Quality Controlled Logistics in Vegetable Supply Chain Networks: How Can an Individual Batch Reach an Individual Consumer in the Optimal State?

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Abstract

Western-European consumers have become demanding on product availability in retail outlets and vegetable attributes such as quality, integrity, safety. When (re)designing vegetable supply chain networks one has to take these demands into consideration, next to traditional efficiency and responsiveness requirements. In post-harvest research, much attention has been paid to quality decay modelling and the development of Time-Temperature Indicators to individually monitor the temperature conditions of vegetables throughout distribution. This paper discusses opportunities to use time-dependent product quality information in supply chain/logistics decision making to improve the design of vegetable supply chain networks. If product quality in each step of the supply chain can be predicted, product flows based on availability predictions can be controlled and better chain designs can be established. A case is presented to illustrate the value of this innovative concept of Quality Controlled Logistics through a Dutch tomato chain.

INTRODUCTION

The variation in quality of vegetables as perceived by the consumer throughout the year is rather staggering. We will take the tomato as example as it is quite ubiquitous in any food retail outlet world wide. Even in Western Europe the quality attributes like colour, taste and texture vary dramatically over the seasons, within seasons and between retail outlets (De Ketelaare et al., 2004, Nunes et al., 2009). The present practice in the Netherlands is growing tomatoes on rock wool in greenhouses, sometimes with additional light (high pressure sodium lamps) in order to be able to produce also in winter. The tomatoes are harvested just after reaching the breaker stage of ripening (Schouten et al., 2007a). They are then stored and transported at the prescribed optimal temperature of 12°C. The period of storage and transport is kept to a minimum given the constraints of the logistics of large quantities and the market demand. The period between moment of harvest and positioning in the retail shelf for sale generally varies between 4 and 10 days. Retail managers try to procure amounts that can be expected to be sold within a few days. In practice the colour and the firmness of the tomatoes in the shelves varies considerably over time. Also the taste can vary from acceptable to far below acceptability (Bruhn et al., 1991) even within the same cultivar and origin of production. This leads to complaints from consumers and retail managers about insufficient quality (Van Kooten, 2006a).

Is it possible to provide a constant, preferably positive, quality experience of the same product throughout the year at any moment of purchase? It has been shown on theoretical grounds that such a constant quality experience leads to heightened consump-

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tion in the agri-food supply chain (Schepers and Van Kooten, 2006). This is confirmed in practise as a major retail chain in the Netherlands tripled its turnover within two years after introduction of ready-to-eat products at a 50% higher price. The ready-to-eat products are characterised by a more constant quality (Van Kooten, 2006b). In this paper it is shown that the concept of QCL (Quality Controlled Logistics) (Van der Vorst et al., 2007), can be implemented by utilizing an acceptance model for tomato batches (Schouten et al., 2007b). Such an implementation could ensure that an individual batch reaches an individual consumer group in the optimal state every time.

MATERIALS AND METHODS

Quality Controlled Logistics

Quality Controlled Logistics (QCL) makes use of variation in product quality, developments in technology, heterogeneous needs of customers and the possibilities to manage product quality development in the distribution chain. Using the definition of logistics management of the Council of Supply Chain Management Professionals (CSCMP), we define QCL as ‘that part of supply chain management that dynamically plans, implements, and controls the efficient, effective flow and storage of food products, services and related information between point of origin and point of consumption in order to meet customers' requirements with specific attention to the availability of specific product qualities in time by using real-time product quality information in the logistics decision process’.

Figure 1 shows the essence of the QCL concept. It concerns product differentiation and maximization of added value created in the food-supply-chain-network (FSCN) by the timely separation in harvesting and processing stages and pro-active control of goods flows. Appropriate strategies for logistics management can be developed based on scientific insights in the dynamic product quality behaviour profiles throughout the supply chain and understanding of the impact of technological and managerial conditions. More in detail, QCL starts with obtaining a detailed knowledge on customer requirements in the different market segments (Table 1). At the harvest (or breeding) stage products are collected and clustered based on variation in quality parameters. It is well known that for example one greenhouse producing tomatoes or one tree with growing apples delivers products with different quality levels. For example, due to sun light exposure apples on the outside of the canopy have a different quality then apples inside the canopy. QCL makes use of these quality distribution profiles by batching products of the same quality at the beginning of the supply chain. In the following supply chain stage comparable decisions have to be made (Table 1), each time a match is made between customer demand for specific products and the price that is paid for the products with the available supply of products with a specific (variation in) quality prediction. Subsequently one has to determine what actions can be taken to either redirect the goods flows to other markets or try to influence the quality level of the products using technological equipment. Figure 2 shows the differences between a traditional FSCN and a network that applies QCL.

The Acceptance Period Model

The acceptance period model (AP) is fully described in Schouten et al. (2007b). Basically it is a combination of a stochastic model with consumer limits of quality related properties. The stochastic model is derived from a mechanistic model that is based on a simplified description of the biochemical processes underlying the change in product properties over time. This derivation is possible under the assumption that the biological variation is normally distributed. In the mechanistic model the rate constant for the process is considered the same for the entire batch and in most cases for the cultivar itself, but temperature sensitive according to Arrhenius’ law and characterized by the activation energy E_a. The stochastic model assumes a random variation in maturity for every product in the batch, i.e. a Δt. This Δt, the biological shift factor, does not change during the postharvest phase. As Δt has a normal distribution it is characterized by the mean μ and the standard deviation σ. Once the rate constant is known through longitudinal analyses at different temperatures, the μ and σ of Δt within a specific batch can be determined through on cross sectional measurement on a random set of products from that batch. When this is know it becomes possible to predict the development of the properties, e.g. colour and firmness, throughout the chain if the external conditions are known before hand.

By consumer research it becomes possible for a specific consumer group to determine the limits of acceptability for the colour and firmness attributes. Acceptance limits have been estimated for acceptance and rejection when purchasing tomatoes for tonight's and weekend consumption by asking three groups of consumers to select tomatoes into two groups, 'acceptable' and 'not acceptable' for both moments of consumption. After the selection process colour and firmness were measured of accepted and rejected tomatoes and limits were determined when the majority of the consumers (Schouten et al., 2007b). When the acceptance limits are combined with the stochastic model it becomes possible to determine when the batch is acceptable for consumption by combining the moment of acceptance for consumption tonight $MA_{tonight}$, the moment of rejection for consumption tonight $MR_{tonight}$, the moment of acceptance for consumption over the weekend $MA_{weekend}$, the moment of rejection for consumption weekend $MR_{weekend}$. From these the overall acceptance period is determined as the intersection of the two specific acceptance periods, i.e. $AP_{tonight}$ and $AP_{weekend}$.

Quality Control Points

Quality Controlled Logistics is a means of combining predictive modelling and logistic critical points to find the moments of intervention in the chain (Romano, 2006) where this can still uphold optimal quality at the final point of sale. By studying the chain conditions and relating that to the dynamic behaviour of quality attributes, it becomes possible to determine the effects of different chains on the final quality of the products and to determine where in the chain certain measurements should be done, in order to determine conditions such as temperature, storage time, and moment of positioning in the shelves (Van Boekel, 2005).

The Case: Tomato Chain Scenario Analysis

The acceptance period model was determined for 10 different tomato cultivars from one Dutch seed company. All cultivars were grown in the same greenhouse and harvested on the same day for each maturation level, i.e. breaker, pink and red. A tomato supply chain from a well known Dutch producer group, known as Prominent, was studied. From this study twelve different actual and possible supply chains were designed. The chains were typical for different seasons, e.g. in the summer the supply is large and so the chain duration lengthens, while in winter the supply is small and the chain duration is short. Storage could be at 12, 16 and 18°C. When the tomatoes were harvested on Friday there was a weekend effect prolonging the chain duration. In Table 2 we see 4 of the 12 different scenarios for tomato supply chains as they can be found in the Netherlands. They consist of short, i.e., about 4 days, medium, i.e., 6 to 7.5 days, and long duration chains, i.e., 10 days.

RESULTS AND DISCUSSION

The best Dutch tomato cultivar shows duration of the AP between 12 and 13 days long compared to the worst Dutch cultivar with an AP duration varying between 1 and 3 days long. However, this is the period that the batch has an acceptable quality for consumers, which is something totally different from shelf life. As you can see in Figure 3 the shelf life, i.e. from the moment of harvest till past the end of the AP, of these batches can be quite considerable, for it is determined by the moment of rejection, while the AP is abysmally short. In Figure 3 we see the different scenarios depicted as horizontal bars. The colours indicate the different chain temperatures the tomato batch experiences throughout the chain. It is clear that the short AP causes a mismatch between acceptability and the moment the batch hits the shelf. In most cases the tomatoes are far from optimal when displayed to the consumer. Except in Scenario 3 (whole chain at 25°C), where the tomatoes are mainly overripe when the consumer can buy them. The only case that we have a good match is in scenario 4 when the tomatoes are harvested in the pink stage of maturity. It is clear that if tomatoes have a short AP duration this demands high precision chain management which is unpractical. The situation could be optimized, but that would mean an exact knowledge of all chain conditions ahead of time. And then decide on the precise chain temperature and harvest maturity per batch. These are rather impossible demands in fast flowing high volume chains like tomato chains. On the other hand in Figure 3 we see the cultivar with the longest AP at the different chains. This allows for more freedom of decision making, however it can go wrong anyway. As we see in scenario 1 the chain is too short for the AP. A proper logistic decision in this case would be to store the tomatoes or keep them at a higher temperature to make sure they reach the shelf in an optimal state. Scenarios 3, at 25°C, shows that part of the AP is lost due to early ripening within the chain. A proper logistic decision would be here to lower the chain temperature. However a substantial AP is left on the shelf considering that the retail wants to turn over their product at the highest speed. We see that the optimal scenario for this cultivar is the autumn-winter-Friday-long chain at 18°C, i.e. scenario 2. And there it would be optimal to harvest the tomatoes in the pink stage. However it is clear when you have such a long AP that it would be wise to harvest in the red stage as you will hardly lose any AP (a day at most) and you will be certain that the consumer will be satisfied.

CONCLUSIONS

By creating Acceptance Period (AP) models instead of shelf life testing, it becomes possible to link chain management to quality management and position batches of products in their optimal state for the consumers. By determining AP values for new cultivars, breeding can optimize the vegetables for fresh produce supply chains. Through consumer research we can determine levels of quality attributes of specific consumer groups. By analysing the chain and its likely conditions it becomes possible to determine the critical points where both quality and logistics need decisions on the further chain conditions encountered. Then quality controlled logistics (QCL) can combine this knowledge into practical decision making in the predetermined chains, including harvest maturity, chain temperature and chain duration. This shall lead to on-line decision making based on actual quality and availability information leading to the optimal quality in the shelf for 365 days each year.

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Tables

Table 1. Overview of specific QCL Decisions.

Generic logistics decisions	**Specific QCL decisions**
Determine generic customer service standards • Customer needs (quantity, quality, etc.) • Customer service levels (lead time, reliability, etc.) • Determine requirements on supply of products in each stage of the chain.	Determine customer acceptance levels and periods for specific market segments using accepted and measurable quality standards. Translate this into specific product quality requirements for each stage in the supply chain (next to of course volume and timing requirements).
Determine facility network design • Number, location of stocking points • Equipment selection, capacity planning	Use customer requirements data, information on supply qualities and volumes and transport scenarios with quality predictions to determine the required network design and equipment.
Determine inventory management • Position Customer Order Decoupling Point (CODP); push-pull strategies • Warehousing policies	Use supply chain data to determine the optimal position of inventory points in the network taking predicted quality changes (and thus environmental conditions) into account.
Determine information flows and order processing • Ordering rules • Order inventory interface procedure • Order picking procedures	Determine Critical Quality Control Points to monitor quality changes. Use quality prediction models and product quality information to apply first-expired-first-out policy. Re-sort batches if needed. Aim for homogenous batches for specific market segments.
Plan order fulfillment • Allocate harvested produce to customer orders and deliver the products without dealing with quality changes and differences that occur in the supply process. A batch is not re-sorted or re-allocated unless serious issues arise. • Determine transport management (mode, scheduling)	Dynamic logistics planning in the complete chain based upon real time product-quality information (using quality control points and predictive models). If needed, batches are re-sorted into homogeneous batches, re-allocated to different market segments, transported with different modes or environmental conditions are adapted to meet customer requirements. Technologies such as data loggers, RFID and GPS are used to capture all relevant information.

Table 2. The different scenarios for tomato chains from the moment of harvest till the moment the tomatoes are in the retail shelf. Different seasons cause different demands. If the harvest takes place on a Friday this usually means a longer supply chain. Prominent is a sales organisation and the chains actually exist.

Scenario	Criteria		
	Chain	Temperature	Season
1. Spring-Winter-non Friday and Temp	Short	Prominent	Spring winter
2. Autumn- Winter-Friday-longer chain	Medium	Optimal 18°C	Autumn winter
3. Spring-Summer-Fridays- Temp 25	Medium	Extreme 25°C	Spring summer
4. Summer-Fridays	Long	Prominent	Summer

Figures

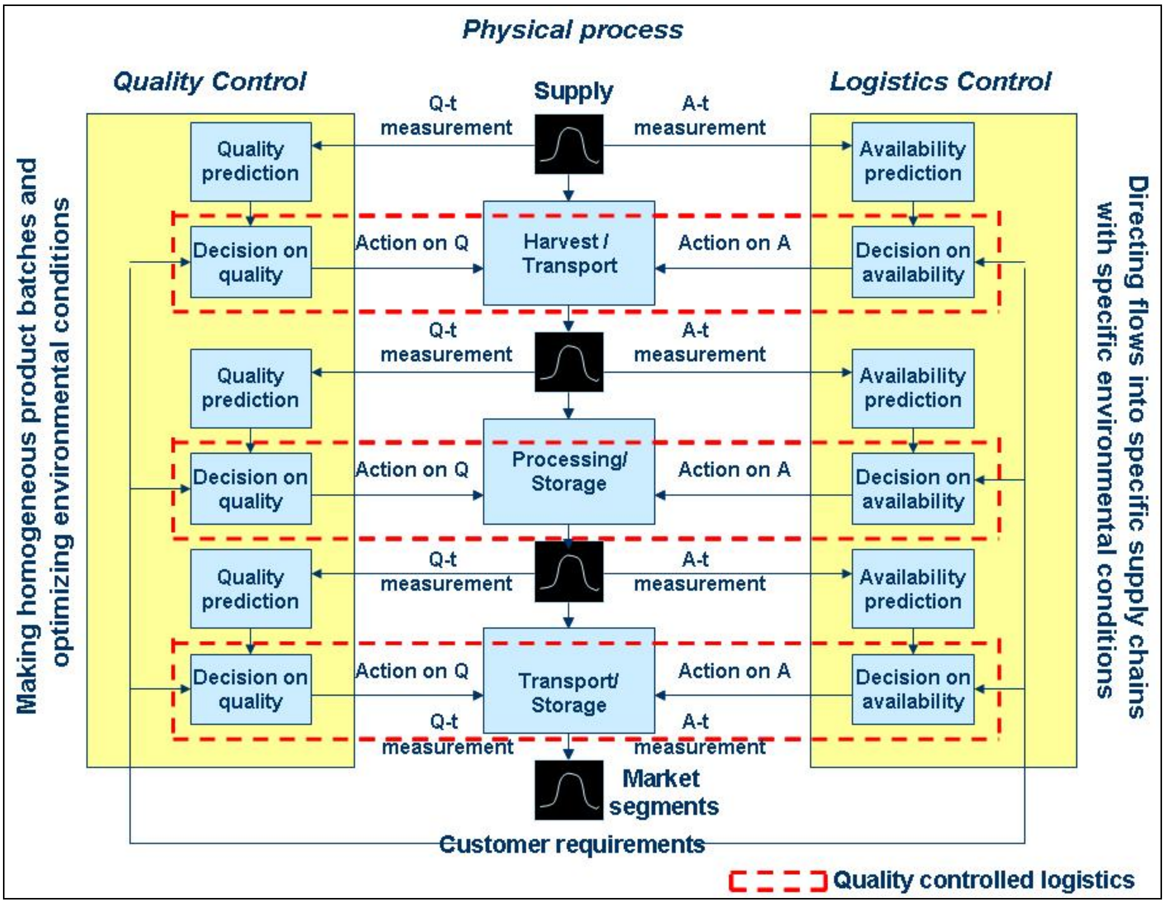

Fig. 1. Quality Controlled Logistics model developed by Vorst et al. (2007) to show schematically where in the chain measurements, predictions and decisions are to be made.

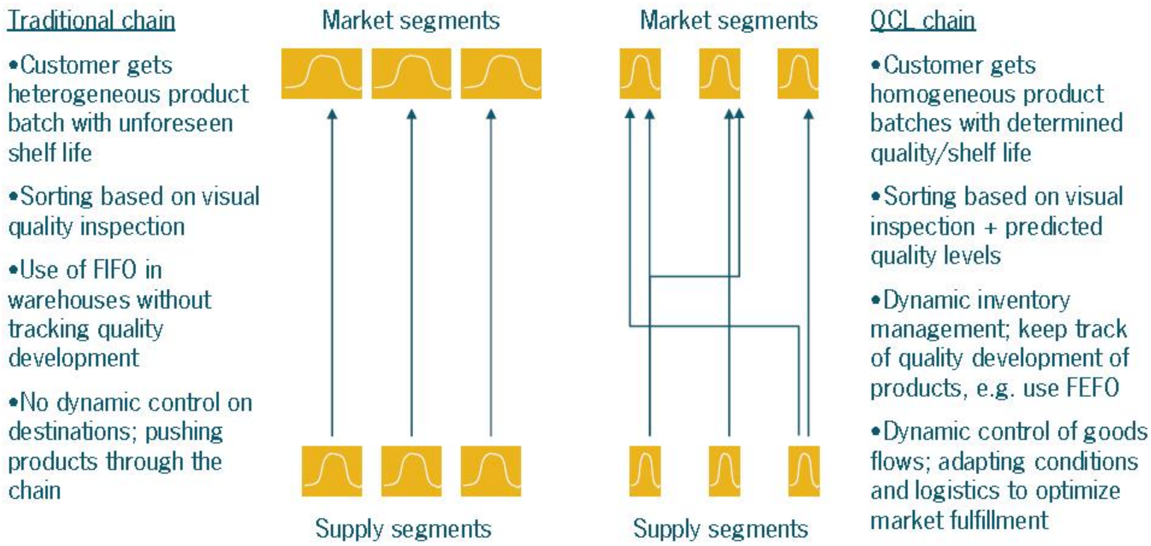

Fig. 2. Comparison of a traditional chain and a QCL chain.

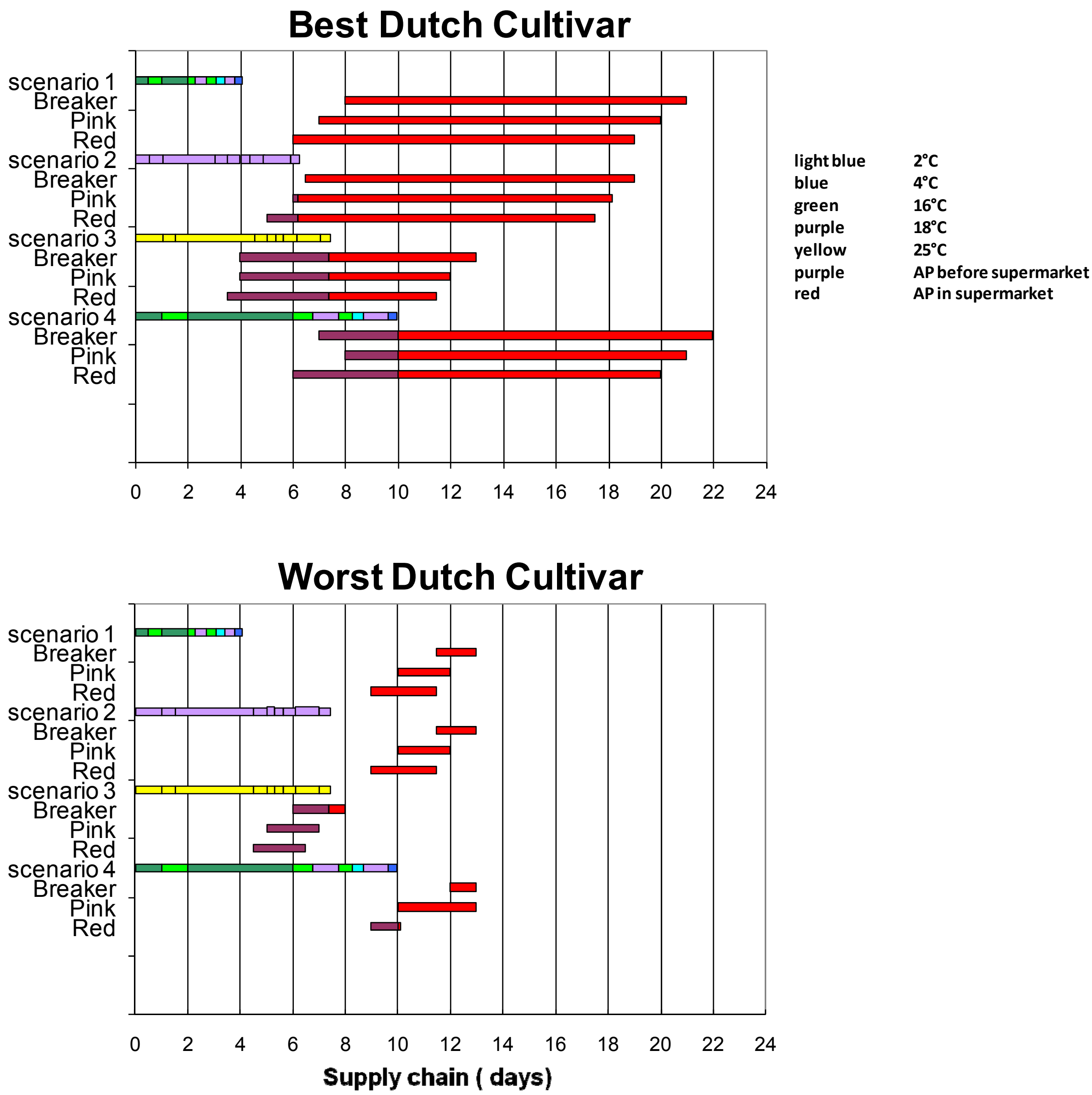

Fig. 3. Scenario analysis of the best and worst Dutch tomato cultivar considering the length of the AP. The length of the chains and the different temperatures are given in Table 2.