

Modelling Fresh Strawberry Supply “From-Farm-to-Fork” as a Complex Adaptive Network

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1 Introduction

The purpose of this study is to model and thereby enable simulation of the complete business entity of fresh food supply. A case narrative of fresh strawberry supply provides basis for this modelling. Lamming et al. (2000) point to the importance of discerning industry-specific product features (or particularities) regarding managing supply networks when discussing elements in “an initial classification of a supply network” while Fisher (1997) and Christopher et al. (2006, 2009) point to the lack of adopting SCM models to variations in products and market types as an important source of SCM failure. In this study we have chosen to move along a research path towards developing an *adapted* approach to model end-to-end fresh food supply influenced by a combination of SCM, system dynamics and complex adaptive network thinking.

Within systems dynamics causal mapping and simulation modelling represent tools towards enhancing knowledge to deal with complexity in e.g. product supply (Sterman 2001). Swaminathan et al. (1998) describe modelling supply chain dynamics applying a multi-agent approach within system dynamics thinking. Their quest is to simplify the complex supply network through modelling enabling simulation of the above mentioned features in a model consisting of multiple interacting firms. A fundamental aspect of systems dynamics, according to Sterman (2001), is “...that the structure of the system gives rise to behaviour”. In a complex system, according to Sterman (2001), behavioural patterns emerge, different people behaving in the same way. However, people (managers and labour) are unaware of the impact of the structure on their behaviour. They believe that other people are cause of operations; “the fundamental attribution error” (e.g. Ross 1977).

Surana et al. (2005), state in relation to the “real world” that: “Many natural systems, and increasingly many artificial systems as well, are characterized by apparently complex behaviours that arise as the result of non-linear spatio-temporal interactions among a large number of components or subsystems”. A complex adaptive system (CAS) is a dynamic network of many agents interacting with other agents (Mitchell Waldrop 1994). Surana et al. (2005) discern CAS, from other forms of complex systems as being systems that accommodate for human decision-making; a decentralized and inherently uncontrollable system. Occurrences of coherent behaviour in the system arise from competition and cooperation among the agents within the system. The structure of this system is accordingly time and location specific; emergent. Overall behaviour of the system is the result of numerous decisions made in dispersed events by its numerous agents.

While definitions of SCM espouse the benefits end-to-end product supply management (e.g. Lambert et al. 1998), SCM practice is limited to management of immediate to the firm, dyadic business relationships looking to procurement on one side and marketing on the

other side (Van Hoek and Mitchell 2006); SCM playing a role from a company perspective as an “arc of integration” (Frohlich 2002) or “pockets of good practice” (Storey et al. 2006). Furthermore, as Christopher (1998) points to and Håkansson and Persson (2004) provide empirical evidence regarding, individual supply chains interact and compete with other supply chains. This calls for a network picture (mental model) of product supply adapted to the fresh food industry studied in this case.

2 Particularities Relevant to Modelling Complete Fresh Food Supply Networks

This section discusses briefly factors of importance when adapting fresh food supply network models. An important aspect of food supply is the need to model a complete supply chain based on the combined forces of product seasonality, perishability, safety and traceability (Van der Vorst and Beulens 2002, Taylor and Fearné 2006). Furthermore food supply chains are impacted by uncertainty due to retail promotions, short lead time requirements, and in general a low degree of supply chain flexibility (Adebanjo 2009). Bijman et al. (2006) point out that increased inter-organisational collaboration in food supply is due to 1) the rise of food safety as prominent societal issue, 2) the raw material in food distribution often closely resembles the finished product, and 3) foods are to varying degrees always perishable goods. An important aspect of food supply is ethically-related since food consumption is a vital aspect of human well-being. Food supply chains seek accordingly to balance food *safety*, a societal aim, with *economic* and *quality* product supply, representing business aims (Engelseth et al. 2009). “Safety” in food supply denotes food product features measurable through the supply chain in relation to human well-being dependent on technicalities of food supply, whilst “quality” involves product attributes measured in relation to customer satisfaction (Van Rijswijk and Frewer 2008). According to Becker (2000), food product quality involves 1) product-oriented quality, 2) process-oriented quality, and 3) consumer-oriented quality.

Fresh food distribution specifically involves challenges including that “...1) fresh products are not standard and subject to quality deterioration, 2) there is a lack of clear product descriptions and coding standardisation, 3) information requirements differ per customer, making standardisation complex, and 4) a relatively low degree of automation of farmers” (Van der Vorst et al 2002). This depicts a picture of fresh foods as a supply network setting demanding responsive supply. According to Lapede (2006) customer-responsive product supply demands context specific solutions crafted based on a strategic framework. However, an organisational environment is multiplex. Uncertainty is only one of several environmental challenges facing supply network actors. According to Daft (2007: 51) the task environment of an organisation may be classified as consisting of: 1) the industry sector, 2) raw materials sector, 3) human resources sector, 4) financial resources sector, 5) market sector, 6) technology sector, 7) economic conditions sector, 8) government sector, 9) sociocultural sector, and 10) international sector. Developing “responsiveness” involves accordingly more than simply developing market-orientation. Accordingly, Engelseth et al. (2009) provide a model regarding how complete (‘end-to-end’) integrated supply chains interact with 1) the natural environment, 2) demand in a marketplace and 3) competition with other supply chains.

3 Method: Single Case Study

Data was collected within the frame of a few weeks during the late spring and early summer of 2009. First the regional fresh fruits and vegetables distributor was contacted. This led to a “snowballing” of interviews, one informant pointing to the next. This snowballing led to that the first formalised interview was carried out with both the manager of the regional fresh fruits and vegetables wholesaler and the manager of the producers’ cooperative in May, prior to the season, providing a “farm-to-fork” perspective of the actual strawberry supply. These two informants were later interviewed individually during the season to provide update regarding the actual 2009 strawberry harvest and distribution, and to secure observations of this supply by observing through a short 1-hour inspection the harvesting process in action. Further interviews were carried out with informants covering different parts of the supply chain. At the same time, visits to these actors’ facilities took place including an inspection of their information systems. Inquiry was carried out using a semi-structured interview technique. The intention of the interviews and observations were communicated to all informants creating the open-minded atmosphere. The interview guides were adapted to the individual informant and included fundamental themes guiding the interview regarding 1) the informant, 2) the company of the informant, 3) perceptions of the strawberry product, 4) picturing the flow of strawberries within and external to the company, 5) the information flow in relation to strawberries, 6) the strawberry product; marketing and profitability, and 7) future prospects for the strawberry product. Six informants took part in this study providing 7 interviews. This involved 2 producers, 2 middlemen, and 2 retailers. The key informant was interviewed prior to and during the harvest season. All interviews were taped and transcribed. An interview lasted on average 45 minutes. Interviews were followed up by telephone conversations to clarify remarks made by informants during interviews. The following case narrative is of fresh seasonal strawberry supply, and describes in the following order: 1) the product including packaging, 2) actors, 3) distribution, and 4) goods identification and information exchange.

4 Case narrative: Strawberry distribution from farm to retailer

4.1 Product and Packaging

Strawberries represent a relatively expensive product that is, since the production is technology-intensive, produced and distributed mainly in economically developed countries. The “strawberry” represents a number of different subspecies permitting strawberries to be grown in a large range of different agricultural conditions. One of the main indicators of different types of strawberry species is their degree of firmness. The firmer strawberries have a longer durability after harvesting. Taking out the stem of strawberries also reduces their durability. In Norway, due to its northern geographical location with a cold climate, strawberry production is seasonal. While the most common type of strawberry produced in Norway for fresh consumption is of the species Korona, in this case the farmers have chosen to grow the Polka type strawberry. This strawberry is slightly firmer and darker in colour than the Korona berry. Due to increased firmness, the Polka strawberry has a durability of up to 72 hours compared with Korona’s 48 hours. The main reason to choose Polka has, however, been that this species is well adapted to the specific growing conditions in Valldal.

While Polka represents about 40% of the produced volume in the studied valley, the remainder consists of the Senga Sengana type strawberry. This species has been used since the 1960-ies in Norway, and was previously used for fresh consumption. Currently Senga Sengana is used predominately as a raw material in industrialised food processing. Strawberry raw-material of either Senga Sengana or Polka strawberries is transformed by the producers cooperative into three product groups it markets shown in figure one below:

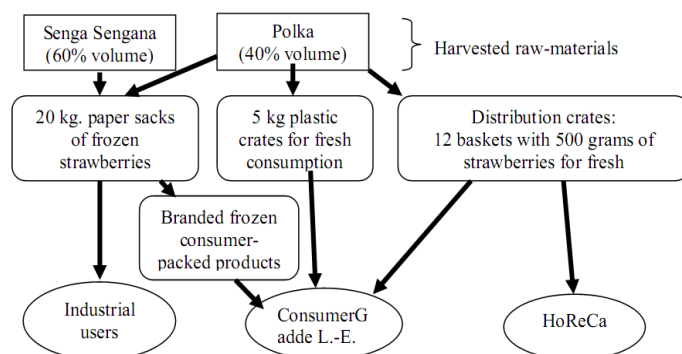


Figure 1. Different types of strawberry products in the case

Fresh berries for consumption packed in 500 gram baskets, 12 baskets placed in distribution-level carton-type packaging (40 cm x 80 cm.) with 40 distribution crates on a Euro pallet (80 cm. x 120 cm.) representing the standard “pallet” volume. The plastic baskets are stamped with a logo reading the name of the producer cooperative. While most baskets used to market strawberries in Norway are coloured, the study’s strawberry product is packed in a see-through plastic basket. In addition, the carton is printed in a manner clearly indicating the name of the supplier. In most other strawberry producing regions, reusable plastic IFCO crates (www.ifco.com) are used. This type of distribution packaging has superior protection and handling characteristics compared to carton crates. IFCO-type packaging, however, weakly differentiate products since it only carries a generic paper tag placed into a slot on the package. Furthermore, strawberries for fresh consumption from the focal producer cooperative are distributed in 5kg plastic crates. The stem of these berries are removed. This product consists of slightly smaller Polka strawberries. These products are purchased by households to be frozen or to make home-made jams. Products for industrial production are frozen and packed in 20 kilo paper sacks. The cooperative has recently started producing consumer-packed frozen strawberries. These are items carrying the producer cooperative brand and marketed through retailers in Norway belonging to a specific retail group which has a market share in Norway of about 40%. This production is growing, but still accounts for a few percent of the production volume.

4.2 Actors

Strawberries from the focal producer cooperative are predominately distributed to immediate region in Norway where this production is located, making this cooperative predominately a regional supplier of fresh strawberries. The main actors involved in the supply of Polka and Senga Sengana strawberries are shown in figure two below:

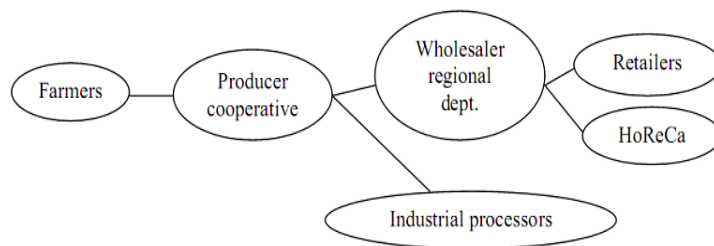


Figure 2. Actors involved in strawberry distribution

The study's farmers are usually small scale producers. A typical strawberry producer in the studied region operates a 20 acre strawberry field. Picking strawberries is a manual task carried out by a migrant labour, predominately from Eastern Europe. On average one labourer picks one acre of strawberry field. This means that a farm with 20 acres of strawberry field needs to hire 20 pickers that need to be housed for the season.

The producer cooperative was established in 1999. It aims to secure marketing and sales of products produced by its owners. It operates a distribution centre for mainly strawberries in a village in the valley, situated on the fjord. It also organises 3 annual meetings with producers to inform about strawberry production, distribution, and facilitate for contact among producers. These meetings take place before, during and after the season.

The regional fresh fruits and vegetables wholesaler department is part of Norway's leading fresh fruits and vegetables wholesaler with 16 distribution centres spread across the country. This group distributes its products exclusively to retailers within the specified retail group. In addition the wholesaler also distributes its products to the HoReCa (hotels, restaurant, catering) market. In the focal region more than 50% of the market share belongs to the producer that we study in the current paper. In addition, the regional wholesaler controlling these retailers has a 33% ownership stake in the regional fresh fruits and vegetables wholesaler. The rest is owned by national fresh fruits and vegetables wholesaler group. The retailer group consists of a range of different supermarket chains with different marketing profiles.

To secure quality supply of fresh strawberries, actors in the supply network need to coordinate a set of terminal and handling facilities and link these facilities through transport. Strawberries are relatively expensive agricultural products with relatively costly production and distribution activities. Profit margins are therefore considerably lower than for other fruits and vegetables products. At the retail facility baskets of strawberries have a profit margin of about 15% compared to 20-30% for most other fruits and vegetables products. This is countered by the large volume of strawberries, and that these are products that usually easily sell out when in supply. In addition, retailers express that when in season, consumers expect the store to be able to provide this product. In Norwegian food culture fresh strawberries for consumption are interwoven with consumer perceptions of "summer". The downstream part of supplies is relatively integrated due to a combination of ownership-based ties (vertical integration) and long-term contracts. The cooperation between the producer cooperative and the regional fresh fruits and vegetables wholesaler has lasted more than 10 years based on renewable annual contracts.

4.3 Distribution

The flow of strawberries is shown in figure three below:

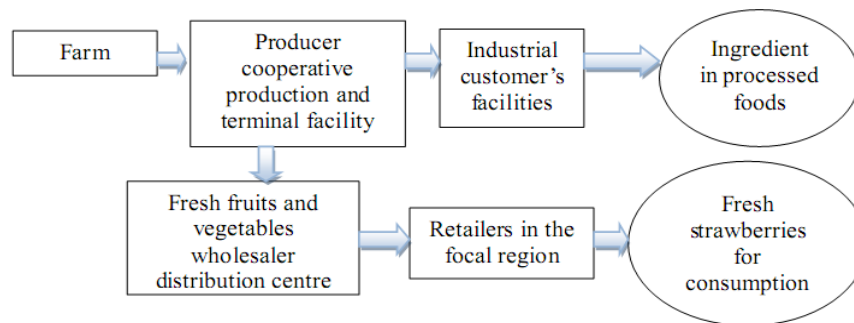


Figure 3. The strawberry flow

The strawberry is an agricultural product demanding storage after harvest at 4 to 6 degrees Celsius. The flow of strawberries as a commercial item starts accordingly with harvesting. Prior to harvest, strawberry production involves a complex combination of different measures to secure both short-term strawberry growth for each season and a more long term side involving product and farm facility development. These production-related issues will not be considered in further detail here. It is rather the daily flow from harvest to sales that is considered. This flow is, as all open-air harvested strawberries in Norway, seasonal. Seasonality in Norwegian agricultural production is due to a Nordic climate that limits agricultural production to summer-centred growth period.

A range of factors have an impact on the daily harvest quality and quantity. Colder weather slows growth. In addition, the age of the plant also affects the yield of strawberries. Rain deteriorates product quality. In cases of rain, the daily harvest of strawberries for fresh consumption purposes may be reduced by about 80% for the entire studied region. Pickers are then directed to harvesting for industrial use. Strawberries designated for industrial use represent a less quality-demanding allocation. Other major threats to strawberry production are soil wear and insects attacks. Growing strawberries year after year on the same field eventually deteriorates soil quality. To return the quality of the soil to an original state appropriate for strawberry production, the land must be used to grow grass for animal feed several years. In the studied valley, specialisation towards strawberry production therefore represents a threat. In addition, insects have attacked strawberry plants reducing harvest up to 80% in certain strawberry fields. This threat has been reduced due to precautionary measures including the use of pesticides.

Strawberries for fresh consumption are harvested by placing them into 500 gram clear plastic baskets. These are again placed in carton crates containing 12 baskets. Strawberries for industrial use are picked in larger plastic baskets that are emptied into plastic crates. Fresh strawberries in 5 kilo crates, and the industrial-purpose strawberries, are treated in the same manner during harvest and in production prior to the freezing process. Only strawberries of the Polka species are used for fresh consumption. These crates are collected at a central position at the farm for collection. At the farm studied this was a garage located at the field. This field was located at a distance of a few hundred meters from the main farm facility itself. Contrary what is common in Norwegian agriculture, this is a typical feature of strawberry production in the focal valley, with fields located not in the proximity of the farmhouse. Trucks run continuous pick-ups of strawberries. At the date of study, early in the

season, two runs were made by two separate trucks following separate routes in the high season an additional truck also collects the strawberries.

The producer cooperative annually produces 800 tons of strawberries at its facility. Out of this volume, about 120 tons is designated for fresh consumption and in this case the facility functions only as a terminal. Daily flow into the producer cooperative facility ranges from zero to 65 tons per day. The average volume range within the season is 40 to 50 tons. This facility also distributes other types of predominately fruit and berry products. The facility has capacity to produce, store and handle fruit and berry products. The main volume, approximately 75%, is used by industrial food processors in e.g. juice, jam and as flavouring in e.g. ice cream. In addition, the producer cooperative's production of consumer-packed frozen strawberry products accounts for less than 10% of the total harvested volume. Less than 20% of the production of fresh strawberries is distributed in-season through retailers to consumers.

At the producer cooperative facility the main volume of strawberries for industrial purposes are handled together with 5 kg. crates of packed products designated for fresh consumption. This involves cleaning (rinsing and removing the calyx), then freezing and finally packing. This production takes place only during the strawberry harvest. Strawberries for fresh consumption are then stored in a refrigerated facility. The production of frozen strawberries exceeds the capacity at the facility located in the valley. Therefore about 40% of the frozen strawberries are transported to an additional cold storage facility rented at a location close to the main industrial customers in Eastern Norway. Customers may, due to the frozen state of these products, order them throughout the year. These individual orders are carried out in the context of annual contracts.

Supplies of fresh strawberries are likewise managed by annual contracts with the regional fresh fruits and vegetables wholesaler. The daily volume of strawberries designated for fresh consumption fluctuates from day-to-day due to weather changes. In addition, an annual season may start earlier or later due to weather conditions impacting on the start, length and volume of production in season. Also the total harvested volume may vary by 20% on a seasonal basis. The fresh strawberries are loaded on two different trucks. Most of the produced fresh strawberry volume for consumption is transported daily to the wholesaler's facility at about 15:00. In addition, the producer cooperative charters a large reefer van that carries other products to retailers in the southern area of the region these products are distributed within. This transport is carried out in agreement with the regional fresh fruits and vegetables wholesaler.

The strawberries from the valley arrive at the wholesaler facility at about 17:00. The goods are unloaded and stored until picked for delivery to retailers. This distribution is in-part coordinated with the retailer's dry-goods wholesaler. Delivery of fresh fruits and vegetables takes place in accordance with routine schedules. Fresh strawberries represent during the season the largest volume fresh fruits and vegetables product for retail. Smaller stores receive deliveries 3 times a week, while the larger retailers may receive goods 5 times a week. Strawberries are usually displayed in crates. A cardboard retail display stand with colourful pictures promoting fresh seasonal domestic strawberries is supplied by the wholesaler. On occasion, a whole pallet of fresh strawberries may be ordered by larger retailers. These pallets are then usually used as display in the store. Due to fluctuations in supplies, strawberries from other suppliers than from the focal producer cooperative are used as supplements at stores in the focal region. In addition smaller volumes of imported strawberries are sold prior to and after the season of fresh Norwegian strawberries. These

strawberries are often stored in refrigerated facilities in the store together with other premium products such as blueberries, tropical fruits, packed lettuce, and salad mixes.

4.4 Goods Identification and Information Exchange

Prices of industrial products are set annually in centralised negotiations. A national producer cooperative negotiates with different industrial customers. Prices of strawberry products for industrial delivery are usually somewhat lower than that of supplies for fresh consumption. Previously a price per kilo was negotiated for the products between the producer cooperative and the regional fresh fruits and vegetables wholesaler. This was primarily due to the fact that the season in the studied Western Norwegian valley coincides with when prices are lowest on the national market for fresh consumption strawberries in Norway. However these prices had proven to be higher in the past years than the negotiated price. It was therefore decided to use the national market price mechanism in the 2009 season. This year, however, growing conditions in the main Eastern Norwegian production areas was exceptionally good providing large volumes at the start of the season. This gave prices in the beginning of July 2009 that actually at times was almost lower than for supplies to the contractually-based deliveries for industrial purposes. The next week, prices rose, due to rainy weather in Eastern Norway, to 30% above the price for industrial delivery. Simultaneously, some retailers sell strawberries at a loss to attract customers. These are usually planned campaigns administered by supermarket chains within the focal retail group.

The business actors shown in figure four are involved in short-term forms of information exchange to manage the flow as depicted in the preceding part. Since the harvest of strawberries fluctuates from day to day within the limits of the season. Farmers inform the producer cooperative logistics administrators the day before their expected harvest at about 14:00-15:00 by using SMS. This volume is measured as a number of pallets. Next morning at about 10:00 this prognosis is updated. When the final truck has collected strawberries in the afternoon at around 15:00 the actual supply from an individual farmer may be accounted for. This information specifies whether Polka or Senga Sengana that is planned to be harvested. The producer cooperative accumulates the first prognosis information and sends it on to the regional fresh fruits and vegetables office informing about how much it may supply for fresh consumption purposes the following day. This information is updated as more exact figures regarding strawberry supply become available. From the 2010 season the producer cooperative will start to use an automated production monitoring system where producers log onto a webpage and report their anticipated and actual production volumes. These data will then be automatically processed by the system and used to inform about total supplies for each day during the season. This system is currently being tested by a few producers and had been used for a number of years to register production of fruits in the Hardanger region of Western Norway.

Retailers simultaneously send in their daily orders of fresh fruits and vegetables products to the regional fresh fruits and vegetables wholesaler. These orders are based on the fruits and vegetables responsible judgement. Mainly a relatively fixed amount is expected to be sold daily of fresh Norwegian strawberries for consumption. A medium-sized supermarket in the local region orders 6 crates of strawberries 5 times a week. In addition retailers receive orders for 5 kg. crates of cleaned strawberries for delivery, at the earliest, the following day. However, weather conditions strongly influence demand. Sales of fresh strawberries for consumption may double compared to sales on a rainy day. In addition, sales are highest on

Fridays and Saturdays. These orders are sent in at around 10:00 the day prior to delivery. Each product has a numerical GTIN (global trade item number, www.gs1.org) code. A hand-held PDF device is used to create orders, and this information is sent using telecommunications direct to a computer at the regional fresh fruits and vegetables wholesaler. In addition orders from HoReCa type customers are received. This represents a small volume. The regional fresh fruits and vegetables wholesaler uses an EXCEL sheet to compare order information with supply information. The task of the regional fresh fruits and vegetables wholesaler is thereby to either push excess amounts of strawberries onto the market by calling up persons responsible for purchasing fresh fruits and vegetables at the retailers, and suggesting price reductions to facilitate purchases of larger volumes. In some cases price promotions have been planned in cooperation with specific differentiated supermarket chains within the focal retailer group in advance. In cases of demand exceeding supply, such as when it has rained the day before, the regional fresh fruits and vegetables wholesaler needs to first attempt to find supplies from other regions. If the demand still may not be met, the regional fresh fruits and vegetables wholesaler representatives call the retailers and inform them about the quantities they actually will receive the following day.

The occurrence of quality discrepancies is attempted avoided through inspections at the different facilities in the materials flow. Inspections involve primarily measuring the temperature of the products combined with a visual control. In cases of quality discrepancies, product traceability is provided by markings on the crates. This information allows the identification of the farm, the picker and the time of harvest. Complaints are usually communicated by telephone. This may in some cases involve communicating by telephone sequentially through the entire chain, from retailer, through the regional fresh fruits and vegetables wholesaler, the producer cooperative, to finally reach the farmer.

5 Modelling – simulation

It has been 50 years since Forrester explained the phenomenon of oscillating demand amplification (the bullwhip effect) with a system dynamics approach of the supply chain (Forrester1961). In the system dynamics approach, the supply chain is modelled as a set of stock levels, interconnected by order rates and resulting, but delayed, goods flows. The values of variables (stocks, order rates, flows, etc.) in a system dynamics model are represented by real numbers. Variables are conceptually continuous with respect to time, although the computer simulation requires discretisation.

By their nature - representing levels, flows, and sources as continuous real variables - system dynamics models have a high level of abstraction, usually at an aggregated level with respect to the individual actors. System dynamics helps to explain and predict phenomena at this abstract macro level. However, this abstraction does not represent the actual supply network process as described in section 3. In such a network individual actors make discrete decisions and take discrete actions. Product entities are discrete lots instead of continuous flows. System dynamics fail to explain how the individual decisions result in emerging macro-level phenomena.

To study the effects of the individual, micro-level, decisions and the resulting behaviours on variables observable at the macro-level, the system dynamics approach can be complemented with the complex adaptive systems approach (Miller and Page 2007). According to that approach systems are modelled as collections of autonomous agents, interacting with their environment and exchanging information with other agents. As a

collection of autonomous entities, such a system is not externally coordinated to produce some output. Outputs emerge as a result of behaviours and interactions, conflicts and cooperation of the autonomous entities constituting the system.

Complex adaptive systems can be simulated by agent-based models (Gilbert 2008). In agent-based models of social systems actors may be represented by cognitive agents: software entities that implement some form of artificial intelligence, act autonomously, interact with their environment, and are able to exchange information. As such, agents-based models can be used to simulate the processes of conflict and cooperation that occur in supply networks. Based on work by Boero and Squazzoni (2005), Gilbert (2008) discerns three levels of abstraction for agent-based models, requiring different levels of empirical validity:

- Abstract models, aiming to demonstrate theoretical properties of social processes lying behind many areas of social life;
- Middle range models, aiming to describe characteristics of a social phenomenon sufficiently general that conclusion can be widely applied;
- Facsimile models (called Case-Based Models by Boero and Squazzoni), providing as exactly as possible a reproduction of a particular target system, often with the intention to make predictions of future states, consequences of institutional changes, etc.

To model the fresh strawberry supply network we aim to develop a facsimile model, based on the data reported in section 3 and other available data about actual network structure, production, labour force, etc. Agent-based models have been applied to supply chains, e.g., in studies aiming to control the bullwhip effect (Moyaux et al. 2007). Information exchange and information sharing play a prominent role in these models. In agent-based models information can be more richly structured than just the value of a continuous real variable. This applies to both the information representation in the agents' "minds" and the information exchange with other agents. Information riches represented in the processes is the point where agent-based models complement system dynamics in the study of supply networks.

Agent-based models can be applied to study the effects of information in organisations, and they can be used to test the design and test work processes and information systems (Clancey et al. 1998). The authors describe an approach based on the "Brahms" software system (Sierhuis et al. 2007) to simulate human behaviour in a particular organization structure, in which information systems can be implemented and their performance and effects can be simulated and tested under different scenarios of human action. Such an approach holds promises for the development of supply chain information systems, which are hard to test in actual situations involving many actors at different stages in the supply chain.

Dessalles et al. (2007) discern agents implementing different levels of cognition

- Reactive agents, that have no cognitive rationality but only respond to environmental events;
- Behavioural agents, that can modify their behaviours according to observed pay-offs;
- Epistemic agents, that are aware of their behaviour and may anticipate the effects, possibly combined with social intelligence, extending the awareness to the effect of collective action.

In order to interpret and use the information, agents in simulated complex adaptive systems must have cognitive capabilities, at least at the level of behavioural agents. To develop realistic models requires detailed data about the agents' decision making and the way they actualize their decisions. Interviews reported in section 3 of the present paper can provide such data.

Supply network modelling and simulation can benefit from the following features of agent-based models:

- Agent based supply network models can be built in facsimile, empirically driven by data about actual network structure, actor properties, ordering patterns etc.;
- Furthermore, modelling of cognitive capabilities, decision making and action of agents can build on empirically validated models formulated in the social sciences;
- Effects of cooperation and competition in networks are simulated from the bottom up; no assumption about macro-level relations have to be made;
- Thus, agent-based simulations improve the understanding of the processes resulting in the behaviour and performance of supply networks as systems (cf. Moss 1999);
- The explicit modelling of information exchange between supply chain actors enables the application of an agent-based supply network simulation as a test-bed for supply chain information.

Drawbacks of the agent-based modelling approach are that it requires vast amounts of data and that validation is often problematic. Boero and Squazzoni (2005) discuss empirical calibration and validation of three types of agent-based models. For case-based (facsimile) models, which are empirical by nature, the micro-level data gathering strategy is the main issue. Janssen and Ostrom (2006) argue that given empirical problems with data collection and the explicit inclusion of cognitive, institutional and social processes, macro-level statistical performance is not sufficient for validation of an agent based model. Additional criteria are, according to Janssen and Ostrom (2006):

- Plausibility of the model, given the understanding of processes,
- Understanding why a model performs well,
- Better understanding of empirical observations gained through the model,
- Stakeholder validation of model behaviour.

One objectives of future research is to evaluate the benefits of applying agent-based models to the fresh strawberry supply case, taking these drawbacks into account.

In the validation phase of model development, the system dynamics approach can be applied. Huet and Deffuant (2008) describe an approach that formulates a macro-level model in differential equations and compares the dynamics of its outputs with those of the individual-based model. Thus, emerging outputs from a agent-based simulation that generates system behaviour from the bottom up can be cross-validated with a system dynamics model implementing relations between macro-level phenomena. The system dynamics model development could for this purpose be guided by an expert panel, applying group model building (Vennix 1996) as a method for stakeholder validation.

6 Concluding remarks

Paths of future research include:

- Implementation of an agent-based supply networks simulation, building on data described in section 3,
- Evaluation of information system design in the simulated supply chain,
- Cross-validation of complex adaptive systems versus system dynamics approach to the problem,
- Evaluation of cost and benefits of agent-based models for the study of supply networks.

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