Using Supply Chain Information: Mapping Pipfruit and Kiwifruit Quality

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Abstract

Fresh produce supply chains are being transformed by increasing demands for information on product origin, production inputs, environment impacts and quality. A key point of differentiation between competing supply chains is their ability to transfer information seamlessly throughout the chain. Frequently, information required by the postharvest and/or marketing components of the supply chain must be sourced directly from the producer. Increasingly, the information sought from the producer needs to be based on complex data collected under a wide range of field conditions. This paper reports on techniques that can add value to the information required of the producer for all chain participants. These techniques include geographic information systems, handheld data capture devices, remote sensing equipment and database management at different levels in the supply chain. Also, the information generated from these techniques can be used to optimise physical and financial aspects of horticultural production systems, in addition to the provision of auditable product traceability. This aspect may help to motivate improvements to current information systems. While there are exciting opportunities for further progress, horticultural production and its supply chain has challenging demands for these technologies, not the least of which is the question “how will it work in practice?” Mapping of pipfruit and kiwifruit information provides case studies that explore the implications, and identify current limitations, for researchers, developers and users of the various technologies.

INTRODUCTION

The key to a successful supply chain is matching consumer requirements with timely and cost effective product supply. Modern industrialised supply chains for perishable product are currently undergoing major changes. Aggregation and differentiation of these chains, for competitive advantage, is being facilitated by innovative technology, in addition to new food safety and security concerns (Opara, 2003). These chains are also adopting strategies based on new understandings in supply chain theory (Mowat and Collins, 2000).

Track and Trace. There is a growing need for improved knowledge of product origin and traceability of product through the supply chain. The driver for this is the ability to provide evidence of Good Management Practice (GMP). There is also a need for improved segregation in order to allow individual supply chains to extract the maximum revenue from increasingly sophisticated future market segments. Availability of new technologies, such as electronic tags, security devices and improved web-based tools, has also hastened the development of track and trace (Praat et al. 2001).

Product Quality. For fresh produce chains, which are under increasing competition from both minimally processed and fully processed products, consistency of quality product is critical. Variability in quality attributes such as size, colour, shape, flavour, sweetness and firmness all detract from the value proposition at the point. Sources of variability arise from both the pre and post-harvest conditions and handling of
the crop. Little is currently made in terms of managing this variability as this information is not relayed back to growers. If producers are to be rewarded for optimising their quality and produce a more uniform product, then systems are required to facilitate this.

**Consumer Interaction.** An important aspect of supply chain theory is the linking of producers to consumers (Aulagnier, 1993), as producers need to know what are the attributes that the consumer values. With this information, the supply chain aims to optimise the supply of fruit that meets these needs as well as the inherent constraints of the supply chain. In general, the quality attributes recorded are based on visual characteristics, providing minimal feedback to producers on the critical determinants of value. However, with the advent of new non-destructive technologies, such as Near Infrared Spectroscopy (NIR), density or impact force sensors have been developed to provide information on internal fruit quality attributes such as dry matter, soluble solids and fruit firmness (Kawano, 2001). With access to such information, it is expected that the supply chain’s ability to respond to the consumer will improve. through positive feedback, with growers optimising fruit quality in response to greater market demand.

**Global Information System.** Tools that improve the information shared by chain stakeholders are expected to facilitate improvement in the overall supply chain performance. In the broadest terms these tools need to provide the means to enable a free flow of relevant information that is available to all the relevant participants in the supply chain. For instance, in the case of EUREP – (GAP), such a system needs to provide retailers and consumers with specific information on the grower and how the crop has been grown. In addition, the retailer can provide feedback on in-market quality assessments to growers, who can, if required, trace back to areas within their orchard. While the overall concept of improving information management systems for the supply chain is a large and complex issue, it may only be solved by addressing individual aspects.

**Information Sources.** There is a significant amount of data collected within a supply chain that is never shared. Often such data is collected for a specific purpose. For example, coolstore temperature data is frequently monitored to ensure correct performance of the refrigeration, but this data could also be used in models that predict shelf life and quality at point of sale. Another major source of information is the packhouse grader. While a grader singulates each fruit and segregates fruit on the basis a number of quality attributes, this device can also store the attributes measured for each fruit. For example, New Zealand apple graders currently measure fruit weight (size) and colour and kiwifruit graders measure weight, brix and dry matter (using NIR for the latter two attributes). With the ongoing development of additional sensors even more information will become available. Although the currently collected information is retained at the packhouse or distributed to the grower it could, in principal, be used more widely within the supply chain. Packhouses currently supply this quality information back to growers in a summarised form. Table 1 provides an example of this for one of the kiwifruit orchards under study. We postulated that the value of the data can only be truly realised when the information is summarised at a significantly more detailed, site specific level, as it gives growers better information on which to base their management decisions. Examples from our work with apple and kiwifruit, demonstrate how grader data may be better utilised within their respective supply chains. Also, we will show how to manage and display exemplary data from the supply chain within a Geographical Information System (Arcview GIS) as an alternative to the traditional tabular form that growers currently receive.

The profitability of an orchard is primarily determined by the value and quantity of fruit produced and the cost to achieve this production. In the case of apples, value can be determined by; variety; fruit size, colour and the quantity of fruit that is of export standard. The value for kiwifruit is similarly structured with differential payments for different sizes and a premium paid for high flavour (high dry matter) fruit.

**Current situation.** Fruit tracking systems in New Zealand comprise a range of manual and electronic techniques. Fruit are picked into bins, which may have individual labels. Once the fruit reaches the packhouse individual bins are aggregated into variety or
block lines and graded as such so that export packs (18kg or less) have the grower and perhaps orchard identified but it is difficult to trace back to individual blocks or picking areas. Export packs are stacked on pallets each with a unique pallet number so from then on fruit is traceable through the supply chain system. The net result for the growers is that they receive general information that represents large portions of their orchard. To improve on this approach, we implemented a system that was able to collect some new data, bin location, and link this spatial data with the data pertaining to quality of fruit within individual bins.

**METHODS**

*Maps.* The apple orchards used for this study were laid out in a series of small blocks (0.5 - 2.0Ha). Often each block has a range of varieties and trees of differing ages. Kiwifruit were more consistent with only one the Hayward (green) variety occurring on the eleven orchards studied. Kiwifruit vines are trained onto a horizontal structure approximately 2m above the ground, known as a pergola. The pergola is supported by posts fixed in the ground at generally a 5m x 5m spacing. The area between four posts is known as a bay and is the common management unit. Each of the orchards was surveyed with a differential global positioning satellites (DGPS) equipment (sub-metre accuracy) to develop digital maps of individual tree/vine locations. Aerial photographs were also taken and integrated with the DGPS maps as a series of data layers using the ArcView GIS package. A routine was developed to automatically map the location of the kiwifruit bays and the location of apple trees on these maps (Gillgren, 2001).

**Identifying bin locations.** Prior to picking, the orchard was marked by row and tree or by bay (row 1 tree 1 etc). As the bins were filled during harvest (400 kg bins for apples and 300 kg bins for kiwifruit), the fill location was recorded along with a bin number. For the apples an electronic tracking system was used. Radio Frequency Identification (RFID) tags (17 mm x 17 mm, Gemplus Ario 10-SM, 13.56 MHz) were attached to each bin. A handheld reader (Minec Memor 2000) was programmed to semi-automate entry of details such as orchard, quality controller, variety, maturity and picker along with location (block, row, tree). The bin unique RFID was scanned with a date and time stamp. At the packhouse the RFID was scanned when the bin entered the grading system to record the bin loading sequence. For kiwifruit, a manual, paper based system was used to record the bays from which fruit were picked to fill a particular bin. Bins were identified with a sequential barcode number. At the packhouse the barcode was automatically scanned as the bin was tipped into the grader. Harvesting techniques differed, apples were picked into single bins by individual pickers from adjacent rows and the block was harvested on 2 or more occasions whereas a group of 10 to 14 pickers moved once through a block of kiwifruit picking from 3 rows at a time. These differences were accommodated in the recording systems.

**Grader data.** At the packhouse individual fruit weights and colour score were recorded for apples and individual fruit weights and NIR estimates of brix (sweetness) and dry matter were recorded for kiwifruit. Each bin was weighed and identified to establish the sequence of bins and the mass flow of fruit across the grader with time.

**Fruit mixing.** An important issue for this project was that of fruit mixing. As the stream of fruit traveled across the grader fruit from separate bins will begin to mix in the region of the tail of fruit from one bin and the start of the fruit stream of the following bin. In order to be assured of relaying appropriate data back to growers it is important that only fruit guaranteed to be sourced from a particular bin, are used as a representative sample of the whole bin. In order to establish the level of mixing in the kiwifruit system a set of six coloured fruit were inserted between each bin at the tip. The fruit was weighted with the addition of lead shot so that they registered as ‘oversize’. The times the marker fruit were inserted into the system were manually recorded and the times that each fruit was dropped in the oversize chute was automatically captured by the grader. A set of 40 bins was evaluated to establish the level of inter-bin mixing.

A sub-sample of the stream of fruit quality data from the grader was associated
with each bin for statistical analysis. Bin locations were catalogued on the GIS database of the orchard and fruit quality data for each bin was associated with each bin location for map generation.

Statistical analysis. The data for analysis was based on average fruit quality per bin. Bin centroids were used as a basis for interpolated maps of fruit quality. Interpolation method for apples was inverse density weighted (IDW, Arcview spatial analyst (ESRI) with a cell size of 0.65m with all points included in the search radius. Kiwifruit data was interpolated using block kriging with a global variogram, onto a 2m grid with Vesper (Minasny et al, 2002). A minimum of 75 points were used.

RESULTS AND DISCUSSIONS

Fruit Mixing. The arrival times for each marker fruit within the sets of six were averaged to establish an estimate of the actual time of fruit convolution between the bins. The offset times from the mean were calculated and the normal score plot indicates that the mixing zone between bins is normal. The standard deviation (σ) of convolution was 4.25s. Six of the 192 marker fruit appear to be delayed relative to the normal distribution. This indicates a small number of fruit were held up in the system.

Based on the assumption of normalcy the 99.7% confidence interval (CI) (3σ) occurs at 12.75s which equates to ~13% of the fruit at normal operating belt operating speed. As there is mixed zone at the end of each bin, 74% of the stream of fruit from a bin can be considered to be guaranteed to have come from a particular bin. Due to the small proportion of marker fruit that were held up it was determined prudent to narrow the band further. All the fruit quality data presented here was selected from the middle 50% of the bin stream to represent the whole bin.

Based on the assumption of normalcy it is possible to calculate a tolerance level for the data. For 99.9% confidence that 99.9% of the fruit in a section of the stream of fruit from a bin is sourced from that bin occurs when at least 13% of the bin has passed. As there is mixed zone at the end of each bin, 74% of the stream of fruit from a bin can be considered to be guaranteed to have come from a particular bin. Due to the small proportion of marker fruit that were held up it was determined prudent to narrow the band further. All the fruit quality data presented here was selected from the middle 50% of the bin stream to represent the whole bin.

Apples. Figure 2 shows the study area on an example apple orchard. The area consisted of 11 rows of Braeburn apples with 5 m row spacing and 3.5 m between trees. An average of 160 bins of fruit were harvested each of the three years of the study. The size frequency distribution was segregated into two classes. Fruit size, known as count size and equivalent to the number of fruit in an 18kg pack, ranged from 60 to 165. Oversize (60 count) and undersize (120 – 165 count) were allocated to a low value class ($10.22/pack) and medium sized apples (70-110 count) were classes as high value fruit ($16.34/pack, May 2000 prices).

Figure 3 shows three sequential years of fruit quality data for Braeburn apples where there was significant variation quality (size) across the block.

Seventy to eighty percent of apples harvested from the West (left) side of the block were in the high value class whereas on the East side only 30-40% were classed as high value. Having the luxury of several seasons’ results in this format shows the temporal stability of spatial variation for this block. Confident decisions regarding remedial actions can be made where consistent effects are found. In this case it appears different nursery sources of what was reputedly the same planting stock have produced quite different fruit quality. Armed with this information a grower can accurately calculate the cost benefit of a range of remedial actions such as grafting new budwood or altering pruning technique. To find such variability has given us confidence in the technique when coupled with the comments the grower offered which were that he suspected differences across the block but had not realised that these differences were in fact quite significant. The differences had previously been masked within the average production figures for the block.

Kiwifruit. Figure 4 shows an aerial view of orchard 7, blocks within, bays and bin
locations for the 2002 picking season, which is an example of the kiwifruit orchards under study. This orchard covered 4 hectares of rolling country. Elevation varied by 19m sloping down from east to west (right to left) and from south to north. Figure 5 shows the distribution of fruit size, dry matter and brix. This format appears to be more informative and user friendly that Table 1. For example, while Table 1 indicates that fruit were smaller in blocks A, B and F, the variation in blocks B and C was not shown in the Table. These finer distinctions may be important as a grower applies his or her local knowledge of spatial features such as the elevation, soil conditions and canopy structure. This local knowledge can be applied to the spatial distribution of dry matter for example where a price premium is paid for fruit with relatively high dry matter reflecting consumer preference. The increased delineation of fruit in the orchard and the ability to relate to management and environmental features on a localised scale may illuminate opportunities to increase the proportion of higher dry matter (value) fruit through manipulation of those features on other areas where fruit of a lower value are identified. Improvements in the knowledge system like this are expected to provide more informed decisions on agronomic aspects with subsequent improvement in product consistency. Implementing GIS based data management and display at a higher, regional level could provide a powerful tool for identifying opportunities for quality improvement with industry wide application.

“How will it work in practice”. Key issues for implementation are identification of bin fill locations and appropriate capture of existing data from the grader. We have shown a relatively low cost system for generating fruit quality maps. For the system to work the grower and the packer must work together but the key driver for change in any supply chain has to be economic. Implementing improved knowledge systems at the grower / packhouse level will add cost. There will be improvements in traceability, logistics, record keeping and quality management. These benefits are useful at all levels of the supply chain but the costs are ultimately borne by only one or two players which makes implementation difficult as the benefits do not all accrue where the costs occur. A further issue is packhouse technology. There are few graders with NIR in New Zealand so only a small portion of growers may benefit fully from the more detailed information. However, all other packhouses use the individual fruit weight for packing management so even without NIR there is still a large untapped resource of data, which could be of value to the grower.

The ease of which this technology could be integrated into existing information infrastructure within businesses will depend on the current state of those systems. Existing systems tend to be a collection of poorly coordinated databases (eg spreadsheets) which would require integration before this technology could be implemented. This research attends a value to this technology for consideration when businesses are upgrading information systems.

CONCLUSIONS

Utilising supply chain information with GIS techniques can provide more relevant information to the grower. These techniques can be integrated with new grader technology such as NIR and increased market requirements in respect to product traceability and security. Currently, existing data generated by the fruit grader is wasted for want of improved knowledge systems. Increased delineation of fruit quality in apples and kiwifruit has highlighted opportunities for product improvement, which may not otherwise have been identified. Fruit quality maps can supplement local knowledge and improve the ability of individuals within the supply chain to respond to market signals such as premium product prices.

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Literature Cited

Tables

Table 1. Summary production statistics for kiwifruit orchard number 7.

<table>
<thead>
<tr>
<th>Block</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<tbody>
<tr>
<td>Number of Bins picked</td>
<td>69</td>
<td>38</td>
<td>37</td>
<td>36</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>Average Fruit Size&lt;sup&gt;1&lt;/sup&gt;</td>
<td>36.7</td>
<td>36.1</td>
<td>35.9</td>
<td>34.8</td>
<td>34.5</td>
<td>35.7</td>
</tr>
<tr>
<td>Minimum Size</td>
<td>35.3</td>
<td>34.1</td>
<td>34.4</td>
<td>33.9</td>
<td>33.4</td>
<td>34.2</td>
</tr>
<tr>
<td>Maximum Size</td>
<td>38.9</td>
<td>39.5</td>
<td>38.6</td>
<td>36.1</td>
<td>36.1</td>
<td>36.8</td>
</tr>
<tr>
<td>Standard Deviation of Size</td>
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<td>1.2</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Average Dry Matter</td>
<td>18.3</td>
<td>19.0</td>
<td>18.9</td>
<td>18.9</td>
<td>19.1</td>
<td>19.1</td>
</tr>
<tr>
<td>Minimum Dry Matter</td>
<td>17.6</td>
<td>18.1</td>
<td>17.9</td>
<td>18.3</td>
<td>18.6</td>
<td>18.6</td>
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<tr>
<td>Maximum Dry Matter</td>
<td>19.2</td>
<td>19.7</td>
<td>19.8</td>
<td>19.3</td>
<td>19.4</td>
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<td>0.2</td>
<td>0.3</td>
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<td>Average Brix&lt;sup&gt;2&lt;/sup&gt;</td>
<td>13.9</td>
<td>14.5</td>
<td>14.4</td>
<td>14.4</td>
<td>14.5</td>
<td>14.4</td>
</tr>
<tr>
<td>Minimum Brix</td>
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<td>13.8</td>
<td>13.6</td>
<td>14.0</td>
<td>14.1</td>
<td>14.0</td>
</tr>
<tr>
<td>Maximum Brix</td>
<td>14.7</td>
<td>15.0</td>
<td>15.2</td>
<td>14.7</td>
<td>14.8</td>
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</tr>
<tr>
<td>Standard Deviation of Brix</td>
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<td>0.3</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

<sup>1</sup> Fruit size, refers to number of fruit per tray, lower number = larger fruit. Average includes all sizes including 46 and above

<sup>2</sup> As predicted by near infrared spectroscopy on the fruit grader
Figures

Fig. 1. Test for normalcy of bin mixing data.

Fig. 2. Aerial view of example apple orchard showing the study area.
Fig. 3. Fruit quality maps for three sequential years for an example apple orchard

Fig. 4. Aerial view of the Kiwifruit orchard 7
Fig. 5. Quality maps for example kiwifruit orchard.