The use of sensing and ICT to improve the sustainability of international food production and distribution systems

Bruce Grieve and Paul Kidd report on the potential use of Information and Communication Technologies to improve sustainability across the food supply chain

Introduction
This summary paper is drawn from a larger report commissioned by the Sustainable Consumption Institute at the University of Manchester (www.sci.manchester.ac.uk) and compiled in conjunction with the retailer, Tesco, and the agriscience business, Syngenta. The project’s main aim was to identify how sensing data and Information and Communication Technologies (ICTs) could be used to improve sustainability, in particular to drive waste reduction in the supply chain from farm-to-retailer. The key points identified in the report are outlined below.

Waste and quality
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 pre-harvest decisions and the natural variability of quality parameters across the growing season as well as at-harvest conditions and actions taken in the immediate post-harvest period. Further quality issues can then arise, post-harvest, 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, however, it 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 systems have a high degree of complexity. There are several reasons for this, including: (i) harvested fresh produce is still alive in the sense that biological processes are still underway; (ii) there are multiple factors contributing to produce quality; (iii) quality is not defined by a single parameter; (iv) there are a vast range of produce characteristics and varietal differences; (v) a large number of growers can be feeding produce into one export hub or packhouse; and (vi) multiple transport modes are used, etc.

Efficiency
Waste in farm-to-retailer supply chains is not a simple concept as 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 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 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 (post-harvest). 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 maintain this quality which sometimes it is unable to achieve. 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 originate from the dotcom business, are somewhat deficient in terms of content. Furthermore, it
is isolated data in the sense that they are not linked back into Enterprise Resource Planning systems and associated to particular suppliers, growers or both. Its main potential use would be for quality improvement activities. This is how the data are 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.

**RFID-based sensors for the farm-to-retailer supply chain**

The use of Radio Frequency Identification (RFID) based sensing and quality prediction, in the context of international farm-to-supermarket fresh produce supply chains, has been analysed from the perspective of its potential to improve the sustainability of food production and distribution systems, specifically by identifying technologies to assist in reducing post-harvest losses. Examined in the context of the research were: (i) the use of quality-based or expiry-based issuing policies; (ii) the use of container level temperature sensing; (iii) the concept of produce redirection; and (iv) the use of quality prediction techniques. Analysis indicates that there are many issues, concepts and limitations relating to the above concepts that effectively render them either impracticable, inappropriate, not feasible or all three.

The results of the investigation suggest 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 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 and across the container in terms of produce quality.

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 predict quality for each cultivar. Moreover, there are several factors at work which point to more than post-harvest environmental factors being important, including both pre-harvest and at-harvest conditions.

**Steps to realising cost effective quality control**

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 R and D actions are needed.

The first research action is to reduce the cost of RFID-based sensors, from tens of Euros down to a few cents, to enable widespread use of these devices at box level or even item level. Research is already being undertaken to achieve this goal and 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 (1). 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 of organic (plastic) electronics and the deployment of low-cost inkjet type printing technologies to print the electronics on to very low cost plastics (2, 3, 4). Passive devices on the other hand 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 (5), which would then enable the recording of a temperature profile. This is known as passive RFID sensing.

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 (6). Early results of this work are promising, both with respect to quality of predictions and most importantly the ability to use available data to train the data mining tools to produce predictions.

The third major research action that needs to be addressed is that of extending sensing and data collection beyond the usual post-harvest 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 prediction process using the data mining approach. The enabling technologies for this are pervasive sensing and computing, or ambient intelligence (7). Increasing the availability of extremely low-cost sensors supported by wireless sensor networks (8), are key enablers for this in-crop sensing and on-farm data collection approach.

**Suggested system concept**

A potential system concept is based on the idea of pre-harvest, at-harvest
and post-harvest sensing data being fed into a quality monitoring, assessment and prediction system (Fig. 1). The system would take as inputs sensed data and other measurements, e.g. quality inspection data from several post-harvest stages, and would include, if available, quality information obtained from retail stores (pre-purchase) and consumers (post-purchase).

The intention would be to use this information for the quality prediction. Other data, such as the results of quality inspections, would also be fed into the system for learning purposes, i.e. training the data mining techniques. It could also be used for post-event analysis with a focus on identifying improvements, e.g., in growing practices, etc.

Figure 1 shows data input from the retail and consumer side. This would include data such as that from the Tesco dotcom business relating to customer complaints (quality and code life data) and 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 could 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.

**Future sensing and ICT research needs**

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 post-harvest 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 post-harvest 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 post-harvest 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.

**References**


Drs B. D. Grieve and P. T. Kidd, are at The Syngenta Sensors Centre, University of Manchester, Oxford Road, Manchester, UK, M13 9PL.
Tel: 44-161 306 8941
Email: bruce.grieve@manchester.ac.uk
Web: www.eee.manchester.ac.uk/research/groups/sisp/research/syngenta/