RFID-enabled quality controlled logistics as a tool to improve the sustainability of chilled produce distribution and supply chains: a critical analysis based on the features of actual international supply chains

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Abstract

Considered is the sustainability of chilled produce distribution and supply chains. A technique known as *Quality Controlled Logistics*, which aims to control logistics based on the current and predicated quality of fresh produce, is critically analysed with respect to the actual features of modern international distribution and supply chains. Several features of these distribution and supply chains render RFID-enabled *Quality Controlled Logistics* unsuitable as a tool for improving sustainability. Hence it is proposed that other, non Information and Communication Technology (ICT) solutions should be pursued to improve sustainability, and that ICT could be better deployed in support of improving the quality of produce that is fed into these distribution and supply chains.

Keywords: Sustainable food distribution and supply chains; quality controlled logistics; RFID; sustainable agriculture; ICT for sustainable growth; sustainable intensification.

1. Introduction

Anecdotal evidence exists which suggests that losses in chilled, fresh produce, distribution and supply chains, are significant. In reality however, hard factual information about the scale of such losses is extremely difficult to find. One of the reasons for this is that most interest in food waste has centred on the consumer side [1, 2]. However, given the growing importance of reducing food losses, efforts are currently underway to establish exactly what losses do occur in chilled fresh produce distribution and supply chains [3].

Even though the scale of the losses is still unclear, it is evident that the food industry is interested in addressing supply chain sustainability issues [4]. Moreover, several techniques exist which may improve the sustainability of chilled fresh produce distribution and supply chains, which initially might be seen as adding some weight to the contention that the technologies already exist that will enable the solution of climate change problems [5]. One of these existing technology sets that could contribute towards this objective are Information and Communication Technologies (ICTs).

One particular ICT of interest is Radio Frequency Identification (RFID) technologies. Of interest in particular are RFID-enabled systems that seek to predict quality of fresh produce, based on measurements taken (using RFID sensors) while the produce is in the distribution and supply chain. Such systems use this use this quality information to control logistics. This approach is known as *Quality Controlled Logistics* [6].

This paper arises from a large scale study, begun in 2010, into the sustainability of agriculture, which has included an in-depth examination of the meaning of sustainability, and the investigation of issues surrounding food production, such as food distribution and supply, and food processing, as well as the biological and agronomy issues that are central to any efforts to apply ICTs in this area [7]. Within this paper the idea of using RFID-enabled *Quality Controlled Logistics*, as a tool to improve the sustainability of chilled fresh produce distribution and supply chains is considered. Using characteristics of actual international distribution and supply chains, issues relevant to the application and use of *Quality Control Logistics* are critically analysed.

2. Quality controlled logistics

The idea of using ICTs for chilled fresh produce distribution and supply chain applications is not new. Morris *et. al.* [8] addressed this matter at shipping container level, by fitting these containers with sensing devices that provided real-time monitoring capabilities. This enabled 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 provided a decision support tool. Suggested by Morris *et. al.* [8] as possible outcomes of this decision support tool, were recommendations to cancel the shipment owing to a predicted loss of quality, or recommendations to adjust storage conditions to preserve storage life. Here can be seen the potential interest in such technologies as sustainability improvement tools, either by reducing losses, or avoiding the transportation of produce that is unlikely to reach its destination with the desired quality.

A similar idea has been proposed by Jedermann *et. al.* [9] only this time the sensing is based on RFID devices. These sensors are then linked to quality prediction models, with the functionality directed at initiating an alarm when produce goes beyond a specified temperature limit.

The concept of *Quality Controlled Logistics* [6] is essentially the same as that proposed by Morris *et. al.* [8], i.e. (typically) using the sensor information and 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 retailers 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 [10], who suggest using RFID-based sensors and a quality prediction model for quality based issuing of produce. Simulation studies have also been undertaken [6] that purport to show 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 of a supply chain [11] 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 produce with a longer remaining shelf life. Elsewhere it has been suggested that any specific produce showing unacceptable deterioration could be identified and removed from the shipment [12]. These studies again demonstrate the potential interest in using the concept as a tool to improve the sustainability of chilled fresh produce distribution and supply chains.

3. Characteristics of international chilled fresh produce distribution and supply chains

This section describes the characteristics of international chilled produce distribution and supply chains relating to the shipment of short shelf-life produce, with specific reference to cut fresh flowers, sent by air freight from Equatorial and Tropical Regions into Europe. The information presented in this section is common knowledge to those working in the sector, but may not be widely known to those outside the sector. No specific supply chain is considered here, just general characteristics based on knowledge of the sector and modern supply chain practices. What is described here also relates to other types of fresh produce with a short shelf life sent to Europe by air freight, mostly from developing countries.

What follows therefore is a typical description of the process, from cutting of the flowers, to arrival at a distribution centre in Europe, at a level of detail necessary for the critical analysis that follows this section.

The first step in the process is harvesting. This is typically done in the early morning (7-9am), the coolest part of the day, thus helping to keep *field heat* temperature of the crop to a minimum. Later in the process this *field heat* will need to be removed, so it makes sense to ensure that it is low as possible at the point of harvest. Sometimes however, it is also necessary to harvest later in the day, in the afternoon, depending upon demand.

Immediately after being harvested, the flowers are placed in buckets which contain post harvest solutions to help preserve the produce. Using open trolleys, the buckets are then carried to a temporary storage area that provides shade for the cut flowers while they a waiting to be transported to a pack house. These shaded temporary storage points typically lie very close to the place (e.g. greenhouses) where the crop is grown. Depending upon the sophistication of the grower, these shaded areas may be temperature controlled, but not always. Ideally the time spent in these shaded areas should be kept as short as possible. If the pack house in located on the farm, then regular collections (every 15 minutes) can be arranged. On smaller farms the pack house is likely to be located off-farm, serving a number of small growers. While being kept in the temporary shaded areas, the flowers may also be sprayed with a post harvest fungicide to help protect the flowers from botrytis infections during the transportation phase; botrytis infections being a major potential for loss of quality, especially for flowers such as roses. Because of the botrytis problem, flowers such as cut roses will need this preventative spraying.

Once flowers arrive at the pack house, cut flowers typically pass thought six stages, including: defoliation; 1st cold storage; grading; 2nd cold storage; wrapping; and blast chilling.

At the defoliation stage, flower stems are defoliated up to a third of the stem length. However, sensitive flowers might not go through this stage. The temperature within the defoliation room is maintained between 12 and 15 ^{o}C which is not optimal for the flowers, but is necessary for the comfort of people working on the flowers. During the 1st cold storage, the flowers are stored at 4-8 ^{o}C for at least 4 hours to help remove *field heat* before being graded. The purpose of this chilling is to ensure a longer vase life.

In the next stage, grading, the flowers are sorted according to their stem lengths and are bunched together as per customer specifications. Those that are bruised, or have shorter stem lengths than specified, or have pests or diseases, are rejected. Overall, this stage takes approximately 40 minutes. From the grading hall, the flowers are conveyed to a cold room for the 2nd cold storage. This period should be at least 4 hours. The storage temperature depends upon the variety of flowers. At the packaging stage, the bunches are wrapped in customer branded plastic sleeves, a packet of flower food is inserted, and bar codes and *display until* labels (as well as price/special offer labels) are attached to the flower bunches, which are subsequently packed into large cardboard boxes for dry shipping. Finally these boxes are sent to the blast chiller room, where they ideally remain for 1.5 hours, to remove the remaining *field heat*, with the aim of reducing the temperature to 3-5 ^{o}C.

When the shipment is complete, corresponding to the size of the customer order for the day, the boxes are loaded onto chilled trucks (on aircraft pallets), and transported to the airport, where they are off loaded into chilled storage conditions, to await loading onto an aircraft.

The whole process from harvest to dispatch can take an average of 11 h. Because of this, flowers cut one morning, would not be dispatched to the airport, till lunchtime on the following day, but in that time the flowers spend most of the time in chilled storage conditions. Journey time to the airport depends upon the distance, but typically in developing countries the flowers may be in the truck for several hours. Typically, each truck would be carrying 750 large boxes of flowers (stacked on aircraft pallets, ready for loading onto the aircraft).

At an appropriate time, the shipment is taken from cold storage at the airport, loaded onto the aircraft, and then transported to Europe. Typically flights tend to depart in the evenings, and arrive in Europe in the early morning, with flight times varying from 7 to 12 plus hours, depending on distance. On arrival, after customs clearance, the pallets are loaded into chilled trucks and transported to the importer’s distribution centre, where they are usually kept in cold storage for a few days before being unpacked and then repacked into the supermarket’s in-store display system, and then sent to the supermarket’s own distribution centres. Sometimes however, flowers might not be stored, but used as soon as they arrive. It depends upon the supply-demand situation.

Overall, the duration from harvest to arrival at the importer’s distribution centre can be between 2 to 3 days, and for most of this time the flowers are kept under varying storage temperature conditions.

While the above refers to cut flowers, the description of the process also corresponds to the handling of fresh food produce (green beans, etc.), with slight variations determined by produce features.

4. Critical analysis of quality controlled logistics applications

RFID can be used for track and trace applications [13], which in Europe are primarily driven by regulation, specifically by food traceability requirements. This is an application that can be expected to grow in use, simply for these regulatory reasons. What is addressed here, are the more sophisticated applications that propose to use quality predictions to control logistics (distribution and supply) chains. Specifically of interest are: the use of *first-to-expire-first-out* issuing policies; the idea of cancelling shipments; removing specific parts of the shipment; and produce diversion. These are considered in the context of the general characteristics of the distribution and supply chains used to ship, by air freight, short shelf life produce, such as cut flowers, into Europe, from developing countries.

With regard to cancelling the shipment, this would be extremely unlikely to be practicable in many cases. There are several reasons for this. The first is because of the short time from cutting to arrival at the shipping airport, which mostly occurs within a typical (approximate) timeframe of 24 hours. Provided that the flowers (and other produce), are properly handled, it is unlikely there would be significant stress issues that would render such a drastic step viable (although there may be some exceptions to this when handling produce that has temperature sensitive flavour characteristics). In some cases however, the sophistication at the growers' site might cause temperature stress problems, as they may not have appropriate on-farm chilling facilities. This however, is a problem of lack of availability of the right technologies at the growers' site. It would not be useful to apply RFID just to predict quality problems in such circumstances, as this would only penalise the growers as they would not get paid for produce that was rejected in this way, and it does not make commercial sense for growers to become involved in such a process. A more appropriate investment would be to make improvements to on-farm facilities. There are also measures that can be taken to reduce heat stress in such circumstances, such as providing shaded short-term storage areas for the cut produce, close to growing houses, as described in the previous section.

Once produce is sent from the farm or growing areas to the pack house, produce enters the cold chain. Provided that chilled trucks are used for transportation to the airport, the cold chain will typically be maintained at least up to the point where produce is taken from the cold store at the airport, out to the aircraft, to be loaded.

At this point it might be argued that it would be worthwhile to forward predict the condition of the flowers when they arrive in Europe. But here there are some difficulties. Generally, with good supply chain practices, and apart from the period between cutting and arrival at the pack house, cold chain continuity will have been maintained. If there are any issues, then they might lie in the area of *field heat* removed, which, if this has not been done properly, might cause problems later on.

In the case of cut flowers, one of the difficulties is that models that predict the vase life of cut flowers are not well developed, and also because the senescence of cut flowers is still not well understood. Another difficulty is that there are several factors at work that can be harmful to cut flowers (and other produce) while in transit; primarily, temperature, humidity, and physical (mechanical) damage. In the case of the latter, this is not something that can be predicted, and reliable models for the former two do not exist. Similar points can also be made in general about other types of fresh produce. To be of use a model for each specific cultivar is needed, and this creates tremendous problems given the large number of cultivars in commercial use.

It should also be noted that there are a few known temperature trouble spots in the air freight distribution and supply chain. One occurs between the flowers being taken out of cold storage at the airport, being loaded onto the plane, and the plane departing. Here the issue of temperature stress can arise if there are any delays in loading the flowers on the plane, or if the plane itself is delayed. Another trouble spot occurs if planes are diverted, on route, because of aircraft technical problems or air traffic control problems. These are essentially unpredictable occurrences. To cancel the shipment at this stage would not be practicable, as it would mean unloading one part of the plane's cargo, thus adding extra costs, and delaying the delivery of other cargo on the plane, which may also be other items of fresh produce, which could suffer damage by being delayed in this way. There would also be additional local disposal costs.

Even if it would be possible to forward predict quality problems, and then cancel the shipment at last minute before the cargo plane departed, the shipper will have booked space on the cargo plane and would still have to pay for this, so in effect they would be paying out for the transportation of nothing. Moreover, once the plane is outbound from the airport there is no choice but to continue with the shipment. This is why the idea of produce diversion is not very practicable, since the plane will not make a detour from its intended destination just because the quality of one part of the cargo is predicted to fall below a defined level.

Another factor that stands in the way of produce diversion, is that the flowers are typically grown for specific customers, and are packed into customer (supermarket) branded wrapping at the farm (an increasing common practice in the fresh produce sector), and consequently these flowers cannot be simply diverted to another market. This would involve significant costs in removing the flowers from the boxes, removing the customer specific packaging, and then repackaging them, or sending them onto a flower auction, for which there are a limited number of options. Thus it is simply not cost effective to consider activities that add costs in a sector where stakeholders generally operate with low profit margins and rely on sheer volume of turnover to make a profit.

The fact that cut flowers are packaged in customer specific packing at source also raises issues concerning the practicability of using *first-to-expire-first-out* issuing policies. Customer specific packaging also comes with specific *display until dates*, which are used by retailers so that they know when to removed unsold items from display. To practice *first-to-expire-first-out* issuing, it would be necessary for a distributor to be able to put together a shipment to a retailer, of the right quantity, with the same or very similar *display until dates.* This is easier said than done, for such an issuing policy implies creating one single shipment to a retailer with what is available, and leaving for later items, with shorter remaining life. Even if this is were feasible, it is very unlikely that retailers would be easily convinced that this was the right thing to do. In effect, one would have to be able to convince them that older produce did in fact have a longer vase life than more recently delivered produce. It could also imply sending produce to retailers with expired *display until* dates. All this has implications.

To implement the above it would be necessary to be able to make very reliable, repeatable and accurate predictions, which is unlikely to be achievable in the short-to-medium term timeframe. There is of course, also the cost implication for the supply chain stakeholders, who would probably have to invest in modifying software and retraining staff, and would also encounter additional costs as they would need to add *display until* labels in Europe, where wages are much higher than they are in developing countries.

Another factor that should also be considered is the size of the shipment, which consists of several hundred boxes, typically with 50 to100 flower bunches in each. These boxes are stacked onto aircraft pallets, which are in themselves large, and are then covered in netting to prevent the boxes moving while in transit. This is another aspect of real distribution and supply chains that does not fit well with *Quality Controlled Logistics*. This method of shipping flowers means that it would be necessary to use several hundred (expensive) RFID based sensors, and what is more, it would be impossible, with the type of boxes currently used and the means of stacking, to extract signals from these, as these signals would be blocked by a mass of biological material (the cut flowers). What is more, to obtain a reliable prediction of quality, internal box level tracking would be needed, as it is what is happening within the boxes which need to be recorded, as this can be quite different to ambient conditions, owing to biological factors such as respiration, among other issues. Conditions within the individual boxes can also vary. This is why container level sensing for quality prediction is not practicable. It is also easy to see that the removal of one box from the shipment would be impracticable.

5. Conclusions

Analysis of the characteristics of international fresh produce distribution and supply chains, the specific features of fresh produce, the technical challenges involved, packaging practices, and the enormous volume of produce involved, suggests that many of aspects of *Quality Controlled Logistics* are impracticable. Some of these issues have been addressed in the preceding section. What then are the implications?

One conclusion that can be drawn is that the concept of *Quality Controlled Logistics* is not well matched to the characteristic of modern chilled fresh produce distribution and supply chains. For this reason, its usefulness as a tool to support improvements in the sustainability of these chains is very doubtful.

This suggests that improvements in sustainability may need to be achieved through other solutions that significantly reduce or eliminate the need for RFID-enabled *Quality Controlled Logistics*. This would then allow the use of low-cost RFID devices in much simpler track and trace applications (for regulatory compliance), which would be beneficial for supply chain stakeholders, as they would be able to use general systems deployed in other logistics applications, thus enabling some economies of scale to be achieved. Applying RFID-enabled *Quality Controlled Logistics* is an additional cost burden, given that it is a specialised application for the fresh produce sector. It is also an application that is probably not needed, as other solutions can be considered.

These other solutions include: (i) plant breeding to develop cultivars more robust to the vagaries of chilled supply chains; (ii) further development and application of existing technologies that will help to reduce loss of quality (e.g. modified atmosphere packing); (iii) improved supply chain practices that reduce exposure to stresses that cause loss of quality; and (iv) attention to developing improved growing practices to ensure that higher quality produce is fed into food distribution and supply chains.

All the above, in effect, should reduce the need for ICT-based solutions and thus the need for *Quality Controlled Logistics*. Instead, ICT-based applications may be better deployed in support of, for example, assisting growers to develop better growing practices that deliver produce of higher quality.

It can also be argued that these other solutions might in fact be better as these reduce the need for the investment in more sophisticated ICTs in the supply chain, which can be difficult to deal with given that there are many supply chain actors involved, no well established mechanisms for sharing costs and benefits, and also often inequality in terms of the power of one actor to influence another or to determine supply chain practices.

In effect, what is being proposed here is actually a systems level approach to sustainability [14], within the context a bio and agronomy centric perspective.

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