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The Use of Sensing and ICT to Improve the Sustainability of International Food Production and Distribution Systems

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Executive Summary

The AWARE project addressed the sustainability of global food production and distribution systems, with a focus on fresh perishable produce. The project's main aim was to identify how sensing, data and Information and Communication Technologies (ICTs) can be used to improve sustainability, in particular, to drive waste reduction. The key points identified are described below.

Waste is not actually the problem, just the symptom of quality problems which are themselves symptoms of other problems, such as decisions taken by growers concerning when to irrigate, when to apply nutrients, when to harvest, and so forth. The quality of fresh produce fed into the supply chain is in fact determined by such pre-harvest decisions, and also at-harvest conditions, as well as actions taken in the immediate postharvest period, including in addition the natural variability of quality parameters across the growing season. Further quality issues can then arise, postharvest, as a result of the way in which produce is handled and stored on its way from the farm to supermarket distribution centres.

Quality of fresh produce is becoming more important to retailers. Quality however can be defined in many ways, including size, weight, shape, appearance, flavour, nutritional value, provenance, shelf life, etc. All are relevant to the issue of waste as these are the quality dimensions against which fresh produce is judged, and either accepted or rejected (by supply chain participants or consumers).

Food production and distribution system are very complicated. There are several reasons for this, which include: (i) harvested fresh produce is still alive in the sense that biological processes are still underway; (ii) there are many factors that influence produce quality; (iii) quality is not defined by a single parameter; (iv) there are a vast range of produce characteristics and, in addition, varietal differences; (v) a large number of growers can be feeding produce into one export hub or packhouse; (vi) multiple transport modes are used; etc.

Waste in farm-to-retailer supply chains is not a simple concept, for it is evident that true waste, in the sense of produce that has no use at all, is not the main concern. Primarily the key issues relate to the additional use of energy and the carbon emissions that arise from the extra transportation and processing of produce that has been rejected as unacceptable by one of the supply chain actors (e.g. the retailer).

Also of importance are issues of efficiency of use of natural resources with respect to food production. The consequence of diverting food grown for human consumption, to non-food uses, which is sometimes the result of produce rejection, has impacts upon the availability of food, as well as price. The sustainability of food production and distribution systems is therefore a complex issue and simple metrics (such as tonnage of food not reaching the retailers' shelves or carbon footprint) will not suffice.

Many quality problems arise as a result of physical handling of produce and the ambient conditions to which the produce is exposed, both of which can lead to loss of quality, and hence, in the end, to waste. There is clearly scope for improvements in supply chain practices, for example, the handling of fresh produce at airports could be improved to ensure that quality is less likely to be compromised.

Quality problems also arise as a result of actions that are taken at the growing stage (pre-harvest), during harvesting (at-harvest), and in the immediate time after harvesting (immediate postharvest). It is here, at the grower/farm/packing end of the supply chain where the quality of fresh produce is determined. All the supply chain can do is to maintain this

quality, which sometimes it is unable to do. Hence, to tackle waste, it is also necessary to address the quality of the produce fed into the supply chain, as well as to make improvements to the supply chain.

The project has established that the data available to Tesco concerning customer complaints about fresh produce, data that originates from the *dotcom* business, is somewhat deficient in terms of content. Furthermore, it is isolated data in the sense that it is not linked back into ERP systems and associated to particular suppliers or growers or both. Moreover, the data is also post-event, meaning that it is of no use, for example, in undertaking real-time quality management of produce in the supply chain. Its main potential use would be for quality improvement activities. This is how the data is used at the present time, but in a manual way. The challenge is to find the means of using the data for automated identification of quality issues in the food production and distribution supply system, by combing the *dotcom* data with other data available from the supply chain, or data that could be generated from sensing and ICTs implemented on-farm.

The use of RFID-based sensing and quality prediction, in the context of modern complex international farm-to-supermarket fresh produce supply chains, has also been analyzed from the perspective of its potential to improve the sustainability of food production and distribution systems, specifically by identifying technologies to assist in reducing postharvest losses. Examined in the context of the research were: (i) the use of quality or expiry based issuing policies; (ii) the use of container level temperature sensing; (iii) the concept of produce redirection; and (iv) use of quality prediction techniques. Analysis indicates that there are many issues, concerns, and limitations relating to the above concepts that effectively render them, in modern supply chains, either impracticable, or inappropriate, or infeasible, or all three.

Broadly the work undertaken points towards a systems level approach to sustainability, where sustainability for the whole system is defined, with sensing and ICT being used as a quality improvement tool, and also, perhaps, to forward predict quality problems. In the light of findings, an outline concept of a Sensor and ICT system for sustainability improvement has been developed. This system is focused on providing capabilities that can be deployed for quality improvement support, as well as quality predictions. Three key research areas have been identified that would need to be addressed to realise such a system. These three areas are: (i) sensor cost reduction to enable box or item level sensing; (ii) the use of data mining techniques instead of predictive models based on equations or data tables; and (iii) extending data collection backwards into the pre-harvest and at-harvest phases. To move forward towards the realisation of the proposed system concept, research is especially needed in the area of pre-harvest and at-harvest sensing, as well as the computational processing of data that is required to extract knowledge and useful information from the sensed data and other data inputs.

1. Introduction

AWARE (*Active Waste Analysis to Reduce Environmental-impact*) addressed the topic of "waste" in fresh (perishable) produce (fruit and vegetables) supply chains. These chains begin with the grower (or farmer) and end with the retailer, but AWARE also considered the consumer in the specific context of a source of "complaints data" concerning fresh produce. The intention was to focus on data, information, and Information and Communication Technology (ICT) systems, and how these potentially could be used to reduce waste.

AWARE was a nine month exploratory project that started on April 1st 2009. The specific objectives of AWARE (as stated in the original proposal) were to:

- Identify the nature of the data available (both from retailers and agri-businesses) and its potential to provide useful information to drive waste reduction (supply-side perspective) and to inform and reassure customers about environmental impacts (demand-side perspective);
- Build upon the outcomes of the analysis phase and on the results emerging from existing projects, to consider and define how the available supply-side and demand-side data, could be utilised to extract value for supply chain participants and to improve sustainability;
- Develop the system concept for the integrated data-driven information and knowledge management system;
- Formulate the research programme that will need to be undertaken to bring the system concept to realisation.

This document is the final project report. It describes what has been done, key findings, and presents conclusions concerning what needs to be done in the sphere of sensing and ICT research, in light of what has been discovered.

2. Background

The Syngenta Sensors University Innovation Centre (referred to as Syngenta Sensors for short) is undertaking research in the area of sensing and data processing relating to fresh produce supply chains. The primary focus of Syngenta Sensors' fresh produce supply chain research has been on postharvest temperature measurement, and the use of this data to predict shelf-life (specifically the vase life of cut-flowers) using data mining techniques. Additionally the group is also developing a new generation of lost-cost RFID (Radio Frequency Identification) temperature sensors for fresh produce supply chain applications.

The principle underlying the work on shelf-life prediction is that shelf-life is influenced by temperature stresses experienced in the supply chain. Hence, predicting shelf-life based on actual temperature stresses experienced, rather than using a standard shelf-life number (days), as is presently the case, would allow better management of fresh produce supply chains, including waste reduction. The AWARE project sought to better understand the potential for waste reduction using a data-based approach.

Syngenta Sensors' research on shelf-life prediction is being undertaken by a PhD student who is investigating and comparing various data mining techniques. To facilitate these investigations, Syngenta Sensors has undertaken two field data collection experiments, involving recording temperatures in cut-flowers supply chains. The first of these supply chains was based on roses shipped from a small grower in Jersey, followed by vase life testing in the

UK. The second of these supply chains was also based on roses, but this time transported in an international supply chain from Kenya to the UK, with vase life testing undertaken both in Kenya and in the UK. This particular supply chain is operated by World Flowers, who supply cut-flowers to Sainsbury and Tesco. The PhD student is currently investigating several different techniques and comparing predictions with the actual vase life established as part of the experimental work.

Undertaking these experiments provided an opportunity for Syngenta Sensors to engage in discussions with both growers and the technical personnel involved with these supply chains. This has proved to be invaluable in developing an improved understanding of the issues and complexities of shipping fresh produce from grower to retail market. This understanding has been further enhanced by the results of the Syngenta sponsored International Business (IB) project, undertaken by a team of MBA students in the Manchester Business School, in the early part of 2009. This MBA study (*In-Package RFID Sensor Technology for International Fresh Produce Supply Chains*) was directed at assessing the potential market opportunities for RFID sensors in fresh produce supply chains, and identifying value propositions and product offerings for the new RFID sensing technologies being developed by Syngenta Sensors. The work involved analysis of two international fresh produce supply chains, as well as discussions with growers, exporters, importers, category suppliers, and retailers.

The start of the AWARE project was specifically delayed until the work of the MBA students was completed, so that learning from the IB project could be used to focus efforts in the AWARE project. This, it turns out, was a wise decision, as the IB project not only helped to further refine Syngenta Sensors' understanding of fresh produce supply chains, but importantly highlighted some critical issues that needed further investigation.

3. Clarification of Scope

Food waste in the developed world has been recognised for a long time as being a significant problem. US Department of Agriculture Economic Research Service figures for 1995, estimate food waste by retailers, the foodservice industry, and consumers, at 96 billion pounds (weight), corresponding to 27% of the edible food available for consumption in the US (Kantor *et.al*. (1997)). Fresh fruit and vegetables account for 19.6% of this loss. Figures for the UK published by WRAP (2008), estimate food loss in UK households at 6.7 million tonnes of food every year, this being around one third of the 21.7 million tonnes of food purchased each year by consumers, with fresh fruit and vegetable accounting for about 21% of this total waste. The Food and Agriculture Organization (FAO) of the United Nations also estimate food losses in the developed world to be around 20%, but these again are at the level of retail, food-service, and consumers (Kader and Rolle (2004)).

Food waste however does not just occur in food retailing, in the foodservice industry, and at in the home (consumers), but also at the farm, postharvest, and in the subsequent processing and shipping before it is delivered to retailers. Reducing these postharvest losses is recognised by the agriculture sector as being an important contribution to the development of sustainable agriculture and thus postharvest losses are included as a metric in a sustainability index proposed by The Keystone Alliance for Sustainable Agriculture (2009).

Interestingly however, information about the scale of these postharvest losses is hard to find. Kantor *et.al*. (1997) report that the US Department of Agriculture Economic Research Service does not collect data on these losses. In the UK, the DEFRA report *Food Matters: One*

Year On (DEFRA (2009)), states that, with respect to reducing food waste and recovering energy, specifically relating to reducing food losses in the supply chain: "... the industry and regulators identified lack of knowledge on the composition and amount of waste in supply chains. WRAP is therefore calculating packaging, food, and non-food waste at all points within the supply chain and identifying opportunities to reduce waste."

This confirms what the AWARE project has discovered, namely, that at the time the study was undertaken there was a lack of information of the actual scale of food losses in fresh produce supply chains.

With regard to these farm-to-retailer food losses, broadly these can be categorised as follows (Kantor *et.al*. (1997)):

- Pre-harvest losses due to sever weather, disease and predation;
- Harvest losses attributed to mechanization, production practices and decisions;
- Storage losses attributed to insects, mould, deterioration, shrinkage, and spoilage;
- Discard of substandard produce;
- Shrinkage in storage;
- Poor handling or package failure;
- Transportation losses.

Shrinkage as used in the above is a trade term that refers to losses generally attributed to theft and fraud, not the physical shrinkage of fresh produce (which tends to be referred to a shrivelling).

The AWARE project focused on fresh perishable fruit and vegetables. Cut flowers were also considered, as this was Syngenta Sensors' starting point for its shelf life prediction research. Typically, the produce addressed in the AWARE project carried *Best Before* dates. Not considered were fresh produce that carried *Use By* dates, since the shelf life of such produce is related to microbial spoilage that often leads to pathogens harmful to human health. Also not considered were crops such as wheat, barley, soya, and the like, as these crops are mostly used in the food processing industry.

The AWARE project was primarily focused on losses that occur from harvest to arrival at the retailers' distribution depot. This therefore excluded several areas of waste. Notably, not addressed was food waste at the consumers' premises arising from wasteful life-styles and ignorance concerning the meaning of *Best Before* dates. Also not considered, were pre-harvest losses that arise from damage as a result of weather conditions. Mainly, the focus was on the pre-harvest period with respect to practices that might have some influence on shelf life, through picking and packing, then local storage and transportation, and finally to storage in a depot prior to shipment to retail premises.

Food waste also occurs once fresh produce leaves cold storage at the retail outlet and is placed in shop ambient conditions, and is then subjected to consumer handling. This aspect of food waste was also outside the scope of the AWARE project. However, this aspect of food waste is clearly important and the food retail industry is well aware that this is a problematic area with respect to quality issues, as do the research community (e.g. see Nunes *et. al.* (2009)). Nunes *et. al.* (2009) for example report that produce with expired *Best Before* dates can account for up to 25% of all in-store waste. This level of waste is very much dependent upon produce type. However, the nature of these in-store problems is much more difficult to resolve than those that lie back along the supply chain.

Finally, also not addressed in the project, was the matter of the sustainability of retailers providing consumers with out-of-season produce, which some might say is an unsustainable business practice. AWARE was seeking not to criticise and condemn this practice, but to understand more about the sustainability of fresh produce provision, both in-season and out-of-season, and to indentify what can be done to improve sustainability.

4. Research Method

The research method was based upon exploratory discussions with actors in the supply chain. These discussions were focused on harvesting, local processing and storage, transportation, and the subsequent storage of fresh produce prior to placement on retailers' shelves. The aim was to develop an understanding about how the processes work, as well as to identify the key issues and problems related to bringing fresh produce to market in a sector that is based on both local and global production, and to identify relevant factors influencing shelf life.

The research was supported by a literature search and study, which was used to both inform the discussions with actors, as well as to follow-up on issues identified during discussions. The literature search and study was also informed by the findings of the IB Project, and results that have emerged from the research of the PhD student working on data mining-based shelf life prediction.

The research method also involved a workshop with Tesco and Syngenta personnel. This was held at the beginning of the project so as to extract useful information from both organisations prior to undertaking more detailed work.

5. Motivation

Addressing the problem of food waste in the supply chain from farmer/grower to retailer (farm-to-retailer supply chain) is not just important because of the unnecessary carbon emissions and the energy use that result from growing, processing, transporting and storing fresh produce that never reaches the retailers' shelves or consumers' tables. Even if the whole farm-to-retailer supply chain were carbon neutral, the issue would still be relevant given the growing demand for food in developing nations, and the longer term challenge of feeding the world's population, which is forecast to grow to about 9.1 billion people by 2050 (United Nations (2005)).

Food is essential to life. Moreover, food prices are also important. Addressing food waste in the farm-to-retailer supply chain could potentially contribute towards both security of food supply, and lower food prices. Moreover, tackling food waste in the supply chain will help to improve the efficiency of use of natural resources (e.g. oil, land, etc.), helping to ensure that the energy that is used to grow crops, and then to process and transport them, is not wasted.

Consequently, food waste in the farm-to-retailer supply chain has a strategic importance that sets it apart from other areas of waste reduction.

6. Sweet Peppers Case Study

6.1 The Farm-to-Retailer Supply Chain

This case study relates to sweet peppers harvested in Israel during the winter season (late November to early April) and shipped to a Category Supplier in the Netherlands, where they are further processed and packed before being transported to the United Kingdom and delivered to UK supermarket depots.

The supply chain from Israel to the UK is complex owing to the number of transport modes utilized, the number of growers involved, and differing facilities at farms.

In Israel there are hundreds of small growers supplying sweet peppers for the European and US markets. Most of these growers sell their produce via a marketing cooperative that works to get the best price for these growers. It is the co-operative that exports the produce, and which works directly with the retailers and Category Suppliers.

Peppers are a produce with a fairly constant demand, with some peaks during hot summer weather in the UK. It is the co-operative (exporter) that agree with the growers the planting that will be needed to meet the expected demand. The growers then work to an agreed weekly target production.

Typically retailers will provide Category Suppliers with forecasts for demand, which are then updated weekly. However, for the Israel supply chain, the Category Supplier will always take the quantities which they have agreed to purchase, even if this means taking peppers that are not needed. Sometimes however the growers are requested to supply more than the agreed quantities to deal with increases in demand beyond forecasts. Moreover, the exporter will also take from the growers any excess supplies, as it is the job of the exporter to find a market for the growers' produce.

Individual growers each own small plots and are organized in small communities (called Moshavim). Each farm is independently owned and managed, and each consists of several glasshouses and a packhouse. Most growers are fairly unsophisticated with regards to growing facilities. The growing houses are generally not cooled or heated. If the growing house gets too hot the grower will open the windows. They also use net and plastic sheets to create shade. Some of the farms have chilling facilities to remove field-heat from produce, but others do not, and this complicates the supply chain. Within a Moshav there are some shared facilities, including a transit station.

Generally peppers are harvested early morning. The main reason for this is to avoid picking during the hottest part of the day when the field-heat in the peppers will be higher. This is important for quality reasons (see later). At each grower, cut peppers are placed into crates, which are then transported on an un-chilled trailer to a packhouse.

At the packhouse the harvested peppers are washed and dried, and then sorted by weight. This sorting stage is an important step, as weight is a key parameter in the supermarkets' quality specification. There are different specifications for each customer as well as country, with the bigger peppers being sent to the USA, and those that fall below European supermarket specifications being sent for sale in local markets.

Once the peppers have been boxed for despatch to market, the supply chain becomes more complicated.

Some produce is placed in chillers at the packhouse (where such facilities exist) to remove the field-heat. These chillers are normally a cold room at 8 ^{0}C. The peppers are then transported in refrigerated trucks to a central transit station where produce is consolidated into a single shipment for export. In other cases produce is sent to a local transit station (a Moshav facility shared among growers) from where it is sent in refrigerated trucks to the central transit station. On receipt at the central transit station the produce then has to be chilled to remove field heat, again in a cold room.

The grower can also reserve some produce and send this to what is called a Traffic Light Packhouse, Traffic Light being the term used to describe the combination of a red, yellow, and green pepper in a single packet. After this stage, the produce can again either be chilled on-farm, and then transported to the central transit station, or sent unchilled, where upon receipt it is placed into chillers.

At the central transit station a data logger will be placed into one box for each shipment, and these boxes are then transported on pallets to port, in a refrigerated truck.

The produce exporter has a new ship specifically designed for shipping fresh produce. This ship has on-board chilled storage rooms that are dedicated to specific types of produce. This enables produce to be stored under ideal conditions. Such facilities are however unusual, and other shipments are transported using ships where produce is placed in on-board storage facilities along with other produce, which means that the peppers are not stored under ideal conditions.

Note that for the case of green peppers, which have a shorter shelf life than other peppers (red and yellow), air freight is sometimes used.

When the shipments arrive at a European port they are transferred to refrigerated trucks and driven to the Netherlands. Here they are further processed, which involves unpacking and repacking as necessary, as well as quality inspections. From the Category Supplier, the peppers are transported by road to the UK in refrigerated trucks.

6.2 Quality Issues

Quality problems for peppers are numerous. A major concern for the exporter and grower is the removal of dust from the peppers. Supermarkets have a zero tolerance to this as consumers might perceive this dust as pesticide residue. The dust comes from the wind, especially sand storms. Although the peppers are washed (with water and brushes and high pressure water jets), some dust remains so it has to be removed by hand. There is therefore a need for better washing of peppers.

Rot on stems is the second most significant problem. This is caused by spores, the growth of which is accelerated by temperature and humidity. Stem rot is tackled by the use of chemicals. Nevertheless, the on-set of stem rot is still problematic, and once underway can cause spoilage of other unaffected peppers. Hence efforts are devoted in the supply chain to spotting this problem and removing affected peppers.

Although peppers are not regarded as a very temperature sensitive crop, temperature problems can occur. The preferred storage temperature range for peppers is in the band 7 ^{0}C to 10^{0}C. If peppers are kept within this temperature range, then there is unlikely to be any significant loss of shelf life. If peppers are allowed to go above 10^{0}C there will be some reduction in shelf life, although a few hours above 10^{0}C can be accepted.

Pepper harvesting normally occurs in the early morning, since high pulp temperatures of harvested peppers can, if left for more than a few hours, lead to shrivelling, softening, and eventually disease infestation. In addition, temperatures greater than 21^{0}C greatly accelerate ripening and colour changes.

Peppers are also sensitive to chill injury. Cooling them to temperatures below 7^0C can result in softening, pitting, and predisposition to decay. Overcooling is just as serious a problem as undercooling.

Because of their high impact and pressure-sensitivity, sweet peppers must be treated with great care during picking, handling, packing, transport and storage, otherwise they may spoil prematurely.

Another feature of sweet peppers is that the shelf life is variable across the growing season. At the beginning of the growing season shelf life can be as low as two weeks, improving towards four weeks in the mid-growing season, deteriorating back to two weeks towards the end of the growing season. Shelf life is shorter for the early harvested peppers because the wall thickness of the peppers is thinner than later in the growing season, and it is the thinner pepper wall thickness that results in the shorter shelf life. As the growing season draws to a close however, plants become tired and more stressed resulting in poorer quality peppers and a short shelf life.

6.3 Rejection and Waste

Quality inspection occurs at several points in the supply chain, starting at the grower and ending with the retailer. At each of these points produce can be rejected. Information provided by a Category Supplier shown in Table 1, is indicative of the reasons for produce rejection:

Rejection Type	Percentage (of total rejections)
Bruising	44%
Under-ripe	10%
Temperature stress	9%
Shrivelled/soft fruit	8%
Decay/rotten	6%
Mechanical Damage	7%
Split Peppers	3%
Chill damage	5%
Transport Damage	2%
Stalk Damage	1%
Other	5%
Total	**100%**
Percentage of Total Rejections for which no Commercial Resolution was found	7%

Table 1: Category Supplier Rejections of Peppers for winter season (Nov 2008 until Feb 2009)

Table 1 shows that the most significant cause of produce rejection lies in bruising, much of which is caused when peppers are dropped into cleaning and sorting machines, reflecting the high impact and pressure-sensitivity of peppers. Note that only 7% of the rejections lead to a circumstance where there is no commercial resolution, meaning that the peppers cannot be sold. Effectively this 7% is the waste that results from quality problems.

Rejections of produce by the category supplier can lead to produce being returned back into the hands of the exporter, who then has the challenge of finding commercial outlets for this produce.

Note that temperature issues for peppers do not represent a significant problem compared with other quality problems and this reflects the peppers' relatively low sensitivity to temperature stresses. Temperature issues are estimated to typically amount to one truck per week, with about one truck every two weeks leading to an insurance claim. One lorry amounts to 3000 pallets, with 110 boxes per pallet, each box weighing 5 kg. Generally, if peppers are allowed to go above 10 degree C, then there is a reduction in shelf life, which is dealt with via an insurance claim. However, a couple of hours above 10 degree C can be accepted. Note also that produce subject to temperature issues is not necessarily wasted. Produce in this circumstance has to be assessed by insurance loss assessors to determine what should be done with it, which might include some commercial resolution, depending upon the circumstance, and this is part of the process of handling the claim.

Note that there is some chill damage experienced in the supply chain. The main reason for this appears to be setting refrigeration in the trucks at levels that lead to damage to produce located close to the chiller unit. This usually happens when the supply system is struggling to meet the availability requirements set by the retailers. Under these circumstances, where availability is an issue, there is a tendency to shift produce before the field heat has been fully removed. The setting of truck chiller units at lower than recommended temperatures, is seen as a way of compensating for this, but at the price of damaging produce close to the chiller units. When chill damage occurs, the damaged produce becomes unusable, and this damaged produce is subject to an insurance claim.

Further produce rejections can occur at the supermarket receiving end of the supply chain. Indicative figures are that rejection rates at the supermarket depot are less than 0.25%.

6.4 Key Observations

The key observations from this case study of relevance to the AWARE project are described below. There are two key points.

The first point is that, not only is the supply chain complex, but so are the factors influencing produce quality, as well as the features that define quality, and it is primarily quality the determines produce rejections. But rejections do not necessarily imply food waste, since just because a supermarket determines that produce is unacceptable, does not mean that the wider market sees it as such. What happens because of the way the supply chain is structured and operates as a system at the present time, is that produce rejections lead to further use of energy (mostly in transportation). This means that the issue of waste is not a simple one, and the sustainability of farm-to-retailer supply chains is unlikely to be adequately measured through simple metrics such as tonnage of food disposed of to waste, or carbon footprinting.

The second point is that quality is clearly also primarily determined at source (the grower). If the quality of produce that feeds into the supply chain is compromised, the supply chain can at best only maintain this input quality, which clearly it is not always successful at delivering. At times the supply chain system may even be itself compromising quality. It is evident therefore, that since quality is the important variable, it is necessary to tackle the factors that influence quality, and to ensure that the whole supply system, from grower to retailer, is designed to maximise quality, and when quality is damaged, the system design is such that the resulting responses involve the minimum possible additional use of energy. The key to achieving this will undoubtedly involve a systems level approach to production and distribution.

7. The Main Issues

The case study considered above, along with discussions with Tesco, Syngenta, an Exporter, and Category Suppliers, and reviews of the literature on postharvest produce management, point towards several important issues.

7.1 Waste is not the Problem, only a Symptom of Other Deeper Rooted Problems

Although the AWARE project addressed waste, it is evident that waste is not actually the problem. Waste is just a symptom of a deeper underlying problem, which is the quality of fresh produce. Fresh produce is normally rejected in the supply chain for only one reason, and that is the quality of the produce. But quality should also not be considered as the problem, but also a symptom of even deeper rooted problems.

As mentioned previously, what ultimately determines whether the quality of fresh produce is acceptable to retailers is the quality of the produce that enters the supply chain, since the supply chain does not improve quality, only maintain it, or ensure that loss of quality is minimal.

There are several factors that can serve to compromise the quality of the produce entering the farm-to-retailer supply chain:

7.1.1 Uncertain demand

The fresh produce sector is one of those areas of business activity where demand can at times be subject to uncertainty, as well as seasonal variations in demand. For example, (unpredictable) very hot summer weather in the UK leads to an increase in demand for salad crops, and a fall in demand for vegetable crops that need cooking. This type of circumstance can lead to a postponement in the picking of vegetable crops, which can have a knock-on effect on produce quality in terms of shorter shelf life. Short shelf life means that the quality of such produce is more likely to be compromised, and this increases the probability of rejection, either in the supply chain, or at retail outlets. Moreover, some types of produce cannot be stored in fresh form (for example most soft fruits) for very long, so the lack of a market for produce owing to uncertainty in demand creates the potential for waste.

7.1.2 Handling practices

Fresh produce is generally cleaned before packing, and also tends to be transported in cardboard boxes in the early stages of the supply chain. Cleaning and scrubbing of produce can result in damage. If cleaning is not done properly it can lead to rejection as off-specification produce. Too much scrubbing can also be deleterious to produce. Use of cardboard leaves produce susceptible to mechanical damage when boxes are handled or stacked. Item level packing (for prepared vegetables) can also be damaged through handling.

7.1.3 Growing practices

The literature on pre-harvest influences upon postharvest quality (e.g. Hewett (2006a)) indicates that factors such as irrigation, growing environments, local climate, weather, maturity of crop at harvest, administration of nutrients and crop protection chemicals, and such forth, can affect produce quality, including both physical appearance and shelf life. For example, there is evidence in the literature that the use of artificial light to extend the daily growing time for roses, causes the stomata on rose leaves to remain open during dark periods (Mortensen and Gislerød (1999)). This results in greater water loss from rose plants, which correlates with shorter vase life. Likewise failure to apply crop protection chemicals such as Botryticides at the right time, can lead to increased likelihood of Botrytis infections in cut roses once they have been packed and shipped.

7.1.4 Temperature Stresses

Temperature stress can be very damaging to the quality of fresh produce. Temperature stresses can occur in several places between harvest and retail store. For example, if produce is picked, but then left in the field too long without protection from direct sun, or is not temporarily placed in a mobile chilled storage units in the field, then the produce can be damaged (e.g. wilting through moisture loss which reduces shelf life). Moreover, if field heat is not properly removed from harvested produce, then this heat is likely, later in the supply chain, to cause temperature stresses. The problem with fresh produce, unlike other items transported in cold chains (such as meat, fish, pharmaceuticals), is that fresh produce is still alive, with biological processes still underway (but without access to the water and nutrients that the plant provided). Consequently, the produce is capable of generating heat. If fresh produce has not been properly taken down to the required chilled storage temperature, remaining field heat could prevent the chillers used in transportation systems from maintaining the desired chilled temperature, since most of these chillers are not designed to remove heat, just to maintain produce at a desired temperature. A further problem is that it is usually very difficult to maintain produce at optimum chilled storage temperature. One issue is that specific produce have unique ideal storage temperatures, and when one type of produce is transported with another type of produce in the same container, which is often the case, then the storage temperature has to be a compromise among the different temperature requirements. Another issue that arises with produce that is packed into item level packs, is that temperatures in the packhouse needs to be set at a level that people can work in, which is not optimum for the produce.

7.1.5 Exposure to Ethylene and Humidity

Different fruits and vegetables not only have different requirements with respect to storage temperature, but also have different requirements with respect to ideal storage humidity. Moreover, sensitivity to ethylene (a plant hormone which triggers ripening) also varies. Exposure to the incorrect humidity can be damaging to fruit and vegetables, leading to increased loss of water from the produce (if humidity is too low), or the onset of disease such as Botrytis (if the humidity is too high). Exposure to ethylene, even very small quantities, can cause premature ripening and then senescence.

7.1.6 Plant diseases

Plant (crop) diseases do not just manifest themselves while the plant is still growing; they can also appear later in the supply chain. Botrytis infections in cut flowers and soft fruit are an example of this. Cross infections can also occur, from one produce to another, when the produce are brought into common storage areas typically found in receiving and storage depots.

7.1.7 Supermarket specifications

Supermarkets in the UK are perceived at being more fussy concerning size, weight and appearance of fresh produce, than those in other parts of Europe. Moreover, the acceptability to consumers of misshapen fruit and vegetables is reported as being higher in some parts of Europe than it is in the UK. It is clearly the case that supermarkets are setting standards through their produce specifications that lead to rejection of produce that is edible, nutritious and fit for consumption, although this does not however mean that such produce is wasted.

7.2 What is Waste?

The term *food waste* conjures up images of food being taken to landfill sites for disposal. This image is probably more correctly associated with food waste at the level of consumers. It does not generally apply however to the farm-to-retailer supply chains that have been considered in the AWARE project, although how general this circumstance is for the sector, is not clear.

Rejection of produce can occur at the farm, or the packhouse, or at various depots (exporter, importer and retailer), on grounds of failure to conform to specifications (usually size, weight and appearance). Moreover, produce can be rejected as a result of failures to maintain the cold chain, that is to say, on evidence of exposure to unacceptable temperature stresses. Such evidence is usually provided by data loggers or RFID-based temperature sensors placed within produce boxes. Some produce is also rejected because of damaged packaging.

Rejected produce however does not necessarily end up in landfill, and this is not just because landfill is expensive.

Clearly any produce that does end up in landfill is a waste and can be quantified accordingly by the tonnage. But quantifying waste in farm-to-retailer supply chains is more difficult because rejection does not necessarily trigger disposal, but redirection to other markets.

Discussions with suppliers and exporters have revealed that produce that does not meet supermarket specifications is not necessarily wasted. The peppers' supply chain illustrates what can happen to fresh produce.

First to note is that supermarkets do not have uniform specifications. With peppers for example, larger ones are shipped to the US since that is the preference in the US market. Those peppers that do fit UK supermarket specifications can be fed into wholesale markets, and some produce can be sold in local markets.

It should be noted however, that this latter option only exists in countries with a local market that is able to pay the prices that would enable growers to recover their costs and make a profit. In developing countries, which is often where fresh produce is grown for markets in developed nations, such local markets often do not exist. In such countries, circumstances could potentially develop whereby local people could be short of food, even though there is plenty of food available. Issues such as this need to be addressed as part of the improvement to the sustainability of global food production and distribution systems.

Peppers that have been exposed to temperature stresses, and are unacceptable to supermarkets, could still have use once they have reached Europe. They might, for example, still be acceptable to the wholesale market. Produce in this circumstance has to be assessed by insurance loss assessors to determine what should be done with it as part of the process of handling the claim. Note that insurance claims are the means by which supply chain participants handle issues of compensation when produce becomes unacceptable owing to supply chain temperature stresses or other types of damage.

In another case examined, fresh produce packed at source, when rejected, is either sent to be used as animal feed, or is given to charities.

The key point is that, what happens as a result of these produce rejection decisions, is not direct waste in the form of produce sent to landfill, but produce redirection and redeployment, which leads to indirect waste as a result of additional processing (e.g. repacking and transportation). Thus the waste issue in these circumstances tends to be one of additional energy use as a result of these redirection activities, which comes on top of the energy that still has to be utilized in providing the produce that the supermarkets ordered. In addition, as a result of the use of fresh produce for animal consumption, there is an issue of efficiency of the use of natural resources (i.e. land and energy) for food production.

The above issues point towards metrics for measuring the efficiency of fresh produce supply chains that go beyond mere measures of food waste of the form seen in publications such as the WRAP (2008) Food Waste Report, *The Food We Waste*. Waste may in fact not be the right term to use for these farm-to-retailer supply chains.

7.3 Quality

Fresh produce is important to supermarket retailers, as it is classed as a *destination category*, that is to say, it is a category for which consumers will switch stores (Feare and Hughes (2000)). Fresh produce is also predominantly own brand and is subject to quality specifications with regard to parameters such as size, weight, appearance, and so forth, depending upon the specifics of a particular produce.

Quality is made up of many attributes, both intrinsic and extrinsic (Shewfelt (1999); Hewlett (2006a)). Intrinsic features of the product include key external attributes such as colour, shape, size, and freedom from defects. In addition, internal attributes include texture, sweetness, acidity, aroma, flavour, shelf life and nutritional value. Extrinsic factors refer to production and distribution systems. These factors include chemicals used during production, package types and their recycling capability, and the sustainability of production and distribution in relation to energy utilisation.

Both intrinsic and extrinsic factors are likely to influence consumer's decision to purchase, and quality in both senses is becoming an important issue for consumers. No longer is price the sole determinant of consumer purchasing decisions; consumers are looking for other attributes such as an organic or a sustainable provenance, nutritional value, produce safety, flavour, etc. with the latter attribute being particularly important with respect to the potential for creating waste.

Traditionally the focus of growers has been upon crop yields and robustness. In the past, plant breeding programmes have been driven by these grower-centred concerns. Unfortunately delivering yield and robustness attributes has tended to result in produce with less flavour.

It is evident that Tesco have a developing interest in the quality of fresh produce, reflecting changing consumer preferences. Syngenta also are moving towards a more consumer-centric view, recognising that the ultimate customer for what they do is in fact the consumer. Implicit in this therefore, is a greater interest in fresh produce that tastes good, as well as fresh produce that has good keeping qualities (shelf life).

This however means that the challenges of maintaining cold chain to ensure that produce is not temperature stressed, will become more important, because temperature stress not only reduces shelf life, but also affects flavour. For example, sweet corn suffers physiological deterioration due to both conversion of sugars to starch and its high rate of respiration. The former leads to a rapid loss of flavour, the latter to the generation of heat, resulting in loss of shelf life and the onset of senescence. Consequently, it is possible for produce such as sweet corn to still have a viable retail shelf life, but to have lost quality owing to loss of flavour.

This observation is an important one, as the orientation of research relating to temperature stresses tends to have a single-minded focus on shelf life prediction. Yet it is evident from discussions with Tesco and Category Suppliers that some produce (such as sweet corn) have more complicated quality issues. These produce also tend to have a high value, and are often transported by air. Such produce pose the most significant problems for suppliers and retailers, and are the source of most dissatisfaction (see below).

7.4 Critical Problem Areas

Much of the fresh produce reaching the supermarket shelves has been moved from farm to depot using either sea or road transportation or a combination of the two. Very little is flown into the UK. Tesco quoted a figure of 1.4% of their total fresh produce coming by air freight. Although this is a very small percentage of the total, air freighted produce is the most significant problematic area with respect to quality issues.

Air freighting of produce is expensive and is used because, to ensure year round supplies, short shelf life produce has to be grown in distant places, and hence air transport is the only feasible means of delivering this produce to the UK within the timescale implied by the shelf life. Most of this produce is also high value, and is often also the produce which is most sensitive to temperature stress. Several types of produce fall under this category, including soft fruits and some baby vegetables. Some of this produce is also pre-packed, or is prepared vegetables placed into modified atmosphere packaging.

This circumstance is somewhat ironical, given that air freighting tends to be the logistics option where maintaining the cold chain is the most difficult. The main problem lies at the airports, and the fact that airports and air traffic movements are not designed to deal with the special needs of fresh produce.

7.5 Data Availability

As part of the AWARE project the availability of data that could help to monitor, control or improve produce quality has been considered.

A primary focus has been on data that is available from Tesco. At the consumer end there are two sources of data: that which is generated from complaints made in-store, or over the telephone; and data generated from Tesco's *dotcom* business.

The former set of data is very limited in terms of the number of complaints in total, as well as for the range of produce complained of. The data is however revealing concerning the nature of the complaints. The exact opposite circumstance prevails with the data provided by the *dotcom* business. While this data does not specify the reason for the complaint, beyond a simple classification (quality or code life) it does provide a good indicator of the produce that is causing the most complaints. To illustrate the difference between the two sets of data, for a given week, there were 12 complaints to the *dotcom* business about Class 1 Strawberries, for every complaint made in-store. For loose bananas the difference was 98 complaints to the *dotcom* business for every complaint made in-store. For 300gm packs of Cherry Tomatoes, there were 9 complaints to the *dotcom* business for every complaint made in-store. For many produce however where there were significant numbers of complaints to the *dotcom* business, but no complaints at all made in-store.

Tesco confirmed that the *dotcom* business provides a very useful data source for identifying produce where customers have experienced problems, and some of these issues are investigated further. However, some complaints are expected. For example, Bananas are always at the top of the list of complaints because they ripen very quickly since that is the nature of the fruit. Likewise complaints about produce that has reached the end of the growing season are normal, as the best quality for most produce is achieved earlier in the growing season. Weather conditions can also influence the quality of produce, so there are times when the weather has been poor, when complaints can be expected.

The important point about the *dotcom* business data is that it is post-event data, in that what caused the quality or code life problem occurred in the past. Moreover the data is limited, so there is no information about the quality problem. It is also a set of isolated data, in that it is not linked to any particular supplier. Hence it is data that needs to be interpreted by people who are aware of other factors and issues.

As a result, the value of this *dotcom* business data, to the work that Syngenta Sensors has been undertaking on shelf life prediction, is doubtful. To be useful it would need to be used in a system that was more focused on quality improvement, rather than real time quality control.

It is however also the case that there is other quality related data available to Tesco arising from its own quality inspection work at receiving depots. In addition there is also quality inspection data available in suppliers' ERP systems. Often temperature tracking data is also available from data loggers that are placed in fresh produce boxes at packhouses at the growing end of the farm-to-retailer supply chain.

Where the data collection opportunities are weakest is at the grower end of the supply chain. Here the availability of data is very much dependent upon the sophistication and the size of the grower, and the growing environment. There are generally three types of growing environment, these being glasshouse, poly-tunnels and open fields. It is more likely that data will be available from greenhouse environments that the other two environments, but this depends of whether environmental control systems are deployed in the greenhouse (which is not always the case).

7.6 Complexity

The above sections hint at a complex set of circumstances that impact upon the amount of waste in fresh produce farm-to-retailer supply chains. This complexity is a significant feature of such supply chains, which point towards more complicated approaches to address the issue of waste.

In addition to the issues highlighted above, there are three further dimensions which add to the complexity.

The first of these is the number of growers that feed into packhouses. It is not unusual for many dozens of smaller growers to be providing produce into a single packhouse. This means that fresh produce leaving the packhouse could potentially be a combination of produce from several growers. Later this produce can be repacked into smaller packages, perhaps at an importers' depot.

Consequently tracking temperature stresses becomes more complicated, owing to loss of batch identity, which creates problems for shelf life prediction. In general terms, the batches of produce from different growers will have different shelf lives, owing to differences between growers in terms of pre-harvest and at-harvest factors that influence shelf life. Consequently, within mixed batches there is at least the potential to have produce with different shelf lives, and this has been noted in vase life tests undertaken by the PhD student working on vase life prediction of roses, whereby a (small) single shipment of flowers from one grower resulted in vase lives in the range 15 days down to 3 days.

But it is also evident that shelf life is variable across the growing season. For the case of sweet peppers, shelf life can be as low as two weeks at the beginning of the growing season, improving towards four weeks in the middle of the growing season, deteriorating back to two weeks towards the end of the growing season. For other produce however, the shelf life can be best at the start of the growing season, decreasing towards the end of the season.

A third complicating factor is that different types of fresh produce are handled in different ways, according to factors such as shelf life. Apples for example, have a long shelf life and can be stored for many months. In the UK apples tend to be harvested in late summer and early autumn, and are then kept in controlled storage conditions and released into the market over the following months. Bananas however are a tropical fruit, and are picked while green, shipped, and then ripened in ripening centers in the country of destination. But once they start to ripen, they do so very quickly, which means, given uncertainty in demand, that there is significant potential for produce to be wasted. Bananas are in fact a produce that sit at the top of the top-ten of the most wasted produce. Bananas are also a chill sensitive produce, which means that they are damaged and rendered unsalable if they are exposed to temperatures below about 13^0C. Bananas are also the produce that generates the most complaints for retailers concerning quality (shelf life and appearance).

Soft fruits (for example, blueberries, strawberries etc.) however have a very short shelf life, and cannot be stored in fresh form (storage involves freezing or canning). Hence they have to be picked, packed, transported, and placed on retail shelves within a short period of time. They are also a temperature sensitive crop and will deteriorate quickly if not maintained at low temperatures.

In general, all varieties of a specific fruit or vegetable have different keeping qualities in terms of shelf life, as well as susceptibilities to diseases in the field, while in transit, and while in storage, and different profiles relating to changes in flavour after harvest.

The net result of the issues addressed above is that trying to maintain the quality of fresh produce is a challenging task.

8. Analysis of Potential Sensing and ICT Solutions to Improve Sustainability

8.1. The use of Sensing and ICT to Monitor Postharvest Quality

The idea of using sensing and ICTs for postharvest applications to monitor the quality of fresh produce while in-transit has been considered in the research literature, mostly from the perspective of ensuring quality of produce, and reducing losses. An example is the application of sensing and ICT to shipping containers. Ostensibly the idea has appeal, as it would seem to provide a means of reducing postharvest losses, which has the potential to contribute towards improvements in the sustainability of food production and distribution systems.

In the context of shipping containers, Morris *et. al.* (2003) refer to a concept, developed by an Australian company and called *SmartContainer*, consisting of containers fitted with sensing devices which can provide real-time monitoring capabilities that makes it possible for actual storage conditions to be monitored. By interfacing the remote real time measurement and tracking system to prediction software, such as a *remaining shelf life* prediction model, the system can also provide decision support. Suggested as possible outcomes of these decisions, are cancellation of the shipment owing to a predicted loss of quality, or adjustment of storage conditions to preserve storage life. Both of these outcomes could potentially be important with respect to reducing postharvest losses and improving sustainability.

Jedermann *et. al.* (2009) discuss an almost identical concept (referred to as an *Intelligent Container*) to the one mentioned by Morris *et. al.* (2003). This *Intelligent Container* is founded on the use of Radio Frequency Identification (RFID) based sensing technologies, linked to quality prediction models, with the functionality directed at initiating an alarm when produce goes beyond a specified temperature limit.

Proposals have been made that these types of systems could be used to implement a concept called Quality Controlled Logistics (van der Vorst *et. al.* 2005). This involves using quality predictions to take logistics decisions. For example, it is suggested that quality predictions (again based on a prediction model) could be used to take decisions about redirection of produce, with produce with a lower quality being directed to customers willing to accept such produce. Another suggestion is that the quality predictions could be used to implement *first-to-expire-first-out* logistics, rather than *first-in-first-out* logistics. A similar proposal has also been made by Dada and Thiesse (2008), who propose using RFID-based sensors and a quality prediction model for quality based issuing of produce. Based on simulations, Dada and Thiesse (2008) investigated the impacts of both expiry-based issuing policies (*first-to-expire-first-out* and *last-to-expire-first-out*) and quality-based issuing policies (*lowest-quality-first-out* and *highest-quality-first-out*).

Van der Vorst *et. al.* (2005) have also undertaken simulation studies. They report on the simulation of a sweet peppers supply chain (from the Netherlands to the USA). This work was aimed at investigating the potential of Quality Controlled Logistics to direct flows of peppers with different quality attributes to different retail segments. One of the conclusions of this simulation study is that by steering logistics flows using quality-oriented data, it is possible to deliver to retailers, produce with longer remaining shelf life, and to reduce by 25% *waste* at importers depots and retail outlets.

Another simulation study (Wienk *et. al.* (2005)) of a supply chain for vine tomatoes (again from the Netherlands to the USA), explores this concept of diverting lower quality produce to other outlets (discount stores). The results show economic benefits for the distribution channel in terms of being able to sell to discount retailers, produce that is unacceptable to supermarkets, while at the same time providing supermarkets with vine tomatoes with a longer remaining shelf life.

These results look promising with regard to the potential of these types of systems to contribute towards reduction in postharvest losses in the supply chain, and hence the systems raise expectations of being able to improve the sustainability of food production and distribution systems, at least with respect to fresh produce. What-is-more, it is clear that the emergence of (small) Radio Frequency Identification (RFID) devices as replacements for paper-based bar codes, and the development of various sensors (for example temperature) using RFID technology, and the coupling of these RFID based sensing systems with remaining shelf life prediction models, does seem to offer a potential for improving the management of quality in postharvest supply chains, which in turn could help to improve availability of produce in supermarkets and also contribute towards improving security of food supply. These potentials are perhaps the reason why several patent filings (for example see Ben-Tzur & Shapiro (2004), Pope *et. al.* (2005), Reznik (2007), Gupta *et. al.* (2008), Grieve & Waltham (2008)) have been made around this concept, indicating that there is commercial interest in using such systems for postharvest quality control of fresh produce.

Nevertheless, looking at the details behind the reported research, it is evident that there are some problems. Referring to Jedermann *et. al.* (2009), the proposed system is limited to producing alarms. The most likely reason for this is hinted at in the closing paragraph of the paper in question, where model accuracy is discussed, and the need to consider both humidity and harvest conditions is mentioned in order to improve model accuracy. This suggests that, the *quality* of quality predictions is not yet at a stage where such models can be used for predictive quality-based control.

Van der Vorst *et. al.* (2005) also mention that to model quality, not only do they need to measure temperature and relative humidity during transport and warehousing, they also need to incorporate biological variation (Tijskens *et. al.* (2003)) into the initial product quality used in their prediction model. Moreover, Wienk *et. al.* (2005) indentify biological variation as being one of the general factors affecting the quality development of perishables, but state that for vine tomatoes, biological variation is less important than environmental factors (temperature and relative humidity). Nevertheless, it is evident from their results that biological variation becomes increasingly significant beyond 7 days postharvest, corresponding to the point in the simulated supply chain when the tomatoes are on-board ship and nearing the destination port in the USA. And it is after arrival in the country of destination that the issue of quality and the matter of diversion to other markets would become important.

One of general conclusions of this work concerning the applicability of the concept considered, is that biological variation of the produce should not predominate over other factors (time, temperature, relative humidity) that affect the quality development of perishables. This assumption could be a limiting requirement with respect to applicability.

One further point that can be made concerning the research results reported by Vorst *et. al.* (2005), Wienk *et. al.* (2005), and Jedermann *et. al.* (2009) is that no comparison is reported in these published papers, between quality (remaining shelf life) predicted by the models, and actual quality (remaining shelf life) experienced in a real supply chain. Although some comparisons between experimental data and quality predictions have been undertaken and reported (e.g. see Nunes *et. al.* (2004), Nunes *et. al.* (2007)), knowledge about the accuracy of prediction models compared with actual remaining shelf life of real produce that has been subjected to actual long distance transportation is still somewhat limited. Moreover, it is also unclear from the reported research, what model accuracy is needed in order to be able to undertake prediction and to then to make Quality Controlled Logistics decisions based on these predictions.

Undoubtedly, the use of RFID and sensing technologies represent an important tool with respect to monitoring the continuity of the cold chains for temperature sensitive products such as pharmaceuticals, and food produce such as meat and fish. The benefits of using RFID-based sensors in supply chains are therefore self-evident in such cases. However, applying RFID-based technologies in combination with model-based quality prediction, in fresh produce supply chains, is clearly more difficult. Ostensibly the case for the use of these combined technologies rests on the proposition that temperature stresses experienced by perishable fresh produce while in the supply chain, as well as the affects of other parameters such as relative humidity (and also exposure to ethylene), impact upon produce quality, most notably, by shortening the remaining shelf-life or keeping quality of fresh produce. Therefore, if stresses can be measured and quality can be predicted, this should provide a means to undertake quality control of perishables in postharvest fresh produce distribution and supply chains. However, it is evident from the research described that the feasibility of this approach is not yet established.

Consequently, using the information that has been obtained through the AWARE project, the feasibility of the above concepts has been investigated. Specifically, the AWARE project considered the feasibility of using quality or expiry based issuing policies, the adequacy of using container level temperature sensing, the feasibility of produce redirection, and the practicality of quality prediction. From these considerations, implications for postharvest quality monitoring, prediction and control systems design have been identified.

8.2 Results of Analysis

8.2.1 Feasibility of using quality or expiry based issuing policies as a sustainability improvement tool

Several researchers (e.g. Dada and Thiesse (2008)) have proposed the use quality-based or expiry-based issuing of produce. Quality-based issuing is founded on releasing produce according to an understanding of the current quality state (using some quality attribute). Expiry-based issuing of produce is founded on releasing produce based on an understanding of produce *Best Before* dates.

Use of models to predict quality or *Best Before* dates has been suggested as the basis for this. Several models are available (e.g. see Fu & Labuza (1993), Tijskens & Polderdijk 1996)). As an alternative, some form of data look-up table (Jederman *et. al.* (2008)) could be used, or even produce respiration data (e.g. see Nunes *et. al.* (2004), Nunes *et. al.* (2007)) could form the basis for prediction.

However, implementing quality or expiry based issuing is not at all easy. To understand why, it is necessary to consider a number of points. Primarily the main issue is one that relates to how well these concepts fit with the design of existing supply chains and the way that they operate. There is also the issue of being able to accurately predict *Best Before* dates and quality attributes, but this matter is further discussed in *sections 8.2.2 and 8.2.4*.

To understand why a quality-based or an expiry-based approach is difficult to implement, first it is necessary to distinguish between two circumstances: long storage life produce, where produce is kept in store for several months (e.g. pears, apples, etc.), and short storage life produce where produce can only be stored for weeks down to a single day (e.g. peppers, tomatoes, soft fruits, etc.).

Participants in the AWARE project reported that one of the problems with the first category of produce is the difficulty of knowing, after the passage of several months, the actual condition of significant quantities of produce kept in a large storage facility. For example, produce may have deteriorated, but show no visible signs of this deterioration (e.g. brown coring in apples). There have been an insufficient number of studies undertaken that compare the actual quality of (very) large quantities of produce, stored for lengthy periods, with the results obtained from remaining shelf life prediction models. Participants also mentioned that attributes such as taste and texture may also have deteriorated.

Realistically, the only way to test these quality attributes when faced with significant quantities of produce, is to carry out physical inspections and destructive testing of samples. It is necessary to mention however that quality prediction in such circumstances is not necessarily infeasible, only that quality prediction models may be unsuitable. There are other ways of tackling the problem, and an interesting candidate is an emerging technique based on genomics (van Wordragen *et. al.* (2008)), which for example, according to the claims made in the patent application, is capable of detecting early stage changes in relative expression levels of indicator genes, which serve as an early warning for sensory decay in fruit, especially apples after harvest.

Another problem mentioned by participants is that it can at times be difficult to verify the age of produce that has been stored for a long period. To do this it is necessary to have a full record of when the produce was picked, and to be able to verify that this information is correct. This is not always an easy thing to do, as it requires full traceability and authentication, which is something that is still being pursued as a goal (primarily for food safety reasons), driven in Europe by food traceability regulations. This is a capability that RFID-systems should be able to offer in the longer term.

For the case of short shelf life produce, most of this moves through the system very rapidly, with the possibility of cross-docking practices being applied (van Donselaar *et. al.* (2006)), resulting in inbound produce being placed in chilled staging areas, where they are sorted, consolidated, and stored for short periods, until the outbound shipment is complete and ready to ship. Consequently, some produce may not even be placed in cold storage prior to issuing. Moreover, much of the produce arriving at distribution centres is packed at source in the country of origin, and comes with *Best Before* dates already applied to the packaging. The consequence of rapid movement of such produce through the system, with little or any storage, is that quality-based issuing becomes extremely difficult, as this implies that there is produce with lower quality that can be issued first, and in the right volumes. Moreover, for expiry-based issuing, the fact that *Best Before* labels have already been applied to produce, precludes this issuing policy, as it could result in produce with close-to-expire dates, being held back, which by the time the produce was released and reached the supermarket shelf, might well have passed the *Best Before* date stated on the packaging. This is something that would not be acceptable to consumers, or to the supermarkets (for brand image reasons). It should also be mentioned that the retail grocery industry tends to use *first-in-first-out* issuing, and this is reported to be optimal in the sense of minimising produce waste as a result of outdating, and revenue loss as a result of missed sales in out-of-stock circumstances, under conditions of constant product utility until outdating (Ferguson & Ketzenberg (2006)).

The obvious way around the problems associated with pre-labelling, is not to apply *Best Before* labels at source. There are three reasons why this is unlikely to happen. The first relates to size of the task. Item level packaging is counted in the millions. It is no small task to place labelling on these packages. It would require a continuous process, and could potentially be a bottleneck on throughput. This then links to the second reason, for such an exercise would involve using higher cost labour (in the UK) instead of the low cost labour used in the country of origin, which would then increase costs. It would not be possible for Category Suppliers to pass on this cost to the supermarket chains, as the latter hold all the power in their relationships with Category Suppliers, and these suppliers are already operating on very small margins, and earning their profits through volume transactions.

Labour cost could potentially be significantly reduced and throughput increased by use of automated machines to place labels on packaging, but this would be a capital intensive approach. This links to the third reason to consider, this being that there is no evidence to suggest that product rejections, for reasons of quality deterioration, are at a sufficiently high level to justify investments in any alternative issuing policies (which would require capital investments in software or labelling machines or both, as well as investments in staff retraining).

Overall, therefore, the analysis shows that there is no significant business case to support the implementation of new issuing policies (expiry-based or quality-based). Moreover several difficulties have been identified that suggest that the concept is impracticable.

8.2.2 Adequacy of using container level temperature sensing as part of a quality monitoring system aimed at improving sustainability

Both Morris *et. al.* (2003) and Jedermann *et. al.* (2009) describe container systems fitted with temperature sensors. Not surprisingly the placement of sensors in a container reveals that the container (Jedermann *et. al.* (2009)) is subject to different temperatures at different points. Industry stakeholders well understand this however, and the matter is discussed in the research literature (e.g. see Zertal-Menia *et. al.* (2002), Carullo *et. al.* (2009)). One reason for the existence of internal temperature profiles, is that the chillers units in containers are normally located in one place (usually at the opposite end to where the doors are located), thus leading to colder temperatures at one end of the container than that experienced at the remotest points from the chiller units. Another reason for the existence of internal temperature profiles is that the doors to the container units may be opened at several instances along a journey, as is the case when produce is delivered to several depots or is subject to customs inspection. Under this circumstance, produce closer to the doors can be subject to warmer temperatures than produce located at the back of the container closer to the chiller units.

Industry stakeholders also report than container temperatures are not representative of the temperatures experienced by the produce packed within individual boxes, which are then stacked onto pallets. An example of the difference between container level temperatures and box level temperatures, recorded on a shipment of plants transported by truck from the Netherlands to the UK, is shown in Figure 1. This illustrates the circumstances that often prevail in containers. Temperatures were tracked both at container level and at box level (using data loggers). Both sensors (container level and box level) follow the same trajectory, but the temperature can differ by up to 9 °C. The recorded difference in temperature can arise from several causes. One possibility is that the temperature of the produce within boxes might be below or above that of the container temperature (this matter is further discussed later– *section 8.2.4*). Another explanation is that produce boxes may have been subject to different levels of exposure to ambient temperatures. Related to this is the fact that boxes stacked at the centre of a pallet would be more protected from external changes in temperature than those on the outer edges of the pallet. In general, the position of boxes on pallets (e.g. top layer, middle layer and bottom layer) affects the temperatures experienced by the produce (e.g. see temperature profiles in Rediers *et. al.* (2009)).

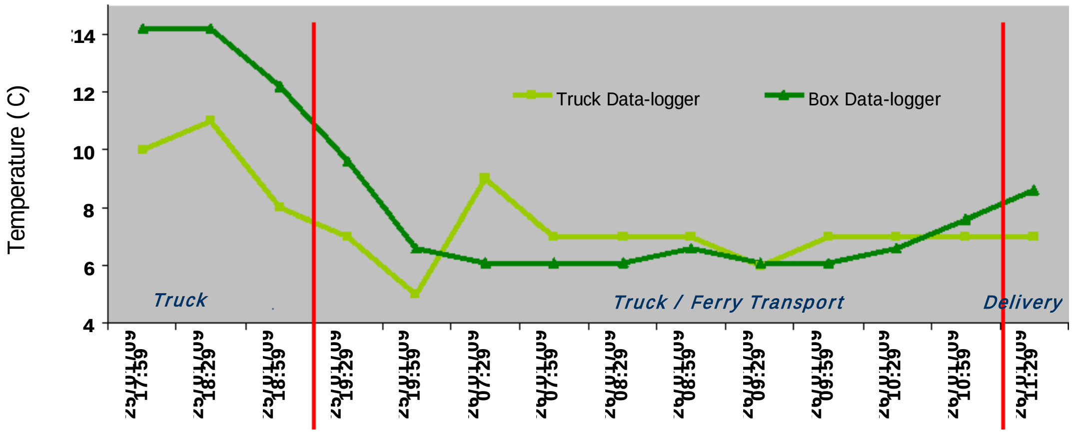

Figure 1: Plots of temperature variation at container and box level, across journey time from the Netherlands to the UK, January 2009.

Another issue that container level sensing does not adequately address, is the internal temperature rises that occur within boxes as a result of respiration occurring in the produce while in transit and storage, and the resulting heat that this can generate, especially in produce with a high respiration rate. This can be especially problematic when field-heat is not fully removed (see *section 8.2.4*).

A consequence of these differences between container level and box level temperatures is that, not only does this mean that changes in quality at box level as a result of temperature stresses will be different across the whole shipment, but also that attempts to predict quality based on container level temperature sensing could give misleading information about the evolution of quality attributes with time. Generally, therefore, the industry regards container level temperature tracking for the purpose of quality prediction as unsatisfactory. The minimum requirement is for box level temperature tracking, which in itself raises cost issues. Box level tracking is also clearly necessary since not all produce spends all its time postharvest, in chilled containers (e.g. produce that is transported by air freight).

8.2.3 Feasibility of produce redirection as a sustainability improvement mechanism

Van der Vorst *et. al.* (2005) and Wienk *et. al.* (2005) have both proposed the idea of diverting produce from one market to another based on quality predictions. Information collected during the AWARE project indicates that this might not always be feasible or appropriate, even though such redirection does happen. The reasons for this relate to circumstances concerning increasing varietal awareness among customers, brand value, as well as packaging.

Supermarkets in the UK serve different markets (as is the case elsewhere), with some at the lower end competing on price, and being less concerned with availability. Others however, compete on quality, price and availability, and therefore require produce on their shelves, so they therefore expect their suppliers to perform to both quality and availability criteria. Moreover, most of the retailers within this latter group offer a range of brands, starting at the value end, ranging up through standard produce (some loose, some packaged), specialised produce, the organically grown alternatives to standard produce, and at the top end, premium produce that is differentiated from other produce through flavour (usually centred on specific varieties, which is one reason why varietal awareness among customers is increasing). Most of the produce is presented to consumers in packaged form carrying the supermarket's brand name. Very little produce in the supermarkets is actually loose, and this is limited to a few items (mostly apples, pears, bananas, broccoli, leeks, peppers, etc.).

There is also the matter of packaging. Owing to low labour costs in developing countries, there has been a shift towards undertaking packaging in the country of origin. Hence, as much of the packaging as possible tends to be done outside of the UK, and this includes special offer labels (e.g. buy one get one free) as well as *Best Before* labelling. Prepared fruit and vegetables are also often processed at source, and then packaged (normally in modified atmosphere packaging) before being transported to the UK. An important point about all this packaging is that it is supermarket specific and comes with *Best Before* dates already applied (in most cases).

A consequence of this own branding and packaging of produce at source, is that shifting produce between markets becomes extremely complicated and expensive. It is complicated because varietal awareness creates a barrier to transferring produce between brands. Customers recognise and relate varieties to specific brands, and transferring produce across brands can devalue a brand when customers realise that they can buy the same produce cheaper elsewhere. The process is also expensive because the produce has to be unpacked. There are also increased energy consumption and carbon emission issues associated with such activities.

Thus, switching produce between market sectors is usually only feasible for unpackaged produce (of which there is very little in supermarkets), and when there is no risk of brand devaluing occurring. This probably therefore means the idea would not be applicable to high value premium produce, but would be limited to regular basic produce sold loose (e.g. broccoli, tomatoes, apples). It is unlikely that the vine tomatoes considered by Wienk *et. al.* 2005 would fit into such a category of produce, as vine tomatoes are mostly sold pre-packed and as a premium product. The environmental consequences of redirection also suggest that the practice should be avoided.

8.2.4 The practicality of quality prediction in support of sustainability improvements

Morris *et. al.* (2003) mention the problem of finding the parameters of an equation (typically an exponential) that will provide the basis for predicting a quality attribute. Mentioned is a data set for 30 produce, published in 1998, which is now regarded as being out-of-date owing to developments such as plant breeding programmes that have led to cultivars with longer storage life.

Tijskens & Polderdijk (1996) also provide a glimpse into the problems of parameterising equations, when they list parameters for 48 produce for a single quality attribute. This highlights a significant problem, since modern supermarkets stock a vast range of produce, with several varieties of each produce being available. Each cultivar has its own unique quality attribute response to temperature stresses and other environmental parameter stresses, meaning that each cultivar requires it own prediction model and associated parameters. This could mean that there would literally be a need for hundreds of models. The circumstance will be further complicated if the ethylene suppressant 1-methylcycopropene (1-MCP) is used to extend the keeping quality of fresh produce (e.g. see Mayers *et. al.* (1997), Blankenship & Dole (2003), Hewett (2006a, 2006b)), a factor which will lead to the need for a new set of parameters for the equations used to predict remaining shelf-life.

To add further complexity, produce is sometimes brought together from several different growers. This means that biological variation is likely also to be a factor that needs to be considered (thus violating the assumptions made by Wienk *et. al.* (2005)). The quality of the produce entering the supply chain may also be variable, owing to the different ways in which the produce may have been handled and stored postharvest by different growers. In fact, in general, produce will also be different owing to pre-harvest conditions, which in terms of environmental factors and crop management factors, will introduce further variability prior to harvesting (McRoberts and Lepreux (2003)). These matters are part of the whole issue of pre-harvest decisions and the impact that these can have upon quality, which could mean that quality is either enhanced or compromised prior to harvest, depending upon specific decisions and actions concerning such matters are irrigation schedules, nutrients applied, time of harvest, etc. (Hewett (2006a)).

There is also the matter of at-harvest conditions, and in connection with this, the variability of field heat removal was raised as an issue during the course of the study. The concern is that field heat is not always properly removed. One reason for this is harvesting practices and facilities (such as lack of on-farm chillers). Another possible reason is the pressure to ship produce to meet availability requirements, leading to produce being transported before adequate time has been allowed for removal of field heat. This factor can impact on quality, as remaining field heat could prevent the chillers used in transportation systems from maintaining the desired chilled temperature for the produce. Most of these chillers are not designed to remove heat, just to maintain produce at a desired temperature. Inadequate removal of field heat also results in produce within containers experiencing different temperature stresses. When combined with heat generated from respiration, this just further complicates the issue of quality prediction at container level.

An interesting observation made by participants in the AWARE project was the variability of produce shelf-life across the growing season. This variability in keeping quality tends to lead to circumstances where produce has better shelf life at the beginning of the season, and poor keeping quality at the end. But not always, for some produce the shelf life may actually improve before reaching a peak and then declining. The explanation advanced for this eventual decline in produce quality towards the end of the growing season is that plants are exhausted and not so able to produce quality produce. Certainly there is evidence in the literature for this decline in keeping quality, for example, Slootweg *et. al.* (2001) report on seasonal changes in vase life of cut roses, as do Jouquand *et. al.* (2008) for strawberries, but generally this is something that is not often mentioned in the research literature. Nevertheless, in fresh produce supply chains this factor does create problems for retailers, so much so that there is an expectation of quality problems at the end of a growing season, something which is also often compounded by unfavourable weather conditions.

Maturity at harvest was also mentioned as an issue affecting quality. Forney *et. al.* (1998) discuss this matter with respect to strawberries. Jouquand *et. al.* (2008) mention that maturity at harvest can vary in commercial settings, leading to variability in chemical composition of strawberries. Within the AWARE project, harvest maturity was raised as an issue with respect to the effect of market uncertainty. A fall in demand can lead to produce being left unpicked for extra days, but this then generally results in produce with shorter shelf life.

Consequently, with such variability, both in produce (e.g. produce from different growers could be combined in a single shipment) and its quality, a real practical difficulty arises with respect to indentifying the initial value of a quality attribute parameter. While ways to tackle this variety in properties have been proposed, for example trying to eliminate biological variance, or to control storage conditions based on batch measurements (Tijskens *et. al.* (2003)), overall there are so many factors influencing quality, both pre-harvest, at-harvest and postharvest, that some way to address this variability is needed, that avoids adding any extra complexity to what is already a complex process, or placing additional burdens on growers. Potential solutions to such problems lie with sensing and ICT systems.

9. Sensing and ICT Research Requirements

Summarising the analysis in section 8, the results suggests that, given the complexity of international farm-to supermarket supply chains, the idea of redirecting produce to alternative markets, as a sustainability tool, using quality predications, is not widely applicable, or very practicable, as it has both cost and environmental impacts. Moreover, new issuing policies based on expiry-based or quality-based issuing are not likely to be financially viable given the investment and operational cost implications of such issuing policies. Furthermore such issuing policies are probably impracticable given the design of the supply chains examined. In addition, container level sensing is unlikely to provide a sufficiently accurate description of temperature profiles at produce box level. Significant temperature differences have been noted between container level and box level sensing. This is further complicated by the fact that there is potentially significant variability across the container in terms of produce quality, as well as by the potential for heat generation as a result of respiration.

The need for quality monitoring and control is axiomatic to ensure that produce quality is not compromised. This however is problematic, as it is clear that monitoring needs to be undertaken at least at box level, and possibly at item level. Furthermore, many predictive models would be needed in order to be able to predict quality for each cultivar. Moreover, there are several factors at work which point to more than postharvest environmental factors being important, including both pre-harvest and at-harvest conditions.

Consequently to transform sensing and quality prediction into a realisable and cost effective means of providing quality monitoring and control, with the potential to improve sustainability, three major research and development actions are needed.

The first of these research actions is to reduce the cost of RFID-based sensors, from a starting price point that is counted in tens of Euros (2009 prices), down to a few cents, to enable widespread use of these devices at box level, or even item level.

To this end, research is already being undertaken to achieve this goal. This research falls into three categories. The first category is to try to use mass produced parts such as low-cost temperature sensors and electronic components, to reduce system costs (Carullo *et. al.* (2009)). The second category addresses the unit cost of active (i.e. powered) RFID-based devices of the kind that contain sensors and storage capacity. The third category addresses extending the functionality of low-cost passive RFID devices of the kind used in electronic bar code applications.

Active RFID devices can be provided with a capability to measure temperatures and store readings, and usually contain a battery as the power source. For these devices, one popular line of research being pursued with cost reduction in mind, is the use organic (plastic) electronics and the deployment of low-cost inkjet type printing technologies to print the electronics on to very low cost plastics (e.g. see Subramanian *et. al.* (2005), Cantatore *et. al.* (2007), Fadlallah *et. al.* (2007)). Passive devices on the otherhand receive their power from physically separate radio frequency energy sources, typically from a reader device. The cost of these passive RFID devices has already been driven down to the few cents level to enable widespread electronic barcode applications. One idea that has been proposed to achieve low-cost sensing, is to use (low-cost) passive RFID, and to extend the role of these by adding some kind of sensing and storage capability (Peters (2006)), which would then enable the recording of a temperature profile. This is known as passive RFID sensing.

The Syngenta Sensors Group is already involved in this area of research, aiming toward a very low-cost sensing device that would be capable of operating at box or even item level. The results of the AWARE project have provided confirmation of the importance of such developments.

The second major research action that needs to be addressed is the development of techniques that do not need to use produce-based data (either in the form of equations or quality curves) to predict quality. A way to do this is to automatically *mine* the available data (such as supply chain temperature profiles) to make predictions of quality. To this end a new area of research is already emerging, that is seeking to apply existing data mining techniques to quality prediction (e.g. In *et. al.* (2007), Doan *et. al.* (2008), In *et. al.* (2009)). Early results of this work are promising, both with respect to quality of predictions, but most importantly, in the ability of such techniques to use available data to train the *data mining* tools to produce predictions, which is something that can be done during the actual growing, harvesting and shipping process, thus avoiding the time consuming and potential expensive activities of parameterising equations for each specific cultivar.

The Syngenta Sensors Group is also already involved in this area of research, and the results of the AWARE project have provided confirmation of the importance of such developments.

The third major research action that needs to be addressed is that of extending sensing and data collection beyond the usual postharvest supply chain and storage stages, back to the pre-harvest and at-harvest stages, so that all the elements that affect produce quality can be factored into the quality prediction process (using the *data mining* approach). The enabling technologies for this are pervasive sensing and computing, or ambient intelligence (Aarts and Marzano (2003)). This is an area of research that has yet to be addressed in horticulture and agriculture on the scale that would be necessary to capture the appropriate information, but increasing availability of extremely low-cost sensors supported by wireless sensor networks (Wang *et. al.* (2006)), are key enablers for this *in-crop sensing and on-farm data collection* approach.

The proposed systems concept is based on the idea of pre-harvest, at-harvest, and postharvest sensing, fed into a quality monitoring, assessment and prediction system. The system would take as inputs sensing data, and other data, e.g. quality inspection data from several postharvest stages where quality analysis is undertaken, and would include, if available, quality information that is obtained from retail stores (pre-purchase) and consumers (post purchase). All this data would be brought together. This is system is illustrated in Figure 2.

The proposed system provides a basis for collecting information that can influence quality at the pre-harvest, at-harvest, and postharvest phases. Such information would, in general, be both sensed data (e.g. temperatures), and also data input (e.g. irrigation schedules). The intention would be to use such information for quality prediction. Other data, such as the results of quality inspections, which are always post-event, would also be fed into the system. Such data would be used more for learning purposes (i.e. training the *data mining* techniques). It would also be used for post event analysis with a focus on identifying improvements (e.g. in growing practices, etc.).

Figure 2 also shows data input from the retail and consumer side. This could include data such as that which is available from the Tesco *dotcom* business relating to customer complaints (quality and code life data). But it could also include (in the longer term), data collected from item level sensing within a future *Internet of Things* scenario. This would however require significant developments in sensing device capability and cost, before item level sensing on the scale necessary would be economically feasible.

At the core of the proposed system is the Quality Monitoring, Assessment and Prediction module. This would most likely to be based on *data mining* techniques.

To bring the proposed system to fruition, several research activities will need to be pursued. These include:

- Key pre-harvest factors affecting the quality of the most sensitive produce need to be identified;
- Sensing requirements related to these key factors need to be identified, and sensor development initiated as needed;
- Means of data capture relating to variables that cannot be sensed need to be explored;
- The data mining techniques best suited to the intended functionality need to be identified and their performance evaluated and compared;
- Data mining techniques capable of forward predicting quality, taking into account, pre-harvest, at-harvest and postharvest data, need to be investigated with respect to their computational performance and validity of predictions.

Implementation of the above research will require a major field data collection exercise so as to construct a valid data-set extending from pre-harvest right through to delivery of produce to the supermarket depot.

What is important however is to first identify the produce that is most suited to such a sensor and ICT intensive approach. Clearly different types of produce have different postharvest temperature sensitivities; some are very temperature sensitive, others are less so. What is not fully clear however, is how sensitive crops are to environmental and crop management factors, pre-harvest, or to factors that prevail at-harvest and in the immediate postharvest period. Moreover, there is a need to identify specific data and sensing inputs that are central to the quality monitoring, assessment and prediction for each crop and cultivar.

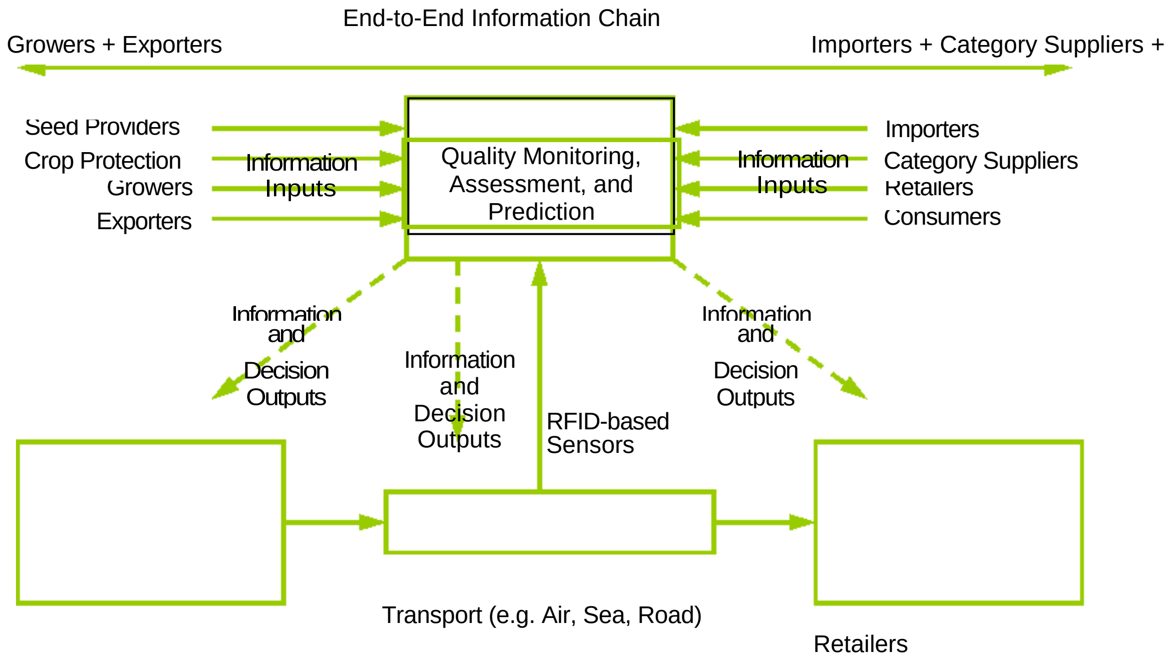

Figure 2: Proposed Systems Concept for Quality Monitoring, Assessment and Prediction

10. Sustainability of Food Production and Distribution systems

Finally some words about the sustainability of food production and distribution systems. It has become clear through the course of the AWARE project that the sustainability of agriculture, of food production and distribution systems, is more complex than first inspection might suggest. A simple approach to sustainability might be to consider carbon footprints. This has some popular appeal, as it perhaps offers some simple understanding that *less is better*. Yet the literature on the sustainability of agriculture points to far greater complexity.

The sustainability of agriculture has already attracted a number of efforts at definition. One such is that proposed by DEFRA following stakeholder consultation (DEFRA (2002)).

- Produce safe, healthy products in response to market demands, and ensure that all consumers have access to nutritious food, and to accurate information about food products.
- Support the viability and diversity of rural and urban economies and communities.
- Enable viable livelihoods to be made from sustainable land management, both through the market and through payments for public benefits.
- Respect and operate within the biological limits of natural resources (especially soil, water and biodiversity). Achieve consistently high standards of environmental

performance by reducing energy consumption, by minimising resource inputs, and use of renewable energy wherever possible.

- Ensure a safe and hygienic working environment and high social welfare and training for all employees involved in the food chain.
- Achieve consistently high standards of animal health and welfare.
- Sustain the resource available for growing food and supplying other public benefits over time, except where alternative land uses are essential to meet other needs of society.

The above definition illustrates the complexity of the topic. Moreover, there are inevitability an enormous range of social and environmental issues, trade-offs, time scales and priorities involved in turning such a sustainability concept into a reality (Smith (2008)). Furthermore, within the chain there are roles for growers/farmers, transport and distribution agents, food processors and manufacturers, as well as retailers. Where the emphasis for action should lie among these stakeholders is however, unclear.

The Royal Society report, *Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture* (Royal Society (2009)), points to the requirement for sustainable intensification of global agriculture, with a requirement for systems that are resilient in the face of changing climates across diverse economic, social and political conditions. The report highlights that there are different perspectives on the problem of feeding the world. For example, some organisations have concluded that the problem is one of distribution rather than production, with others believing that waste in the food chain needs to be reduced. Many other views are also expounded.

The Royal Society report however places its emphasis on the importance of biological science and technologies, and the related strategies such as soil management, crop management, etc. to achieve this sustainable intensification. The results of the AWARE project also points towards looking beyond food losses in supply chains, often referred to as waste, which are no more than symptoms of deeper rooted problems, to which science and technology can also provide solutions.

Sustainability as a concept in agriculture therefore needs to be better understood. This is therefore one further area of research that is needed in order to be able to better define the sensor and ICT systems that need to be developed in the future.

11. Conclusions

Information in the published literature about quantities of waste in farm-to-retailer supply chains is elusive. Moreover, there is an understandable reticence on the part of those involved in these supply chains, to openly reveal the levels of waste as this information is commercially sensitive. However, there was no expectation that the AWARE project would be able to quantify levels of waste, and this was not the intention of the project. The aim was to better understand these supply chains and to consider how the data that is available along the supply chain might be used in some way to drive waste reduction.

What has been achieved is a greater understanding of the many complexities of farm-to-retailer supply chains and some insights into the complexities surrounding the matter of the sustainability of food production and distribution systems.

Importantly, a key understanding is that waste in farm-to-retailer supply chains is not a simple concept, for it is evident that true waste, in the sense of produce that has no use at all, is not the main issue. Primarily the key issues relate to the additional use of energy that arises from the extra transportation and processing of produce that has been rejected as unacceptable by one of the supply chain actors (e.g. the retailer). This rejection effectively increases the energy use. Also of importance are issues of efficiency of use of natural resources with respect to food production. The consequence of diverting food grown for human consumption, to non-food uses is clearly important as it ultimately impacts upon the availability of food as well as price.

Another key understanding is that waste (whatever that may in fact be) is not actually the problem, but just a symptom of deeper rooted problems that impact upon the quality of fresh produce, with quality being the important element determining waste (rejected produce). There are two specific areas where problems exist.

The first of these is in the supply chain itself, and the problems here mostly relate to the physical handling of produce and the ambient conditions to which the produce is exposed, both of which can lead to loss of quality, and hence, in the end, to waste. Without doubt there is scope for improvements in supply chains practices, for example the handling of fresh produce at airports could be improved to ensure that quality is less likely to be compromised. Identifying these improvements however is not the main focus of the AWARE project, as the aim has been to consider how data (and the use of Information and Communication Technologies (ICTs)) might help to improve quality. This data-driven approach is very relevant to the second important problem area that has been identified, which is those actions that are taken at the growing stage (pre-harvest), during harvesting (at-harvest), and in the immediate time after harvesting (immediate postharvest), that significantly impact upon quality.

The AWARE project has established that the data available to Tesco concerning customer complaints about fresh produce, originating from the *dotcom* business, is somewhat deficient in terms of content. Furthermore, it is isolated data in the sense that it is not linked back into ERP systems and associated to particular suppliers or growers or both. Moreover, the data is also post-event, meaning that it is of no use for example in undertaking real-time quality management of produce in the supply chain. Its main potential use would be for quality improvement activities, which is how the data is used at the present time, but in a manual way. The challenge is to find a means to use it for automated identification of quality issues in the food supply system, by combing the *dotcom* data with other data available from the supply chain, or which could be generated from ICTs implemented on-farm.

The AWARE project has considered the use of RFID-based sensing and associated quality prediction, in the context of modern complex international farm-to-supermarket fresh produce supply chains, as a sustainability improvement tool. Several techniques proposed in the literature have been examined from the sustainability perspective. The results indicate that several of theses concepts proposed in the research literature might be difficult if not impossible to apply. Particularly it is noted that there are several features of modern supply chains, such as packaging and the application of *Best Before* dates in the country of origin, high throughputs of produce, cross-docking, low levels of stock holding, brand value, and increasing varietal awareness on the part of consumers, that raise questions about the value, feasibility and cost effectiveness of both new issuing policies as well as the notion of redirecting produce to alternative markets.

The concept of RFID-based sensing combined with quality prediction to undertake quality monitoring and control also raises some concerns about feasibility. These concerns stem from the fact that container level sensing, as discussed in the literature, does not capture what is happening to produce at box level, with the implication that quality predictions based on container level temperatures would not provide results that reflect the quality difference across the shipment. Moreover, quality prediction itself is also problematic owing to the vast range of produce and cultivars passing through supply chains, each potentially requiring its own prediction model. In addition, there are so many other factors at play, pre-harvest and at-harvest, and so many growers feeding produce into the system, that realistically any prediction system that does not take such variation into account, is unlikely to produce results that can be used to take important decisions concerning what best to do with a particular shipment of produce that has been subjected to stresses while in transportation.

Yet for reasons of food safety, as well as sustainability and security of food supplies, such decisions do need to be taken. The answer therefore appears to lie in adapting concepts to the reality of the supply chains and the nature of produce variability. To this end three key research areas have been identified as enablers. A reduction in sensor costs to enable box or item level tracking, coupled with application of *data mining* techniques that in effect learn from the available data and predict quality based on the information that is buried in the data, and the extension of sensing and data collection back to the grower, provides the basis for a system that is better fitted both to the produce, its inherent variability, the many factors that affect quality, and the supply chain system characteristics.

Broadly the work undertaken points towards a systems level approach, where sustainability for the whole system is defined, with sensors and ICT being used as a quality improvement tool, and also, perhaps, to forward predict quality problems. The proposed Sensors and ICT systems concept for this, is based on ubiquitous sensing and ICT, starting pre-harvest at the growing site, and extending through subsequent stages, including at-harvest, and postharvest.

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