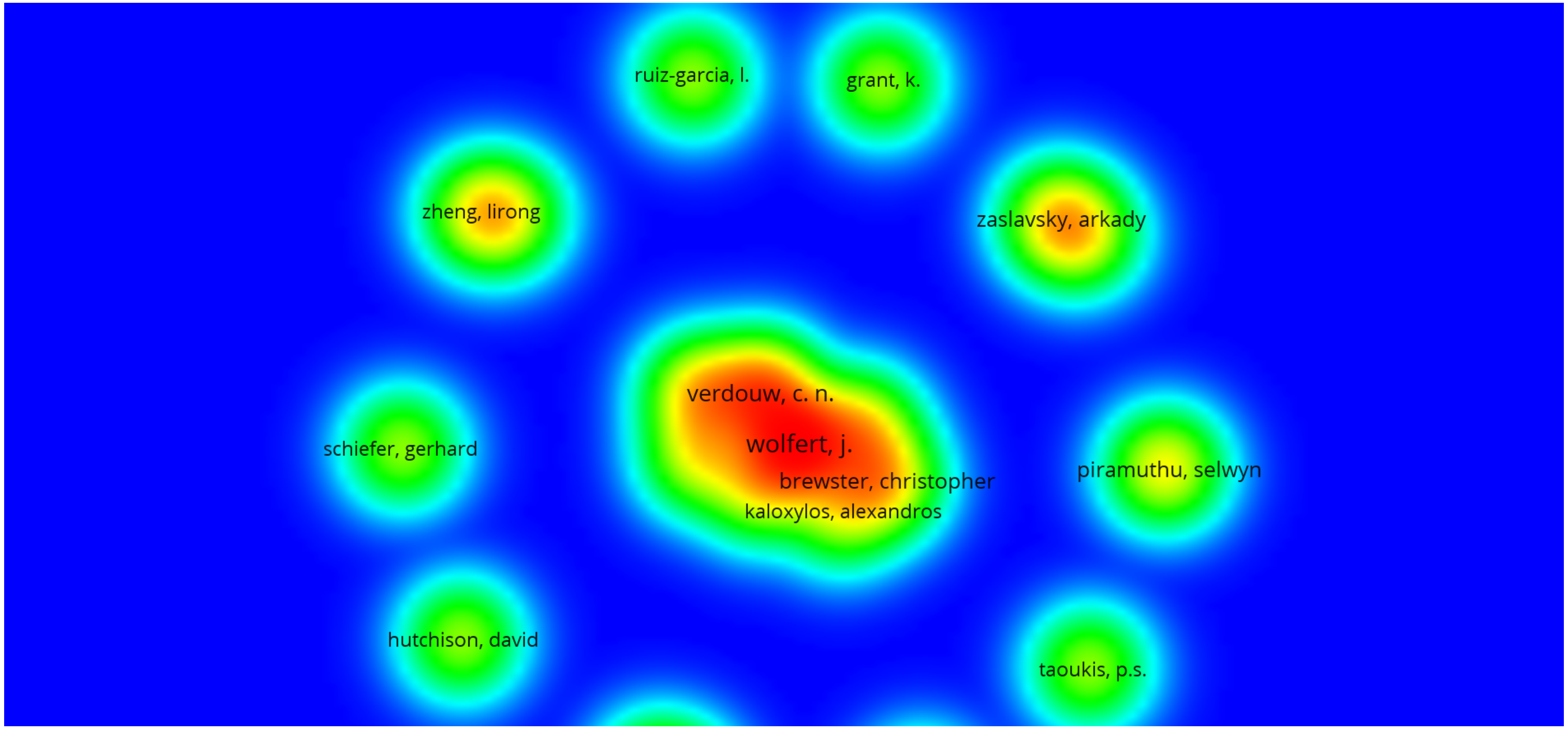
20 http://scoop.it
21 http://www.scoop.it/t/internet-of-food-things

Appendices

List of Appendices

9) Appendix A: Key papers of key players

The survey highlights several key players in the Agri-IoT area and we summarise the highest profile people and groups in the following table, showing their main areas of activity. This also highlight the research grouping GISAI (investigating advanced internet services) Future Internet public-private partnership (FI-PPP)' (An EU based project under Future Internet).



Name and Organisation (grouped by colour)	No of articles on IOT & food	Home Page		Areas of interest
Alcarria, Ramón	(Gonzalez-Miranda et al., 2013; Robles et al., 2014)	http://www.dit.upm.es/~ralcarria/index.html https://www.researchgate.net/profile/Ramon_Alcarria http://gisai.dit.upm.es/index.php/projects	Universidad Politécnica de Madrid	'Future Internet' is mentioned as an interest. He seems to have an interest in healthcare and RFID/sensors etc…
Atzori, Luigi	(Atzori et al., 2010; Atzori, Iera, & Morabito, 2011)	http://people.unica.it/luigiatzori1/ (Note that there are 2 Luigi Atzori academics at Unica)	Dipartimento di Ingegneria Elettrica ed Elettronica, Università di Cagliari	Social implications and domestic applications of IoT http://people.unica.it/luigiatzori1/prodotti-della-ricerca/
Brewster, C	(Brewster, Wolfert, & Sundmaeker, 2012; Brewster, 2012; Ge & Brewster, 2016; Kaloxylos et al., 2013, 2014; Solanki & Brewster, 2014; York & Brewster, 2013)	http://www.cbrewster.com	Senior Scientist in the Connected Business team, Business Information Services TNO, The Netherlands	the application of Semantic Web technologies in the agri-food domain and in emergency response
Celik, Duygu	(Çelik Ertuğrul, Elci, Akcicek, Gokce, & Hurcan, 2014; Çelik Ertuğrul, 2015) (Çelik Ertuğrul et al., 2014; Çelik Ertuğrul, 2015, 2016)	http://aydin.academia.edu/DuyguCelik	Istanbul Aydin University, Computer Science	Side Effects of Food Additives Via Semantic Web

Choi, Jaz Hee jeong	(J. H. jeong Choi & Graham, 2014; Farr-Wharton, Choi, & Foth, 2014; Hearn, Collie, Lyle, Choi, & Foth, 2014)	http://staff.qut.edu.au/staff/choih/	Creative Industries Faculty, School of Design Office, Interactive and Visual Design, Queensland University of Technology	Ubiquitous technologies to cultivate sustainable food cultures in urban environments.
Compton, Michael	(Compton et al., 2012; Perera, Zaslavsky, Liu, et al., 2014; K. Taylor et al., 2013)	https://scholar.google.co.uk/citations?user=Lq5D3Q0AAAAJ&hl=en http://www.csiro.au/en	Commonwealth Scientific and Industrial Research Organisation, Australia	Semantic Web, Formal Methods
Divakaran, Ajay	(Puri, Zhiwei Zhu, Yu, Divakaran, & Sawhney, 2009; Weiss, Stumbo, & Divakaran, 2010; W. Zhang, Yu, Siddiquie, Divakaran, & Sawhney, 2015)	https://www.sri.com/about/people/ajay-divakaran	Leads the Vision and Multi-Sensor group in SRI International's Vision and Learning Laboratory	Multimodal modelling and analysis of affective, cognitive, and physiological aspects of human behaviour, interactive virtual reality-based training, tracking of individuals in dense crowds and multi-camera tracking, technology for automatic food identification and volume estimation, and audio analysis for event detection in open-source video.
Farinella, G.	(Farinella, Allegra, Moltisanti, Stanco, & Battiato, 2015; Farinella, Allegra, & Stanco, 2015)	http://www.dmi.unict.it/~gfarinella/	Department of Mathematics and Computer Science - University of Catania	Computer Vision, Image Analysis, Computer Graphics, Pattern Recognition and Machine Learning. Food recognition.

Farr-Wharton, Geremy	(Farr-Wharton et al., 2014; Hearn et al., 2014)	http://www.ncl.ac.uk/computing/people/profile/geremy.farr-wharton	Newcastle University, Computing Science	The interrelationships between energy, water and food within domestic settings; environmental sustainability
Fitzpatrick, Geraldine	(Ganglbauer, Fitzpatrick, & Comber, 2013; Reitberger, Spreicer, & Fitzpatrick, 2014)	http://igw.tuwien.ac.at/hci/index.php/people/geraldine-fitzpatrick	Head of Human Computer Interaction Group, Institute for Design & Assessment of Technology	Use of innovative technologies to support everyday life and social interaction
Fountas, S.	(Fountas, Carli, et al., 2015; Fountas, Sorensen, et al., 2015)	http://agreng.agr.uth.gr/node/9	Laboratory of Farm Mechanisation, University of Thessaly, Greece	Soil, Water and Agricultural Engineering; new technology of precision farming
Fryer, Peter J.	(Charalambous, Fryer, Panayides, & Smith, 2015a; Saguy, Singh, Johnson, Fryer, & Sastry, 2013)	http://www.birmingham.ac.uk/staff/profiles/chemical-engineering/fryer-peter.aspx http://www.journals.elsevier.com/current-opinion-in-food-science/editorial-board/peter-fryer	School of Chemical Engineering, The University of Birmingham	Cleaning and hygienic design of process equipment, microstructure and food properties, thermal processes and electric fields in food and bioprocessing
Georgakopoulos, Dimitrios	(Jayaraman, Palmer, Zaslavsky, Salehi, & Georgakopoulos, 2015; Perera, Zaslavsky, Christen, & Georgakopoulos, 2014; Perera, Zaslavsky, Liu, et al., 2014; Zaslavsky, Perera, & Georgakopoulos, 2012)	http://www.rmit.edu.au/contact/staff%2Dcontacts/academic%2Dstaff/g/georgakopoulos%2Dprofessor%2Ddimitrios/	RMIT, Melbourne, Australia	Digital agriculture, IoT, semantically enhanced IoT platforms

Groumas, Aggelos	(Barmpounakis et al., 2015; Kaloxylos et al., 2014)	http://uoa.academia.edu/AggelosGroumas	National & Kapodistrian University of Athens, Informatics and Telecommunications	Cloud-based farm management
Grunow, Martin	(Grunow & Piramuthu, 2013a; Piramuthu, Farahani, & Grunow, 2013)	http://www.scm.wi.tum.de/index.php?id=13	TUM School of Management, Technische Universität München, Germany	Food production, logistics and supply chain in flexible services and manufacturing
Gutiérrez Jaguey, Joaquín	(Gutierrez Jaguey, Villa-Medina, Lopez-Guzman, & Porta-Gandara, 2015a, 2015b; Gutierrez, Villa-Medina, Nieto-Garibay, & Porta-Gandara, 2014)	http://intranet.cibnor.mx/personal/egen_cv.php?CIB_ID=00072 http://intranet.cibnor.mx/personal/joaquing/joa.html	CIBNOR, Mexico	Acuicultura, Automatización de procesos Inteligencia artificial Robótica, Vehículos autónomos
Han, Weili	(Yun Gu, Han, Zheng, & Jin, 2012; W. Han et al., 2015; W. Han, Gu, Zhang, & Zheng, 2014; Pang, Chen, Han, & Zheng, 2015)	http://crypto.fudan.edu.cn/people/weili/ https://www.researchgate.net/profile/Weili_Han https://scholar.google.co.uk/citations?hl=en&user=n5g_EI0AAAAJ&view_op=list_works&sortby=pubdate	Fudan University, Shanghai	University page specifically says his interest is in IoT security His focus seems to be on security and trust in IT, not just in food supply chain
Harper, Richard	(Grimes & Harper, 2008a, 2008b; A. S. Taylor et al., 2007)	https://profharper.wordpress.com/about/	Previously: Microsoft Research in Cambridge, UK	a philosophically inclined, technophile sociologist who explores and tries to invent new ways of being human in the age of computing

Hou, Rui Chin	(Hou, Wang, & Wang, 2013; Hou & Zhu, 2012) (Hou et al., 2013; Hou & Zhu, 2012)	https://www.researchgate.net/researcher/2050947339_Ruichun_Hou	College of Information Science and Engineering, Ocean University of China, Qingdao	Application of RFID Technology in the Food Traceability System
Jacxsens, L.	(Jacxsens et al., 2015; Kirezieva et al., 2015; Luning et al., 2009, 2015)	http://www.foodscience.ugent.be/LFMFP/Staff?StaffID=78	Ghent University	Food Safety Management Systems
Jevšnik, Mojca	(Likar & Jevšnik, 2006a; Ovca & Jevšnik, 2009)	https://www.researchgate.net/profile/Mojca_Jevsnik	Faculty of Health Sciences, University of Ljubljana, Slovenia	Agricultural Science, Food Science, Animal Science, Waste Management
Kaivosoja, J.	(Kaivosoja, Jackenkroll, Linkolehto, Weis, & Gerhards, 2014; Pesonen et al., 2014)	https://www.luke.fi/en/personnel/jere-kaivosoja/	Natural Resources Institute Finland (Luke)	precision agriculture, automation system for plant production, automatic steering, farm information management
Kaloxylos, Alexandros	(Barmpounakis et al., 2015; Kaloxylos et al., 2012, 2013, 2014)	http://users.uop.gr/~kaloxyl/	Department of Telecommunications Science and Technology, University of Peloponnese	Specification, performance evaluation and implementation of protocols for wireless and mobile networks
Krüger, Antonio	(Krüger, Spassova, & Jung, 2010; Spassova, Schöning, Kahl, & Krüger, 2009)	http://www.dfki.de/~krueger/Antonio_Kruger/Welcome.html, http://www.innovative-retail.de/index.php?id=17	DFKI GmbH Saarland Informatics, Saarbrücken Germany	ubiquitous computing: personalized adaptive mobile, intelligent instrumented environments
Little, C.L. (Christine)	(Gormley, Little, Grant, de Pinna, & McLauchlin, 2010; Little, Amar, Awofisayo, & Grant, 2012; Little, Barrett, McLauchlin, & Grant, 2007)	http://www.labome.org/expert/uk/health/little/christine-little-339784.html	Gastrointestinal, Emerging and Zoonotic Infections, Health Protection Agency, Centre for Infections, London	Microbiological safety of food
Luo, Suhuai	(B. Li, Hathaipontaluk, & Luo, 2009; Luo, Xia, Gao, Jin, & Athauda, 2008)	https://www.newcastle.edu.au/profile/suhuai-luo	University of Newcastle, Australia	Health informatics

Mena, Carlos	(Mena, Adenso-Diaz, & Yurt, 2011; Mena, Terry, Williams, & Ellram, 2014a)	http://www.cranfield.ac.uk/About/People-and-Resources/academic-profiles/som-ac-profile/dr-carlos-ch-mena-madrazo	Cranfield School of Management	Supply Chain and Logistics Management, Agrifood
Morales, Augusto	(Gonzalez-Miranda et al., 2013; Robles et al., 2014)	http://gisai.dit.upm.es/index.php/projects?view=member&task=show&id=1	Universidad Politécnica de Madrid	Seems most interested in mobile services and 'Future Internet'
Piramuthu, Selwyn	(Grunow & Piramuthu, 2013a; Piramuthu et al., 2013; Piramuthu & Zhou, 2013; Urien & Piramuthu, 2013; W. Zhou & Piramuthu, 2015a, 2015b)	http://warrington.ufl.edu/contact/profile.asp?WEBID=2049	Information Systems and Operations Management, University of Florida, Gainesville, Florida	RFID & sensor network automation in the food industry
Poppe, K.J.	(Eiff, Selnes, & Poppe, 2015; Moreddu & Poppe, 2013; Poppe, Wolfert, Verdouw, & Verwaart, 2013; Poppe, Wolfert, & Verdouw, 2013; van Galen & Poppe, 2013; Verdouw, Beulens, Poppe, Robbemond, & Wolfert, 2014a, 2014b)	https://www.wageningenur.nl/en/Persons/drs.-KJ-Krijn-Poppe.htm	Wageningen, 'S-Gravenhag, NL	accounting, agribusiness, farming systems, financial management, economics, informatics
Robles, Tomas	(Gonzalez-Miranda et al., 2013; Robles et al., 2014)	http://gisai.dit.upm.es/index.php/component/jresearch/?view=member&task=show&id=3	Universidad Politécnica de Madrid	'Future Internet', amongst other interests

Saguy, I. Sam	(Saguy et al., 2013; Sam Saguy, 2015)	http://departments.agri.huji.ac.il/biochemfoodsci722/teachers/saguy_sam/	Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem	Consumer research, food frying, dehydration and rehydration, shelf‐life prediction, heat processing, aseptic packaging and processing, technology assessment, implementation of food engineering and processing, optimization of fermentation processes.
Schiefer, Gerhard	(Fritz & Schiefer, 2009; Lehmann, Reiche, & Schiefer, 2012; Reiche, Lehmann, Schiefer, & und Informationsmanagement, 2012; Schiefer, 2004)	https://www.foodchain.uni-bonn.de/team/schiefer	Chair of the Research Group 'Food Chain Management', University of Bonn	Business and Chain Management, Organization, Information Management
Solanki, Monika	(Solanki & Brewster, 2014; Solanki, 2009)	http://users.ox.ac.uk/~coml0597/	Department of Computer Science University of Oxford Oxford, United Kingdom	Semantic web, Supply chains, The agri-food industry, Plant biology
Sundmaeker, Harald	(Brewster et al., 2012; Kaloxylos et al., 2013; Sundmaeker & Einramhof, 2015; Verdouw, Sundmaeker, Meyer, Wolfert, & Verhoosel, 2013; Verdouw, Vucic, Sundmaeker, & Beulens, 2013; Vermesan et al., 2009)	https://www.atb-bremen.de/index.php?id=65&L=1	ATB Institute for Applied Sciences, Bremen, Germany	Has an interest in Future Internet and food, although not specifically IoT and food

Verdouw, C. N.	(Poppe, Wolfert, Verdouw, et al., 2013; Poppe, Wolfert, & Verdouw, 2013; Verdouw et al., 2014a, 2014b; Verdouw, Wolfert, Beulens, & Rialland, 2016; Verdouw, Robbemond, Verwaart, Wolfert, & Beulens, 2015; Verdouw, Robbemond, & Wolfert, 2015; Verdouw, Sundmaeker, et al., 2013; Verdouw, Vucic, et al., 2013; Wolfert, Verdouw, Verloop, & Beulens, 2010)(Poppe, Wolfert, Verdouw, et al., 2013; Poppe, Wolfert, & Verdouw, 2013; Verdouw et al., 2014a, 2014b, 2016; Verdouw, Robbemond, Verwaart, et al., 2015; Verdouw, Robbemond, & Wolfert, 2015; Verdouw, Sundmaeker, et al., 2013; Verdouw, Vucic, et al., 2013; Wolfert et al., 2010)	https://www.wageningenur.nl/en/Persons/Cor-Verdouw.htm	Wageningen University, Netherlands	Agricultural supply chains
Wang, Junyu	(W. Han et al., 2015; Yi Liu et al., 2014)	http://autoidlab.fudan.edu.cn/r_junyuwang.html	Auto-ID lab at Fudan University, China	Anti-counterfeit solutions, tracking and tracing system for food/drug safety, RFID authentication protocols, anti-collision algorithms, implantable sensor tags

Wolfert, J (Sjaak)	(Barmpounakis et al., 2015; Brewster et al., 2012; Kaloxylos et al., 2012, 2013, 2014; Poppe, Wolfert, Verdouw, et al., 2013; Poppe, Wolfert, & Verdouw, 2013; Verdouw et al., 2014a, 2014b, 2016; Verdouw, Robbemond, Verwaart, et al., 2015; Verdouw, Robbemond, & Wolfert, 2015; Verdouw, Sundmaeker, et al., 2013; Wolfert, Goense, & Sorensen, 2014; Wolfert et al., 2010)	https://www.vcard.wur.nl/Views/Profile/View.aspx?id=2634	LEI Wageningen UR, Wageningen, NL	Crop Ecophysiology
Xu, Li Da	(Chi, Yan, Zhang, Pang, & Xu, 2014; Whitmore, Agarwal, & Da Xu, 2015; L. Da Xu, He, & Li, 2014)	http://dblp.uni-trier.de/pers/hd/d/Da:Xu_Li	Department of Information Technology and Decision Science, Old Dominion University, Norfolk, USA 2352	Sensor data collection of industrial wireless sensor networks (WSN) in IoT environments
Zaslavsky, Arkady	(Jayaraman et al., 2015; Medvedev, Zaslavsky, Khoruzhnikov, & Grudinin, 2015; Perera, Zaslavsky, Christen, et al., 2014; Perera, Zaslavsky, Liu, et al., 2014; Zaslavsky et al., 2012)			
Zhang, Lei	(Yanan Li, Peng, Zhang, Wei, & Li, 2015; L. Zhang & Zhu, 2015)			

Zhang, Qiannan	(S. Yan et al., 2012; Q. N. Zhang, Huang, Zhu, & Qiu, 2013)		Shanghai Jiao Tong University, Shanghai	-
Zheng, Li-Rong	(Yun Gu et al., 2012; W. Han et al., 2014; Yi Liu et al., 2014; Pang et al., 2015; Zou, Chen, Uysal, & Zheng, 2014)(W. Han et al., 2015)	http://www.it.fudan.edu.cn/en/show.aspx?info_lb=25&info_id=78&flag=5 https://www.kth.se/en/ict/forskning/professorer/li-rong-zheng-1.283888	Fudan University, Shanghai	Publications suggest a recent interest in wireless sensors, RFID, food (specifically; logistics, intelligent packaging & supply chain management), agriculture and particularly healthcare

10) Appendix B: Initial Search

a) Search strategy

For the initial phase of the survey a wide-ranging view of IoT and Food was take
limited this initial search to the years 2013-2015 because of the large number of
(journal, newspapers, reports and related documents) that the searches returne
closer inspection, were not really at the intersection of IoT and Food. In subsequ
of the research for the review we are searching earlier in fewer well-defined area

The initial search when pruned yielded circa 150 documents published since 20
were first sorted into 24 categories, some of which were combined and then gro
three headings: **Production, Distribution, and Care**, where the latter grouping
articles dealing with lifecycle (even though that word is used only rarely in the ar

Production

- Farm management
- Water management
- Intelligent packaging

We took the view that the 3 categories under this heading all related to the begi
food chain, although it is certainly arguable that *intelligent packaging* belongs wi
'Distribution'.

Distribution

- Supply chain basics
- Systems
- Specific foods
- Logistics
- Refrigeration
- Intelligent shelf systems
- Automatic ordering
- Personalised grocery services
- Connecting consumers

We took the view that the 8 categories under this heading related to supply chai
There is a lot of overlap between supply chain management and traceability, so
the two categories.

Care

- Benefits of IoT in food and Agriculture
- Health/Nutrition
- Control of spoilage
- Waste management
- Lifecycle monitoring
- Specific applications

Each group was then analyzed to prepare the digest presented in the following s
full list of articles obtained at this stage is given in the table of references and ar
a Mendeley open group, which gives the full reference together with the abstrac

b) Digest of search results

i) Farm management

The survey results include 11 articles about “smart farms” and the use of IoT as the basis for intelligent management of farm production.

One article from India (Kirubakaran, 2014) talks about monitoring factors such as humidity, water level, temperature and *human machination* (“reduce or eliminate the need of human labor.” – the agricultural workforce can rest easy, though, this is one of the system design papers.) In (Misra, Simmhan, & Warrior, 2015), smart agriculture is one of the use cases in an analysis of different domains that can potentially benefit from an IoT infrastructure. Section 2.3 is primarily concerned with water management and control of micro-irrigation systems. Other articles deal with granary storage (Peng & Yindi, 2013) (R. Tao, Yang, Tan, & Zhang, 2014), livestock, vegetable cultivation, specifically tomatoes (sic), organic tea (ZHANG & SHEN, 2013), edible fungus (mushrooms, presumably) (L. Y. Zhang, Zhang, Zhang, & Yuan, 2013), and aquaculture (Bo; Yan & Ping, 2014) (Y. Yang & Fang-Tsou, 2014). The livestock article is a ‘real’ system that uses an “ontology-enabled architecture” (K. Taylor et al., 2013), but the vegetable paper is a database design (N. Lin & Yu, 2013). Of all ca.150 articles, only 3 refer to “precision agriculture”. Article (Ye, Chen, Liu, & Fang, 2013) provides architecture diagrams and design detail, but regrettably devotes just one short and self-congratulatory paragraph to the application at the study site. We deal with the other two articles under the ‘Care’ heading.

ii) Water management

Although article (Robles et al., 2014), which is from Spain, refers to ‘food production’ just once and only proposes a water management model, it does appear to cover all aspects of water management. Water saving is the subject of two other articles (O’brien, Jeffery, 2012; Z. Zhang, Yu, Wu, & Han, 2015)the former focussing on underground sensor networks and the latter on sensor deployment in vineyards. Intelligent irrigation is the subject of (Qingsheng et al., 2014).

iii) Intelligent packaging

The Department of Agrotechnology and Food Sciences, Wageningen University, the Netherlands is the source of a **review** of the role of intelligent packaging in supply chain management (11 pages) (Heising, Dekker, Bartels, & Van Boekel, 2014). The **review** from the Department of Food Safety and Food Quality, Ghent University, Belgium provides considerably more technical and technological detail (16 pages, 57 references) (Vanderroost, Ragaert, Devlieghere, & De Meulenaer, 2014). Even with comparing it to the two reviews, the Forbes article (Wilder, 2015b) seems superficial.

iv) Supply chain basics, including 3 reviews

Review (Badia-Melis, Mishra, & Ruiz-Garcia, 2015) was published in 2015, is from Spain, and is more wide-ranging than its abstract might suggest; it also has a long list of references. Review (Dongting; Wang, Rao, & Ying, 2014), published in 2014, covers agricultural product traceability systems across the world, and the abstract cites a range of relevant publications. The full text is not readily available but if a subsequent deeper analysis of the Chinese literature is undertaken then this will provide a good basis for the investigation. Although article (S. Xu, Yinsheng, & Hongpeng, 2014) says that the authors have reviewed supply chain information systems research with regard to domestic agricultural products, the second half of the abstract is about broiler chicken. The full text is not readily available and looks to be in Chinese, so this report is of limited value.

Five of the articles address the basic supply chain structure and the potential for IoT to improvement control and risk assessment. Basic issues are the focus for these five papers, but they are by no means the only ones to cover the more general aspects. After stressing the opportunity for supply chain management in China, Zhang (F. Zhang, 2013a) observes: “At present, there is still a big gap between theoretical research and practical applications, Especially in China, most of the literature of the IOT still remain in the introduction of the IOT itself and its application” and concludes with “the road is tortuous.” Of the other articles, two are available as PDFs (Ha, Song, Chung, Lee, & Park, 2014) (Ludena & Ahrary, 2016; F. Zhang, 2013b)[39, 154 but the other two have abstracts only. One (YAN, SHI, & DING, 2014) deals particularly with risk assessment, and is reasonable detailed, but (G. Zhang, 2014) gives little useful information.

v) Systems

Most of the articles about traceability systems propose architectures, but it’s not always easy to see how far they have gone towards implementing their ideas, although the factors that the authors take into account might be of some interest (Bai et al., 2013)(B. G. Zheng & Wang, 2014)(R.-Y. Chen, 2015)(Hou & Zhu, 2012)(Yanfei Liu, Peng, & Peng, 2013)(Min-Ning, Li, Yong-Heng, & Feng, 2014)(B. Xu, Li, & Wang, 2013)(Q. N. Zhang et al., 2013)(Y. J. Zhang & Chen, 2014). One paper (T. Xing, 2014) appears to be a fairly comprehensive requirements analysis. Some do provide implementation detail and discuss specific use cases (Brizzi, Conzon, & Pramudianto, 2013; Furdik et al., 2016)(F. J. Xu, Zhao, Shan, & Huang, 2014). One somewhat unusual article, unfortunately lacking a full text, describes an approach to visualising a “trajectory on circulation for agricultural products”, aiming to reduce visual overload by clustering original data points (L. Lin, Yu, & Li, 2015). A pilot project for managing stock levels on shelves is the subject of a well-illustrated, 19-page, paper from Parma, Italy (Bertolini, Ferretti, Vignali, & Volpi, 2013). The article that we believe is the only one to use the term “Internet of Agricultural Things” is about developing a quantitative model to describe the trustworthiness of foods delivered in supply chains (W. Han et al., 2014). It uses a Bayesian model to so that most of the parameters are set by the data rather than by human “experts”.

vi) Specific foods

The difficulty with discovering just how far authors have gone towards implementing their ideas is still apparent when specific foods are under consideration: China’s dairy industry (W. Han et al., 2014); supply chain and retail store monitoring (Thoma, Fiedler, Matting, Sperner, & Magerkurth, 2014); vegetables (Shilong, Shixi, Ya, & Ma, 2014)(F. Yang, 2014); wine in Brazil (Campos & Cugnasca, 2015); eggs [70](B. W. Liu, Wei, & Li, 2012); meat (Jia;, Yuan-jing;, & Ye, 2014) (Liang, Cao, Fan, Zhu, & Dai, 2015) (LUO, DUAN, & DA, 2013) (Meng, Cui, Wang, & Li, 2015)(H. Y. Zhang & Chen, 2013). Notably, article (LUO et al., 2013) proposes iris recognition for identifying individual large animals. In one case, dealing with aquatic products (specifically tilapia) (Bo Yan, Shi, & Huang, 2012), the abstract provides good evidence of implementation, but the full detail is not available (because the PDF is in Chinese). An intelligent container for shipping bananas is the subject of a simulation study from Bremen, Germany (Haass, Dittmer, Veigt, & Lütjen, 2015). Article (R. Z. Shi, Yang, Su, Zhou, & Shi, 2013) is about tracing individual food items, rather than types of food.

vii) Logistics

We have collected the following articles under this heading because they all refer in their abstract to IT solutions for logistics challenges in the context of food and agriculture. The more comprehensive studies, with full texts available, are the EU SmartAgriFood project (Verdouw, Sundmaeker, et al., 2013)(Verdouw, Vucic, et al., 2013) and the review of RFID and WSN technologies for “intelligent packaging and logistics for the fresh food tracking and monitoring service” published in Phil. Trans. Roy. Soc. (Zou et al., 2014). The logistics of food shipping by sea is the subject of article (Wei, Yang, Zhou, & Zheng, 2013), from China, but it does not give any results from an actual application. (C Jones, 2014) is in this context a rather superficial, single page, overview.

viii) Refrigeration

We have collected the following articles under this heading because they all refer specifically in their abstract to temperature monitoring and/or control. One paper from Taiwan, which proposes replacing semi-passive tags with passive tags to reduce the cost, contains considerable design detail but no real evidence of an actual application (Y. Y. Chen, Wang, & Jan, 2014). Only the abstract for (L. Z. Wu & Zhao, 2013) is available, and it has little useful detail. There are also three very general (and short) articles about the potential impact of IoT on commercial refrigeration (Kaneshige, 2015a)(Kaneshige, 2015b)(Vanderpool, 2015).

ix) Intelligent shelf systems

We have collected the following articles under this heading because they all refer specifically in their abstract to monitoring shelf life but these do not have much useful detail though there is an emphasis on real-time data (H.-F. Zhang & Zhou, 2013)(B. W. Liu et al., 2012)(M. Z. Wu, Wang, & Liao, 2013).

x) Automatic ordering

Obtaining groceries from Amazon is apparently coming to the UK, with the added “attraction” of a Dash button for instant ordering (Gibbs, 2015). Only the abstract for is available, and it has little useful detail (Huang, 2014).

xi) Personalised grocery services

A Spanish group have developed a pilot for linking product information with consumer preferences, as part of the EU SmartAgriFood project. They obtained feedback from a panel of consumers through a series of workshops (Gonzalez-Miranda et al., 2013).

xii) Connecting consumers

The two projects covered under this heading are both funded as part of the Digital Economy programme. A team from Lancaster University have teamed up with a coffee and tea merchant, with the aim of reconnecting consumers with the history and the business and with the production and retail of food (coffee in particular) (Edwards, Mullagh, Dean, & Blair, 2013). The Aberdeen team have investigated the issues that prevent rural food and drink SMEs from expansion, based on qualitative user-engagement studies, leading them to develop an IoT-based platform to improving the visibility of the food supply chain by using QR codes generated by the producers (van der Loo et al., 2015).

xiii) Benefits of IoT in food and agriculture

The article (Xiong, Yang, Yang, & Pan, 2015) is a review of IoT applications in animal husbandry in China, referring to three aspects of livestock breeding and management in a lengthy abstract, indicating that they are discussing real implementations. In 2015 Beecham Research produced a report that “focuses on the worldwide adoption of the Internet of Things in smart or connected farms within the agriculture industry sector.” The full report costs over GBP1700, but we have downloaded the impressive Executive Summary (Beecham, 2014).

There is then a set of articles covering applications of IoT in food and agriculture from a general perspective, usually (but not always) without specific exemplars. We have collected them here for their generality, even though on closer inspection some of then could probably be categorised elsewhere. Several web pages carry reports or discussions [on a meeting to introduce the EU projects on Agriculture 4.0 and the role of IoT, regulation (Foley, 2015)(Gilpin, 2015)(Thomas, 2015) (Z. Wu, Li, Yu, & Wu, 2015). Of this set, some are of limited use, (Y. P. Duan, Zhao, & Tian, 2014). (P. Wang, Valerdi, Zhou, & Li, 2015) is a special issue on the advances in IoT research and applications of which 3 articles are relevant to agriculture and the food with an emphasis on trust and pedigree (W. Han et al., 2015, 2014; Whitmore et al., 2015). There are also three Guardian articles that discuss the use of smart devices in the kitchen (Kobie, 2015a, 2015b, 2015c).

Four articles focus on financial benefits: poverty reduction in rural areas of South Africa and Zambia (Dlodlo & Kalezhi, 2015); future productivity growth (Dobbs, Manyika, & Woetzel, 2015; Manyika et al., 2015); protection and management of "tourism food" (Q. Chen, Ma, Li, Journal, & Science, 2015); and a proposal for a "value-centric business-technology joint design framework" (though the full meaning is not that clear) (Pang et al., 2015), all suggesting that technology can improve agricultural production and that reduce poverty.

Five articles relate to technology aspects of food research: shelf-life estimation for new food products (Wilusz, Flotyński, & Sielicka, 2013); a rather theoretical advocacy of physics-based rather than empirical modelling in food engineering (Sam Saguy, 2015) (c.60 references) following a related paper (Saguy et al., 2013); the programme for a 2011 symposium entitled "Urban food futures: ICTs and opportunities" [23](J. H. jeong Choi & Graham, 2014); a proposed "vertical farm ontology", in which IoT information is recomposed as context information [99(Sivamani, Bae, & Cho, 2013)]; and an abstract only, arguing that precision agriculture is a technology of the past, so it would be better to use IoT to support biodiversity and other natural resources, such as water: sustainability [58](Kidd, 2012).

Unsurprising, there are a few articles of a general nature that do not really fit any category: team building for digital agriculture applications (relevance questionable) (Shui-juan, Wen-wen, Yong, & Ming-wei, 2013) an Agricultural Sightseeing System, using examples from the Modern Agriculture Exhibition Center of Hubei (B. Chen, 2014); food image recognition (implementation detail but not really about IoT) (P. Duan et al., 2013; Farinella, Allegra, Moltisanti, et al., 2015); and post-earthquake demand management (mentions food once) (L. Xing, Zhang, Wu, & Xie, 2015).

xiv) Health/nutrition purposes

There is one review in this section, dealing with "food ontologies", together with other relevant non-food ontologies (e.g., about diet-sensitive disease conditions), and how they can supplement the cloud-based lookup databases (e.g., food item barcodes, previously identified food images, etc.) The objective is to enable progression from the mere automated identification of food and drinks in our meals to a more useful application whereby we can automatically reason with the identified food and drink items and their details to assist users in making the correct, healthy food and drink choices for their particular health condition (Boulos, Yassine, Shirmohammadi, Namahoot, & Brückner, 2015) (21 pages). The article (Reitberger et al., 2014) reports a four-week field study in eight households, which involved showing a household's collective food consumption patterns via situated displays in the home and through mobile devices in-store. The authors say that their approach showed the potential to foster reflection about shopping and nutritional choices and for integration with people's everyday practices. The article (Vazquez-Briseno, Navarro-Cota, Nieto-Hipolito, Jimenez-Garcia, & Sanchez-Lopez, 2012) proposes a mobile health platform intended to increase children's health awareness, by tracking their food intake and sending notifications and messages based on food choices.

There are two articles in this section relating to a diet monitoring system based on IoT (X. Xing, Liu, Zhang, Su, & Zhang, 2013)]; and adjusting nutritional components with regard to health care and to match dietary needs (Wei et al., 2013) which discuss technical possibilities and some realistic limitations**.** Article (Lee, Lee, Seo, & Kim, 2015) describes a smart bottle to monitor and improve water intake for older people, so not strictly about food, but a related application of IoT but a clear application to a serious health issues and indicative of an important target group.

xv) Control of spoilage

With regard to detecting contamination, a comprehensive survey of spectrometry and spectroscopy based approaches to detecting food fraud and contamination is provided in article (Ellis, Muhamadali, Haughey, Elliott, & Goodacre, 2015). The Article (abstract only) ("HighBeam Research," 2014) states that the paper "mentions that the development of rapid chemical and microbiological testing methods using biosensors could soon make it possible to detect contamination in products directly." Cross-contamination in the food supply chain is the subject of a simulation study (S. Yan et al., 2012).

Two of the articles relating to disease prevention and pest management have only short abstracts: environment control system for raising disease-free livestock and poultry (Cheng, Ma, & Liang, 2014); and a comparison and analysis of the mainstream technology for pest and disease warning (Dengwei Wang, Chen, & Dong, 2014) which may merit further study. The article (Y. Shi, Wang, Wang, & Zhang, 2015) discusses a long-distance monitoring system for collecting disease and insect pest information, but the full text addresses architecture diagrams, which might not yet be implemented.

The two articles that deal with pesticide residue detection both base their system on the acetylcholinesterase biosensor (G. Zhao, Guo, Sun, & Wang, 2015; G. Zhao, Sun, & Wang, 2015), which is an example of the type of sensor that could in the future be networked via IoT systems.

xvi) Waste management

Two of the six articles are about recycling: a review, involving ethnographic research, looking at an infrastructure for a sustainable composting community of practice, aiming to improve efficiency and keep nutrients within the soil (Pasquini, Miller, Moynihan, & Mcleod, 2014); and a one-page discussion of organic waste digestion with a device called Orca (Mccourt, Dym, & Simmons, 2015).

The article (Amores, Maes, & Paradiso, 2015) is a conference paper from MIT Media Lab, describing a prototype self-contained gas detector that analyses organic trash odour compounds and releases subtle burst of scent when bad odour is detected. The development of a mechanism for avoiding major fire accidents in garbage dumps is the subject of article (P. Ponmalar & V. Sampath Kumar, 2014). It contains several architecture diagrams, as does article (Hong et al., 2014), which is about a smart garbage system, in which battery-based smart garbage bins exchange information with each other using wireless mesh networks. Unlike the former article, this one has clearly been run as a pilot project in Seoul. An analysis of IoT in the management of solid waste: municipal, medical, hazardous, electrical and electronic is presented in (R. C. Song, Sun, Zheng, Hu, & Li, 2015).

xvii) Lifecycle monitoring

An analysis from Australia of IT requirements for "digital agriculture" is possibly the most thorough study in this section (Jayaraman et al., 2015). It proposes an architecture based on the EU FP7 OpenIoT project and is well illustrated. A short but wide-ranging article in Food Safety News deals with areas of impact for IoT (Andrews, 2015b).

There is no shortage of architectures, models, and proposals: architecture to track and trace agriculture from the field through the supply chain and in food processing environments (notable for its illustration of food supply chains) (X. Zhao, Fan, Zhu, Fu, & Fu, 2015); food safety supply chain traceability management system (K. Liu, 2015); monitoring system (Ying & Fengquan, 2013); IoT name service for agricultural product supply chain management (Yi Liu et al., 2014); food security information platform (Yanan Li et al., 2015; L. Zhang & Zhu, 2015); pedigree system for food safety (Yun Gu et al., 2012; W. Han et al., 2015); smart sensor data collection strategy for IoT; would improve the efficiency and accuracy of provenance of food (Q. N. Zhang et al., 2013).

The article (Qiu, Xiao, & Zhou, 2013) presents a framework for monitoring and controlling a range of environmental conditions, with a case study in Shanghai. Article (X. Zheng & Cheng, 2015) focuses on lighting control, implying in its conclusion that they are still looking for a food enterprise in which to test their system. Few environments are as controlled as a clean room, so Fujitsu is growing lettuce in a sterile facility once used to manufacture chips, with the help of sensors and cloud computing ("Fresh from the clean room, leafy Fujitsu lettuce," 2014).

Two articles specifically address greenhouse monitoring: in Vietnam, with technical detail but little evidence of putting into practice (Thu Ngo Quynh, Nien Le Manh, & Khoi Nguyen Nguyen, 2015); a mathematical model of IoT capacity, with regard to bandwidth, network delays, packet loss, and power consumption (B. G. Zheng, 2013).

Two articles discuss data collection on food product over the lifecycle: an 11-page overview from Romania, which claims to highlight the advantages of integrating technologies and digital standards for protecting consumer rights, but is actually about food production and safety (DOINEA, BOJA, BATAGAN, TOMA, & POPA, 2015); a system for tracking the lifecycle of vegetables, leading to improved efficiency and reduced costs (Ji, Zhang, Dong, & You, 2013). The abstract says that results show a significant effect, but the full text we had available was incomplete.

xviii) Specific applications

Article (Xie, Yin, Lu, Sheng, & Lu, 2013) is about aspects of managing food in "smart fridges": iFridge comprises an ordinary fridge, an RFID system, and a tablet PC. Four newspaper and magazine articles discuss "smart fridges" and the application of IoT to other kitchen gadgets (Kobie, 2015a)(Gould, n.d.; Steiner, 2012; Wolf, 2014).

Three applications can lay claim to being unique: an intelligent cooking robot, which can automatically complete cooking procedures such as heating, stir-frying, seasoning, and feeding; experimental results show that the cooking robot can cook most Chinese cuisines and is easy to operate (H. Zhao, Hao, Wang, & Li, 2015) in an intelligent oven (B. Li et al., 2009); a mobile electronic nose instrument for the detection of beef quality (Wijaya & Sarno, 2015); and food ordering by tablet ("Shared Goal: Happier Diner," 2015).

11) Appendix C: Second Search

a) Search strategy

We extended the search to look specifically at Precision agriculture and the use of IoT like systems (for example sensor networks and farm information management systems) and to cover to the detailed decision making and control of farming and agriculture with a view tp the provenance and quality control.

b) Digest of results

The 48 articles resulting from the second search were grouped under the following seven headings, with summaries of the content of the papers:

- Use of precision agriculture data to inform practices and decisions
- Measuring and monitoring soil characteristics and usage
- Environmental considerations
- Software architectures and applications
- Specific crops, resources, and other produce
- Macro-scale studies
- Effect of technology on information communication

The last group could be regarded as a separate search area, given that the articles were primarily about communication rather than the agriculture data itself.

i) Use of precision agriculture data to inform practices and decisions

Farm Industry News article (Hest, 2012) discusses farm data management systems, such as Prime Meridian[22], which enables farmers to store as well as share their data. Another News article includes tips and lessons, such as making prompt adjustments in the field, how to collect good data, store data securely, and hiring an expert (Birch, 2012).

Results from Brazil have shown that a mobile applications approach based on precision agriculture principles is capable of handling field observations to assist small farmers in automated detection of late blight, one of major disease affecting tomato plants in Brazil (da Cruz, Vieira, & Marques, 2015).

ii) Measuring and monitoring soil characteristics and usage.

In Australia, Landsat and MODIS surface reflectance data has been used, together with field observations, for measuring vegetation fractional cover, both in pastoral and agricultural settings, to monitor land management (Guerschman et al., 2015). Estimating fractional cover was the object of a model simulating the transfer of tritium from the atmosphere to soil–plant systems, tested following an accidental release (Le Dizès, Aulagnier, Henner, & Simon-Cornu, 2013).

Potential environmental and economic benefits that can be generated by implementing site-specific topography-driven cover crop management in row-crop agricultural systems, particularly supplying adequate amounts of soil Nitrogen for plant growth is discussed in (Ladoni, Kravchenko, & Robertson, 2015).

Efficient soil characterization, based on measuring soil organic carbon change, comes from collecting soil data in situ, thus minimizing soil sample transportation, processing, and lab-based measurement costs. Article (“Big Sky Partnership,” 2011; Lee Spangler, Ross Bricklemyer, & David Brown, 2012) describes an evaluation of two spectroscopic techniques

[22] http://www.primemeridiandata.com

that have the potential to meet the need. The article also talks about a data model for soil characterisation.

Article (Rivers, Weaver, Smettem, & Davies, 2013) is about a model to illustrate watershed Phosphorus flux and to predict future Phosphorus loss, using parameters sourced from extensive surveys of local agricultural practices and regional soil testing data in SW Australia.

iii) Environmental considerations

Five of the articles report work that relates food production to environmental issues:

A survey carried out to understand the contributions of dairy practices to greenhouse gas emissions by collecting complex farm level data (Popp et al., 2013).

The use of a wireless sensor network (WSN) to look at both energy consumption and the energy efficiency of the data collection approaches in terms of the energy conservation techniques adopted (Abdul-Salaam, Abdullah, Anisi, Gani, & Alelaiwi, 2015).

A real-time soil sensor and several comprehensive field surveys used to investigate carbon sequestration through agricultural soil, specifically paddy fields (You Li, Shibusawa, & Kodaira, 2013).

A multistate, transdisciplinary project to study the potential for both mitigation and adaptation of corn-based cropping systems to climate variations. The team is measuring the baseline as well as change of the system's carbon (C), nitrogen (N), and water footprints, crop productivity, and pest pressure in response to existing and novel production practices (Kladivko et al., 2014).

Peripheral, but included for completeness, an examination of the influence of mining operations on community health (Caxaj, Berman, Varcoe, Ray, & Restoulec, 2014).

iv) Software architectures and applications

Of the ten articles in this group, four deal with applications from a general perspective:

For industrial and academic food researchers to benefit from each other’s data, models and experimental knowledge, the exchange of both general and more specific food knowledge provides a basis for ontologies (Koenderink, Hulzebos, Rijgersberg, & Top, 2005).

The article by (Ktori, 2014) examines the application of informatics in the agricultural sector. It notes that agricultural organisations are aware of the need for a comprehensive platform which extends to the considerations that Informatics has a role in dealing with big data, which must be analysed to support risk assessment, prevention, and mitigation to optimize food safety outcomes (Armbruster & Macdonell, 2014).

The article (Steele, 2013) discusses the technological underpinnings, analyses the implications and applications of increasing digitisation of food-related information, and identifies seven priority directions to advance informatics-based systems for achieving an integrated ‘paddock to plate’ food supply system.

The remaining six articles in this group deal with specific applications and technological approaches:

Article (T. Li et al., 2012) describes an architecture said to have three distinctive features, of which the most important from a user perspective would seem to be the data-flow-driven subsystem in which a user can define his/her own data processing workflows to analyse precision agriculture data. The tool has been successfully used in a project on canopy management for specialty crops, sponsored by the US Dept. of Agriculture.

An agricultural information service platform, called FieldTouch, is being built and tested on geospatial data infrastructure and crop modeling framework. More than 100 farmers in Hokkaido, Japan, have been participating on this development and are utilizing the services for optimizing their daily agricultural practices (Honda et al., 2014). The article (Roussey, Chanet, Cellier, & Amarger, 2013) describes an ontology module for the observation of pest attacks in crop production and in a way related to this food safety informatics can be used as a technological tool to protect consumers, in real-time, against foodborne illnesses(Tucker, Larkin, & Akers, 2011).

The article (Gul, Mutlu, & Bal, 2004) presents a mobile based Farmers' Advisory Information System: farmers need access to agricultural information and knowledge in timely, complete and quality manner which can be contrasted with a study has determined the level of information technology use, perceptions and the future e-commerce plans of food companies in Cukurova Region of Turkey (Gul et al., 2004).

v) Specific crops, resources, and other produce

Enabling the management of tea croplands and cropping assessment, using a geo-spatial data model for land use planning and consumption management (Ozcelik & Nisanci, 2015).

Improving the understanding of production methods, crop and fish yields, and profitability of commercial aquaponics in the United States and internationally, potentially enhancing commercial operations (Love et al., 2015).

Surveying the potential of natural resources that have comparative advantage, and determining the growth centres for building and accelerating agribusiness development (Darmansyah, Rochana, Sutardi, & Zuraida, 2014).

Investigating the environmental sustainability and competitiveness perceptions of small livestock farmers in a region in northern Brazil, aiming to foster effective sustainable development policies (Nunes, Bennett, & Marques, 2014).

Developing a small scale precision farming approach where fast soil moisture sensing via wireless sensor networks provides a low-cost, low-power option to reduce the potential for water induced plant stresses and increase yields (Zeni et al., 2015).

vi) Macro-scale studies

Optimizing industrial structure in agriculture as an important way to promote energy efficiency and increase farmers' income in Western China (Pan, Liu, & Gao, 2015).

Using mathematical programming to obtain the optimal crop mix and resources needed to maximize output and provide the families in Burundi farm households with food containing sufficient energy, fat, and protein (Niragira et al., 2015).

Mapping the land use of local communities, which is critical to resource planning, by combining participatory mapping methods with satellite image interpretation and GPS data collection (Nackoney, Rybock, Dupain, & Facheux, 2013) (Jiao et al., 2014).

vii) Effect of technology on information communication

As indicated previously, the content of the articles in this group is primarily about communication rather than the agriculture data itself.

Reviewing the impact of information and communication technologies on agricultural development in developing countries. Although there remains a wide gap in access between rural and urban areas, the spread of mobile phones in rural areas has led to important changes in the agricultural sector (Nakasone, Torero, & Minten, 2014). Results indicate that improved access to market information through mobile phone use is associated with an increase in the selling price of rice in Cambodia (Shimamoto, Yamada, & Gummert, 2015).

Examining the impact of information and communication technologies (mobile phones and radios) on market participation in developing country agricultural markets using a novel transaction-level data set of Ghanaian and examining the impact of the recent massive penetration of mobile phones and radios, in developing countries to investigate the role of information in economic transactions and participation in food crop markets farmers (Zanello, Srinivasan, & Shankar, 2014; Zanello, 2012).

Making farmers in developing countries more informed about market opportunities as an important step toward development of the agricultural sector and increasing individual farmers' income. In Bangladesh, what is still lacking is the useful services adapted to the rural usage patterns and social context (Islam & Grönlund, 2011).

Examining the potential of recent mobile technology trend to enhance the functions and reach of m-services, with a focus on promoting agricultural development among smallholder farmers (Baumüller, 2013).

Examining the use of ICT tools and ICT-based services by rural grain traders in Kenya. The implications are that market development agents must focus on removing constraints limiting the use of ICT tools in rural areas (Okello, 2011). More specifically examining the awareness and use of mobile phones for smallholder farmers in Kenya. In many developing countries smallholder farmer participation in agricultural input and output markets continues to be constrained by lack of market information (Okello, Okello, & Ofwona-Adera, n.d.).

Providing market price information to rural farmers and cooperatives through mobile phones, a Rwandan Ministry of Agriculture project (Vrakas, 2012) and the related reporting on ways mobile phones are helping farmers in developing countries, for example, weather forecasting service (Bennett, 2012) and extending to marketing of produce using a novel SMS-based double auction mechanism that has been designed for farmers in Uganda (Ssekibuule, Quinn, & Leyton-Brown, 2013). Investigating agricultural experts' perceptions of barriers toward implementation of mobile marketing programs, as accessible and transparent markets are necessary to raise income and improve livelihood of farmers (Najafabadi, 2012). Using mobile phones in e-agriculture, with examples of sustainable e-services which are already, or have the potential to deliver benefit over the medium to long term, and policy and strategy implications (Cranston & Painting, 2010).

Article (Kikulwe, Fischer, & Qaim, 2014) while it is not specifically about mobiles for access to market info, but results suggest that mobile money can help to overcome some of the important market access constraints of smallholder farmers. This extends to for example exploring the roles of motorized transport and mobile phones in the diffusion of agricultural information within and between Indonesian farming communities (Matous, Todo, & Pratiwi, 2015).

12) Appendix D: Third Search

a) Search Strategy

Following the initial analysis of the first two searches, where the literature was largely from the period 2012-15, we used these papers as a basis for searching back to earlier years for relevant papers, using cited and cited by references, and related papers in special issues and conference proceedings. This search contains a significant proportion of slightly older literature as well as some parallel topics that arose from links to the publications located in the first two surveys.

b) Digest

i) Farm management

Kaloxylos et al report the architecture and implementation of Fi-WARE, a cloud-based farm management system (FMS) that was developed in the context of the SmartAgriFood project (Kaloxylos et al., 2014), having previously discussed their vision in two articles (Kaloxylos et al., 2012, 2013), although only the former is cited in the 2014 paper. The substance of their report is *an instantiation of the FMS architecture that has been developed and used for the management of a greenhouse. The Greenhouse Pilot has been deployed in an actual greenhouse in Crete (Local FMS) and within the University of Athens premises (Cloud FMS)*. Curiously, their conclusions do not mention the pilot, but refer rather to *a marketplace of services and applications that can be used by farmers*.

ii) Supply chain basics (including Traceability)

One general discussion paper relates the supply chain model to sustainable patterns of food behaviour (Cesaretti, Angelis, Misso, & Shakir, 2015).

As we noted in the digest of the initial search, several articles propose architectures and models based on IoT, commonly with cursory mentions of food applications, but give little or no indication that the proposals have been tested in real practice (Huo & Xu, 2014)(L. Li, 2011)(Z. Z. Liu & Gong, 2014)(Thoma et al., 2014)(Zhu & Fu, 2015).

Two articles advocate the use of Semantic Web technologies and a linked data approach to supply chains. Brewster asserts that not much knowledge flows upstream, but producers need to understand consumers. Moreover, events in the supply chain can involve everyone (Brewster, 2012). Solanki examines linked pedigrees in a 29-page paper that includes a comprehensive requirements analysis, a plausible scenario, and comprehensive implementation detail (Solanki & Brewster, 2014).

Fritz and Schiefer consider the importance of tracking and tracing activities in supply chains. They summarise the decisions involved in a *cost-benefit decision table that provides a framework for future developments* (Fritz & Schiefer, 2009). We reviewed a further 11 papers dealing with the issue of traceability.

A 13-page Korean paper, undertaken from an academic perspective, looked at *whether reduced uncertainty provides benefits for producers and consumers, thereby warranting the adoption of the food traceability system* (Choe, Park, Chung, & Moon, 2009). They noted that there had been few studies of consumer reaction to price premium or about the *sources of uncertainties and the mechanisms of uncertainty reduction through the Food Traceability System*. The conclusion states that *consumers were willing to buy more food and pay more for it when they used the traceability system*, but does also contain qualifying remarks.

Naturally, the articles covered in this survey include the usual crop of proposals, frameworks, and models with, at best, limited information about implementation (Bechini et al., 2005; Bing Jia, Yongjian Yang, Jia, & Yang, 2011; Ji et al., 2013; Maksimovic, Vujovi, & Omanovi, 2015; W. Zhou & Piramuthu, 2015a, 2015b).

Of the papers that do provide implementation detail: Cao et al describe a framework that uses the GS1 global traceability standard (Cao, Zheng, Zhu, & Wu, 2010); Furdik et al present a prototype, implemented as a pilot application of the FP7 Ebbits project (Furdik et al., 2016); Regattieri et al analyse the legal and regulatory aspects of food traceability and describe the system used by the cheese producer Parmigiano Reggiano (Regattieri, Gamberi, & Manzini, 2007); and a system based on the work of Sugahara is in use in farms and agricultural cooperatives around Japan (Sugahara, 2009).

The potential for mobiles to be used in food supply chain and traceability systems for consumers is achieving recognition: the need for a successor to barcodes (Dani, 2016); a Guardian article about enabling people to understand the food supply chain in simple terms, which notes their willingness to pay higher prices for a product that shares such information, and refers to the European 'RFID from Farm to Fork' project(Trebar, 2014); and tracking at point of sale (Zwingmann, 2012). QR codes are the basis for other developments: research by Michigan State University into a programme to allow smartphone identification of the exact animal and farm origin of beef(Parker, 2011); using mobile handheld devices to capture information of farming operations from QR codes (Y.-C. Liu & Gao, 2016).

Perhaps inevitably, traceability issues also arise in articles dealing with logistics, as discussed in the third paragraph of the Logistics section.

iii) Systems

The papers that focus on systems aspects include: an ontology for agriculture IoT, addressing the challenge of dealing with the semantic heterogeneity of multiple information resources (Hu, Wang, She, & Wang, 2011); an IoT name service for agriculture products (Yi Liu et al., 2014); and the extraction of semantic relations for the food domain (Wiegand, Roth, Lasarcyk, Koser, & Klakow, 2012). Wolfert and others, mostly from Wageningen University, provide the greatest detail, describing in one paper a service-oriented approach to information integration in agri-food (Wolfert et al., 2010), and in a more recent article, an examination of possible future internet applications in smart farming, with the aim of contributing to the global challenge of producing enough safe and healthy food for the future within planet Earth's carrying capacity (Wolfert et al., 2014).

One article describes an architecture for detecting security situations, but the does not seem to cover implementation (B. Song & Xing, 2011); another offers a design for an agriculture MIS, with an implementation example (Yan-E, 2011).

iv) Specific foods

Only one paper came into this category, a system for monitoring the pH and conductivity of the nutrient solution used in the hydroponic growth of lettuce (Domingues, Takahashi, Camara, & Nixdorf, 2012).

v) Logistics

Eiff et al report the results of an EU Standing Committee on Agricultural Research (SCAR) foresight exercise on how Agricultural Knowledge and Innovation Systems (AKIS) might develop towards 2050 (Eiff et al., 2015). Using three scenarios - High Tech, Self organisation, and Collapse - they considered how policy could anticipate future needs regarding the agricultural sector, food demand and supply. They use the results to address how to establish resilient institutions and organisations for future agriculture and food. They emphasise that *scenarios are not created to choose from, but to prepare for the situation that they might come true*, noting that *the scenarios will most likely not become history in exactly the way they have been described*. In the final paragraph they advocate *a much more informed discussion in Europe on the need for a real European Research Area and how it should look like and function*.

On a smaller scale, the *FOODIE (Farm-Oriented Open Data in Europe) project aims at building an open and interoperable agricultural specialized platform hub on the cloud for the management of spatial and non-spatial data relevant for farming production* (Charvat, 2014).

Four articles consider aspects of collaboration and interoperation (Aghazadeh, Seyedian, Cimino, Garguiolo, & Hart, 2006; Barmpounakis et al., 2015; Verdouw et al., 2014a, 2014b) Seven other articles discuss logistics information systems, platforms, and models from various perspectives, with (perhaps inevitable) overlap with traceability issues (Aung & Chang, 2014)(Yanan Li et al., 2015)(Lianguang, 2014)(Z. Z. Liu & Gong, 2014)(Verdouw, Robbemond, Verwaart, et al., 2015; Verdouw, Robbemond, & Wolfert, 2015)(Verdouw et al., 2016). In a review of food traceability, specifically from a safety and quality perspective [Aung2014], Aung and Chang adopt the following definition of food traceability:

> *Food traceability is defined as a part of logistics management that capture, store, and transmit adequate information about a food, feed, food-producing animal or substance at all stages in the food supply chain so that the product can be checked for safety and quality control, traced upward, and tracked downward at any time*.

Quoted from (Bosona & Gebresenbet, 2013).

In a paper that appears to adopt a logistics perspective without actually using that term, Gu et al analyse Chinese food standards and the key risks in the five main phases: production, processing, transportation, storage, and sale, then consider how IoT technologies might be used to mitigate the risks (Yun Gu et al., 2012).

Two articles adopt different frames of reference. Esposti examines *how digital devices and platforms are reshaping the way we eat and the way we socialize through food consumption practices*, while *also offering an opportunity of reducing food waste through a better organized logistic process, based upon traceability of almost everything in the globe* (Esposti, 2014). The paper also considers the merging of production and consumption as 'prosumption'. On a different scale - but possibly rather dated - is a paper about modelling of the impact of number of internet users on food trade between OECD countries (Bojnec & Ferto, 2010).

Four papers consider models and systems for tracking and tracing in supply chains (Fritz & Schiefer, 2009)(Solanki, 2009)(Urien & Piramuthu, 2013)(J. Wang & Min, 2013). Although Wang and Min said that they expected to be able to use the system they were developing by the end of 2013 to monitor more than 10 types of food, a Google search does not find any subsequent papers.

vi) Refrigeration

Two articles report research into consumer behaviour with regard to fridges, aiming to understand practices around domestic food waste (Farr-Wharton et al., 2014; Ganglbauer et al., 2013). Shih and Wang consider the manufacturers' choice between frozen storage and cool storage in delivering products to retailers or consumers. They propose a time-temperature system and critical control point (Shih & Wang, 2015). A recent showed that the chilled food sector is more willing to share time-temperature information than the frozen food sector (Hsiao & Huang, 2016). More information in this area is provided by the ITaaU Network FSA projects.

vii) Intelligent shelf systems

A 2010 paper reports research into personalised shopping assistants, intelligent shopping carts, recipe-based advice, and other ‘smart’ options (Krüger et al., 2010).

viii) Personalised grocery services

The two articles that came into this category are about a mobile food ordering system prototype (Kulkarni, Dascalu, & Harris, 2009) and intelligent shopping assistance (Spassova et al., 2009). Three other articles discuss aspects of tailoring apps: helping consumers to learn about and buy local goods (Bond, 2012); the differences between making shopping more convenient and making it more personal (Hamstra, 2012); enabling shoppers to scan items on shelves and trace their origin(Sixsmith, 2010)]. A fourth article offers advice about making the most of mobile retailing, with statistics about the consequences of not optimizing websites for mobile access (Ingram, 2016).

ix) Connecting consumers

This category includes a range of studies of consumer behaviour. Case studies in the online grocery sector suggest that the technologies used *positively encourage anti-choice* (de Kervenoael, Elms, & Hallsworth, 2014). Case studies and interviews examining the relationship between ICTs and ethical consumption find that the use of ICTs *has not significantly altered the way in which citizens engage with fair trade in the alternative or mainstream marketplace* (Lekakis, 2014). Vallauri describes a London community project, related to parallel work in Kenya, using ICTs to increase awareness and community participation in the production and consumption of locally grown food (Vallauri, 2014). Another investigation provided a qualitative dataset of respondents' sentiments toward the implications of domestic IoT (van Ditmar & Lockton, 2015). Considering the user perspective, the authors noted that subjectivity is largely missing or founded in simplistic assumptions, encouraging them to acknowledge the importance of humans in making sense of data, not just as producers of data. In the community context, the Isle of Wight aims to become the UK’s *first truly sustainable region*, which would clearly involve self-sustainability in food, although the paper describing this ambitious project mentions ‘food’ once only (Crampsi, 2012).

x) Benefits of IoT in food and agriculture (including Agriculture)

A 2008 paper reviews sustainable development in agriculture, land and rural development, drought and desertification, and Africa. Technological developments mentioned in this review are all agricultural, there being no mentions of the internet, so it is at least questionable whether this review is relevant to IoT and/or systems in food and agriculture (Netherlands Ministry of Agriculture, 2008).

This survey found a range of articles dealing with the potential benefits of IoT or ICT in agriculture, some of which have only limited or casual mentions of food. Two of the articles relate to a foresight exercise instituted by the EU Standing Committee on Agricultural Research (SCAR): possible scenarios for European agriculture, with reviews of the challenges (Constantin Severini, 2009); and an analysis of how policy could meet future needs, previously covered in the Logistics section (Eiff et al., 2015). Datta examines how computer-aided engineering could benefit the food production process (Datta, 2015) and Hearn et al offer a theoretical description of emerging innovations in urban food systems (Hearn et al., 2014). Lehmann et al give an overview of the state of the art for three use cases in the domain of the food sector: agriculture, food industry, and consumer (Lehmann et al., 2012). Two papers appear to be of special interest with regard to benefits and potential: a 6-page analysis of ICT as driver for change, arguing from ‘long wave theory’ that use will increase (Poppe, Wolfert, & Verdouw, 2013) and a longer (12-page) and more technical article, suggesting where technology could come in (Poppe, Wolfert, Verdouw, et al., 2013). Poppe is also a co-author of a paper asserting that it is hard to measure innovation in the agri-food business (van Galen & Poppe, 2013). Two papers consider the challenges and requirements of the agri-food sector on the basis of research carried out for the SmartAgriFood project (Brewster et al., 2012)("Future Internet for safe and healthy food," 2014).

Koenderink et al observe: *For industrial and academic food researchers it is at present difficult to benefit from each other's data, models and experimental knowledge* … [they] *recognise the need for the possibility to exchange both general and more specific food knowledge*. Their approach is to create ontologies from existing knowledge: thesauri, food models, and ontologies (Koenderink et al., 2005).

Technology perspective: review of wireless sensors in agriculture [Aqeel-ur-Rehman2014]; wireless sensor networks for monitoring HACCP ((Hazard Analysis Critical Control Point)) practices in Japan (Hanyu, Shimura, & Fukui, 2011); an early IoT Conference Proceedings, with 26 mentions of 'food' (Hutchison & Mitchell, 2008); a book chapter about use cases and scenarios for evaluation of the ARM with 2 mentions of 'food' (Jardak & Walewski, 2013); a survey of technologies, applications and research challenges, with 3 casual mentions of 'food' (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012); a 91-page Swedish survey of technologies and architectures of IoT for health and well-being, containing one page on food (Pang, 2013); a view of the potential for IT in the agri-food sector (Schiefer, 2004); a 40-page review of the IoT future by the Government Office for Science that, among other points, notes the danger of trivialising with stereotypes such as the 'fridge that orders fresh milk' (The Government Office for Science, 2014); and a water monitoring platform to promote the application of IoT to agriculture in India (Vijay, Vishal, & College, 2015).Two articles discuss the use of mobile technologies for delivering information and real-time assistance to farmers in India (Saha, Ali, Basak, & Chaudhuri, 2012)(Uddin & Hossain, n.d.).

xi) Health & Nutrition

This section also includes a range of articles relating to safety issues, food poisoning, surveillance and quality control.

Articles reporting the use of internet technologies for the analysis of safety issues are: determining trends in food-borne illness over time (Bahk, Kim, & Park, 2015); using text-mining techniques to identify and mine food safety complaints posted by citizens on web data sources (Kate, Negi, & Kalagnanam, 2014); food poisoning factors limiting agricultural production in China (Lam, Remais, Fung, Xu, & Sun, 2013); extending previous reports on network analysis relating to food notifications by including an optional filter by type of notification (Nepusz, Petróczi, & Naughton, 2012); and microbiological surveillance of food safety in China (Pei et al., 2015).

Articles whose primary aim appears to be the improvement of food safety are: the use of omics' technologies to improve functionality and safety, particularly for fermented foods (Alkema, Boekhorst, Wels, & van Hijum, 2016); an exploration of the perceptions of public health inspectors in Ontario of the key food safety issues in public health, and their opinions and needs with regards to food safety information resources (M. T. Pham, Jones, Sargeant, Marshall, & Dewey, 2010).

A body of papers discuss the challenges of identifying what people actually eat, in several case with the aim of monitoring diet: a data-driven investigation of the cultural diversity of culinary practice and the patterns of ingredient combinations (Ahn, Ahnert, Bagrow, & Barabási, 2011); dietary monitoring by on-body sensing of the core activities, arm movements, chewing, and swallowing (Amft & Tröster, 2008); use of lightweight photo-based recording in mobile food journals as part of a survey of capture food choices in daily life

(Cordeiro, Bales, Cherry, & Fogarty, 2015); *FoodMood*, a visualisation project giving citizens an opportunity to appreciate the connections between emotion, obesity, and food (Dixon, Jaki, Lagerweij, Mooij, & Yudin, 2012); understanding the relationship between people and their meals by automatic analysis and classification of food items from images, and the use of food images to help diet monitoring, using a benchmark dataset (Farinella, Allegra, Moltisanti, et al., 2015; Farinella, Allegra, & Stanco, 2015); a Rapid Evidence Assessment (2013, 80 pages) for better understanding of the 'food aid' landscape in the UK and the 'at risk' individuals who access such provision (Lambie-Mumford, Crossley, Jensen, Verbeke, & Dowler, 2014); food intake assessment using mobile phones to capture images of foods, recognize food types, estimate their respective volumes, and finally return quantitative nutrition information (Puri et al., 2009); self-monitoring of food intake of people with chronic kidney disease (Siek et al., 2006); and the use of photography to reduce the measurement error associated with maintaining a food intake record (Weiss et al., 2010).

Beyond monitoring comes increasing consumer awareness and then recommending appropriate diets and consumption levels: a mobile system for ontology-driven safe food consumption, identifying additives with health risks and aiming to improve life quality by supervising what and how much we eat (Çelik Ertuğrul, 2015); participatory backcasting to analyse how we might eat more sustainably, predicated on eating practices being at the heart of the food futures debates and noting that technological advances alone are unlikely to generate the significant transformations required (Davies, 2014); a content-aware fridge that can recommend recipes such that each family member has well-balanced diet (Davies, 2014); child-centric food advisory system based on a smart fridge (Mulay, Kumar, & Patil, 2014); the use of mobile devices to increase consumer awareness of food products, not just their quality, safety, and integrity (Reiche et al., 2012); social navigation as the basis for a food recipe system (Svensson, Höök, & Cöster, 2005; Svensson, Höök, Laaksolahti, & Waern, 2001); and a mobile food recognition system that estimates the calorific and nutrition content of foods automatically without any user intervention (W. Zhang et al., 2015).

Mobile apps have been developed for providing information in one form or another about food safety: a cradle and app that turn a smartphone into a handheld biosensor, able to run on-the-spot tests for food safety, environmental toxins, medical diagnostics and more (Ahlberg, 2013). an Android app introduced by the Food Safety Helpline in India (Food Servce India, 2014); an app that rates food based on its nutrition, how processed it is and, any concerns about its ingredients(Martin, 2014); the 'Ask Karen' app launched by the U.S. Department of Agriculture's Food Safety and Inspection Service, for answering questions from consumers about food safety (Telesca, 2012).

Concerns about an increase in illness resulting from unsafe handling of higher risk produce at farmers markets led to a smartphone data collection tool for recording vendor practices, without being detected (Machado, Scheinberg, Pivarnik, & Cutter, 2015; Vandeputte, Pivarnik, Scheinberg, Machado, Cutter, & Lofgren, 2015); for direct concealed observations of the food safety practices of food handlers, it was found that smartphones would not be regarded as evaluative (by handlers) whereas a clipboard would be(Vandeputte, Pivarnik, Scheinberg, Machado, Cutter, Lofgren, et al., 2015).

This survey revealed three other papers that do not really fit any of the previous health and nutrition considerations: the existing and potential design space for HCI in human-food interaction, aiming to celebrate the positive aspects (Grimes & Harper, 2008a); the rather bizarre notion of the 'social stomach' for understanding the relationship between food and technology (Kera & Tuters, 2011); and the evaluation of product intelligence using fuzzy rules and an SOM model, validated in several domains (H. Van Pham & Tran, 2015).

xii) Control of spoilage

Perez-Ruiz et al report the development of new pest control tools, based on the use of an autonomous tractor, as an outcome of the RHEA (Robotics and associated High-technologies and Equipment for Agriculture) project, which is an *EC-funded research project conducted by a consortium composed of 15 research partners from eight European countries*. The motivation for RHEA is the requirement for new technologies for *safe, site-specific and efficient control of weeds, pathogens and insects in agricultural crops and in forestry* (Pérez-Ruiz et al., 2015).

xiii) Waste management

All three papers in this category are about the reduction or prevention of food waste in domestic situations: a *social recipe recommender* that would also log household practices and *persuasive technologies* to influence behaviour (Yalvaç, Lim, Hu, Funk, & Rauterberg, 2014); two articles about the use of FridgeCam to understand practices around food and waste, and to investigate interventions to influence consumer behaviour (Farr-Wharton et al., 2014)(Ganglbauer et al., 2013).

xiv) Specific applications

Four articles report research into monitoring the food chain in specific contexts: an investigation of mobile phone data, suggesting that, *in the future, proxies derived from mobile phone data could be used to provide valuable up-to-date operational information on food security throughout low and middle income countries* (Decuyper & Rutherford, 2014); a study of the extent to which each section of the food supply chain is represented in Twitter and use the hashtag #food (York & Brewster, 2013); a monitoring system for the citrus industry chain [(X. Liu & Sheng, 2012); a colorimeter with IoT functionality that the article states could be used in food applications (Mignani, Mencaglia, Baldi, & Ciaccheri, 2015).

In the smart environment context: the City of the Future Living Lab in Milan has designed an interactive IoT vending machine (Vicini, Bellini, Rosi, & Sanna, 2013); Zhang and Shen have proposed the framework for a smart supermarket based on IoT (Y. G. Zhang & Shen, 2012)

We have simply cited without comment the articles about household devices, which are well represented in this survey, the majority being related to smart fridges: (Bigler, Gaderer, Loschmidt, & Sauter, 2011; J. H. jeong Choi & Graham, 2014; Grogan, 2012; Kobie, 2015a; Luo et al., 2008; Rothensee, 2007, 2008; Rouillard, 2012; Swan & Taylor, 2005). Other topics are: intelligent oven (B. Li et al., 2009); smart kitchens (Soucek et al., 2000)(C.-L. Wu, You, Chen, Chuang, & Chiang, 2014); interactive surfaces (A. S. Taylor et al., 2007); an investigation of respondents' sentiments toward the implications of domestic IoT, which is mentioned in the Connecting consumers section (van Ditmar & Lockton, 2015).

xv) Mobile market services (new category)

Use of mobile phones has spread rapidly in many developing countries, as they provide an enabling technology, especially for money services. The indications in Kenya are that mobile money can help to improve market access for smallholder farmers (Enoch & Fischer, 2013) (Kikulwe et al., 2014).

xvi) Precision Agriculture

In the arena of farm management systems, their architecture and design, we have covered the work of Kaloxylos et al in the Farm management section (Kaloxylos et al., 2012). Li et al tackle challenge of analysing and using the data from heterogeneous devices to improve farming decisions, and propose an architecture for analysing and visualising farm data. *The tool has been successfully used in a USDA-sponsored project on canopy management for specialty crops* (T. Li et al., 2012). Peets et al consider the potentials and procedures for on-soil sensors, as part of an FP7 project, FutureFarm; they present an architecture and case study in some detail, but it is unclear whether they conducted any field tests (Peets, Mouazen, Blackburn, Kuang, & Wiebensohn, 2012).

Several articles report research into specific aspects of precision agriculture: prescribing fertiliser amounts on the basis of real-time yield monitoring (Birch, 2012); a system for supervising the utilisation of land resources in China, evaluated in Guizhou Province (Fang et al., 2015); a farm machinery MIS, addressing communication and interoperability between tractors, conceptual models having been tested and validated with 15 farm managers from the initial reviewing panel (Fountas, Sorensen, et al., 2015); a Web-based farm MIS with a barley spraying test case (Nikkilä, Seilonen, & Koskinen, 2010) and an irrigation controller for small farms, apparently subjected to a bench test only (Plotog et al., 2015).

xvii) Food policy

DEFRA has produced two reports concerning UK food security: an evidence and analysis paper (DEFRA, 2006) and an assessment of the UK Government's approach (DEFRA, 2009). In 2007, RuSource, an Arthur Rank Centre project, published a 4-page briefing saying that the decline in self-sufficiency relates to agriculture's ability to meet consumer demands, but food supplies are remarkably resilient (Spedding, 2007). A more recent House of Commons report focuses on food production, supply and the systems necessary to ensure food security in the future (McIntosh et al., 2015); this report *highlights some examples of good practice and how Government and food producers could plan for projected changes*. A future study of the food sector in Denmark developed five scenarios, which are under consideration in future policy planning (Sundbo, 2016).

Three papers consider issues relating to sustainability: Arcese et al advocate the adoption by food sector companies of an *open sustainability innovation approach*, highlighting the *empirical results of ten case studies* (Arcese, Flammini, Lucchetti, & Martucci, 2015). Ge and Brewster argue that *current informational institutions are increasing the information entropy of communications concerning environmental sustainability* in the agri-food sector (Ge & Brewster, 2016); and suggestions that national governments and the EU could both contribute to improving innovation in the agri-food sector by strengthening coordination and cooperation (Moreddu & Poppe, 2013).

Mobile apps are being developed to support food security by improving access to field data and other agricultural information: in Burundi the 'EthnoCorder' app aims to improve the capacity of organizations to collect and analyse field data that can be used for monitoring and evaluation (Horst & Nduwayo, 2012); a study assessing the relevance of mobile telephony to food security in Nigeria found that mobiles are most used for booking appointments with labour, so recommends training farmers on the use of mobile phones for accessing innovations on agriculture (Falola & Adewumi, 2013).

In a regulatory context, a study of food safety regulatory systems in China and the EU considers the role of public-private partnership, submitting that it would bring significant benefits and opportunities for China (K. Chen, WANG, & SONG, 2015).

13) Appendix E - Temperature Monitoring in the Sandwich Market

Related to the IoT Food projects funded by the ITaaU and FSA we requested a specific literature review on the role of temperature monitoring in an important part of the consumer prepared food market. This was prepared by M. Smith and A. Alaizuki.

a) Introduction

Durability extension of foods while still maintaining high quality is the ultimate aim of the chill chain. This can achieve customer satisfaction and reduce the burden of food cost (Lan, Zhao, Su, & Liu, 2014). Most unsaleable foods result from quality deterioration and durability expiration (Grunow & Piramuthu, 2013b). Therefore, chilling technology has a crucial role in keeping food in a stable condition, especially for highly perishable products, to maximise safety, quality and durability. Chilled food maintenance is required in all parts of the food trade chain including transport, storage and retail (Likar & Jevšnik, 2006b). However, the food cold chain has been growing rapidly due to the increased demand for specifically prepared foods and changing in lifestyles, especially in European countries (Coulomb, 2008). The globalisation of food supply and increase in the number of large-scale food producers has contributed to expanding the cold chain in concert with the dramatic technological improvements (Global cold chain market for food industry 2013 report, 2013). This has led to a flourishing market of commercial refrigerators, especially meeting the increasing demand for ready to eat (RTE) foods (M2 Presswire, 2016). These foods occupy a significant portion of the cold chain and they are intended to be consumed without further processing as stated by European regulation EC 2073/2005 (Kovačević, Burazin, Pavlović, Kopjar, & Piližota, 2013). The term RTE foods covers a variety of products including cooked meat products, sandwiches and salad all of which can support the growth of pathogenic and spoilage bacteria. Therefore, RTE foods must be controlled in the cold chain under HACCP principles as stated by the Article (5) of Regulation 852/2004 to ensure their safety. In England they also require storage and handling at temperatures below 8 ^{o}C as stated by “The Food Safety, Hygiene (England) Regulations 2013”. This is to restrict the microbial growth. (Food Standards Agency, 2007; Sofos, 2014; *The Food Safety and Hygiene (England) Regulations 2013*, 2013).

b) Food Safety

Food safety in the chill chain is still the biggest concern for food industry and trade. Foodborne outbreaks caused by RTE products at retail and food service have more potential to cause harm due to the direct access by consumers with no further processing step before ingestion. It has been determined that food manufacturers of RTE food in the United Kingdom apply more rigorous control measures than retailers (Lianou & Sofos, 2007; Likar & Jevšnik, 2006b). This has been partially achieved through the use of food safety systems such HACCP to control manufacturing, storage and transport conditions ensuring all foodstuffs are kept safe during their shelf life (Likar & Jevšnik, 2006b). The HACCP system has been accompanied with application of quality systems to improve the handling and hygiene practices of the circulated RTE products so that the quality attributes of foods can meet customer expectations. Additionally, these systems help reduce food waste and protect consummers against health hazards (Stahl *et al*., 2015). However, small and medium sized businesses (SME’s) have more difficulty implementing HACCP than major manufacturers (Charalambous, Fryer, Panayides, & Smith, 2015b; Walker, Pritchard, & Forsythe, 2003), and many retailers selling chilled RTE foods are SME’s. This is a possible weak link in the cold chain.

c) Time-Temperature Profile

One of the most significant factors which affect the safety and quality of RTE food is the time-temperature profile. The history of food temperature during its shelf-life can account for its microbial content and some changes in chemical and physical attributes. This draws attention to the necessity for temperature control of RTE foods. Guaranteed safety and best quality can be obtained by keeping the products at temperatures below 5 ^{o}C during their short shelf life (Likar & Jevšnik, 2006b; Stahl et al., 2015). Temperature control maintenance during shelf life is particularly crucial to restrict the growth of *Listeria monocytogenes* as it is the most prevalent pathogen in chill chain, and it causes serious health hazards to humans (EFSA, 2013; Warriner & Namvar, 2009). This bacterium is highly problematic in the chill chain for food operators and competent authorities as it is ubiquitous, able to survive the processing environment and grow at temperatures as low as 0.5 ^{o}C (Stahl *et al*., 2015). It is also tolerant to salt concentration up to (10%) and grows in a wide range of pH values (4.7-9.2) (Magalhães *et al*., 2016). *L. monocytogenes* is persistent in the food chain with the ability to form biofilms and attach to processing equipment. It appears to be getting more resistant to sanitisers (Piercey, Hingston, & Truelstrup Hansen, 2016). Moreover, it is still causing serious listeriosis cases despite the food safety regulations. In Europe, it was reported that 191 deaths were caused by listeriosis in 2013 (European Food Safety Authority, 2015). *Salmonella* and pathogenic *E. coli* have also been associated with RTE food outbreaks (Sant'Ana, Barbosa, Destro, Landgraf, & Franco, 2012). One example includes a shiga-toxin producing *E. coli* outbreak in Europe with eleven cases, nine of them developing haemolytic uraemic syndrome (HUS). It was associated with consumption of salad containing sprouts which was served in a birthday party in Germany (Scharlach *et al*., 2013). Spoilage bacteria may also grow in RTE foods in the chill chain even at low temperatures, for example lactic acid bacteria are able to proliferate at low temperatures (2-4 ^{o}C) under optimum values of pH and water activity. These conditions are frequently provided by RTE products containing meat, fish, dairy and salads (Stahl *et al*., 2015). Spoilage bacteria induce changes in chemical and physical attributes of RTE food causing quality loss. The changes can include off-flavours, off-odours and modification of texture and colour (Leroy, Vasilopoulos, Van Hemelryck, Falony, & De Vuyst, 2009).

d) Chill Chain

Chilled RTE products in retail may have spoilage or pathogenic bacteria introduced with raw materials or during processing. Temperature control within the chill chain is the guarantee of product stability; it restricts the bacterial proliferation and prevents the population from reaching an unacceptable level during the shelf life (Everis & Betts, 2013). The durability of RTE products is based on the safety perspective and determined by a scientific assessment which ensures pathogenic bacteria are unable to compromise the product safety under the specified chilling conditions (Food Standards Agency, 2007). The Food Business Operators rely on standard techniques to ensure compliance with the food safety regulations. Microbiological challenge testing and predictive modelling are the major tools adopted to specify the shelf life of RTE foods (Everis & Betts, 2013). For RTE foods as stated by the EU Regulation EC 2073/2005, *L. monocytogenes* is the reference pathogen used to determine their stability in chill chain. The final product should have less than 100 cfu/g at the last day of durability (Ec No 2073/2005, 2005). These assessments all rely on continuity of temperature control through the shelf life of the product. Any upward variation of the storage or distribution temperature will negatively impact on the shelf life and may compromise the safety of the product.

Temperature control of foods through the cold chain has a vital role in the reduction of food waste. A substantial portion of chilled foods are wasted when there is temperature abuse during storage, distribution or retail. This shortens the product shelf life and causes quality deterioration and big economic loss (Mena, Terry, Williams, & Ellram, 2014b). Moreover, uncontrolled refrigeration temperature is the major cause of foodborne diseases as the persistent pathogens in the food cold chain, such as *Listeria monocytogenes*, can grow and risk the customer's health. Therefore, failure in controlling food temperature in the cold chain leads to a huge burden on food industry and governments due to foodborne diseases and economic loss (Newell et al., 2010; World Health Organization, 2015). Numerous foodborne outbreaks have been reported, especially in food catering where large numbers of ready meals are served daily (Rosset, Cornu, Noël, Morelli, & Poumeyrol, 2004). An important outbreak occurred in northern Italy when 1473 students and 93 staff members in two primary schools had symptoms of febrile gastroenteritis. A high population of *L. monocytogenes* in the cold tuna and corn salad was the cause behind the outbreak. The investigators have reported that temperature abuse during storage of the salad allowed *L. monocytogenes* to proliferate reaching 10^6 cfu/g as confirmed by the laboratory sample test (Aureli *et al*., 2000). In France, uncontrolled storage temperature of lunch foods was one of the major factors responsible for the 3500 reported cases of foodborne illness associated with schools. (Rosset *et al*., 2004). Recent sampling investigations revealed a significant non-compliance in regard to RTE foods in European countries in 2013. This included fishery, meat and soft cheese products with an unacceptable level of *L. monocytogenes*. The test results have shown that 1.6% of fishery products samples, 1.0% of poultry samples and 0.6% of soft cheeses samples exceeded 100 cfu/g (European Food Safety Authority, 2015). Poor temperature control during storage can permit and enhance the proliferation of food pathogens.

e) Sandwiches

Sandwiches are among the most popular RTE foods in the United Kingdom. Nearly 16 million sandwiches are produced per year in the UK which cost £13 million (J. Winship, British Sandwich Association, personal communication). It has been reported that sandwiches are a major concern to public health as they are made up and served cold, and contain various high risk filling ingredients, such as meat and salads (Little, Barrett, Mclauchlin, & Grant, 2007). Sandwiches have been associated with outbreaks in the United Kingdom. A *Salmonella* outbreak was linked with turkey sandwiches served in a private hospital in 1994 (Little, Barrett, Mclauchlin, et al., 2007; Maguire et al., 2000), and an *E. coli* O157 outbreak was also linked to cold meat sandwiches which resulted in 26 infections in England (McDonnell *et al*., 1997). In 2010 a serious outbreak in Birmingham affected the policing of a demonstration, compromising the security of the city. Sandwiches with various fillings were provided to three shifts of police officers responsible for controlling an English Defence League march. The sandwiches proved to have been contaminated with coagulase positive *Staphylococcus aureus*. The source was a food handler with infected eczema. After assembly the FBO failed to keep the sandwiches under temperature control and 47 officers became ill. Some were so seriously affected that they needed to be hospitalised. Microbiological examination revealed levels of 2.0×10^2 - 4.8×10^4 cfu/g in uneaten sandwiches and 1.2×10^7 cfu/g in left over tuna filling stored at the food premises (Berlin, 2010; Anon 2010).

However, the risk of *L. monocytogenes* outbreak is still the biggest challenge to sandwich retailers as *L. monocytogenes* can persist through preparation and chill storage (Warriner & Namvar, 2009). Sandwiches have been associated with four *L. monocytogenes* outbreaks in the UK. Five listeriosis cases were reported in an outbreak linked to consumption of prepacked sandwiches bought from a hospital retail in 2003 (Dawson *et al*., 2006). Another *L. monocytogenes* outbreak associated with sandwich consumption in a hospital resulted in 2 listeriosis cases in 2003. The sandwiches were supplied from outside producer and stored in a chiller cabinet where the storage temperature fluctuated widely and exceeded the required temperature of 8^{o}C to reach 11 ^{o}C (Shetty *et al*., 2009). Therefore, there is urgent need to apply rigorous monitoring of the integrity of the cold chain in catering, in particular, sandwich preparation and sale.

f) Recoding Obligations

Food Business Operators are obliged under Article 5 of Regulation (EC) No 852/2004 of The European Parliament and of The Council to keep records of the monitoring at Critical Control Points in their Food Safety Management Systems. For Food Business Operators (FBOs) selling ready to eat foods, the delivery and storage would be Critical Control Points (CCPs) which they would be required to monitor and record. For the majority of small businesses, the operatives will make point measurements of temperature at pre-agreed times during the operation. However these are normally air temperatures in the chillers or refrigerators rather than actual food temperatures. The monitoring equipment used across the industry is not consistent. Some Food Business Operators use probes but many prefer laser thermometers as being easier to use. Others rely on the readout on the refrigerator or chiller (if there is one) or used static thermometers lying in the chiller. One of the advanced approaches used to evaluate the efficiency of the cold chain is to integrate the time-temperature profiles with microbiologically predictive models. Temperature monitoring of food products during their shelf life gives highly informative data. This can help in improving temperature control, assessing the customer's exposure to microbial hazards (Rosset *et al*., 2004), and critical evaluation of cold chain integrity in regard to the quality and safety of foods in retail shops, transport and distribution areas (Koutsoumanis, Taoukis, & Nychas, 2005). Furthermore, ensuring product temperature remains under 5 ^{o}C is crucial to control the transmission and concentration of *L. monocytogenes*. It has been demonstrated that *L. monocytogenes* is able to grow and exceed 1 log cfu/cm^2 on uncured turkey breast when stored at temperature of 7 ^{o}C for three days (Lianou, Geornaras, Kendall, Scanga, & Sofos, 2007; Lianou & Sofos, 2007; Rosset et al., 2004). Time-temperature data can be obtained by using a temperature data logger. A data-logger is an innovative technology to record product temperature in equal intervals. The profiles retrieved from the data loggers give an accurate record of product (rather than air) temperature and can be used to predict the growth of *L. monocytogenes* and other pathogens in food products. Food products placed in retail chillers may witness variation in their temperature even if the chiller appears to be working at the required temperature. This may be due to defrost cycles or product placement, for example if the product is close to the cabinet light, there may be a high temperature in the immediate locale (Lianou & Sofos, 2007). A study on monitoring time-temperature history of RTE foods has been conducted in 11 school canteens and 5 kitchens in France, where data loggers were inserted inside the products to reflect their real temperature variations. The resulting Time-Temperature profiles were unsatisfactory when extended storage periods at high temperatures between 8.5 and 9.5 ^{o}C were observed. This occurred over weekends. These findings have revealed temperature abuse during the foods durability and potential risk of high microbial growth (Rosset *et al*., 2004). Another investigation showed that 15.6% of pate sold at retail were at temperatures ≥ 8 ^{o}C (Lianou & Sofos, 2007). Additionally, the data loggers are essential to evaluate the food quality alongside safety, especially for the prepacked sandwiches which are sensitive to temperature variations of cold storage. This was obvious in the study on sandwiches sold in hospitals and residential homes in the UK. The findings showed that 3.3% of the sandwiches sampled had poor quality due to unsatisfactory *Enterobacteriaceae* levels. Further, *L. monocytogenes* and *L. species* were more likely to be detected in mixed salads from sandwich retailers with storage temperature above 8 ^{o}C (Little, Barrett, Mclauchlin, et al., 2007).

g) Conclusions

In conclusion, the literature provides evidence that the integrity of the cold chain is essential for ready to eat foods, including sandwiches. Upward variance of the temperature compromises the quality of the foods, shortening the shelf life and causing wastage. It may also compromise the safety of the food and there is ample evidence in the literature of cases of food borne illness associated with ready to eat foods, including sandwiches, which have been temperature abused. Monitoring the food temperature using point measurements is inadequate to ensure continuity and the use of data loggers which can deliver a time-temperature profile over the shelf life of the product allows more accurate monitoring and the opportunity to focus on areas which need improvement.

14) Appendix F: IoT & Food: Sensors, Semantics and Provenance

a) Search Strategy

From the literature searches it was clear that the role of transparency and provenance will be a significant application of IoT sensors and the data generated by these sensors. The overlap with one of the IoT projects provided a source of background literature in these areas.

b) Stream Processing Semantic Platforms

i) A Knowledge-Based Approach for Real-Time IoT Data Stream Annotation and Processing

(Kolozali, Bermudez-Edo, Puschmann, Ganz, & Barnaghi, 2014) give a description of an approach for abstracting sensor data using the Symbolic Aggregate Approximation (SAX) technique. Abstracted data is published as linked data using a suite of ontologies including Stream Annotation Ontology (SAO), PROV-O, and the Quality of Service and Quality of Information (QoS|QoI) ontology.

ii) OpenIoT Middleware Platform

The paper by (Soldatos et al., 2015) describes an open source project for managing the deployment of large IoT infrastructures. The middleware platform also supports continuous semantic queries over sensor data using the OpenIoT ontology, which extends the Semantic Sensor Network ontology. The Project website can be found at https://github.com/OpenIotOrg/openiot

iii) A Semantic Processing Framework for IoT-Enabled Communication Systems

(Ali, Ono, Kaysar, Griffin, & Mileo, 2015) describe a semantic application of the OpenIoT middleware platform extended to continuously query and process stream data using CQELS (Continuous Query Evaluation over Linked Streams) query engine and event-condition-action (ECA) rules in AnsProlog. The example application links sensor data annotated using SSN to geographic data, user-generated data and implicit information (e.g. user profiles).

c) Food & Smart Product Ontologies

i) The Linked Open Vocabularies for Internet of Things (LOV4IoT) project

LOV4IoT is a repository containing collections of links to a number of IoT related ontologies. A separate section entitled Food, Beverage, Recipe & Restaurant ontologies contains 30 ontologies (LOV4IoT, n.d.).

ii) Realizing Networks of Proactive Smart Products

The paper, (d'Aquin, Motta, Nikolov, & Thomas, 2012) includes descriptions of smart product ontologies, which are implemented in a framework for realizing networks of smart products with agent-based technologies. The ontology is available via the project web page ("Smart Products Ontology," n.d.) .

iii) Ontology Construction: Cooking Domain

A thorough description of designing a cooking ontology, which consists of five modules including Food, Kitchen Utensils, Actions, Recipes and Auxiliary modules (dish types, units of measurement, etc.) is provided by (R Ribeiro, Batista, Pardal, Mamede, & Pinto, 2006).

iv) FOODS: A Food-Oriented Ontology-Driven System

(Snae & Bruckner, 2008a) includes a description of a food ontology describing various food items based on their kind, origin of the ingredients (e.g. animal based), nutrition values, and is further built upon in (Boulos et al., 2015)

v) Food Track & Trace Ontology for Helping the Food Traceability Control

The paper, (Pizzuti, Mirabelli, Sanz-Bobi, & Goméz-Gonzaléz, 2014), describes the Food Track&Trace Ontology (FTTO) - a part of a general framework devoted to managing food traceability. The main goal of the proposed FTTO Ontology is to include the most representative food concepts involved in a supply chain in a single ordered hierarchy. The paper contains a table summarising a number of existing food-related ontologies.

d) Food Monitoring & Traceability

i) Sensor Network for HACCP Food Safety Management

(Hanyu et al., 2011) describes a platform for managing and recording continuous readings from wireless sensors. Alarms are triggered if readings cross some HACCP threshold and users can also inspect daily reports of sensor readings.

ii) A Case Study of Sensor Data Collection and Analysis in Smart City: Provenance in Smart Food Supply Chain

Authors, (Q. N. Zhang et al., 2013) use machine learning techniques to calculate the probability of contamination of non-sampled food items based on provenance of food movements throughout the food supply chain, with aspects of reasoning built on thjois described in (S. Yan et al., 2012).

iii) A Low Cost Internet of Things Solution for Traceability and Monitoring Food Safety During Transportation

The paper (Maksimovic, Vujovi, et al., 2015)describes a GS1 compliant infrastructure based on instrumenting individual transport vehicles involved in the transportation of food with low cost (Raspberry Pi) sensor processing units. Such units are then connected to RFID readers, which provide information about the current inventory loaded onto the vehicle. The Raspberry Pi then hosts a RESTful web service that provides access to the inventory in real-time. Additional data such as temperature and humidity readings inside the vehicle are also provided, related work is described in (Maksimovic, Vujović, & Mikličanin, 2015).

iv) Food Traceability using RFID and Wireless Sensor Networks in an Aquaculture Enterprise

Master's thesis testing feasibility of an automated traceability platform based on the use of RFID tags in the fishing industry. The report also includes a detailed overview and custom test results of some existing hardware (e.g. RFID printers, readers, temperature loggers, etc.) and third party management platforms (de Master, 2011).

v) The Design of an Electronic Pedigree System for Food Safety

(W. Han et al., 2015) describe an extension to the GS1 standard for food monitoring with an ability to record additional data about the production and transport environment (e.g. temperature) and data collected during food inspections. The data storage is handled by an independent third party in a secure master repository.

vi) Traceability in the Meat Industry – The Farm to Plate Continuum

In the paper (Shackell, 2008) discusses various motivations and requirements for meat traceability at different stages of the food chain. In addition, the paper discusses the roles of various stakeholders (e.g. producers and customers) in relation to meat traceability.

vii) Food Traceability Chain Supported by the Ebbits IoT Middleware

In this paper, (Furdik et al., 2016) describe an XML-based, event-driven, service-orientated middleware platform for monitoring meat (from farm to fork) using RFID tags and other relevant sensor readings such as temperatures observed in cold storage or transport stages. More detailed deliverables of this EU project can be found at http://www.ebbits-project.eu/news.php

viii) Value-Centric Design of the Internet-of-Things Solution for Food Supply Chain: Value Creation, Sensor Portfolio and Information Fusion

This paper, (Pang et al., 2015) proposes a design framework for IoT infrastructures in the Food Supply Chain that opposes the traditional traceability-centric approaches. It is argued that in order to increase the adoption of IoT technologies in the Food Supply Chain both business and technological challenges have to be addressed. **A comprehensive report on real field trials exploring the added values including shelf life prediction, sales premium, precision agriculture, and reduction of assurance cost is given.**

ix) A Field Test Study on a Dynamic Shelf Life Service for Perishables

The paper reports on a series of interviews and field tests in relation to the deployment of IoT sensors for dynamic prediction of product shelf life with a view to reduce food wastage. The results highlight the importance of temperature sensor accuracy in shelf life prediction (Jevinger, Båth, & Göransson, 2014).

x) iFridge: An Intelligent Fridge for Food Management Based on RFID Technology

(Xie et al., 2013) In describes an application that tests the feasibility of using RFID tags to determine the position of food items inside a fridge.

xi) Virtualization of Food Supply Chains with the Internet of Things

Virtualization enables supply chain actors to monitor, control, plan and optimize business processes remotely and in real-time through the Internet, based on virtual objects instead of observation on-site. This paper analyses the concept of virtual food supply chains from an Internet of Things perspective and proposes an architecture to implement enabling information systems. As a proof of concept, the architecture is applied to a case study of a fish supply chain (Verdouw et al., 2014b, 2016).

xii) IOT Based Provenance Platform for Vegetables Supplied to Hong Kong

In (Shilong et al., 2014) the authors describe a traditional web-based application built on collections of provenance data documenting the lifecycle of vegetable products from farm to supermarket. Information about the movement of the vegetable products is obtained via an IoT network utilising RFID technology.

xiii) Provenance System for Livestock Supplied to Hong Kong Based on RFID Technology

In (Yin, Chen, Lu, Li, & Wu, 2011)The paper describes the use of RFID technology to monitor livestock supplied to Hong Kong; RFID ear tags and vehicle cards are both employed to create a provenance record.

e) Trust & The Food Industry

i) Data Driven Quantitative Trust Model for the Internet of Agricultural Things

The paper (W. Han et al., 2014) describes a data-driven trust model based on Bayesian networks. The model utilises historical data received from the AIoT network (Internet of Agricultural Things) and eliminates the need for expert experience.

f) Sensors Relevant to The Food Domain

This section provides just a few examples of relevant sensing technologies.

i) Food Contamination Monitoring via Internet of Things, Exemplified by using Pocket-Sized Immunosensor as Terminal Unit

In (Seo et al., 2016)the authors describe a sensing solution designed to monitor food contamination, and use the pathogen *V. parahaemolyticus* for testing purposes. The sensor is based on a CMOS image sensor and is designed to interoperate with a smartphone.

ii) Battery-Free Radio Frequency Identification (RFID) Sensors for Food Quality and Safety

The paper by (Potyrailo et al., 2012) describes an unobtrusive battery-free RFID sensor that enables freshness monitoring of various food products. Examples discussed in the paper include monitoring freshness of milk and fish, as well as direct monitoring of bacteria growth.

iii) Silk - Based Conformal, Adhesive, Edible Food Sensors

RFID-like edible sensors based on silk antennas that can be attached directly onto a food item to detect spoilage based on changing chemical properties, which affect the signal broadcast by the antenna (H. Tao et al., 2012).

iv) Monitoring of Bacteria Growth Using a Wireless, Remote Query Resonant-Circuit Sensor: Application to Environmental Sensing

A short–range (14 cm) wireless method for determining changes in the environment based on observing changes in the impendence spectrum recorded by a printed inductor-capacitor circuit (Ong, Wang, Singh, Bachas, & Grimes, 2001).

v) Wireless Sensors in Agriculture and Food Industry - Recent Development and Future Perspective

A survey of wireless communication standards, sensors and actuators for agriculture and the food industry is given by (N. Wang, Zhang, & Wang, 2006). The paper identifies a number of sensor application areas including traceability, M2M communication, food safety inspections, precision farming, weather monitoring, and updates an earlier review (N. Zhang, Wang, & Wang, 2002) in applications to precision farming.

vi) Radiofrequency Identification and Surface Acoustic Wave Technologies for Developing the Food Intelligent Packaging Concept

This paper provides a comprehensive overview of the state of the art in RFID and SAW technologies in the context of smart food packaging. Amongst other things, the paper mentions the potential of active RFID tags, which can include various sensors (e.g. temperature and humidity sensors). It also describes the advanced properties of SAW-based tags, which can operate with lower energy levels and can withstand a wide range of temperatures (López-Gómez et al., 2015).

15) Appendix G - Journals

In all 269 different literature sources (journals etc) were located giving over 600 references. The top 20 journals were:-

- "Computers and Electronics in Agriculture"
- "Food Control"
- "International Journal of Food Microbiology"
- "Applied Mechanics and Materials"
- "Journal of Food Engineering"
- "Journal of Hospital Infection"
- "Advanced Materials Research"
- "Futures"
- "International Journal of Production Economics"
- "Food Microbiology"
- "Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)"
- "Information Systems Frontiers"
- "Trends in Food Science {\\&} Technology"
- "Advance Journal of Food Science and Technology"
- "IEEE Sensors Journal"
- "Journal of Web Semantics"
- "Trends in Food Science and Technology"
- "Enterprise Information Systems"
- "Personal and Ubiquitous Computing"
- "Procedia - Social and Behavioral Sciences"

16) Appendix H - keyword reference table

Keyword	References
IoT	(Abdul-Salaam et al., 2015; Atzori et al., 2010; Barnaghi et al., 2012; Yu Gu & Jing, 2011; Lee et al., 2015; M. Z. Wu et al., 2013)
Benefits of IoT in Food and Agriculture	(Beecham, 2014; B. Chen, 2014; Q. Chen et al., 2015; J. H. jeong Choi & Graham, 2014; Dlodlo & Kalezhi, 2015; Dobbs et al., 2015; P. Duan et al., 2013; Y. P. Duan et al., 2014; Foley, 2015; Gilpin, 2015; Huang, 2014; Kobie, 2015c, 2015a, 2015b; Pang et al., 2015; Saguy et al., 2013; Sam Saguy, 2015; Sivamani et al., 2013; Thomas, 2015; P. Wang et al., 2015; Wilusz et al., 2013; Z. Wu et al., 2015; L. Xing et al., 2015; Xiong et al., 2015)
Connecting Consumers	(Fountas, Carli, et al., 2015; van der Loo et al., 2015)
Control of spoilage	(Cheng et al., 2014; Ellis et al., 2015; Y. Shi et al., 2015; Dengwei Wang et al., 2014; S. Yan et al., 2012; G. Zhao, Guo, et al., 2015; G. Zhao, Sun, et al., 2015)
Farm Management	(Kirubakaran, 2014; N. Lin & Yu, 2013; Misra et al., 2015; R. Tao et al., 2014; K. Taylor et al., 2013; Y. Yang & Fang-Tsou, 2014; Ye et al., 2013; L. Y. Zhang et al., 2013)
Food & Smart Product Ontologies	(Aung & Chang, 2014; Batista & Pardal, 2006; M. F. Chen & Huang, 2013; d'Aquin et al., 2012; LOV4IoT, n.d.; Maksimovic, Vujovi, et al., 2015; Pizzuti et al., 2014; R Ribeiro et al., 2006; Ricardo Ribeiro, Batista, Pardal, Mamede, & Pinto, 2006; "SmartProducts Network of Ontologies," n.d.; Snae & Bruckner, 2008b)
Food Monitoring & Traceability	(2011 The International Bank for Reconstruction and Development / The World Bank, 2011; Akoh et al., 2011; Aquin, Motta, Nikolov, & Thomas, n.d.; Gnimpieba, Nait-Sidi-Moh, Durand, & Fortin, 2015; W. Han et al., 2015; Hanyu et al., 2011; Jebb, 2012; Karoppacheril, Rios, & Srivastava, 2011; Maksimovic, Vujovi, et al., 2015; Pang et al., 2015; Qiang, Kuek, Dymond, & Esselaar, 2011; Qin et al., 2016; Sakthipriya, 2014; S Sen & Choudhary, 2011; Soham Sen & Choudhary, 2009; Shackell, 2008; Sources, 2008; Sylvester, 2012; Verdouw et al., 2016; S. Yan et al., 2012; Yin et al., 2011; Q. N. Zhang et al., 2013; X. Zhao, Fan, et al., 2015)
Health & Nutrition	(Boulos et al., 2015; Lee et al., 2015; Reitberger et al., 2014; Vazquez-Briseno et al., 2012; Wei et al., 2013; X. Xing et al., 2013)
Intelligent Packaging	(Heising et al., 2014; Chad Jones, 2014; Vanderroost et al., 2014; Wilder, 2015b)
Lifecycle Monitoring	(Andrews, 2015b; J. Chen, Hu, Wu, Si, & Lin, 2014; DOINEA et al., 2015; W. Han et al., 2015; Hornyak, 2014; Jayaraman et al., 2015; C Jones, 2014; K. Liu, 2015; Qi & Zhang, 2013; Qiu et al., 2013; R. Z. Shi et al., 2013; Thu Ngo Quynh et al., 2015; Verdouw, Sundmaeker, et al., 2013; A. Wang & Zhang, 2014; M. Z. Wu et al., 2013; Ying & Fengquan, 2013; L. Zhang & Zhu,

	2015; X. Zhao, Fan, et al., 2015; B. G. Zheng, 2013; X. Zheng & Cheng, 2015; L. Zhou, Song, Xie, & Zhang, 2013; Zou et al., 2014)
Logistics	(He & Chu, 2014; C Jones, 2014; Verdouw, Vucic, et al., 2013; Zou et al., 2014)
Precision Agriculture	(Anderson, 2016; Bajwa, Mahajan, & Chauhan, 2015; M. T. Bamsey, Berinstain, & Dixon, 2014; M. Bamsey et al., 2012; Bash & Fallis, 2015; Beecham, 2014; Blank, Bartolein, Meyer, Ostermeier, & Rostanin, 2013; Car, Christen, Hornbuckle, & Moore, 2012; Casadesús, Mata, Marsal, & Girona, 2012; E.-Y. Choi, Yoon, Choi, & Lee, 2015; Coates, Delwiche, Broad, & Holler, 2013; Del Frate, Latini, Picchiani, Schiavon, & Vittucci, 2014; Domingues et al., 2012; Feshback, 2015; Gebbers & Adamchuk, 2010; Goumopoulos, O'Flynn, & Kameas, 2014; Gutierrez Jaguey et al., 2015a, 2015b; Gutierrez et al., 2014; Harper & Siller, 2015; Iftikhar & Pedersen, 2011; Jackenkroll, Weis, & Gerhards, 2013; Jahanshiri & Shariff, 2014; Kaivosoja et al., 2014; Kanoun et al., 2014; Kim et al., 2013; Kloppenburg Jr, 2008; Kloppenburg, 2014; Lemmens, 2010; Link, Senner, & Claupein, 2013; Lowenberg-deboer, 2015; Morales, Álvaro, & Urrestarazu, 2014; Nicolosi & Ruivenkamp, 2013; O'Shaughnessy, Evett, & Colaizzi, 2015; Pantazi, Moshou, Mouazen, Alexandridis, & Kuang, 2015; Pardossi & Incrocci, 2011; Pesonen et al., 2014; Pontikakos, Tsiligiridis, & Drougka, 2010; Rankin & Rankin, 2015; Rickard, 2015; Rius, Andrade, & Riu, 2014; Rodríguez, Reca, Martínez, & Urrestarazu, 2015; Ruiz-Garcia, Steinberger, & Rothmund, 2010; Schütze, de Paly, & Shamir, 2012; Security, 2015; Stewart, 2005; Story & Kacira, 2015; Szilágyi & Tóth, 2015; Tey & Brindal, 2012; Tsioumani, Muzurakis, Ieropoulos, & Tsioumanis, 2015; von Haaren, Kempa, Vogel, & Rüter, 2012; Winge, 2006; Winner, Grant, & Murrell, 2016)
Refrigeration	(Y. Y. Chen et al., 2014; Kaneshige, 2015a, 2015b; Vanderpool, 2015; L. Z. Wu & Zhao, 2013; Xie et al., 2013)
Supply Chain	(Badia-Melis et al., 2015; Ha et al., 2014; F. Zhang, 2013a; G. Zhang, 2014; B. G. Zheng & Wang, 2014)
Systems	(Bertolini et al., 2013; Brizzi et al., 2013; R.-Y. Chen, 2015; W. Han et al., 2014; Hou & Zhu, 2012; Yanfei Liu et al., 2013; Min-Ning et al., 2014; T. Xing, 2014; Q. N. Zhang et al., 2013; Y. J. Zhang & Chen, 2014)
Waste Management	(Amores et al., 2015; Hong et al., 2014; P. Ponmalar & V. Sampath Kumar, 2014; R. C. Song et al., 2015)
Apps	(Aizaki, Nakashima, Ujiie, Takeshita, & Tahara, 2010; Albrecht, Larvick, Litchfield, & Weishaar, 2012; Antonopoulou, Karetsos, Maliappis, & Sideridis, 2010; Badia-Melis et al., 2015; Behnke & Seo, 2015; Çelik Ertuğrul et al., 2014; Çelik Ertuğrul, 2016; Delgado, Kowalski, & Tebbe, 2013; Enenkel et al., 2015; Fridholm & Fridholm, 2014; Gassner, Vollmer, Prehn, Fiedler, & Ssmoller, 2005; Gómez-Robledo et al., 2013; Gutierrez Jaguey et al., 2015b, 2015b; Hossain, Jigyasha, Local, & Content, 2011;

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Specific Foods	(Campos & Cugnasca, 2015; Haass et al., 2015; Y. Han & Wang, 2015; Jia; et al., 2014; Liang et al., 2015; LUO et al., 2013; Meng et al., 2015; Shilong et al., 2014; B. Xu et al., 2013; Bo Yan et al., 2012; F. Yang, 2014; H. Y. Zhang & Chen, 2013)

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