Logistics modelling of pork supply chains;

Application of quality controlled logistics for sustainable development

Willem Rijpkema, Operations Research and Logistics Group (ORL),
Wageningen University and Research Center

Abstract

The European pork supply chain network is characterised by a complex aggregation of small-medium farms, in which rearing takes place, and of (mainly) large industrial meat processing factories that serve the market for meat products. Within this market, several segments have their own specific demand for product specifications and logistics services. Moreover, pork supply chains have specific characteristics that make them unique. Logistics processes, however, are still subject to a number of inefficiencies, such as poor material usage, operational inefficiencies or low perceived product quality at final customers, resulting in suboptimal market performance and in a limited sustainability of production processes.

In order to address these inefficiencies effectively and to ensure product quality throughout the chain, innovative logistics management concepts and decision support models are needed. These concepts and models should make effective use of possibly new product quality information gathered by means of technologies recently introduced, in order to optimise the match between supply and demand for different product classes. Meat with specific quality features should be directed to designated processes and specific market segments, resulting in an improved processing performance (less waste, higher efficiencies, etc.) and more added value by an improved product-market combination.

This research focuses on the design of Quality Controlled Logistics concepts for pork supply chain networks. The objective is to reduce current inefficiencies, to lower costs, to improve the quality perceived by consumers and to increase added value through a better matching of production systems, processing systems and market segments. A general overview of the methodology adopted in my PhD-research and a detailed description of one of the planned case studies are discussed in the following sections. This case study aims at using Water Holding Capacity information in logistics planning of pork processors.

1. Problem Introduction

Many food processors claim that consumer demand has become more difficult to understand and predict, especially in the developed world. Grunert (2006) states that this complexity results from the combination of increasing differentiation of the food products from the supply side, and increasing dynamics, and heterogeneity of consumer demands. He adds that this complexity creates new opportunities for food producers for adding value and differentiating products.

This differentiation in demand for quality features is related to topics like taste and sensory characteristics, health, ease of use (convenience), and process characteristics (e.g. slaughtering method) (Brunsø, Fjord et al. 2002), and leads to different customer segments. Simultaneously, the meat sector is experiencing scale intensification; Dutch pig farmers, for instance, increased their average number of pigs from 240 pigs in 1980 up to 1200 in 2005 (CBS 2009). The meat processing industry has also experienced increasing company sizes, and many companies in this industry have evolved from local companies towards global meat players. Industrial Q-porkchain partner 'Vion Food Group' for instance, has increased its turnover through a number of acquisitions from 467 million € in 1999 up to 8.64 billion in 2008, and is now present in all continents except Africa (Vion 2003-2008).

These market and industry trends have led to an increased emphasis on production costs, quality, and environmental issues in the pork supply chain. At the same time, complex customer demand forces this industry to differentiate its product streams to suit the needs of specific market segments. To ensure individual customer demand is met efficiently, new logistics concepts that incorporate product quality information in supply and demand planning are required. This PhD-project aims at developing such concepts for the pork supply chain.

This research is part of the EU-funded Q-porkchains project (FOOD-CT-2007-036245). The Q-porkchains project aims at the development of high quality pork products in production systems with low environmental impact (see http://www.q-porkchains.org/ for details). 63 Project partners and 16 PhD students are involved in various fields of research. This PhD-project is aimed at "logistics modelling of sustainable pork supply chains".

This project description will start with an overview of pork supply chain specific characteristics (chapter 2), after which an overview of supply chain developments relevant to this research will be given (chapter 3). This chapter will include a description of sustainable development (section 3.1), and Quality Controlled logistics (section 3.2), and their relation to this research. We will proceed by specifying the research objective and the research questions derived from it (chapter 4), followed by a description of the research methodology (chapter 5). Chapter 6 will provide a more elaborate description of one of the future case studies, and this paper ends with a conclusion (chapter 7).

2. Pork supply chain characteristics

The pork supply chain can be characterized as a Food Supply Chain Network (FSCN). A FSCN is a specific type of network that deals with production and distribution of vegetable or animal-based food products (van der Vorst, Kooten et al. 2007). A schematic overview of different actors and interactions in the FSCN analyzed in our research is given in Figure 1. This FSCN involves a complex network of farmers supplying pigs to processors, markets with differentiated demand for quality features, meat processing companies, and (inter)national distribution networks that interconnect the chain actors in the FSCN.

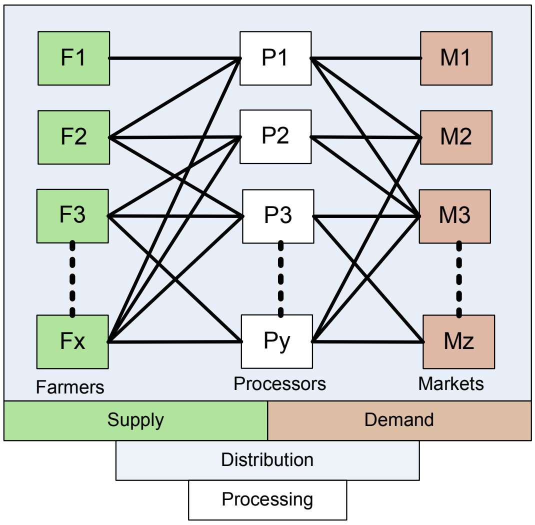

Figure 1 Schematic overview of the pork processing chain

FSCN's differ from other supply chains by the specific product, market, and process characteristics they have. Examples of these characteristics related to pigs / meat products are the long production period, a supply, quality and price that is variable and inflexible. The processing plants in this industry often use expensive processing equipment, causing the

processing capacity to be scarce and inflexible. At the same time the production planners have to deal variable yield and processing time in production processing. This implies that the production rate is limited by a combination of production capacity and product quality. (selected from (van Donk 2001; van der Vorst, Tromp et al. 2009))
These characteristics often have conflicting implications for production planning in FSCN. For this reason efficient production planning in FSCN is a complex task (van der Vorst, Dijk et al. 2001).

3. Supply chain management

To deal with the complex environment of FSCNs effective chain-wide co-operation is required. This topic has received increased attention in the Operations Research and Operations Management literature in the last two decades, during which the focus changed from optimization of an individual operation or organization towards optimization of the entire chain in so called Supply Chain Management (SCM) (Lambert and Cooper 2000; van der Vorst 2000). The main goal of SCM is to increase the added value throughout a supply chain while minimizing integral logistics costs. SCM encompasses a variety of planning and management activities, like sourcing, procurement, conversion, logistics management, and coordination and collaboration with channel partners. This research focuses on logistics management, which is defined by the Council of Logistics Management as:

"That part of the supply chain that plans, implements and controls the efficient, effective forward and reverse flow and storage of goods services and related information between the point of origin and the point of consumption in order to meet customer & legal requirements."

Logistics management includes aspects like transport, storage, plant site selection, inventory control, distribution, return goods handling and demand forecasting.

Central in SCM is the coordination of processes and the exchange of information between partners in the supply chain. As stated before, pork supply chains are characterized by variable quality and quantity. Having more detailed quality information makes it possible to improve planning performance. Recent developments in both Information and Communication Technology (ICT) and sensory technology provide the means to gather, communicate and process this quality information more effectively (Kumar, Reinitz et al. 2009) enabling the use of innovative logistics concepts.

Effective use of quality information not only affects the quality and /or added value of the final product, but might also reduce waste by reducing the number of products that have to be thrown away, resulting in a lower environmental impact and reduced logistics costs. By doing so, use of quality information affects multiple factors of interest, which can be monitored by using a number of Key Performance Indicators (KPIs). KPIs represent critical dimensions that reflect the success or failure of a process / company (Christopher 1998). Defining KPIs is critical in decision making, since it enables decision makers to monitor current performance and impact of previous actions.

Three relevant performance dimensions to monitor in the pork supply chain are product quality, logistics costs and sustainability (van der Vorst, Tromp et al. 2009). The following two sections will focus especially on sustainability and quality related to logistics decision making.

3.1 Sustainable development

During the last 25 years there has been a growing pressure on companies to pay attention to environmental and resource consequences of products and services they offer (Kleindorfer, Singhal et al. 2005). Furthermore, legislation pushes companies to use production methods that reduce environmental impact. This results in demand for sustainable development, which was defined by the Brundtland commission (1987) as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Sustainability of production systems is often linked to environmental impact. Edwards-Jones, Milà i Canals et al. (2008) divided KPIs to quantify environmental impact into several categories, being the number of products that have to be thrown away, amount of ‘food miles’ a product has travelled, and greenhouse gas emission linked to a product. Walley and Whitebread (1994) argue that substantial reduction in environmental impact are in most cases only possible with considerable investments, bringing none or negative financial returns. Achieving such a reduction requires companies to re-design their logistics networks and adopt business strategies not only driven by costs, but in which profitability and environmental impact of production methods are balanced (Frota Neto, Bloemhof-Ruwaard et al. 2008). Most literature on logistic network design, however, either aims for minimization of costs or environmental impact; little research is done in integration of both objectives (Bloemhof-Ruwaard, Krikke et al. 2004). Frota Neto, Bloemhof-Ruwaard et al. (2008) are one of the first researchers to combine both objectives by determining Pareto fronts between costs and environmental impact. These authors argue that identifying these frontier points in production systems is useful to evaluate current performance with regard to environmental impact and costs, determine trade-offs between costs and environmental impact, and assess the impact and necessity of policies and legislation on costs and environment.

Next to sustainability and costs as performance dimensions, product quality is also an important factor. This research aims effective management of quality differences in FSCNs by means of Quality Controlled Logistics (QCL), which will be discussed in the next sub-section.

3.2 Quality controlled logistics

Quality Controlled Logistics (QCL) is a relatively new logistics management concept, described by van der Vorst, Tromp et al. (2005) as:

“Directing goods flows with different quality attributes to different distribution channels and/or different customers”

By doing so, QCL aims at improving the match between product supply and demand by effective use of product and process quality information.

For meat products, quality is a rather complex, time-dependent, multi-dimensional, and in some cases non-stationary property. Time-dependent quality characteristics, like microbiological quality, have a certain level directly after slaughtering. After this point, quality deteriorates, influenced by environmental variables like time, temperature or oxygen level (Luning and Marcelis 2006).
A literature review revealed that the interaction between time-dependent quality attributes and logistics decisions is a relatively new field of research. Some research is done in inventory management of perishable goods under uncertain supply and demand (e.g. (van Donselaar, van Woensel et al. 2006)), but without using quality as a dynamic variable. Giannakourou and Taoukis (2003) showed that quality decay in perishable products can be predicted by Time Temperature Integration (TTI) and used to determine dynamic shelf-life periods of product batches in “Least Shelf-life, First Out” product distribution management systems. This research, however, neglected initial quality and heterogeneity between individual products. Furthermore, logistics decisions at hand were straightforward, without interaction between product quality and the logistics decisions. For FSCN with a large heterogeneity of supplied quality, the use of information on both initial product quality and its decay are important in determining the final quality and shelf life. Having information on these time-dependent quality characteristics and environmental variables makes it possible to direct products with different quality attributes to different distribution chains, linking up to the QCL framework suggested by van der Vorst, Tromp et al. (2005).

Only a limited number of articles base logistics decisions upon product quality information. Dabbene, Gay et al. (2008) used quality decay models in discrete event simulation, to minimize logistics costs while maintaining pre-specified quality levels. Van der Vorst, Tromp et al (2009) developed a simulation toolbox called Aladin™ that incorporates continuous quality decay effects into a discrete event simulation software package. Akkerman, Rong et al. (2008) developed a Mixed-Integer Linear Programming (MILP) model to integrate food quality in production and distribution planning, by using temperature at different chain stages as a decision variable in the optimization of a logistical network. This integrated both costs and product quality in a network optimization. Final quality, however, was used as a restricting variable rather then as an optimization goal, and initial heterogeneity in quality characteristics was disregarded.

Similar methods may be applied in fresh meat chains to improve logistics control and supply chain setup in supply networks with large heterogeneity in both stationary and non-stationary quality. This research aims to contribute to this field of research.

4. Field of study

QCL can be applied at different planning levels in the pork supply chain, like strategic (e.g. network design), tactic (e.g. weekly slaughtering plan), or operational (e.g. decisions on individual pigs), and it can be applied throughout different supply chain components, like supply, demand, processing and distribution (see Figure 1). This research will assess the impact of QCL at these different levels and components of the pork supply chain on different performance dimensions (financial performance, quality and environmental impact) by means of several case studies within the Q-porkchains project. These pilot studies incorporate partners from industry and research to ensure company support and data availability (e.g. VION Food Group, Bonn University, LEI (Dutch Agricultural Economic Institute)).

Besides these case studies, the existing literature on logistics and applicability of QCL in pork supply chains will be surveyed. More details on these case studies and other expected outcomes are given in the methodological design section.

5. Research objective and research questions

We argue that innovative logistic management concepts should be introduced in order to guarantee sustainable and economically feasible pork production chains. This PhD-research aims to contribute to this by the design of QCL concepts for sustainable pork supply chains, and the development of decision support models to assess the impact of these concepts.

The main research question that belongs to this research objective is:

What Quality Controlled Logistics concepts might improve the economic and sustainable effectiveness of pork supply chains, through better matching of production systems, processing systems and market segments?

We will address our main research question in three steps. Firstly, we will investigate (RQ1) what the relevant KPIs and the opportunities for applying QCL are in pork supply chains.

Secondly, we will analyze (RQ2) what improvements can be brought by innovative logistics concepts in pork supply chains on a tactical, operational and strategic level. More specifically, we aim to assess the impact of QCL at different decision levels in the pork processing chain. In order to do so we will consider three sub-questions, being: (RQ2a) how can QCL be applied in

slaughterhouse supply planning? (RQ2b) How can QCL be applied in pork processing activities? (RQ2c) How can QCL be applied in distribution / network planning?
Each of these sub-questions will be investigated by means of a case study. A description of these case studies can be found in the 'Case studies' section.

Finally, we will explore (RQ3) what general design principles can be derived from the case studies analyzed in RQ2 for the successful application and assessment of QCL in meat supply chains.

We will now give an overview of the methodology we expect to apply to address the different research questions. An overview of the methodology, the expected outcome and the scientific contribution related to the research questions can be found in Table 1.

The first research question (RQ1) will be addressed by a literature review on pork supply chains and discussions and interviews with experts in this field.

The second research question (RQ2) will be addressed by means of three case studies. Each case study is based on a different type of quality information, and requires a separate literature review. The performance indicators will be case-study specific. The case studies will include interviews with experts, a process analysis, data gathering, and the development and analysis of a quantitative decision support model. A description of one of the three case studies can be found in the 'Case study example' section.

The third research question (RQ3) will be addressed by combining the results of the three case studies, and by deriving general principles for the use of QCL in meat chains. These principles will be assessed by expert interviews and/or expert workshops and the results will constitute the answer to this question.

Table 1 Methodology overview

Research question	Method	Expected outcome	Scientific contribution
RQ 1	Literature review Interviews with experts	An overview of logistics developments, performance bottlenecks and suitable KPIs in pork supply chains.	Book chapter: Performance measurement and bottlenecks in pork supply chains. (Q-porkchains book, 2011)
RQ 2	Case studies (interviews, process analysis, data gathering and analysis) Literature review Quantitative decision support model design	Decision support models based on QCL at different decision levels. Insight in applicability of QCL at different levels.	3 scientific journal articles
RQ 3	Review on case studies Expert interviews / workshops	A framework for the application of QCL in pork supply chains.	Scientific article: Development and assessment of QCL concepts in pork chains.

6. Case study example

This section describes the case study that will use to address RQ2b. This case study, titled '*Use of water holding capacity estimates of meat in logistics decision making*' involves the use of quality information in production planning of meat processors. A brief introduction to the problem and the available data is given, followed by a description of the methods we plan to apply in this case study.

Water Holding Capacity (WHC) is an important meat quality feature that affects sensory characteristics, processing properties and product weight of pork meat. WHC is influenced by many factors like genetics, pig husbandry, animal transport, slaughtering method, and carcass cooling. This variety of factors makes it difficult to counter the occurrence of poor WHC effectively. Furthermore, information on the WHC is currently not used in production planning due to the lack of a non-destructive, in-line and cost-effective measurement technique. Near InfraRed Spectroscopy (NIRS) has been identified as a potential on-line, non-invasive technique to determine WHC of meat products. A PhD-student involved in the Q-porkchains project has determined both NIRS patterns and actual WHC of approximately 2000 meat samples. By application of regression techniques, this dataset is used to predict the WHC based on NIRS measurements. Predictions of WHC based on NIRS measurements might be used to improve product yield. This case study aims to assess the use of this quality information in production planning.

Our research on the use of WHC in logistic decision making will be structured as follows. Firstly, a process analysis will be conducted, which will include a literature review and expert interviews. Based on the outcomes of the process analysis, the most promising application(s) of the NIRS sensor will be selected for use in a decision support model.

The development of decision support models can be split into several separate stages. At first, a list of model requirements, input parameters, KPIs and variables will be drawn. Furthermore, we will provide an overview of relevant scenarios for use of quality information, The next step involves building a model and verifying its behavior based on expert interviews, and / or field experiments. After model development and verification, the sensitivity of the model outcomes for changes in inputs will be analyzed. Input parameters for which significant deviations might be expected are identified and along with boundaries within which they are expect to vary. Within the NIRS-project, this may include an impact analysis of a lower or higher prediction accuracy of the NIRS, or to see what the effect of changes in other variables is. Finally, the overall suitability of the NIRS of a scenario is evaluated based both on model outcomes and the sensitivity analysis.

The findings of this case study will be presented in a scientific publication, and will be used in the PhD-thesis to address RQ2b.

7. Conclusion

We described a research proposal on the application of QCL in pork supply chains. Several key aspects of pork supply chain have been discussed together with their implications for logistics decision making. We outlined our main research objective and the associated research questions that should be answered in order to attain this goal. Finally, we discussed the methodology we are planning to apply in order to address these questions and achieve our goal. Mainly, our methodology builds upon a number of industry driven case studies. A description of one of these case studies that will be conducted in the future has been provided. In our future work, we aim to combine the outcomes of the case studies to get insight into application of quality controlled logistics in pork supply chains.

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