Logistics strategies to improve quality of fresh fruits at retail outlets: The case of year-round sourcing of strawberries

Willem A. Rijpkema[a], Roberto Rossi[b,a], Jack G.A.J van der Vorst[a]

a:Logistics, Decision and Information Sciences, Wageningen University, Hollandseweg 1, 6706 KN, Wageningen, The Netherlands, willem.rijpkema@wur.nl , Jack.vanderVorst@wur.nl,

b: Management Science and Business Economics, University of Edinburgh, 29 Buccleuch Place, EH8 9JS, Edinburgh, UK, roberto.rossi@ed.ac.uk

Abstract

The quality of most fresh products deteriorates as a function of environmental conditions and time, resulting in reduced market value and ultimately in product waste. Although product spoilage significantly impacts the performance of perishable supply chains often supply chain design strategies do not sufficiently account for the perishable product nature. One such strategy is dual sourcing, a common practice adopted in supply chain management to enhance sourcing flexibility while reducing transportation costs. In this paper we examine the use of a common dual sourcing strategy, the dual-index policy, in an international strawberry supply chain. We propose to incorporate costs for expected losses of product quality in dual-index order policy parameters. Costs for product quality decay are determined using expected shelf life reductions during transport and storage steps in the supply chain, predicted using microbiological growth models of a spoilage driver. The performance of the different dual-index strategies is assessed using a discrete event chain simulation model that includes continuous quality decay. The scenario analysis of this strawberry supply chain revealed that standard dual-index sourcing policies are ineffective in delivering a sufficient product quality with reasonable waste, resulting in large amounts of product waste. Furthermore findings indicate that use of product quality information in dual-index sourcing policies significantly improves chain performance.

Keywords

Food Supply Chains, Supply Chain Design, Fresh Produce, Dual-index Sourcing Policies, Microbiological Growth Models

1 Introduction

In the past decades many food supply chains have become globalised, and consumers demand year-round availability of fresh products in retail outlets. As a result of seasonal production producers have to source from multiple production regions throughout the year. For each of these production regions a specific supply chain design is required to supply consumers with fresh products of high quality while minimizing overall costs and product waste.

An important consideration in supply chain design is the sourcing and purchasing decision, that is: where to obtain your materials, how much and when to order? An established sourcing strategy in international supply chains is dual sourcing (Tyworth J.E. and A. 2000; Klosterhalfen, Kiesmuller et al. 2011). Companies that apply dual sourcing typically rely on multiple suppliers for their material procurement to serve demand at low costs without compromising on service (Klosterhalfen, Kiesmuller et al. 2011). It could, therefore, be of particular use for supply chains that struggle with effective sourcing of perishable products. Dual sourcing strategies found in literature (e.g. (Veeraraghavan and Scheller-Wolf 2008; Klosterhalfen, Kiesmuller et al. 2011)) do, however, not take the perishable nature of products into account.

We hypothesize that the perishable product nature significantly affects the applicability of dual sourcing strategies, and that existing dual sourcing strategies can be improved by taking expected losses in product quality into account while generating dual sourcing order policies. We test this hypothesis by presenting a case study in an international perishable supply chain. The distributor in this chain adopts a dual sourcing strategy to obtain Egyptian strawberries in Belgium. The performance of different dual sourcing order policies, obtained with standard parameter values and parameter values that incorporate costs for expected quality decay, are assessed using a chain simulation tool.

2 Research contribution and approach

Food supply chains characteristics affect the design of supply chain networks and planning in food supply chains. Actors in food supply chain networks therefore need effective mechanisms to serve end consumers with food products of the right quality in the right quantity and overcome the challenges posed by food supply chain characteristics. A review of a number of recent literature review articles (Akkerman, Farahani et al. 2010; Karaesmen, Scheller–Wolf et al. 2011; Rajurkar and Jain 2011; Bakker, Riezebos et al. 2012) revealed that incorporating food quality decay models in logistics decision making is important in design of food supply chains. Most quality decay models of perishable goods found in literature are based on microbiological growth models and predict decay op product quality as a function of time and environmental conditions (i.e. temperature and/or gas composition).

We consider use of a dual sourcing strategy in a strawberry supply chain. Various dual sourcing strategies can be found in literature (Sheopuri, Janakiraman et al. 2010), of which the dual-index policy (DIP) was found to perform close to the real optimal policy (Klosterhalfen, Kiesmuller et al. 2011). Despite the attention for dual sourcing strategies in literature, a review article on 227 articles on inventory systems with deterioration published between 2001 and

2011 (Bakker, Riezebos et al. 2012) mentions no articles that consider dual sourcing of perishable items.

The research aim of the case study presented in this paper is twofold. First of all the effectiveness of DIP obtained with normal cost parameters is assessed in a perishable supply chain, particularly whether these policies guarantee sufficient product quality at the point of sale and reasonable waste. Second, we assess whether including costs for expected quality decay during transport and storage will improve the overall supply chain performance of the DIP obtained with normal cost parameters.

Data on a prototype supply chain network for the international trade of fresh strawberries is gathered. The structure of this chain is derived from data collected during several company interviews with an international fresh fruit distributor that operates in Belgium. This distributor sources strawberry punnets from various production regions throughout the year, of which we study the longest and most complex supply chain: that for Egyptian strawberries. To assess dual order policies generated with and without included costs for expected quality decay a hybrid discrete/continuous simulation model is developed. This model includes both discrete features (i.e. individual strawberry punnets that move through a supply chain), and continuous factors (e.g. the infection rate of strawberry punnets). For an elaborate overview of hybrid discrete/continuous simulation models the reader is referred to (Zeigler, Praehofer et al. 2000).

3 Case study

3.1 Supply chain description

We consider the case of a Belgian distributor of fresh fruit. The names of the distributor and supplier in the case analyzed in this work are not disclosed for confidentiality reasons. We will therefore use the more generic terms ”supplier”, ”distributor”, and ”retailer” instead of the actual company names. The distributor imports strawberries from different production regions to provide its customers year-round with fresh strawberries. The supply chain network we consider includes a large Egyptian strawberry grower that ships strawberries to the Belgian distributor. The distributor supplies strawberries to a number of retail outlets, and each of these retail outlets face consumer demand. The distributor adopts a dual sourcing strategy, orders strawberries once a week using a regular transport mode, and may order products each day from Monday to Saturday using an expedite transport mode. A schematic depiction of the strawberry supply chain from Egypt to Belgium is given in Figure 1. We will now describe the individual parts of the supply chain. Data on environmental conditions throughout the supply chain is obtained from our industrial partner, and summarized in Table 1.

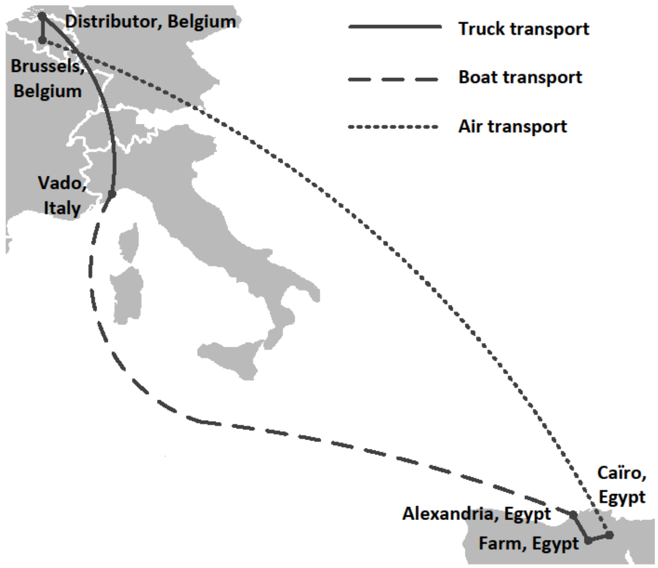

Figure 1 Schematic overview of a strawberry supply chain from Egypt to Belgium

Farm supply

Strawberries are picked each day at the strawberry farm to serve the Belgian distributor and other clients. The Belgian distributor has a special arrangement with its supplier, who ensures them to deliver day-fresh strawberries; strawberries that are not sold on the same day are sold to other customers that bring them to end customers nearby. Based on information provided by the distributor, we assume that the supplier is always able to fulfil the demand of the distributor. Every morning, from Monday to Friday, strawberries are picked from 6.00 am to noon. Employees pick strawberries, and put them into punnets of approximately 250 grams each, which are stacked on pallets. Each pallet remains on the field, at ambient air temperature, for about 1 hour, while it is being filled and then transported to a refrigerated storage room. Pallets remain in the storage room until an order arrives from the Belgian distributor or other customers, and will be shipped according to the preferred transport route.

Distributor

The distributor orders a number of strawberry punnets every Monday using the regular transport mode, and he may order an additional number of strawberry punnets by expedite transport from Monday to Saturday. In the regular transport mode the strawberries are transported by truck from the Egyptian farm to the harbour of Alexandria, Egypt. From Alexandria the strawberries are shipped to Vado in Italy, where they are loaded on trucks that deliver them to the Belgian distributor. Strawberries that are transported using the expedite transport mode are transported by truck to the airport of Caïro, Egypt. The strawberries are then flown to a Belgian airport in Brussels, from where they are delivered to the Belgian distributor by truck. The duration and environmental conditions throughout the supply chain and in the different transport modes are summarized in Table 1. The distributor reviews his orders each day at noon, based on a regular and an expedite order-up-to position. Products that arrive at the distributor are stored in a refrigerated room until retail orders arrive, or until they are thrown away due to spoilage.

Table 1 Consecutive steps during regular and expedite transport mode

	Duration (hours)	Temperature (°C)	σ (°C)
Supply chain conditions			
Ambient field conditions	1	15 [1]	2
Grower storage room	variable	1	0.25
Distributor storage room	variable	1	0.25
Truck transport to retail outlet	3	2	0.25
Retail outlet	variable	3	0.5
Expedite transport mode			
Truck transport from farm to airport	2	2	0.35
Customs operations	4	10	1.5
Loading, flight and unloading	6	1	0.25
Customs operations + delivery	3	2	0.35
Regular transport mode			
Truck transport from farm to harbour	4	2	0.35
Customs operations	4	10	1.5
Loading, shipping and unloading	48	1	0.25
Customs operations + delivery	24	2	0.35

Retail demand

The distributor serves a number of retail outlets. Each retail outlet places a replenishment order every day around midday, and the distributor serves orders on a first come first serve basis. Before midday, shop assistants remove spoilt products. Ordered strawberries are delivered to the retailer by truck three hours after the order is placed. Once the strawberries arrive at the retailer they are stored in the retail shelves until they are either sold or spoilt.

3.2 Quality deterioration

In this paper we model strawberry quality decay by modelling the growth of Botrytis cinerea, one of the main spoilage drivers in strawberries. Shelf life reductions are obtained using the microbiological growth model provided by (Hertog, Boerrigter et al. 1999). The coefficients of

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[1] Based on data obtained from the World Meteorological Organization

this growth model are all taken from Hertog et al (1999), and from this paper we adopt 0.798 ± 0.709 %, and 5.0 % for the initial infection rate and the maximum acceptable infection rate of strawberries respectively. For the prediction of shelf life reductions during product storage and transport we use the exponential approximation of the strawberry infection rate. As the allowed infection rate of strawberries is low (<5 %) the exponential approximation is a close approximate of the sigmoid growth model proposed by (Hertog, Boerrigter et al. 1999).

3.3 Relevant KPIs

The supply chain performance is measured using common cost drivers in dual-index policies (expedite transport costs, regular transport costs, inventory holding costs, stock-out penalty costs) plus two quality-related quality indicators: i.) product waste costs of €1.00 per punnet (punnets with infection rate > 5 % that are thrown away by distributor), and ii.) penalty costs for products delivered to retailers with less than three days remaining shelf life. Penalty costs for strawberry punnets with insufficient shelf life increase linearly with reductions of shelf life. For strawberry punnets without any shelf life left the penalty costs equal the average punnet cost price (€1.00 per punnet).

3.4 Scenario description

We distinguish five scenarios in this study. Dual sourcing based on the DIP is considered in all scenarios, and DIPs are obtained using a heuristic procedure proposed by (Veeraraghavan and Scheller-Wolf 2008). We obtain cost parameters for DIPs that include costs for expected losses in shelf life, as shelf life reductions reduce the market value of perishable goods (Wang and Li 2012). Following findings by (Tsiros and Heilman 2005), who found that the consumer willingness to pay for perishable products decreases linearly with remaining shelf life for products with a low product quality risk, a linear relation between losses in product shelf life and product value is assumed. We incorporate costs for expected shelf life losses at each DIP input parameter that involves quality degradation, i.e. during i.) regular transport, ii.) expedite transport, and iii.) inventory holding at the distributor. Expected shelf life reductions of both the regular and expedite transport mode are predicted using microbiological growth models in combination with the chain data in Table 1. Average initial infection rates are used to predict expected losses in product quality during transport and storage steps. Costs for expected shelf life losses are obtained by multiplying the expected losses in shelf life during storage (11.01 % in 24 hours), regular transport (39.01 %), and expedite transport (9.10 %) with the average value of strawberry punnets. To assess the effect of the magnitude of costs for expected shelf life losses we analyse scenarios with 0.00 (i.e. the standard cost parameters), 0.25, 0.50, 0.75, and 1.00 time the costs of expected losses in shelf life. The resulting policies will be more (less) sensitive with higher (lower) rates of included costs for expected shelf life losses. The specific values were chosen since the resulting policies cover the complete spectrum from sourcing only by expedite transport in case of backlogs (0.00) to complete sourcing by expedite transport

(1.00), as can be observed in Table 3. The cost parameters for scenario 1 to 5 are obtained by adding the costs of expected shelf life reductions to the cost parameters of scenario 1, and are given in Table 2**.**

Table 2 Cost parameters used to determine dual-index policies

Cost driver	**Penalties (€*unit^{-1})**	**Inventory (€*unit^{-1}*day^{-1})**	**Expedite transport (€*unit^{-1})**	**Regular transport (€*unit^{-1})**
DIP without decay costs	0.500	0.050	0.5	0.1
DIP + 0.25 * decay costs	0.500	0.078	0.523	0.198
DIP + 0.50 * decay costs	0.500	0.105	0.546	0.295
DIP + 0.75 * decay costs	0.500	0.133	0.568	0.393
DIP + 1.00 * decay costs	0.500	0.160	0.591	0.49

The performance of the scenarios is determined in two steps. First of all optimal DIP that follow from the cost settings in Table 2 are determined using a set of 50.000 demand observations that were generated following a Poisson distribution with the average demand of the 10 retail outlets: λ = 6000 units per day. The DIP with the lowest integral costs for each of the five scenarios can be found in Table 3. In this table we observe that including costs for expected quality decay reduces the number of products shipped using the regular transport mode. The sourcing policy based on the DIP parameters without decay costs completely relies on regular transport, whereas the inclusion of costs for expected quality decay reduces the number of products sourced using regular transport. In the second step of the scenario analysis the performance of the DIP in the strawberry supply chain is analysed using the chain simulation tool described in Section 3.5.

Table 3 Dual-index order-up-to positions

Order up to position	**Expedite mode (punnets)**	**Regular mode (punnets)**
DIP without decay costs	0	42102
DIP + 0.25 * decay costs	6213	24206
DIP + 0.50 * decay costs	6231	18166
DIP + 0.75 * decay costs	6231	12106
DIP + 1.00 * decay costs	6245	-

3.5 Simulation details

Our system is implemented using the Stochastic Simulation in Java (SSJ) library (http://www.iro.umontreal.ca/~simardr/ssj/indexe.html). SSJ is an object-oriented simulation library that provides facilities for modeling of hybrid discrete/continuous simulation systems. For each continuous object in the system we provide the associated differential equation and the initial condition. During simulation, SSJ performs the required integration and updates the dynamic property by using the Runge-Kutta integration method. The integration step is fixed to one hour, since smaller integration steps did not prove to be beneficial.

A simulation length of 264 days is used for scenario assessment, which is sufficient to obtain stable simulation outcomes. Performance data gathered during the first 14 simulated days is excluded from the analysis to ensure a representative filling of the complete supply chain with fresh produce. The analysis therefore includes approximately 1.5 million strawberry punnets, for which results were obtained within 3 hours. To ensure comparable results of the scenario analysis a random number strategy is used based on a random number generator that is initialized with the same seed.

3.6 Results

The performance of the scenarios on the respective KPIs can be found in Figure 2. In this figure we observe that including costs for quality decay in the DIP leads to 1.) a reduction in regular transport costs, indicating that fewer strawberries are shipped using the regular transport mode 2.) an increase in expedite transport costs, indicating that more strawberries are shipped using the expedite transport mode 3.) a reduction of inventory costs, indicating that the average stock-levels are lower 4.) a reduction of penalty costs, indicating that the distributor is able to deliver more reliably 5.) a reduction of distributor waste, indicating that fewer strawberries spoil at the distributor, and 6.) a reduction of expected claim costs, indicating that the strawberries delivered to the retailer have a higher remaining shelf life.

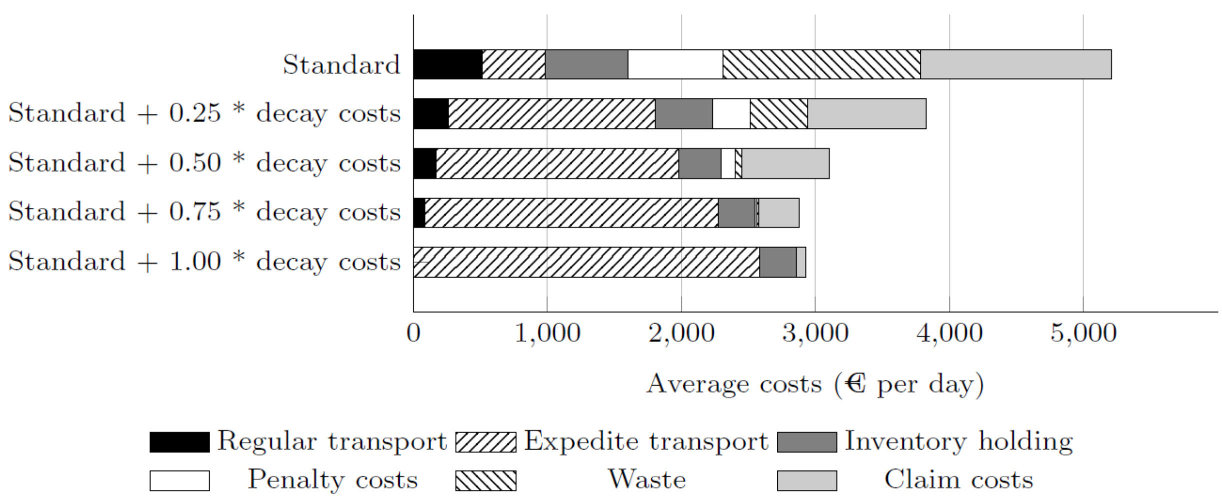

Figure 2 Performance analysis of dual-index policy scenarios

We observe that the sum of cost drivers traditionally used in dual sourcing strategies (i.e. regular transport costs, expedite transport costs, inventory holding costs, and penalty costs) increases by including costs for quality decay while determining DIP. This cost increase is, however, offset by reductions in product waste and expected customer claim costs. Please note that strawberry spoilage at the distributor has some side-effects. First of all, product spoilage may lead to stockouts, leading to an increase in penalty costs. Furthermore the distributor will order extra products using the expedite transport mode when stockouts occur. Based on the expedite order-up-to position of the standard DIP given in Table 3 (i.e. 0) one would not expect much expedite transport costs. Stock-outs, caused by spoilt products, however, lead to negative inventory positions. This results in a significant number of strawberries ordered using the expedite transport mode.

To get insight in the product age at the point of sale for the different scenarios we provide Figure 3. In this figure we observe that including costs for expected shelf life losses considerably reduces the product age at the point of sale. For the standard DIP we observe that approximately 20 % of the strawberries are transported using expedite transport (ordered as a result of stockouts caused by product spoilage), and consumed within 70 hours after picking. The other products are shipped using regular transport and consumed more than 120 hours after picking. Please note that several relatively flat areas can be observed in Figure 3. This is caused by three combined phenomena, being i.) the difference in transport duration of the expedite and regular transport mode (± 70 - 120 hours), ii.) products that are transported using regular transport on Mondays are either sold and consumed before Saturday evening or after Monday morning, but hardly any in between (± 140 - 170 hours), iii.) retail outlets are closed during night-time, resulting in low sales levels during the night.

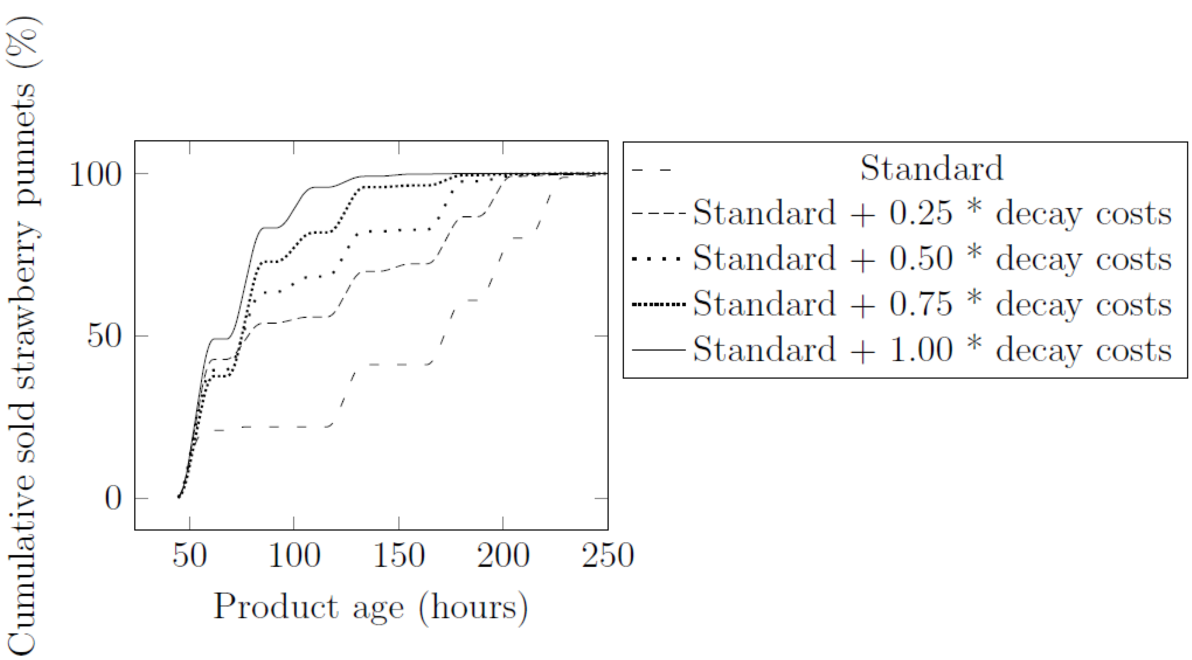

Figure 3 Strawberry age at point of sale

4 Conclusions and discussion

The findings of this research indicate that standard DIP are ineffective in delivering a sufficient product quality with reasonable waste in this strawberry supply chain. Application of a standard DIP policy would, in fact, result in large amounts of product waste at the retailer and distributor can be expected for products with insufficient shelf life to satisfy retailers. The simulation results indicate that including costs for expected losses of shelf life in standard DIP is beneficial for product quality at the point of sale, and reduces the average product throughput-time. As a result product waste and expected customer claim costs are reduced significantly, whereas transportation costs rise. The findings of this study illustrate that decision makers in perishable supply chains should make a trade-off between transportation costs, stock out penalty costs, inventory costs, product waste, and expected losses in product shelf life.

We present a case study where product quality is included in the design of a distribution network, an area that is still in its infancy (Akkerman, Farahani et al. 2010). We contribute to literature by presenting a case study in which i.) a generically applicable product quality decay model based on microbiological growth is applied, ii.) the performance of the policies we propose is assessed using a discrete event simulation model of continuous systems, iii.) multiple dimensions of uncertainty (e.g. demand, initial product quality, temperature) are included effectively. In future research it might be interesting to see whether including costs for expected shelf life reductions while obtaining DIP yields similar results if applied in supply chains with other fresh products. Furthermore, future research might assess the applicability of including costs for expected losses in shelf life of perishable products in other supply chain strategies then dual sourcing.

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