Managing Global Supply Chain Relationships:

Operations, Strategies and Practices

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Chapter 3
Control Model for Intelligent and Demand-Driven Supply Chains[1]

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ABSTRACT

Orchestrating supply chains is challenging. This chapter describes how to control a supply chain to make it truly demand-driven – based on the assumption that all relevant information is made available to all partners in real time. The chapter explores the elements of a framework for intelligent and demand-driven supply chain control, with regards to the overall concept and associated principles, and demonstrates these in a case example. Challenges to the realization of the proposed control model include trust and power, supply chain dynamicity and uncertainty, and required investments in competence, standardization, and information and communication technology. Some of these can be met through initial small-scale implementations of the proposed model, to demonstrate effects, and by exploiting facilities for information sharing and collaboration, like supply chain dashboards and control studios. Future research within operations management, technology and information and communications technology (ICT) will support broader realization of the proposed control model.

INTRODUCTION

Integrating and coordinating supply chain and network operations are considered prerequisites for achieving high efficiency and competitiveness.

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Focusing on the performance and competitiveness of the supply chain, rather than the single company is a trend in several industries. Increased outsourcing and globalization greatly expands the complexity of supply chain operations and planning and control processes. A supply chain often has a decentralized geographical structure with complex logistics, where the various organizational units have a high degree of autonomy. Thus, supply chain operations require a well-defined orchestration of a broad set of activities, resources and companies, with the common goal of fulfilling the demand of the end customer.

Designing supply chains is challenging due to their heterogeneous system characteristics, diversified product and material flow structure, trade-off situations, and conflicting interests and goals of the participants. Products vary in value, volumes and shelf life. Today, offering high customer service means either maintaining a high stock level or having frequent deliveries. Conflicts of interest often arise when a manufacturer aims to utilize economies of scale by producing large volumes and buffering products in stock, only to discover that there is end customer demand only for a minor part of the volume. Meanwhile, the wholesaler strives to keep stock levels low and buy only according to end customer demand.

A number of challenges related to supply chain and network operations can be identified. First, operations of supply chains require development of a unified set of control principles which simultaneously harmonize the interests of the involved companies and the entire network. These control principles should also adapt operations to end customer demand, and provide for the right balance of cost, time and service performance measures for each product and the supply chain as a whole. Second, a number of technical challenges are related to the information and communication technology (ICT) solutions that are required to provide supply chain members with access to real-time information on network operations. This includes data capturing technology, communication platforms, visualization technology, and decision support tools which require solutions to standardization issues and considerable investments. Third, the aspects of trust and companies' lack of willingness to share market and demand information is an obstacle to achieving demand-driven collaboration. Many companies perceive demand information to be a key element in protecting their own power position and staying competitive.

The main focus in the work described in this chapter is the interplay of the first two challenges; *how to control a supply chain to make it truly demand-driven,* based on the assumption that all relevant information is made available to all partners in real time. The objective is therefore to explore the elements of a framework for intelligent and demand-driven supply chain control with regards to the overall concept and associated principles, and to demonstrate these in the case of a supply chain for processed salads.

In this chapter, a concept and a number of associated principles are illustrated, in the form of a control model based on the use of real-time information. The chapter contributes to theory and knowledge through its description of an integrated framework for supply chain control and associated principles and the demonstration of these in a practical case. The aim of the framework and principles is to assist managers of supply chain organizations by highlighting and exploring possibilities and some key issues related to control of supply chain operations. A further contribution to practice is derived through the exemplification of how the framework and proposed control model can be applied in an actual supply chain.

The work is based on the *control model methodology* (Alfnes, 2005; Alfnes & Strandhagen, 2000). Viewing network and supply chain operations from a control model perspective is a systematic approach that enables integration and network partnerships for increased competitiveness. This methodology has been applied in numerous industrial cases over the past decades, with the experiences and results serving as a practical platform for a deductive research approach. This action-based, reengineering type of methodology, focusing on visual presentation and communication between involved supply chain members, also enables them to meet the challenges related to lack of trust and understanding between supply chain partners.

BACKGROUND

The supply chain approach is assumed to be a winning strategy for improving competitiveness and conducting business development. A vast amount of literature shows how a holistic and integrated supply chain strategy can lead to competitive advantages and other synergy effects, such as increased trust and less complex contract mechanisms between business partners, increased service levels, reduced costs and increased economies of scale (see e.g. Bowersox, Closs, & Stank, 1999; Christopher, 1998; Min & Mentzer, 2004). However, the success of a supply chain strategy depends on a number of factors, such as how well the supply chain as a whole is operated and controlled, to what extent operations are in line with demand and customer requirements (Simchi-Levi, Kaminsky, & Simchi-Levi, 2008; Slack, Chambers, & Johnston, 2001; Vollmann, Berry, Whybark, & Jacobs, 2005), how responsive the chain is to changes and uncertainty (Reichart & Holweg, 2006), and whether the companies involved are able to collaborate as if they where a unified entity (Tyndall, Gopal, Partsch, & Kamauff, 1998). In addition, ICT provides unprecedented potential as enabler of new ways of operating the supply chain and for companies to interact and share information (Clark & Lee, 2000; Ellinger, Taylor, & Daugherty, 1999).

Supply chain operations extend the control span and increase the complexity of the planning and control task. The increasing need for coordination, integration and collaboration among organizations has led to a wide range of business initiatives and projects that seek to investigate the potential of supply chain strategies, solutions and developments this requires, and how this will affect existing business models and relationships. Some relevant examples from past and ongoing research and development (R&D) projects are described below.

The pharmaceutical industry is characterized by a wide variety of products, both prescription and non-prescription drugs, with limited shelf life. These products are offered through a supply chain that experiences continuing pressure for reducing costs, lead times and stock levels, while simultaneously increasing turnover rates and product availability. A significant challenge for pharmaceutical supply chains is how to achieve improvements and shorten the time from production to market. The R&D project Automed (2004-2007, see www.sintef.no/automed) focused on the supply chain from a pharmaceutical production plant, through a pharmaceutical supplier and a wholesale unit, to a chain of Norwegian pharmacies. Analysis found that supply chain performance could be significantly improved, for instance, that cost levels could be reduced by 25-30%, lead time could be halved and stock levels reduced by 30%. In order to realize this potential, the involved companies had to change their entire supply chain approach towards tighter integration and application of demand-driven, pull-based control principles based on sharing of point-of-sales (POS) data. Part of the potential was realized through the implementation of an automated replenishment solution, where the responsibility for pharmacy replenishment was shifted backwards in the chain to the wholesaler.

A study of the grocery sector shows similar challenges. In a project called Smart Vareflyt, or Smart Flow of Goods (2007-2009, see www.sintef.no/smartvareflyt), nine supply chain members in the Norwegian grocery industry (fresh food producers, packaging producers, grocery wholesalers and retailers, and logistics service providers) cooperated, in order to investigate how real-time information would affect the flow of goods and information and what effects sharing of demand information in the supply chain could have on performance. Reducing supply chain lead time and increasing shelf life for perishable products in stores is a high priority issue in the grocery industry. A main objective of the project was to test and demonstrate the potential of radio frequency identification (RFID) of products and packaging and application of electronic product code information services (EPCIS) for information sharing. Analysis showed that the various supply chains could improve their performance if the traditional make-to-stock (MTS) approach were replaced by holistic demand-driven control principles utilizing real-time demand information, such as POS and RFID captured data. The potential effects of reduced lead times and stock levels were of particular importance for perishable products. The project also demonstrated how access to both real-time and historic demand information could be utilized to develop automated decision support and visualization systems supporting supply chain operations.

For global manufacturing operations, important challenges include how to coordinate geographically distributed and diversified networks of plants and facilities and how to control and execute operations according to demand and customer segments. In the Origo project (2006-2008, see www.sintef.no/origo), a Global Control Centre environment was developed to deal with coordination of planning and control tasks in a global network of fishhook production facilities (see Dreyer, Alfnes, Strandhagen, & Thomassen, 2009). A similar project was Optilog (2005-2010, see www.sintef.no/optilog) where the focus was on developing new collaboration models and associated supply contracts that capture the need for improved operational coordination and information sharing along a construction supply chain, from pipe manufacturer, through wholesaler to contractors.

A number of common elements can be seen in the above mentioned examples:

- A rethinking of the traditional manufacturing planning and control (MPC) paradigm, such as MTS, push and batch principles, towards demand-driven control principles such as make-to-order (MTO), pull and continuous, automated replenishment
- Fulfillment of demand based on replenishment and collaboration concepts, instead of traditional ordering and purchasing practices
- Potential for performance improvement and achievement of reduced costs, lead times, stock levels, and throughput time, through sharing of demand information and utilization of updated and real-time information
- Redesign and adjustment of supply chain operations to demand and customers' needs, including coordination and integration of supply chain processes into a unified control model
- Utilization of updated and real-time information in automated decision support systems and control models, enabled by modern ICT solutions

The remainder of this section will describe essential elements of these topics, as well as recent developments and the authors' views on how these developments are expected to shape the future business environment.

The MPC task in a supply chain involves determining what, who, when and how to act, in order to meet customer demand with the exact supply in a coordinated chain (Jonsson & Lindau, 2002; Vollmann, et al., 2005). Each node in the chain cannot be managed in isolation (Shi & Gregory, 1998), and the MPC system must support cross-company processes in a manner that avoids increasing amplifications, stock levels, and lead and response times (Dreyer, et al., 2009). Today, most of the planning and control systems used in supply chain operations are based on the traditions of MTS and MRP/MRP II, where forecasts and expectations of future demand are the main inputs (Zijm, 2000). In addition, economies of scale arguments are frequently used when dimensioning and controlling processes like production, warehousing, distribution and transport. The main planning and control logic of ERP (Enterprise

Resource Planning) systems is still based on aggregation, optimal batch sizes, order quantities, transport frequencies, and sequencing (Alfnes & Strandhagen, 2000). The consequences are that a number of supply chain operations are decoupled from actual end customer demand, and inventories are used as a buffer against uncertainty and fluctuating demand.

The next generation supply chain MPC models are derived from the principle of sharing demand information among all members of the supply chain, so that production, warehousing, distribution and transport can be operated based on demand, rather than expectations and forecasts. Moving the information decoupling point backwards in the supply chain is an essential element in this. The more members of a supply chain that have an undistorted and near real-time view of consumer buying behaviour, the more responsive the supply chain is as a whole (Mason-Jones & Towill, 1999).

In order to develop demand-driven MPC models, several collaborative models for orchestrating supply chain and network activities have been developed. The aim of models such as collaborative planning, forecasting and replenishment (CPFR), vendor managed inventory (VMI) and automated replenishment programs (ARP) is to achieve seamless inter-organizational interfaces by specifying control principles and operations models for the flow of materials and information (e.g. Daugherty, Myers, & Autry, 1999; Mattsson, 2002; Sabath, Autry, & Daugherty, 2001). The main principle is to tie and adjust network operations to customer demand and MTO strategies, instead of the traditional forecast and MTS approaches.

Performance monitoring is essential to ensuring efficient optimisation of operational processes, and, over the last few years, the focus has shifted to incorporate a supply chain perspective (e.g. Chan & Qi, 2003; Holmberg, 2000; Lapide, 2000; Van Hoek, 1998). Supply chain performance measurement requires continuous follow-up, based on a consistent and comparable holistic structure or hierarchy of indicators. These are used to measure the performance of the supply chain as a whole and of the individual members, based on agreed upon strategies, performance targets and priorities. Both reactive or "lagging" indicators showing how the supply chain has performed, and proactive or "leading" indicators showing the efficiency in operational supply chain processes, are required (Bititci, Turner, & Begemann, 2000; Holmberg, 2000; Neely, et al., 2000).

In any supply chain or network, there will be a mixture of principles which must be aligned with the manufacturing environment and the specific control situation of the supply chain. Automation can be built into the control model through the use of ICT tools and a conversion of control principles into mathematical algorithms, expressions and logic (Strandhagen, Alfnes, & Dreyer, 2006), making it possible to replace much of the current manual decision-making with status monitoring, surveillance, and exception handling.

Increasing access to real-time demand and event information in the supply chain is expected to lead to a shift in planning and control concepts towards purer demand- and pull-driven supply chains (Kärkkäinen & Holmström, 2002). Technology advances within areas such as RFID, sensor technology and EPCIS will enable access to more real-time information than the existing technology solutions. RFID tags contain information that can be read from a distance, considerably increasing the number of points where data can be obtained throughout the supply chain, compared with today's barcode system. Combining RFID technology with sensor technology further enhances the intelligence of such data capturing technologies, and will enable the development of intelligent and automated planning and control concepts. Advances in ICT have also enabled the development of control center concepts, where dashboards, real-time monitoring systems and visualization applications support information transparency and control on all process levels

(Boyson, Harrington, & Corsi, 2004; Dreyer, et al., 2009).

A control model can be used as a tool for developing a common understanding and organizing operations (Alfnes, Strandhagen, & Dreyer, 2006). The model is a formalized way of describing the underlying logic and the defined control principles of the MPC, which can be used as a foundation for reengineering and improvement processes. The model consists of six "views" on enterprise operations that should be mapped and modeled: *resources* (machines, equipment, facilities, etc.) *materials*, (products, components and materials), *information* (information elements accessed, stored, processed, and transferred), *processes* (administrative, physical and support processes), *organization* (organizational entities, assignment of responsibilities and authority, etc.), and *control.* Control is the key perspective of the model, describing how operations are organized and controlled in manufacturing and distribution, through the following building blocks (Strandhagen, et al., 2006):

- Control principles and methods; defining main principles for how operations are controlled in the chain and for each operations area (e.g. push, pull and ordering)
- Customer order decoupling points (CODP); dividing the supply chain into parts based on forecasts and parts based on customer orders/demand
- Main operation processes and buffers/ stocks
- Operations areas; specifying operations that constitute separate areas of responsibility
- Material flow; specifying the main routes through the operations processes
- Information flow; specifying the flow of information related to the supply chain

Summing up the developments and key issues described above, we see that control models provide a foundation for unified and shared control that enables demand-driven and intelligent control concepts. Such control models should enable flexible networks to respond to customer demand by utilizing their own and suppliers' capacity and resources. However, to avoid conflicting interests, the unified control model should contain a number of carefully designed and collaboratively developed control principles. In addition, access to and sharing of real-time information in the network and the utilization of ICT for information processing, visualization and decision support are key elements in the realization of intelligent and demand-driven supply chain concepts.

TOWARDS A FRAMEWORK FOR INTELLIGENT AND DEMAND-DRIVEN SUPPLY CHAIN CONTROL

The complexity and variety of global supply chains, as described in the previous section, points to the need for capturing a more holistic picture of supply chain planning and control that will support future developments in industrial business cases. In response to this need, a conceptual framework and associated methodology have been developed, based on the above elements and experiences from numerous cases. Capturing control as its key element, the framework is called a c*ontrol model for intelligent and demand-driven supply chains*, consisting of the following parts:

- *A concept;* providing an overview and general description of each of the key elements
- *A set of principles;* describing the shifts required in moving towards demand-driven supply chains based on real-time information
- *Case illustrations;* describing of a set of business cases illustrating application of the concept and associated principles within a number of different industrial sectors,

types of supply chains, product segments and/or particular processes

- *Generic control model;* a generic model template that allows for specific model development for individual business cases
- *Guidelines;* a set of additional and practical guidelines (supporting the general guidelines of the control model methodology) that specifically address issues related to real-time based demand-driven supply chain

At the current state of this research, the concept and the principles have been developed, and the remainder of this chapter will focus on describing their essential elements. A first version of the generic control model has been used as a template in a number of cases and projects where the framework has been applied, and one of these cases is used in this chapter to illustrate the principles and model. The generic model and guidelines are the focus of our ongoing research.

A Concept for Intelligent and Demand-Driven Supply Chains

The concept is the starting point of the control model for intelligent and demand-driven supply chains. Figure 1 shows the individual elements that need to be addressed and interconnected, in order to realize the concept. Each of the elements is described in more detail below.

Control

The control element consists of a description of the processes and principles applied to direct the flow of goods and information in the supply chain. For each process in the supply chain (supply of material, production, assembly, wholesale, retail, etc.) the control principles (including placement of CODP) specify issues such as when, how, and where to act, upon which criteria and in what quantities.

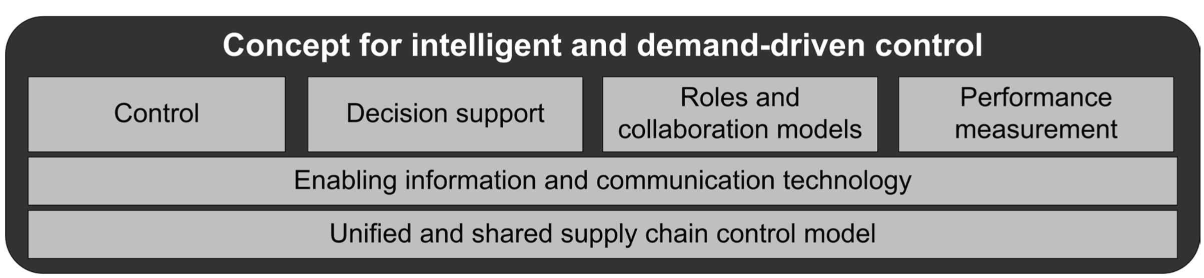
Decision Support

This element is the description of how decision support is applied in supply chain control. It describes all application areas of decision support, with particular focus on applications related to operative decision-making. Examples include the use of optimization methods or advanced simulation tools in evaluation of lot-sizes or order quantities.

Roles and Collaboration Models

Roles and collaboration models outline how supply chain processes are coordinated and who is responsible for what. All processes and information flows that cross organizational boarders, as well as business and organizational mechanisms such as contracts and price instruments, are also described.

Figure 1.



Performance Measurement

Performance indicators show how good and effective supply chain operations are, indicating when and where changes and improvement actions should be made. This description contains the three main application areas of monitoring, cause-effect analysis and management reporting, and it describes the processes of data collection, analysis and presentation, as well as the systems assigned to support such processes.

Enabling ICT

All the other elements of the control model emphasize the need for ICT tools and an architecture which can support transactions, information processing and decision-making in real time. This element of the concept identifies and describes the key technologies and systems applied to support the supply chain control tasks.

Unified and Shared Supply Chain Control Model

All the elements of the control concept are collected into a unified control model. The control model can be seen both as a way to structure and formalize operations activities, and as a fundament for reengineering and improvement processes.

Principles for Intelligent, Demand-Driven Control

Essential to the framework is a set of principles that will support the shift towards demand-driven supply chain control based on real-time information, where each principle is a general rule for how to realize the concept. Table 1 briefly describes the general topic of each principle.

Each of the eight principles should be applied and described in a unified control model. This control model must be established between all partners in the supply chain and communicated to all those involved in supply chain operations. The control model should also be the logical

Table 1. Principles for intelligent, demand-driven control

	Topic	Main principle
1	Capturing and utilizing real-time information	Real-time information on POS data, stock levels, marketing plans, manufacturing and transport status, etc. should be captured and utilized for decision-making.
2	Information sharing	Information should be shared continuously with supply chain partners through databases, information hubs or portals that store, integrate, process and present relevant information from the ICT systems of each actor.
3	Reconsidering the CODP	CODP placement should be differentiated and moved up or down stream in the supply chain according to product and market characteristics.
4	Pull control	Decisions on manufacturing, shipment, etc. should be proactive and based on a “buy one – produce and deliver one” strategy.
5	Supplier-driven replenishment	Replenishment responsibility should be moved upstream in the supply chain (supporting VMI concepts).
6	Individual product and process control	Control of each product or product segment should be determined individually according to product, demand and market characteristics.
7	Automated and integrated decision support	ICT should be used for automated decision-making and provide decision support tools. Human decision-making should be shifted to surveillance and status monitoring.
8	Measuring supply chain performance in real time	A new set of leading and lagging performance measures should be developed and integrated with control parameters. These measures should be implemented in a visual dashboard showing supply chain performance in real time.

basis for the development of supply chain control dashboards or studios. The following sections describe each principle in more detail.

The Principle of Capturing and Utilizing Real-Time Information in the Supply Chain: Information on supply chain operations is often historic data on POS data/demand, stock levels, marketing plans, manufacturing and transport status, etc. and typically based on batch, periodic, or entry point approaches which accumulate demand. Consequently, decisions are made based on the past, not on the current situation. However, technological developments have now enabled access to up-to-date and real-time information, which will lead to a major shift towards supply chain control based on continuous insight into the current situation, thus allowing real-time execution and handling of events. Information on actual events is available, and instead of waiting until the next period or an order-point is passed, the information can immediately be made available to supply chain partners. This is particularly relevant and critical for immediate suppliers of the items in question. Access to real-time information means decisions can be made based on facts and realities rather than on assumptions and expectations, which contributes to a more precise statement of demand, stocking of the right product mix, etc.

The Principle of Information Sharing: The ability to capture real-time information, described in principle (1), provides for improved information quality. However, if information (real-time or otherwise) is not continuously distributed and shared among supply chain partners, the value of information for improved decision-making is highly limited. Since the benefits, in terms of improved supply chain responsiveness, increase as the information order decoupling point is moved up the chain, information on consumer behaviour should be made available as far back in the chain as possible. To increase usefulness of market information, filtering and aggregation routines should be established for each node. The information volume will be significant, and establishment of a unified ICT architecture and development of tools for processing and presenting relevant information elements is necessary. One solution would be the establishment of databases, information hubs and portals to store, integrate, process and present information from the entire supply chain, integrating information from the ICT systems of each supply chain member.

The Principle of Reconsidering the CODP: The access to real-time information will allow reconsideration of the placement of the CODP in general and individually, by product or product group. The move could be upstream, as well as downstream, in the supply chain. Where to place the CODP depends on a number of variables, including product and market characteristics, and a main rule for demand-driven supply chains whether real-time information is available is to move the CODP upstream. An argument for this is that real-time information makes the administrative lead-time near zero, increases responsiveness, and thereby eliminates the need to make or move goods based on forecasts. For products with high value and customer-specific elements, this will be a main principle. For standard products and commodities with long transportation time, where the decision on final destination can be made while the goods are being moved, real-time information can allow moving the CODP as far forward in the supply chain as to the unload process.

The Principle of Pull Control: The overall planning and control principle should be make-to-order according to a "*buy one – produce and deliver one"* strategy. A pull-based solution is therefore essential in demand-driven supply chains. However, with access to real-time information control, decision-making can be shifted from reactive to proactive. A supplier can act and send shipments based on real-time insight into customers' stock levels and thus not have to wait for an order before initiating the appropriate activities. Additionally, since information is made available continuously, the existing control principles based on economy of scale reasoning, such as order point, periodic batch review, economic order quantity (EOQ), etc., will be challenged. Real-time planning and control models differ from more traditional models by:

- Dynamic and continuous determination of order quantities and shipment frequencies
- Individual and automatic product decision-making
- Decision-making based on:
    - A holistic perspective, taking into consideration a number of factors such as sales, stock levels, manufacturing, transport routes, substitution products, packing quantities, etc.
    - Simultaneous handling of information on history, current status and forecasts
    - Aggregated information (from items to product-groups, components and materials)

The most radical shift is that decisions on manufacturing and shipping order quantities and frequencies are dynamic, continuous and event-based. As systems are designed to be triggered by events and automatically recalculate, fixed order quantities and batch processing of information is abandoned.

The Principle of Supplier-Driven Replenishment: In a more traditional control situation, the customer is responsible for communicating a demand signal to the supplier in the form of an order. With access to real-time information, the responsibility for ordering is shifted to the supplier, who replenishes the customer with the exact product quantities at the right time, for instance through VMI solutions. However, such solutions require that the supplier has continuous access to correct information on the customer's demand, stock levels, marketing plans, etc. The need for a more holistic supply chain perspective requires that replenishment decisions (automated or manual) are made as far upstream as possible. The principle is that the upstream supply chain members have the advantage of being able to combine information for all subsequent nodes and can utilize this to adjust capacity and achieve economies of scale benefits.

The Principle of Individual Product and Process Control: Ideally, each product or product group should be dealt with individually, in order to take into account specific product, demand and market characteristics when handling the product through the supply chain. A real-time and demand-driven supply chain should therefore have a clear process orientation, where control is organized around the product and how it flows through the main operations processes (manufacturing, warehousing, distribution, replenishment, etc.). This will typically be in line with concepts such as multi-echelon inventory control, automated replenishment, and collaborative planning, forecasting and replenishment (CPFR). Real-time information, integrated decision support and ICT tools enable such differentiated control models down to an individual product level, thus creating flexibility.

The Principle of Automated and Integrated Decision Support: Real-time information, in combination with a unified control model, can be combined with decision support tools to automate operative decision-making. Such tools include mathematical algorithms, optimisation functionality, ICT, automated analyses, and integrated support tools, such as simulation and what-if analysis. Decisions will not be made in isolation, but rather will be based on a unified foundation, in order to handle trade-offs and alleviate sub-optimization. Through its processing capacity, ICT can identify patterns in demand and supply much more quickly and provide more accurate forecasts for short- and long-term operations. ICT tools can integrate information from several nodes, as well as integrate forecasts, current status and historical data. As the degree of automated decision-making is radically increased, it is essential that information on decisions is presented automatically and visually in dashboards or studio environments for human surveillance and status monitoring.

The of Measuring Supply Chain Performance in Real Time: Within a traditional control paradigm, supply chain operations are evaluated based on past performance, and indicators seldom predict consequences on future performance, thus providing a weak foundation for corrective actions and improvement efforts. With access to real-time information, a new set of performance measures which include leading and lagging parameters should therefore be developed and integrated with control parameters. Real-time key performance indicators (KPIs), showing the exact current performance for the entire supply chain (e.g. lead time, average stock levels, inventory throughput time and fill rate), should be continuously accessible to all partners. Further, ranges for acceptable performance should be established for each KPI. Automatic and electronic procedures can be programmed to generate alerts whenever an indicator falls outside of the agreed ranges. The whole set of performance measures should be integrated in a visual dashboard solution, thereby providing a powerful tool for supply chain performance improvement. Ideally, supply chain members should have access to a flow map showing, in real time, the movement of goods and materials through the supply chain and how the supply chain as a whole is performing.

Case: Control Model in a Fresh Food Supply Chain

In this section, a control model for an intelligent and demand-driven fresh food supply chain will be described in terms of the principles presented above applied to a case study in the Norwegian grocery industry - the production and distribution of processed fresh salads. The information from the case stems from a three-year user-driven R&D project called *Smart Flow of Goods* (2007-2009, see www.sintef.no/smartvareflyt). The project was initiated by major players in the grocery industry (three food manufacturers, two manufacturers of packaging material, two wholesaler – retailer dyads, and two logistics solution providers). The aim of the project was to develop new intelligent and demand driven control models for the supply chain, enabled by RFID technology and intelligent control principles.

The focus and activities in the case were determined in cooperation between practitioners and researchers, based on the specific needs and challenges of the participating organizations and their supply chains. Data was derived using the control model methodology (Alfnes, et al., 2006). Solutions were developed through scientific methods (combined action research and case methodology, use of theory, literature, scientific methods for data collection and analysis, etc.), combined with practical knowledge and experiences from the food and grocery industry.

The following sections provide a description of the fresh food industry and the salad supply chain, including current problems and challenges facing the supply chain members. Then, a new control model will be outlined based on the principles described in the preceding sections.

The Salad Supply Chain

The fresh food industry is influenced by a number of trends affecting most global businesses, e.g. globalization, increasing cost focus, time pressure, environmental concerns, customization, and financial rationalization and consolidation (see e.g. Christopher, 2005; Hofmann & Reiner, 2006; Turban, Leidner, McLean, & Wetherbe, 2006). Food supply chains are complex and form large networks, and the grocery industry's solution to its logistics challenges has tended to set a standard for other industries. The logistics structure is often centrally coordinated, enabling use of cross-docking and terminal facilities in distributing goods to retailers in parallel with direct shipments from producers. Control concepts in the Norwegian grocery industry are dominated by traditional push and forecasting based control. Information on consumer demand is, in many cases, not accessible due to lack of, or infrequent, information sharing, and those who have access to demand information do not necessarily utilize it for control purposes.

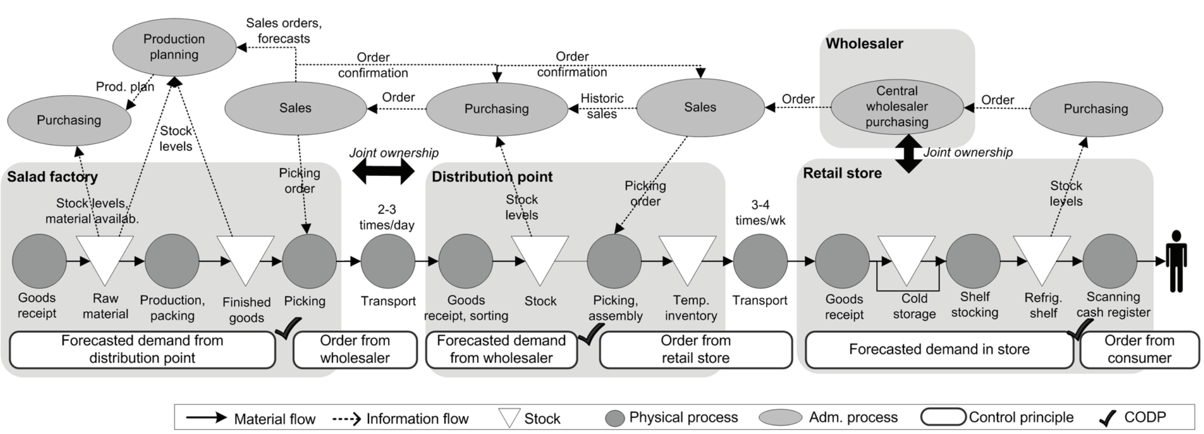
Despite the limited cooperation and information sharing along the food supply chain, Norway is seeing signs of a shift towards more dialogue and collaborative search for industry solutions that can create more efficient and demand-driven supply of food products. The Norwegian grocery market is dominated by a handful of large players within each stage of the supply chain and there is a near full consolidation into four chains of wholesaler – retailer dyads, which control 98% the market. In the past few years, a number of collaborative initiatives have been launched by government and the industry itself, with the aim of increasing efficiency, ensuring supply of safe and high quality food products, reducing waste or scrapping along the food supply chain, etc.

Traditional food items are produced in high volumes with small profit margins. Simultaneously, changing consumer preferences and tough competition are forcing food producers to offer a broader product selection, while continuously reducing costs, which requires increased efficiency in production and logistic operations (Bolseth & Alfnes, 2001).

The case example consists of a supply chain for the distribution of salads from the producer, through a distribution point to a typical grocery store. The focal product consists of various types of processed salads, all with a shelf life of around 8-10 days from the production date. The current supply chain for salad is illustrated in Figure 2, showing supply chain members, material and information flows, stock points, physical and administrative processes, and control principles and associated CODP.

The physical flow starts at the salad factory, where raw materials are supplied from a set of local, national and international primary producers. In total, the factory produces 200 variants, of which salads represent an atypical product, distributed both directly to restaurants and larger institutions and through wholesalers or distribution points to retail stores. The production process for most products consists of quality inspections, cutting, washing, and assembly into various product mixes, before packing and storing. Salads are manufactured to stock. Orders from distributors or wholesalers are used for procurement and production and supply planning. The weekly production plan is based on the principles of

Figure 2.



optimal batch-sizing. Products are kept in stock until orders arrive from distribution points or wholesalers, and turnover for salad products is high, due to the extremely short self life.

From the factory, products are shipped to a distribution point, where retailer orders are assembled. Requirements at the distribution point are calculated by the sales department based on a combination of historic sales data and forecasting techniques. In this particular supply chain, the distribution point is a cross-docking facility, and within a 8 – 10 hour timeframe the products are transported to retail stores. Operations at the distribution point are based on orders from retailers. Accumulated orders are received from a central information system operated by the retail chain's wholesale unit. Orders from each store are placed daily into the central system, based on predefined ordering principles and manual inspection routines. Orders from stores vary in both quantity and items. Throughout the supply chain, products are kept within a strictly regulated temperature zone.

The main challenges and problems associated with current operations and control in the supply chain are:

- A high number of stock points or buffers along the supply chain
- Large amounts of waste/scrapping, due to long lead times and temperature sensitive products
- Forecasting and planning in each node, based on forecasted demand from subsequent node
- Forecasting based on historic sales and extensive manual parameter adjustments, based on experiences and market knowledge
- Limited information sharing and use of available information for operations planning and control
- Limited use of POS data in operations planning and control backwards in the chain

A New Control Model for the Salad Supply Chain

Based on the above challenges and issues, a number of potential improvements to the as is situation were developed, as part of the *Smart Flow of Goods* project. The following section describes how each of the principles above can be addressed through a new control model for the supply chain. Some of the proposed solutions were implemented in the case during the project, while others reflect the ideal intelligent and demand-driven control situation for this supply chain.

The new control model involves changes related to the control and structural aspects of the supply chain. The main principle for the new control model is demand-driven control of the entire supply chain, based on continuous sharing of real-time demand and stock information in retail stores. Also, activities related to order, supply and production should be automated, to as a great an extent as possible, with only exceptions and corrections handled manually.

The new control model is based on real-time POS and inventory information being captured and communicated backwards in the supply chain from retail shops (principle 1). This information is an essential input to the proposed replenishment model between the distributor and the retailer. The information will also be made available to the salad factory, for improved production planning and control. Due to the very short shelf life of salad products, demand information must be made available continuously or daily at worst, to enable the factory and the distribution centre to respond quickly to any changes or disruptions in consumer demand.

Due to the high perishability of processed salads, any time spent in stock reduces the quality of the product. The current finished goods stock point in the factory is mainly there as a demand and transport buffer and therefore represents non-value adding activities and time. The finished goods stock point will therefore be moved downstream, such that only the distribution point has a stock of finished goods. CODP will be at production/packing line in the factory (principle 3), with activities in the supply chain based on a combination of a push and pull strategy (principle 4). Downwards from the factory transport, picking, packing and labeling will be based on the replenishment needs of retail stores. Upwards, production at the factory will be based on a push strategy, where production is executed on forecasted accumulated demand, adjusted with consumer demand information. Production batch sizes will be set according to availability of raw materials and production capacity.

As part of an automated,VMI strategy, the distribution point will assume the responsibility for replenishing all retail stores, based on real-time information on POS and stock levels (principle 5). In this way, stock at the distribution point and the entire retail chain will be controlled according to multi-echelon principles, where the stock levels of the two echelons of the supply chain are considered in concert. Operations at the distribution point will be planned and controlled based on aggregated information about replenishment needs for all retail stores. For retail stores, the VMI solution will eliminate the need for traditional purchasing and order processes, while the manufacturer will be able to control the goods flow, from the purchasing of raw material to production, through access to real-time information on distribution needs.

ICT is a key enabler of the new control model, and the implementation of an efficient infrastructure for capturing and sharing information is essential. A supply chain dashboard will be implemented to store, aggregate and visualize demand information (principle 7). In addition, decision support tools will be integrated into the dashboard. POS data and stock information from retail stores will be transferred to the system on a continuous or daily basis, where the distributor and factory can use the information in their own planning.

The new IT infrastructure will also involve the acquisition of commercially available software to support the VMI solution. Such software will calculate the replenishment needs of finished goods for the distribution point and all retail stores, based on historic demand patterns, lead time, demand uncertainty, specified service levels, and information on ongoing and upcoming campaigns and other market activities.

A jointly developed system of performance indicators will be integrated into the supply chain dashboard (principle 8). These parameters will enable supply chain members to continuously measure and monitor performance against established objectives for the supply chain and each individual member. The indicators will form a hierarchy showing how the performance of individual supply chain members affects overall supply chain performance. Lagging indicators include sales, productivity, quality control costs, and rush order costs, while leading indicators include measures of service levels, stock levels, stock values, returns, product and delivery quality, lead times, and supply chain responsiveness.

This proposed control model refers only to one product group: processed salads. Since this is an atypical product for the factory and the rest of the supply chain, separate control models should be created for other products and product groups. Although there will be differences between the specific models, they will all be based on the same principles of demand-driven control enabled by sharing of real-time information. Each model should take into consideration the characteristics of the products, their demand patterns and variability, particular requirements related to production and distribution processes, etc.

Issues, Controversies, Problems

The previous sections of this chapter have highlighted possibilities and the essential elements managers must deal with in order to realize intelligent and demand-driven supply chain operations.

However, the control model presented is based on a normative approach for dealing with complexity and improving supply chain efficiency. The model was developed using a general approach based on some simplifications and introducing several elements and principles as building blocks in a new environment for operating supply chains. In addition to the recommendations and principles set forward in this chapter, there are a number of other issues which supply chain managers will have to address, both within their own organizations and in their supply chains, before such a normative model can be applied in a real supply chain setting. Some of these issues, controversies and problems are discussed below.

Efficient Coordination Across Organizational and Geographical Boundaries: Although the case dealt with in this chapter focuses on a domestic supply chain, the issues discussed and the model developed is possibly even more relevant in the context of global network operations. In any situation where the scope of operations span is beyond a single organization single-site, the planning and control task takes on a supply chain or network perspective. The high complexity and coordination challenges involved in supply chain operations therefore require a holistic and integrated approach to planning and control, where one single, agreed-upon control model should support seamlessly integrated processes across organizational and geographical boundaries. However, the unified supply chain control model presented here does not guarantee efficient coordination of all operations, particularly since it does not solve the issues related to the lack of a central coordinating facility or unit in a supply chain of autonomous members. The joint development of a unified control model is, however, a step in the right direction.

Dealing with Inter-Organizational Issues Related to Information Sharing, Diverging Interests, and the Power and Trust Balance: The power position and relative strength of supply chain members is discussed both in the literature and practice. In the food supply chain, many retailers have gained a major strategic position through integration of retailing and wholesaling activities, allowing them to control access to demand information. This information is frequently not shared with other partners in the supply chain, because retailers are worried that suppliers might use it to gain a competitive advantage. In the normative framework explored in this chapter it is assumed that retailers share demand information, even though, in reality, retailers tend to be restrictive in sharing this information. Also, in many instances, suppliers lack models for how to utilize demand information to improve their own operations.

Ability to Handle Dynamics, Uncertainty and Variation: For supply chain operations, it is extremely challenging and resource-demanding to cope with variation and uncertainty. This means that the models suggested in this chapter need to be dynamic and flexible, which somewhat breaks with the normative approach of the models. Still, this is one of the most important issues to address, in order to handle supply chain complexity.

Simultaneous Participation in Multiple Supply Chains: Each partner in a supply chain needs to deal with the fact that they most often are part of several supply chains simultaneously. Thus, solutions developed in cooperation with partners in one supply chain might not be appropriate for all or indeed any of the other supply chains the company participates in. Also, solution working well for one partner in a particular supply chain may not be successful or applicable for other partners due to the heterogeneous nature of business processes and relationships. The "one size fits all" approach is hardly applicable in a supply chain setting, thus, a major challenge is categorizing and finding principles which simultaneously differentiate and harmonize.

Use of and Investment in ICT: Electronic data capture and information processing and sharing requires considerable investment in technology (RFID, dashboards, EPCIS, etc.) and competence. This can be particularly challenging for small and medium sized enterprises (SME) with limited resources. For many companies and sectors, this is a contributing factor to the limited interest in and application of new technologies, such as RFID and automated replenishment systems. The investment level, the upgrading of competence and the pace of technological development are all obstacles to a higher degree of ICT application.

Standardization of Information and Interfaces: Information has to flow freely with low friction and be understandable for all members of a supply chain, in order to create value. This means that data should be standardized and that the organizational and technology interfaces should be harmonized. Thus, advances within global information standards are highly important in enabling a greater degree of information sharing in a supply chain.

Explosion in Information volume and Information Security: Developments in data capturing technology, mobile and wireless communication platforms, track and trace solutions, etc. have led to an explosion in information volume. The ability and capacity to deal with ever increasing information volumes in an appropriate and secure manner is an issue of high relevance. This also includes the question of data protection in general, and personal information in particular.

Solutions and Recommendations

Despite the challenges and issues outlined above, there are developments and initiatives which can provide support in overcoming some of the obstacles. This section outlines some recommendations and solutions which can assist supply chains in realizing the concept of intelligent and demand-driven supply chains.

At present, there is a lack of business cases which demonstrate solutions using the proposed control model. By implementing a well-defined model in a variety of representative contexts and sectors, the potential effects and implications for supply chains can be evidenced. One first step could be to implement selected elements of the control model. Although the technical solutions for capturing real-time information are still not in place in most supply chains, each supply chain member already captures large amounts of data which can be very beneficial to their supply chain partners. A manufacturer might find that regular updates containing the POS data, stock levels and marketing plans of key customers could be used to improve production planning and control.

Development within the area of system standards is continuously evolving. Through, for instance, the EPCIS standards and interfaces, the ability to exchange information with supply chain partners is improving. Further, technology and system developments with regards to integration, functionality and cost are paving the way for smoother and more efficient supply chain cooperation. Data collection devices such as RFID, antennas, mobile broadband solutions, etc. will soon be reaching a level of functionality and cost that make implementation on a broader scale realistic.

Of particular importance in the realization of efficient supply chain collaboration and information sharing is the development and implementation of supply chain control dashboards. Such dashboards originate from executive information systems and control rooms in the process industry. A dashboard integrates relevant information from all supply chain partners' information systems (e.g. enterprise resource planning, supply chain management, advanced planning, manufacturing execution, etc.), thus supporting a true supply chain perspective, enabling visualization of performance indicators, and supporting operations, planning and control on all process levels (Dreyer, et al., 2009). In the Automed R&D project referred to earlier, a prototype of a dashboard for pharmacy products was developed in cooperation with Oracle. *Figure 3* shows a screen shot of the "Stock availability" function, where forecasts and sales for a stock keeping unit (SKU) is shown graphically for the manufacturer, supplier, wholesaler, and, in this case, aggregated for all pharmacies

Figure 3.

in the pharmacy chain. The dashboard allows aggregation and drill-down between levels, to get more detailed stock level information from an overall supply chain status and down to individual pharmacies.

The use of supply chain dashboards can either be individually by employees within each company, or as part of a collaborative environment where groups and teams are involved in the execution of supply chain activities. In a studio environment (virtual or physical) members of distributed and complex supply chains can cooperate and make decisions in a holistic and integrated manner. Distributed and linked studios in a supply chain can serve as information and communication nodes that enable integration of operations activities and distributed and interactive supply chain planning, across geographical distances and organizational levels. Supply chain studios provide members with access to network-wide real-time information (Wang & Wei, 2007), enable visualization of the available information (Boyson, Corsi, & Verbraeck, 2003) through, for instance, supply chain dashboards, secure interaction between advanced ICT based decision support tools and human decision-making (Barthélemy, Bisdorff, & Coppin, 2002), and create a coordinated and collaborative environment (Deek, Tommarello, & McHugh, 2003) for planning, control and decision-making.

FUTURE RESEARCH DIRECTIONS

True real-time operations of supply chains are still seen only very scarcely and only at very limited subparts of supply chains, for instance, between two members of a complete chain. There are numerous development and research areas that need to be addressed, in order to realize real-time controlled supply chains.

Within the operations management area, the following issues remain to be addressed:

- Further development of control principles and collaboration mechanisms, from the level of principles into guidelines, rules, formulas and algorithms.

- Shift toward applying optimization and simulation (operations research) at a truly operative level, integrating optimization and simulation with control algorithms and systems like ERP, DRP (distribution requirements planning), scheduling, etc.
- New perspective and role of performance measurement, shifting perspective from a focus on lagging indicators to support for on-line decision-making
- Study and understand obstacles and possible solutions with regards to power issues, willingness to cooperate, collaboration models, incentive mechanisms, etc. in different industrial sectors.
- Study and understand obstacles and possible solutions regarding the human role and behavior in the new paradigm, where human and manual decision-making is replaced by surveillance, status monitoring and automated decision support through visual monitoring facilities.

Regarding new technology, including the ICT perspective, relevant and important issues for future R&D include:

- General development of ICT performance: processing capacity versus cost, system integration capability, visualization facilities, man-machine interfaces, etc.
- Future of RFID, sensor and mobile technology for close-to-zero cost of tracking individual items
- Standardization of data exchanges based on global coding (EPC)

It will be in the true interplay among these R&D challenges that we will see the realization of future demand-driven supply chains.

CONCLUSION

Increasing the competitiveness of supply chain systems requires a supply chain which is integrated and coordinated, where operations are driven by demand and real-time principles. A supply chain is, by nature, a complex and heterogeneous system with a wide range of products, processes and companies, as well as diversified material and informational flow structures. A unified planning and control model is an efficient approach to coping with the associated issues and challenges. In this chapter, we have explored and developed such an approach in the form of a framework for intelligent and demand-driven supply chain control, where we assume that all relevant information is made available to all partners in real time. In order to capture a more holistic picture of supply chain planning and control that supports future developments in industrial business cases, the framework consists of a concept and a number of associated principles. Based on the control model methodology, these principles have been demonstrated through a control model for processed salad products.

The following is a brief description of the main elements of the principles. Replenishment and shipping decisions should be based on real-time information about POS data, stock levels, marketing plans, manufacturing and transport status, etc. CODP placement should be differentiated and moved upstream or downstream in the supply chain, according to product and market characteristics. Manufacturing and shipment of goods should be based on the principle of *"buy one – produce and deliver one"*. Replenishment responsibility should be moved upstream in the supply chain. Human and manual decision-making should be replaced by surveillance, status monitoring and automated decision support through visual monitoring facilities. The control of each product or product segment should be determined individually according to product, demand and market characteristics. Information hubs should be established to collect, store and present information from the entire supply chain, integrating information from the ICT systems of each supply chain member. A new set of performance measures, showing leading and lagging parameters, should be developed and integrated with control parameters. Finally, these measures should be implemented in a visual dashboard and made available for monitoring.

Implementation of truly demand-driven supply chains is dependent on developments and improvements within technology and standards. Solutions that are affordable for ordinary companies and SMEs are expected to become readily available in the near future. A major implementation obstacle, however, is the lack of trust, open sources and collaboration between supply chain members – issues that require further research. The concept and principles proposed in the chapter have already proven their potential through a number of cases, where results have been achieved, and further changes and solutions are being developed.

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KEY TERMS AND DEFINITIONS

Control Dashboard: A decision support tool which presents and visualizes key performance measurements that are used to support control processes in a company or supply chain/network.

Control Model: A formalized description of how operations are organized and controlled in manufacturing and distribution, including control principles and methods, CODP, main operation processes, buffers and responsibility areas, and material and information flow.

Control Principle: A definition of what initiates processes in the system. In a pull system the amount of work in process is limited by orders from the subsequent process, while a push system has no limits and work is initiated based on forecasts.

Control Studio/Centre: A physical or virtual workspace and interface supporting collaboration between supply chain planning teams and local managers at different nodes of a network/supply chain. Information to support decision-making is made available through modern and integrated ICT solutions.

Customer Order Decoupling Point (CODP): The point in the supply chain where demand changes from dependent to independent, where the firm becomes responsible for determining the timing and quantity of material to be purchased, made, or finished (Vollmann, et al., 2005); usually coinciding with an important stock point from which customers are supplied.

Information Decoupling Point: The point in the information pipeline where market driven and forecast driven information flows meet, i.e. where information on real customer demand is available to upstream supply chain participants.

Point of Sale (POS) Data: Information about an individual sales transaction (product code, price, number of units), traditionally captured by a bar code scanner at the cash point of a retail outlet. The information is stored in a database and often consolidated on chain level.

Supply Chain Planning and Control: The task of determining what, who, when and how to act to efficiently manage the flow of material and information in order to meet customer demand with the exact supply in a coordinated chain.

ENDNOTE

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