QUALITY CONTROLLED LOGISTICS IN FOOD SUPPLY CHAIN NETWORKS: INTEGRATED DECISION-MAKING ON QUALITY AND LOGISTICS TO MEET ADVANCED CUSTOMER DEMANDS

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ABSTRACT
Western-European consumers have become more demanding on product availability in retail outlets and food attributes such as quality, integrity, safety. When (re)designing food supply chain networks one has to take these demands into consideration next to traditional efficiency and responsiveness requirements. In food science literature, much attention has been paid to food quality decay modeling and the development of Time-Temperature Indicators to individually monitor the temperature conditions of food products throughout distribution. This paper discusses opportunities to use time-dependent product quality information to improve the design of food supply chain networks. If product quality in each step of the supply chain can be predicted in advance, goods flows can be controlled in a pro-active manner and better chain designs can be established. A case is presented to illustrate the value of this innovative concept of Quality Controlled Logistics.

Keywords: Supply Chain Design, Food Quality, Logistics Management

INTRODUCTION

Consumers expect food in retail stores to be of good quality, to have a decent shelf life and to be fit for purpose (Smith and Sparks, 2004). Furthermore, consumers demand great product diversity, safety, convenience (e.g. ready to eat products) and (sometimes) sustainability. More powerful well-informed customers are stimulating retailers and other actors in the food supply chain network to adapt new business concepts. For example, Tesco has pledged to cut down on its 'food miles' by opening offices in England and Wales responsible for buying food from nearby farmers and suppliers. ‘Food miles’ is an expression for the concept that the mileage of food before it reaches the consumer (or the plate) is a potential indicator for the environmental impact of the food and its components. Whereas this development might result in local-for-local business concepts, the continuous consumer demand for year-round availability of high-quality fresh products (such as pine-apples, citrus fruits, kiwis) requires global-to-local concepts. Furthermore, the food miles discussion is recently redirected towards the total CO_2 output (i.e. the ‘Carbon foodprint’), as it is not only *how far* the food has traveled but *how* it has traveled that is important to consider. Global competition together with advances in information technology have stimulated partners in food industry to pursue a coordinated approach to establish more effective and efficient supply chains, i.e., supply chain management (SCM). We conclude that consumer demand has a significant impact on the design and management of food supply chains.

Supply chain design and management has received a lot of attention in the academic as well as business world (c.f. the books of Simchi-Levi et al, 2007, Chopra and Meindl, 2007, Slack et al, 2006 and the recent special issue in *The International Journal of Operations and Production Management* (IJOPM, 2007)). SCM is about matching supply and demand; it is about the integrated planning, coordination, and control of all business processes and activities in the supply chain to deliver superior consumer value at less cost to the supply chain as a whole, while satisfying requirements of other stakeholders (e.g. the government or NGOs) in the supply chain network (Van der Vorst and Beulens, 2002). SCM should result in the choice of a supply chain scenario, i.e., an internally consistent view on how a supply chain should look like (within the total network) in terms of supply, production and distribution processes and their coordination. From a logistics point of view, it mainly deals with choices regarding the design of distribution networks, transport and production infrastructures, inventory management and management of goods and information flows.

The design and management of Food Supply Chain Networks (FSCNs) is, however, complicated by an intrinsic focus on product quality (Luning and Marcelis, 2006). The way in which food quality is controlled and guaranteed in the supply chain, is of vital importance for performance. Also, apart from being a performance measure of its own, product quality is directly related to other food attributes like integrity and safety. For example, product’s appearance, safety and or shelf life can be adversely affected due to failing to control appropriate temperature conditions (Smith and Sparks, 2004). Therefore investments in chain design should not only be aimed at improving logistics performance but also at the preservation of food quality so that the right products are delivered with the right quality at the right place and time.

Typically, food degradation is related to intrinsic properties (like, initial microbial contamination, composition, respiration rate and specific breed or cultivar characteristics), environmental conditions (like temperature, humidity and the presence of contaminants in all stages of the supply chain network) and the time the product is exposed to these conditions. Here environmental conditions may be influenced by, for example, the type of packaging, and the availability of temperature conditioned warehouses. In recent food science literature, much attention is paid to food quality decay modeling and the development of Time Temperature Indicators (TTI) to individually monitor the temperature conditions and impact on the quality level of food products throughout distribution (Sloof et al. 1996, Taoukis and Labuza 1999, Schouten et al. 2002, Bobelyn et al. 2006). When we combine these food quality decay models with logistics models, new opportunities arise to improve the performance of FSCNs.

This paper discusses opportunities to use time-dependent product quality information in a pro-active way to improve the design and management of FSCNs. Fresh product quality in consumer markets is influenced by the product quality at origin (when harvested) and the conditions that the products have been exposed to during their way through the supply chain network. The logistics concept therefore influences market opportunities and vice versa. If quality is known in advance, goods flows could be steered in all phases of the FSCN in a pro-active manner.

The next section will discuss the ins and outs of temperature-controlled FSCN. Next, we will discuss the concept of Quality Controlled Logistics, followed by a case that illustrates the potentials of this new concept. We will end the paper with conclusions and further research.

TEMPERATURE-CONTROLLED FOOD SUPPLY CHAIN NETWORKS

What are Food Supply Chain Networks?

A FSCN comprises organisations that are responsible for the production and distribution of vegetable or animal-based products. Figure 1 depicts a generic supply chain within the context of a complete supply chain network. Each firm is positioned in a network layer and belongs to at least one supply chain: i.e. it usually has multiple (varying) suppliers and customers at the same time and over time. Other actors in the network influence the performance of the chain. In a FSCN different companies collaborate strategically in one or more areas while preserving their own identity and autonomy. As a result, organizations may play different roles in different chain settings and therefore collaborate with differing chain partners, who may be their competitors in other chain settings. In brief, chain actors may be involved in different supply chains in different FSCN, participate in a variety of business processes that change over time and in which dynamically changing vertical and horizontal partnerships are required.

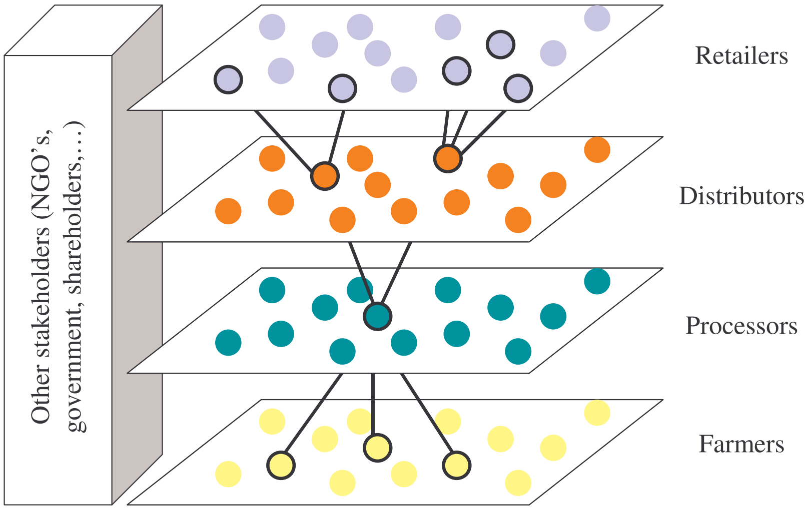

Figure 1. Schematic diagram of a supply chain from the perspective of the processor (bold flows) within the total FSCN (Van der Vorst et al., 2005).

In general, we distinguish two main types of FSCN. First a FSCN for fresh agricultural products (such as fresh vegetables, flowers, and fruit) can be distinguished. In general, these chains may comprise growers, auctions, wholesalers, importers and exporters, retailers and speciality shops and their input and service suppliers. Basically, all of these stages leave the intrinsic characteristics of the product grown or produced in the countryside unprocessed. The main activities are handling, conditioned storage, packing, transportation, and especially trading of these goods. Determining the remaining shelf life (in days) is one of the main difficulties for these products. Second, a FSCN for processed food products (such as portioned meats, snacks, desserts, canned food products) can be distinguished. In these chains agricultural products are used as raw materials for manufacturing of consumer products with higher added value. In most cases, conservation and conditioning processes extend the shelf life of the agricultural products; best-before-dates are used to indicate the remaining shelf life. Actors in both types of chains understand that products that have a good quality at origin (once harvested or processed) are subject to quality decay as they travel through the supply chain. This natural decay may be increased because of an inconsiderate action of another actor, for example storing a unit load of milk on a dockside in the burning sun.

Due to the typical characteristics of food products, working together with other partners in the FSCN have already received a lot of attention over the past years. Table 1 summarises a list of typical process and product characteristics of FSCNs, categorised by (potential) stage in the supply chain, which may impact logistics. It is vital for industrial processors to contract suppliers to guarantee the supply of raw materials in the right quantity, right quantity, at the right place and at the right time. Furthermore, these processors coordinate the timing of the supply of goods with suppliers to match capacity availability.

Table 1. Overview of main characteristics of FSCNs and their impact on Logistics (based on Van der Vorst et al., 2005).

SC stage	*Product and process characteristics*	*Impact on Logistics*
Overall	• Shelf life constraints for raw materials, intermediates and finished products and changes in product quality level while progressing the supply chain (due to quality decay) • Recycling of materials required	• Timing constraints • Information requirements • Return flows
Growers cq. Producers	• Long production throughput times (producing new or additional products takes a lot of time) • Seasonality in production • Variability of quality and quantity of supplied products	• Responsiveness • Flexibility in process and planning
Food industry	• High volume, low variety (although the variety is increasing) production systems • Highly sophisticated capital-intensive machinery focusing on capacity utilisation • Variable process yield in quantity and quality due to biological variations, seasonality, random factors connected with weather, pests, other biological hazards • A possible necessity to wait for the results of quality tests (quarantine) • Alternative installations, alternative recipes, product-dependent cleaning and processing times, carry over of raw materials between successive product lots, etc. • Storage buffer capacity is restricted, when material, intermediates or finished products can only be kept in special tanks or containers • Necessity to value all parts because of complementarities of agricultural inputs (for example, beef cannot be produced without the co-product hides) • Necessity for lot traceability of work in process due to quality and environmental requirements and product responsibility	• Importance of production planning and scheduling focusing on high capacity utilisation • Flexibility of recipes • Timing constraints, ICT-possibility to confine products • Flexible production planning that can handle this complexity • Need for configurations that facilitate tracking and tracing
Auctions / Wholesalers / Retailers	• Variability of quality and quantity of supply of farm-based inputs • Seasonal supply of products requires global (year-round) sourcing • Requirements for conditioned transportation and storage means • Demand for high quality food products, convenience and sustainability	• Pricing issues • Timing constraints • Need for conditioning • Pre-information on quality status of products

What are Temperature-Controlled Food Supply Chain Networks?

A temperature-controlled FSCN requires food products to be maintained in a temperature controlled environment, rather than exposing them to whatever ambient temperatures prevail at various stages of the supply chain (Smith and Sparks, 2004). In this paper we focus on fresh foods that need controlled temperatures to maintain or even improve product quality (due to ripening of fruits, think of "ripe-on-arrival"), more in particular we focus on fresh meats and poultry, dairy and meat based provisions and vegetables and fruits. Considering the increasing consumer demand for ready-to-eat products (like ready meals and prepared salads) the delivery of high quality products becomes increasingly important.

There are a number of difficulties in managing temperature-controlled FSCNs such as the short shelf life which puts additional requirements on speed and reliability of logistics systems and require specialized transportation and storage equipment. Furthermore, modern chains distribute multiple types of products – often with multiple temperature regimes. This means that a 'best fits all' solution is taken, which means that the temperature is not optimal for any of the products. Moreover, one must be careful for product interferences, for example, bananas produce ethylene which accelerates the ripening process of other fruits. Finally, in these chains temperature control and prevention of product interferences are very important from the perspective of food safety, typical safety problems concern *Listeria* in cheese products, *Salmonella* in chickens and eggs, *BSE* in cattle etc. These typical food related issues should be considered when designing a FSCN, using risk assessment as an important tool.

It is clear that the design and management of temperature-controlled FSCNs is a complicated process; how, for example, can a retailer ensure that products are always under the appropriate temperature regime when they travel from a field in Australia to a store shelf in Ankara? Fruit and vegetables might look fresh from the outside, but what is the real intrinsic quality hence remaining period of consumer acceptance? Retailers and chain partners realize that they can distinguish themselves in the market place by setting up a reliable temperature-controlled FSCN that guarantees product quality and reduces shrinkage (price cuts) in retail outlets.

Managing product quality variation in FSCN

In practice, a lot of work has been done to improve the absolute quality of food products at the market place. From logistics point of view, main emphasis has been on the development of new distribution systems, using new management concepts that improve delivery reliability and lead times via increased information exchange and changes of roles in the chain, e.g. Cross Docking, Vendor Managed Inventory, Efficient Replenishment, Collaborative Planning Forecasting and Replenishment and Factory Gate Pricing; and via innovations in logistic means, such as reefers (a reefer is a refrigerated container used in intermodal freight transport for transportation of temperature sensitive cargo). Smith and Sparks (2004) give a nice overview of the changes that took place at Tesco between 1980 and 2002. It is clear that logistics improvements go hand in hand with technological developments and quality assurance systems. However, up to now the inherent heterogeneity in quality of product batches is scarcely considered.

Fresh FSCN are characterized by heterogeneous batches of products (i.e. product quality differs in the batch and between batches) delivered by a diversity of producers to multiple market outlets that have different demands. Long supply chains of perishable products suffer from high risk of quality degradation. Storage, handling, transport and distribution conditions have a strong impact on freshness and shelf-life of the produce. The common strategy for dealing with the variability in quality is tailoring the supply chain towards ‘average’ quality. This might not be, however, the most effective approach, since variability can also be strategically exploited through the flexible management of quality differences for specific market outlets. Instead of homogenizing food product quality in the chain, we advocate differentiation of product flows based upon the absolute batch quality and quality variation at different stages in the FSCN. This might improve chain revenues via improved product quality on retailer shelves and/or improved matching of supplied products at a certain price to specific market segments. As an example, Figure 2 presents an overview of variation in product keeping quality at incoming and outgoing products at a specific supply chain stage; it shows that there is inherent variation in product quality that, if determined, can be used to select specific supply chain designs to optimize the delivery of products with a specific quality level to specific market segments. Batches of high quality could be sent to different market segments with higher added value. New technologies like RFID and GPS provide innovative means to manage such concepts. Furthermore, new stock rotation systems can be implemented which are not based on First-In-First-Out (FIFO) or Last-In-First-Out (LIFO), but on First-Expired-First-Out (FEFO); in this case the products with the closest expiration date are advanced first.

Recent technological advancements have created new opportunities to measure and adjust food product quality as it proceeds through the supply chain network, which brings us new methods for managing these networks to optimize chain performance.

MEASURING AND PREDICTING PRODUCT QUALITY IN THE CHAIN

The quality of fresh food products is strongly dependent on its temperature exposure history, from production through distribution and storage to consumption. Monitoring critical parameters, such as temperature history throughout the product's entire life cycle is of crucial importance since the introduction of quality assurance systems at different stages in the supply chain. Moreover, monitoring temperature history allows accurate prediction of shelf-life and could replace the sometimes meaningless expiry dates on fresh produce (Bobelyn et al., 2006). As one does not know the quality at origin and the time-temperature history of the product, any prediction on shelf life is just a guess.

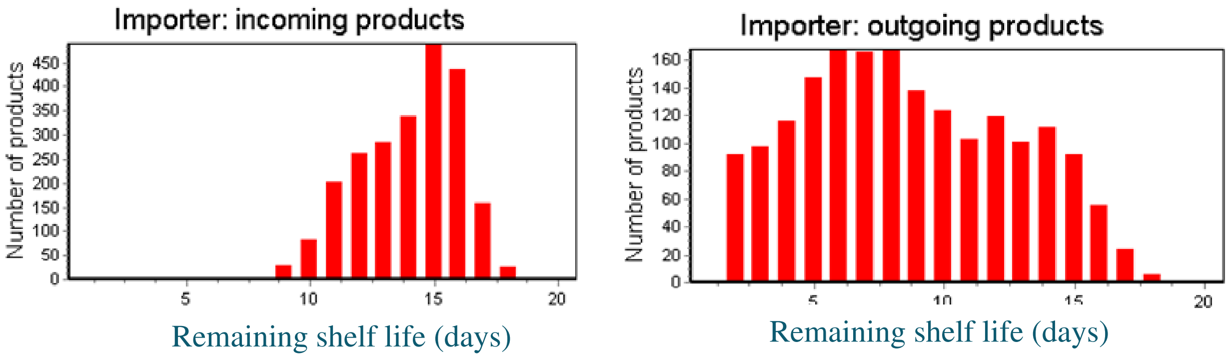

Figure 2. Example of variation in product quality at an importer warehouse.

Time Temperature Indicators
Time–temperature Indicators or Integrators (TTIs) can be used to help control the realisation of an unbroken cold-chain, since the indicator shelf-life is dependent on the time–temperature history of the package throughout the whole distribution chain. TTIs attached to the package surface integrate the cumulative time–temperature history of the product starting from the moment of indicator activation. The integrated time–temperature history is visualised as a colour change or colour movement. The change of the indicator proceeds as a function of time, the rate of visible colour change being proportional to the temperature (Smolander et al., 2004). The indicators monitor temperature exposure, not product quality. Their purpose is to signal when product quality should be checked due to temperature exposure.

The use of time-dependent product quality information in the design of distribution systems is only scarcely addressed in literature. For example, Giannakourou and Taoukis (2003) consider the potential of a TTI-based system for optimisation of frozen product distribution and stock management using Monte Carlo simulation techniques. TTI-responses are translated to the level of product deterioration, at any point in the distribution system, which enables the classification of products according to remaining shelf life. They compare the FIFO stock rotation system with the FEFO system (which they called the Least-Shelf-Life-First-Out (LSFO)). Their results show that the amount of rejected products at the consumer can be minimized using a TTI-based management system such as FEFO.

Quality decay modeling
At present there are several techniques in development that enable us to measure and predict the dynamic quality development of fresh food products in the FSCN objectively. They enable us to predict the ripening development under different environmental conditions, which allows the development of Quality Controlled Logistics in the fresh FSCN and positioning of food in retail shelves precisely at the optimum quality window of the product. If this can be accomplished it might lead to higher consumption levels of fresh fruits.

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 follows: *Quality Controlled Logistics is that part of supply chain management that plans, implements, and controls the efficient, effective flow and storage of food products, services and related information between the point of origin and the point of consumption in order to meet customers' requirements with respect to the availability of specific product qualities in time by using time-dependent product quality information in the logistics decision process.*

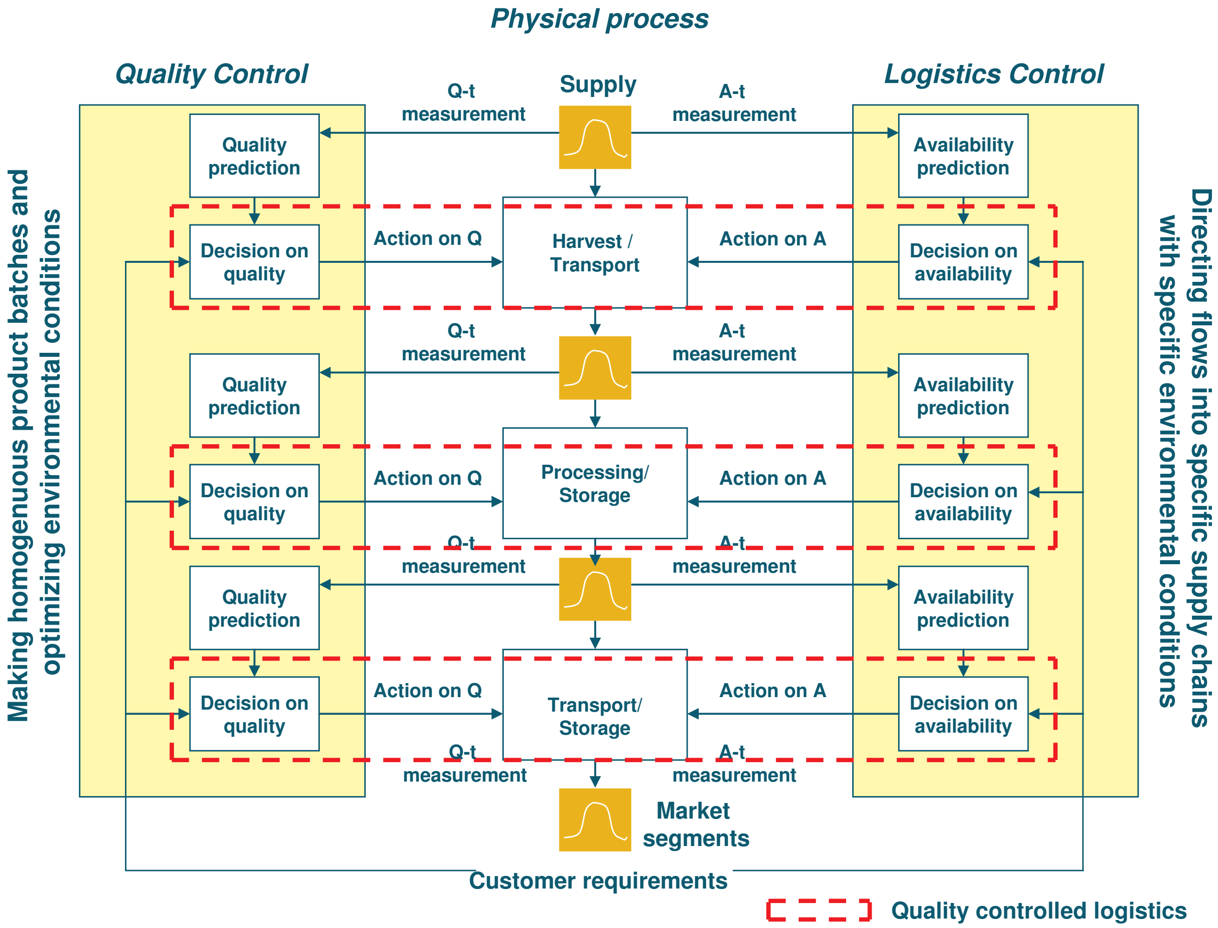

Figure 3. Overview of the Quality Controlled Logistics concept

Figure 3 shows the essence of the QCL concept. It concerns product differentiation and maximization of added value created in the 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 2). 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 stable with pigs or one tree with apples deliver products with different quality levels. For example, due to sun light exposure apples on the outside of the tree have different quality then products inside the three. 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 2), 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 4 shows the differences between a traditional FSCN and a network that applies QCL.

Table 2. Overview specific QCL decisions.

Generic logistics decisions	**Specific QCL decisions**
Determine customer service standards • Customer needs (quantity, quality etc.) • Customer service levels • Determine requirements on supply of products in each stage of the chain.	Determine customer requirements for specific market segments. Use product quality information to cluster harvested products into homogeneous batches and choose the best distribution channels.
Determine facility network design • Number, location of stocking points • Equipment selection • Capacity planning	Use product quality information to determine required network design and equipment. Think about the use of RFID and GPS to capture the relevant information.
Determine inventory management • Position Customer Order Decoupling Point (CODP); push-pull strategies • Warehousing policies	Use product quality information to determine position CODP and specific environmental conditions in the complete supply chain needed to meet specific market segment requirements.
Determine information flows and order processing • Ordering rules • Order inventory interface procedure • Order picking procedures	Use product quality information to apply First-Expired-First-Out policy. Focus on homogeneous product batches for specific market segments.
Determine transportation management • Mode selection • Vehicle scheduling • Freight consolidation	Use product quality information to determine transport mode and means (container, etc. including environmental conditions) needed to meet customer requirements.

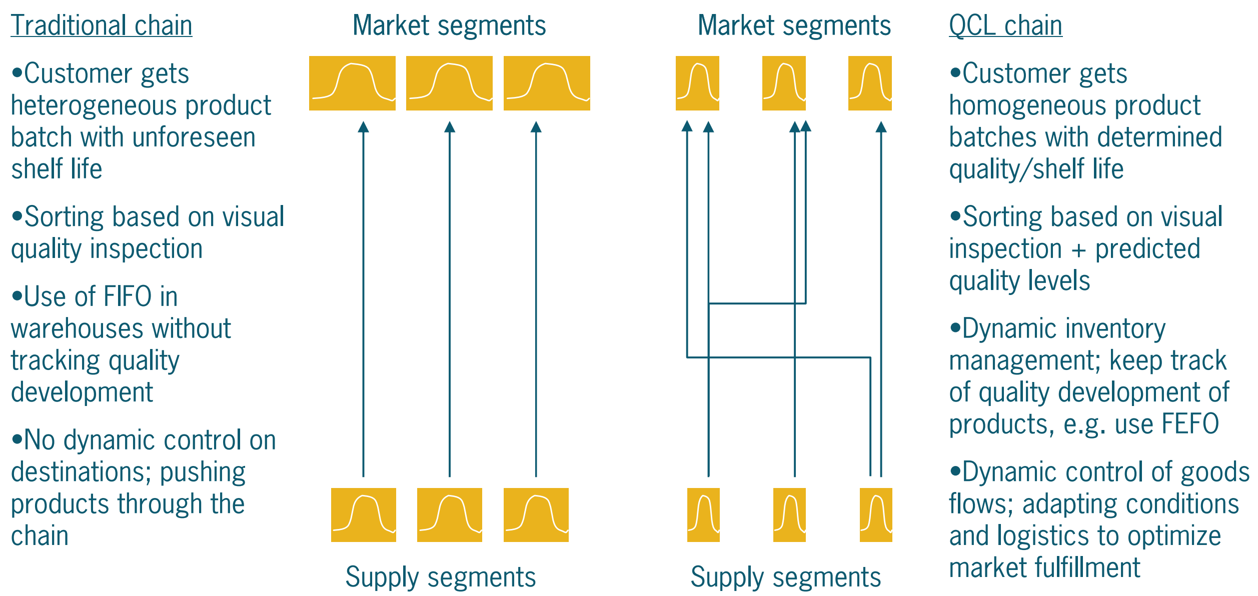

Figure 4. Comparison of the traditional chain and the QCL chain

THE CASE OF TOMATOES

This section describes a case of a tomato supply chain network (based on Schouten et al. 2006) to illustrate the QCL concept. Growers associations produce tomatoes with differences in quality due to differences between individual growers and between batches of one grower. This is troublesome since customers demand constant product qualities with a maximum consumer acceptance period (shelf life). Current practice in the horticultural chain is to harvest tomatoes just after they reach the breaker stage (when they are still green) and transport them at the lowest temperature that will not induce chilling injury. This may result in an insufficient color (pink color stage) and firmness development (too firm) at the moment of consumption. On the other hand, when tomatoes are harvested and transported over long distances or stored too long in retail shops, firmness can become a limiting quality attribute, now due to tomatoes being too soft. In other words: the quality attributes of both color and firmness are of importance for consumers (Tijskens and Evelo, 1994) and thus determine price settings.

Consequently consumer research was used to determine the acceptance levels for both color and firmness of tomatoes when consumers want to buy them for direct consumption and also for consumption after several days. This determines an acceptance period in which the tomatoes are optimal from the consumer view. Based on a new quality development model using biological variation in batches of products it is possible to predict the development of both color and firmness through time at different temperatures. This can be done on batches of products and allows predicting the time it takes, depending on the temperature, before the batch becomes acceptable and until when the batch will stay acceptable. In Figure 5 the result of these measurements is shown for batches harvested at different maturity and from different growers; the period between the lines is the acceptance period for each batch. Consumers will experience the tomatoes as optimal when consumed in this period. It is clear, that though all tomatoes are genetically identical (one cultivar) and the climatological conditions of growth were also very similar, there are still large differences in batch quality development between growers and to a lesser extend between harvest maturities. QCL uses this information to get the product at the right time in the right shelve (at the right price!) to optimize consumer response and market revenues.

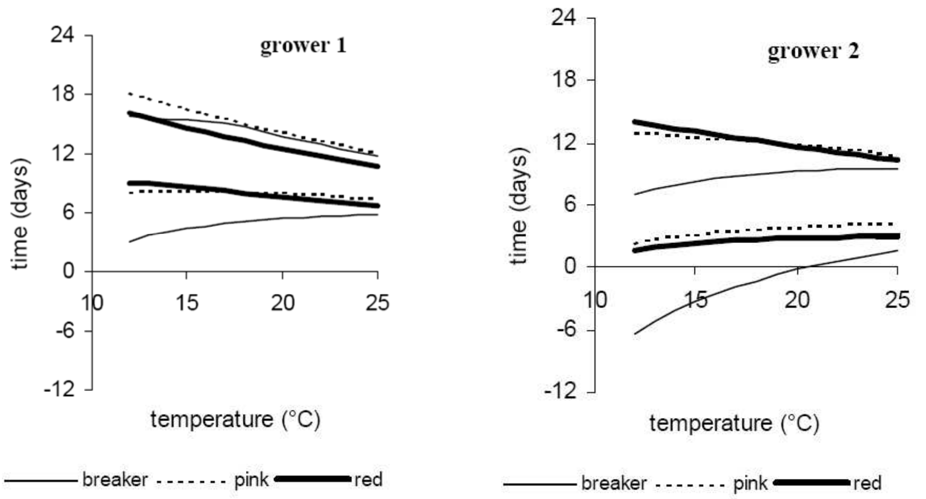

Figure 5. Consumer acceptance period in days for different tomatoes at different storage temperatures. The area between the lines indicates the acceptance period. Breaker, pink and red are maturity stages at harvest. Taken from Schouten et al. (2006).

Market segments with specific customer requirements need to be identified to design the best FSCN. Different batches will need different lead times (and/or conditions) in order for the consumer to perceive optimum quality, putting an extra demand on just-in-time delivery ("ripe on arrival" concept). In each stage of the network the time dependent product quality information can be used to segregate product batches and direct them to specific customers. By changing the environmental conditions during storage or transport we can now control (steer) the quality level of the product and send it to designated markets. Data loggers send with logistics flows capture relevant information on these environmental conditions for all possible supply chain configurations. The data on these loggers can be used to predict the remaining acceptance period for a particular batch providing the information that is needed to activate the QCL concept.

CONCLUSIONS

We have introduced a new concept called Quality Controlled Logistics that provides means to optimize product quality and availability in market outlets concurrently and minimizes shrinkage. Using time dependent quality information and quality decay models we can now predict product quality in much more detail enabling us to control supply chain processes and direct specific products batches – under specific environmental conditions – to specific market segments. Operations management in FSCN usually takes quality as given; if one approaches product quality as a dynamic issue and uses time dependent quality information more degrees of freedom come to the forefront that will improve supply chain performance significantly. Further research will focus on further developing the QCL concept and quantifying the potentials in performance improvements for multiple cases.

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