INTELLIGENT AND DEMAND DRIVEN MANUFACTURING NETWORK CONTROL CONCEPTS

Ragnhild Bjartnes[1], Jan Ola Strandhagen[2], Heidi Dreyer[2], Kristian Solem[3]

[1] SINTEF Technology and Society
Department of Operations Management
N-7465 Trondheim

[2] Norwegian University of Science and Technology
Department of Production and Quality Engineering
N-7465 Trondheim

[3] Norwegian University of Science and Technology
Department of Industrial economics and technology management
N-7465 Trondheim

ABSTRACT

Traditional control in a manufacturing network, based on push and forecasting principles, must be reconsidered due to increasing complexity in collaboration structures, internationalization, customer requirement and market competition. This can be done by focusing on real market demand and responsive driven supply chains. The new control models for manufacturing networks should be based on transparency and pull principles, aiming to optimize globally by monitoring, controlling and coordinating all members in the network. Performance measurement across company borders, integration within and between networks, ICT and access to real time information will be crucial when controlling and monitoring the activities across the network. This article will present a concept for achieving the above mentioned key elements by introducing the Planning Studio, which will facilitate access to real time control information.

Keywords: Demand driven, integrated decision support, ICT.

INTRODUCTION

Nowadays, there is a trend towards optimisation of the entire network or supply chain, focusing on the performance and competitive situation for a supply chain rather than a single company. The supply chain perspective implies an increased need for orchestrating a broad set of activities, resources and companies, often with decentralised geographical structure and high complexity (Rudberg and Olhager, 2002; Cooper and Gardner, 2003; Jonsson and Mattson, 2003; Busi and Dreyer, 2004; Chopra and Meindl, 2007). Capturing market trends and satisfying customer demand by supplying high quality products is the dominant challenge in manufacturing. Tomorrow's successful companies must meet this challenge by adopting the concepts of modern manufacturing with a true supply chain perspective. Key concepts in this respect are lean thinking, automation, modularisation, integration and collaboration, process focus, information sharing and transparency.

The enabling technologies in information systems and communication technology (ICT) constantly increase manufacturing companies' ability to react fast and reliably to demand through increased transparency, visualization and processing capabilities. The supply chain perspective is a necessity for manufacturing companies, and business processes must be integrated along the supply chain. Automation and ICT in manufacturing has changed the roles of operators, engineers and managers, creating more cross functional knowledge-based working environments. The concept of automation must also be taken further into the administrative processes of the value chain.

The development within ICT, enabling access to real time information, is expected to contribute to major productivity improvements and enhancement of competitive strengths in supply chain operations (Hansen and Nohria, 2006; Beardsley et al., 2006; European Commission, 2006). In near future, ICT-based supply chains will include sensor and radio frequency identification (RFID) technology, real time monitoring systems and visualisation applications. Since this development challenges traditional models and tools for supply chain operations and control (Olhager and Wikner, 2000), there is a need to establish new ICT-based control concepts where digital information and signals replace more traditional manual and physical control processes, by applying real time technology in integrated teams cooperating independently of physical location.

In this paper we address future control concepts for manufacturing networks, examining what will be the characteristics and main elements in intelligent and demand driven control concepts.

This concept will be illustrated by describing a case from a network project in the Norwegian grocery industry. This case will illustrate the challenges, potential and proposed solution towards more intelligent and demand driven control of goods.

BACKGROUND

Manufacturing and industrial activities take place in networks and supply chains environments where the total responsibility for finalizing products is divided between a set of companies, each with specific roles in the value creating activity (Chopra and Meindl, 2007; Simchi-Levi et al., 2005). This trend has become vitalized due to increased specialization and focus on core activity in order to be competitive, and outsourcing of resource demanding operations to low cost areas is resulting in more complex operation environments. Additionally, customer demand have become challenging with respect to product variability and individualization which have resulted in the need for developing demand driven and responsive systems combined with lean principles. Development of advanced ICT systems has enabled this progress, which is expected to increase and open for new manufacturing and operations concepts.

In operations of manufacturing and supply chains systems the planning and control process is vital. Planning and control secures an efficient utilization of resources when fulfilling demand from customers (Vollmann et al., 2005). The aim is to decide how much to produce and deliver when, and how products and information should flow throughout the supply chain, as well as monitoring, performance measurement and event management. Important aspects characterising the planning and control activities in a company or a supply chain could be as follows (Alfnes et al., 2006):

- Control principles (pull, push, ordering), defining main principles for how operations are controlled
- Customer order decoupling point (CODP), dividing the supply chain in one part based on forecasts and one part based on customer orders/demand
- Key performance indicators, defining which parameters should be used to monitor and evaluate performance in the supply chain and each part of it
- Control/responsibility areas, defining areas or processes that share responsibilities for specific output and are controlled as one unit

- Differentiation criteria, defining which criteria should be used to identify products or processes that should be controlled in the same way

The complexity of the planning and control process is closely connected to the number of different products, the variation of demand and the number of companies in the supply chain.

Earlier, when manufacturing operated under less complexity, when manufacturing capacity was regarded as the limitation, when sold were what was produced, and when companies had a much leaner and less variable product range – simple two-bin system were sufficient to control the flow of components and products. Later the MRP and MRP II principles were developed and became the common planning engine in industrial environments. Still the MRP/MRP II principle is the main principles in ERP-systems (Alfnes and Strandhagen, 2000). The Toyota Production System, and later Lean Manufacturing, emerged as a contrast to the push-based control principles in MRP/MRP II. These new pull-based concepts focus on value adding activities and avoiding waste and non-value adding activities. The philosophy is to increase profits by reducing costs through eliminating waste such as excessive production capacity, waiting time, inventory and/or work force (Slack et al., 2007).

An important element in the lean oriented and pull-based concepts is to tie and adjust the activity to demand and customer requirements, and to base the planning and control process on information gained from the customer or the supplier. Concepts as efficient consumer response (ECR), quick response (QR), vendor managed inventory (VMI), collaborating planning replenishment and control (CPFR), continuous replenishment programs (CRP) and automated replenishment programs (ARP) are all based on the exchange of more or less real time demand information (Christopher, 2005; Danese, 2005; Sabath and Autry, 2001; Skjoett-Larsen, 2003). Information as stock levels, forecasts and plans, point of sales (POS) data, etc. is used to estimate future demand in order to prevent stock out situation or excessive stocks. A combination of advanced information processing techniques and information technology has enabled the development of these concepts, and new technology will bring this development further.

Access to real time demand and events information in the supply chain is expected to lead to a shift in the planning and control concepts, allowing pure demand and pull driven supply chains. A significant enabler will be technology as radio frequency identification (RFID), sensor technology and Electronic Product Code Information System (EPCIS) which will allow the access to real time information more frequent that the existing technology. RFID-tags contain information that can be read from a distance, which considerably increase 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 allow the development of intelligent and automated planning and control concepts.

Recently, new control concepts for decentralised supply chains have emerged based on physical or virtual control studios (Jonsson and Lindau, 2002; Chase et al. 2004; Eckerson 2005). In these studios, information that is relevant for control and decision-making in the supply chain is gathered and processed. However, the scope of these studios is often limited to the control of a selection of specific processes in contrast to entire supply chains. In order to enable the control of global and complex supply chains, there is a need for a more holistic solution that primarily includes ICT-based solutions supporting real time information and communication.

Based on the past and current development of control concepts described above, combined with the challenges and opportunities of manufacturing networks, it is expected that the next generation supply chain planning and control concepts will contain the following characteristics:

- Demand driven control throughout supply chains
- Integrated and automated operations

- Unified supply chain control model
- Intelligent and advanced processing of information, data mining, visualization and decision support
- Information sharing and transparent information flow

To enable and utilize the characteristics of a holistic control model, research should be done in real manufacturing networks through case study in an exploratory approach.

METHODOLOGY

The research approach in this paper is a combination of a case study and an exploratory approach. The control concept that is presented is a conceptual description of how manufacturing networks could be controlled in the future. The development of this concept is based on existing literature within supply chain and operations management focusing on production planning and control, combined with existing and expected challenges for companies in manufacturing networks. A research project focusing on improved control based on access to real time information is used as case for the concept, and serves as an empirical background for the development. Empirical data from this case have been collected through observations, interviews and written documentation. The case will also be used as an illustration in this paper.

CASE

The concept described in this paper is based on a case from a research project in Norwegian grocery industry (Smart Flow), and is illustrated by a meat processor company and a supplier of reusable plastic bins. Smart Flow is a research and development project aiming at developing tomorrow's intelligent, responsive and efficient supply chains by utilizing the full potential of RFID-technology. Industrial partners in the projects constitute a network of dominant actors in Norwegian grocery industry, including retail- and wholesaler chains, food industry, packaging producers and transport and logistics providers. Supply chains in the Norwegian grocery industry face a situation where requirements from customers, government and competitive situation call for improved and innovative control concepts, and technology developments (e.g. RFID) are expected to be important enablers for these developments.

The dominating control concepts in Norwegian grocery industry are traditional push- and forecasting based control. Consumer demand is in many cases not accessible, due to lack of or infrequent information sharing, and those who have access to this information does not necessarily utilize it for control purposes. Although measures have been taken in order to streamline the supply chain, neither information nor products can be described as having a seamless and demand driven flow from producers to customers. The results are supply chains with limited responsiveness and substantial potential for efficiency improvements. For the participants in Smart Flow, track and trace requirements are another important incentive to improve their control capabilities. Due to food safety considerations, they have to be able to withdraw products from the market, if it is suspected that ingredients or processes might involve health consequences. Without satisfactory supply chain control, such a market withdraw will be extensive, costly and harmful for the public reputation. Better control and knowledge on the origin and processing of the food are also increasingly used to add customer value. Many customers want to know where the food is produced, how it is processed, if it has environmental or ethical consequences and so on, and companies able to provide and present this kind of information will therefore have a competitive advantage.

The fundamental for the Smart Flow case is a joint effort to close the gap on the improvement areas described above (e. g. inefficiencies, lack of responsiveness, food safety and added customer value), through the utilization of RFID/EPC technology and standards. This technology is considered to play an enabling role for more intelligent control concepts in Smart Flow, due to the fact that it makes it possible to identify and perform automatic data collection related to an item throughout the entire supply chain. RFID gives the possibility to collect large amounts of data without manual operations, and EPC standards enables standardized information sharing between companies.

The concept developed in Smart Flow involves tagging products with RFID (primary on aggregated levels, but later this is expected to be implemented on consumer packages). Data is to be captured on selected places in the supply chain, and then immediately utilised and shared without delays due to registration or processing. To provide decision makers and systems with information that is actually useful, data from RFID reading must be related to other information, such as orders, customers, processes and so on. Realising this concept will give access to information that is extensive, real-time updated, and shared through the value chain. A main question in the challenge is to develop solutions for how to utilise this new information access to more intelligent and demand driven control concepts. This question is both addressed in development of general models and frameworks, and through development of functioning solutions in the participating companies and in the interfaces between them. The supply chain in Smart Flow is illustrated in Figure 1, as is also the areas and interfaces where development activities are going on within the project. One of these development areas is used to illustrate the case, and is further described in the following sections.

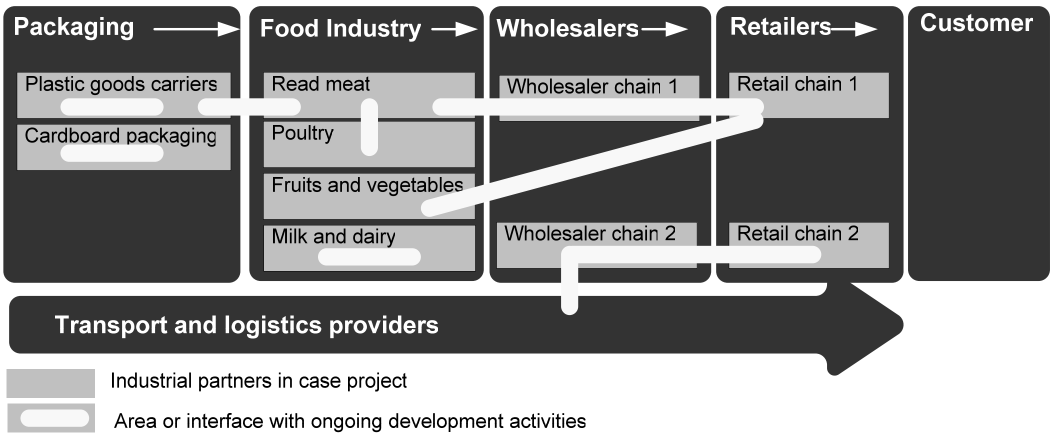

Figure 1 Smart Flow Supply Chain

The problem addressed is an investigation of how RFID can innovate the supplier-customer-relationship between a manufacturer of reusable plastic bin goods-carriers and a processor of red meat. The processor will use RFID tags, attached to the plastic bins, to track and trace its products throughout the entire supply chain. Thus, there will also be a lot of real time information available about the plastic-bins as well as the track and tracing of the meat products. This raises some interesting research questions: Is it possible that real time information from track and tracing of products also can be utilized to manage the flow of plastic-bins? Today, the management of the flow of plastic-bins can be described as manually and random, depending of what persons who are involved in the management process, whereas the aim is to use RFID to provide real time information, and to use this information to improve the control of the plastic bins between the supplier and processor. To illustrate this development, a brief presentation of the AS-IS situation will be given, followed by a TO-BE scenario.

AS-IS

The supplier uses historical data and forecasting techniques to predict the annual demand for plastic-bin goods-carriers. Thus, the plastic bins are pushed through the supplier in a make-to-stock (MTS) production strategy in large batches. CODP is therefore in the finished goods (FG) inventory. The processor of red meat orders large quantities in short notice, typically one or several truckloads. The delivery times are usually one day and the transportation is managed by the supplier by 3PL. The processor aggregates the needs of the 30 processor plants, and one responsible person places every order by phone calls. The supplier experiences three seasons of demand during one year and there is no communication what so ever between the supplier and processor in off-seasons. The supplier often makes their own calls to the processor plants to be ahead of the unpredictable "official" demand. Due to manually information collecting and demand uncertainty, both inside the processor and from the processor to the supplier, there are often canceled orders or extra orders. Overstocking and lost sale expenses are common.

To handle unpredictable demand in short notice, the supplier has to start production long time before the first order arrives and finds it very difficult to maintain a FG inventory level that is in accordance with the actual demand. Management by the push-principle makes the supplier little adaptive to changes in the processor's marked. Slow communication and lack of information from the market makes the supplier a victim of the bullwhip effect. The same phenomenon is also documented by several other researchers in cases with lack of information up steam the supply chain (Chen et al., 2000; Christopher, 2005; Simchi-Levi et al., 2005). Causes of little control over the amount of plastic bins inside the processor's plant are manually and spurious controlling procedures. In addition, since the plastic bins are reusable, the flows of the plastic bins are very complex to control. The material flow, communication patterns and control principles are shown in Figure 2.

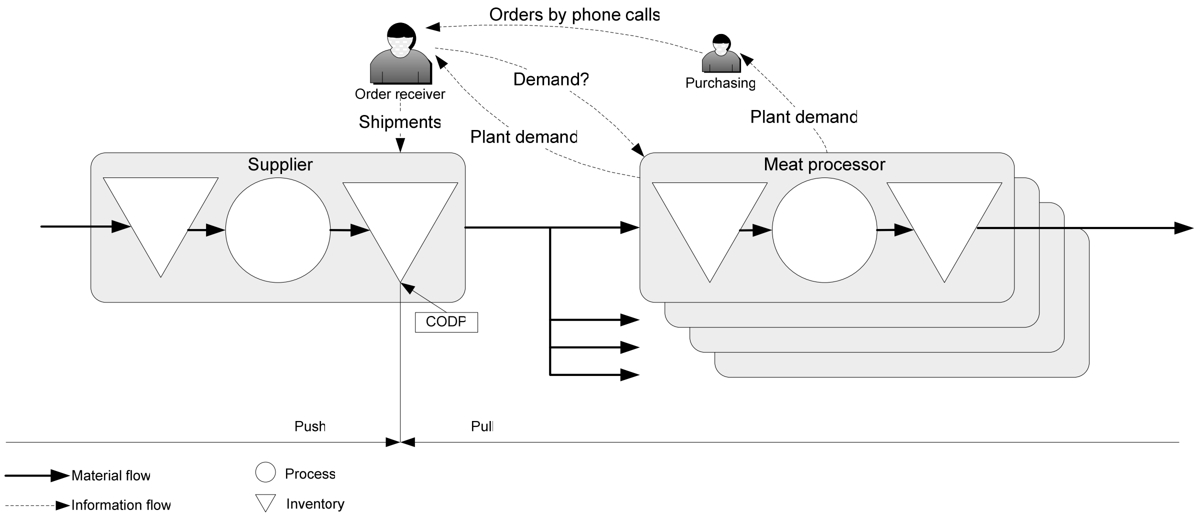

Figure 2 AS-IS

TO-BE

According to findings in AS-IS, the lack of accurate information is the main reason for difficulties of controlling the flow of plastic bins, both inside the processor and from the supplier to the processor. Using RFID to track and trace the meat processor's products will automatically also track and trace the available plastic bins. Thus, RFID has the potential to monitor and give real time information about the level of plastic-bins in every processor plant, while at the same time get rid of the manually information handling processes (Solem, 2007). This of course requires RFID-antennas to monitor the processors inventory level of plastic-bins.

To utilise the real time information potential in controlling the material flow, this information should also be available for the supplier. Access to real time market data, or POS-data, will give the supplier the opportunity to utilize this information together with planning and controlling its own production and inventory level. By integration through information sharing, the information decoupling point can be moved up stream right before the supplier's production. Production planning can therefore use POS-data, *together* with historical data, to balance asset utilization with market demand and minimizing the bullwhip effect. The decision of shipment destination can be postponed to the FG inventory. This is possible since the plastic bins are the same, irrespective of what processor plant they are shipped to, e.g. the decoupling point of the material flow will still be in FG inventory. Thus, POS-data facilitate a make-to-order (MTO) strategy with less capital bounded in FG. Further, accurate real time information may arrange a concept of supplier ARP by a mixture of VMI and CRP. In other words, the processor is controlling their plastic bins inventory level by setting the required inventory level, while the supplier monitors the processor's inventory automatically and are responsible for the replenishment. This also means that the time consuming manual information handling processes, ordering and order receiving, can be eliminated. In summary, production planning can be based on the aggregated demand for plastic bins, while the shipment to the different processor plants can be postponed to the FG inventory. In addition, accurate real time market information makes it possible to introduce supplier ARP strategies. The new demand driven concept is illustrated in Figure 3.

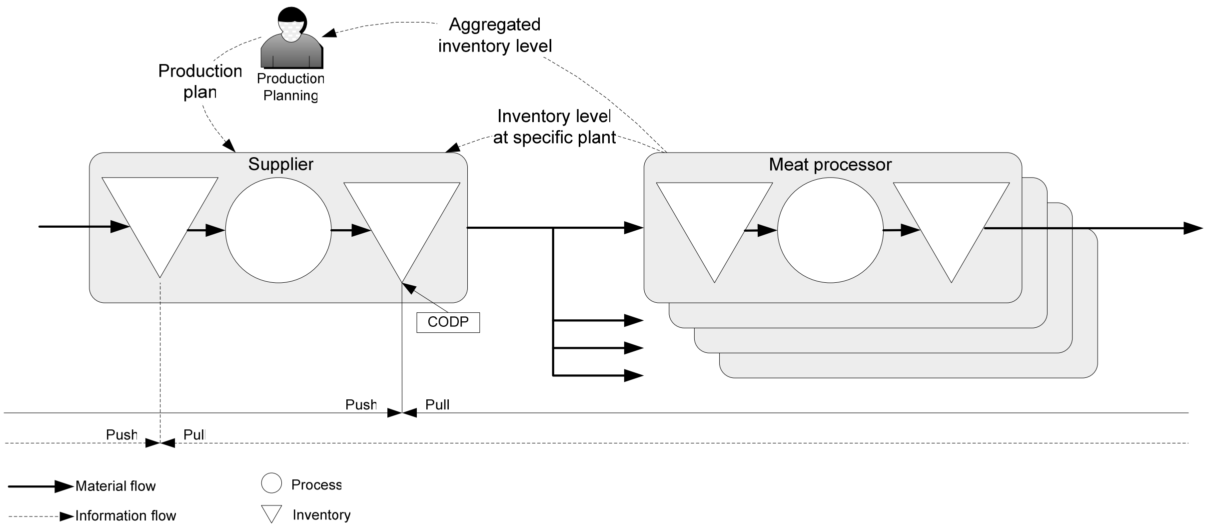

Figure 3 TO-BE

THE CONCEPT OF INTELLIGENT AND DEMAND DRIVEN CONTROL

The challenges and improvement potentials identified in the different relations throughout the Smart Flow case has been inspiring the exploratory research work. In a joint effort merging these results with results from other ongoing research activities, it has been possible to systemize a set of requirements leading to the development of a new control concept. The experience from the case studies can be summarized as follows:

- The need to improve performance in each supply chain by increasing speed, responsiveness and precision of flows in combination with reduction of total cost

- The need to coordinate, collaborate and integrate within and between the supply chains, supporting the perspective of the entire manufacturing network
- The need to have a shared and unified view of how the supply chains and the network is operated and controlled
- The challenge of exploiting the ICT related to track and trace, system integration and information processing, enabling real-time processing

Thus, the following concept for intelligent and demand driven manufacturing network control is proposed, consisting of the main elements illustrated in Figure 4:

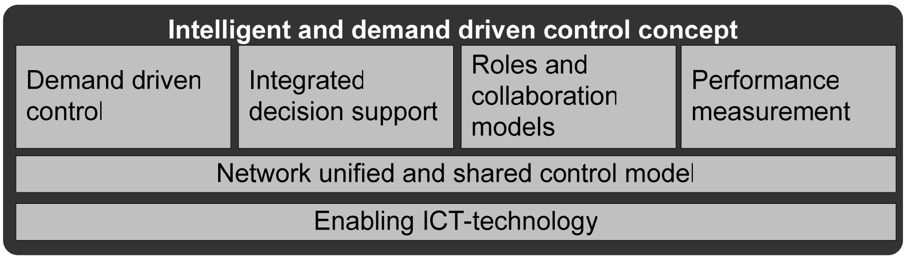

Figure 4 Concept for intelligent and demand driven manufacturing network control

Enabling ICT-technology

RFID technology enables automatic and real time acquisition of data regarding the material flow, which gives access to information vital to the intelligent and demand driven control concept. Planning and control in supply chain has to be performed in a setting where relevant information from several ICT systems is integrated and up to date, and can be accessed in real time from anywhere in the network. This information visibility depends on the exchange of critical data required for the efficient management and control of the flow of products, services and related information between members in the supply chain. Each node should ideally be able to see the real time situation in the supply chain, downstream as well as upstream, from boardroom to shop floor, enabled by automatic data acquisition. Although very few networks have actually achieved information visibility and system integration, these elements are regarded as keys for enabling collaboration and network efficiency.

Network unified and shared control model

The essential task of supply chain planning and control is to efficiently manage the flow of material, the utilization of people and equipment, and to respond to customer requirements by utilizing the capacity of suppliers and internal resources to meet customer demand. Planning and control across organizational boundaries is a sensitive task due to conflicting interest and objectives (Vollmann et al. 2005). This emphasis the need for a unified design of the control principles, and the planning and control model should be carefully defined in order to avoid conflicting interest.

One approach to develop such a common understanding and execution of operations is The Operations Model (Alfnes et al., 2006). The Operations Model can be seen both as a way to structure and formalize operations activities, and a fundament for reengineering and improvement processes. The model proposes six views regarding enterprise operations that should be mapped and modeled, including *resources* (products, components, documents, etc.), *materials* (material flows between resources) *information* (how information is accessed, stored, processed, and transferred), *processes*, *organization* (organizational entities, responsibilities and authorities). *Control* is the key perspective in this model, which will also constitute a fundamental for unified and shared control in demand driven and intelligent control concepts. The control perspective is a representation of how operations are organized and controlled in manufacturing, normally describing building blocks such as CODP, control principles and methods, main operations processes, operations areas, material flows and information flow (Strandhagen et al., 2006).

Demand driven control

In order to shorten lead times, reduce stock levels, increase inventory turnover, and to be more marked responsive, the overall planning and control concept should strive for *"buy one – produce and deliver one"*. Pull and replenishment based solution is therefore an important part of future control concepts. This implies that supply is effectuated based on knowledge of real demand, and insight into the customer's stock level. This is inline with concepts as ARP and VMI. What is missing in these concepts today is the use of real time information automated captured by i.e. RFID and sensor technology. RFID information is continuously registered and will be more up-dated and automated collected and processed, and thus future control concepts will increase focus on real demand information. Real time planning and control models will differ from the more traditional models by:

- Automatic and product individual decision making
- The issue of frequency (for order placing) is abandoned
- Supply quantities will be decided based on a holistic perspective (sales, stock levels, transport routes, substitutional products, etc)
- Information on history, current status and forecasts is handled simultaneously

Integrated decision support

The emphasis on intelligence in future control concepts implies that decision support is an integrated part of the control model. This integrated decision support will explicitly address strategic as well as operational uncertainties and risk, and help decision makers to cope with the dynamicity and complexity of manufacturing systems through a combination of automatic handling of routine tasks, exception alerts and on-line real-time simulation capabilities. Systems will be dynamic and react on the continuously updated flow of information both from sources as customers, company specific plans, forecast and sale activities, and RFID systems. Visual, intelligent and interactive information presentation is a key to enable proper comprehension and control in this context.

Roles and collaboration models

Development of control models that are unified and shared throughout the supply chain, implies that the material flow and the whole process should be coordinated, securing a continuous flow not disturbed by the crossing of company borders. Process and system integration is a significant premise for this kind of organizational boundary crossing solutions. Thus, the business and organizational mechanisms as contracts and price instruments have to be designed in order to allow collaboration. Collaboration is defined as the activities and environment related to the "joint planning and execution of supply chain activities" (Ayers, 2006), and is therefore an essential element in planning and coordinating activities (i.e. managing interdependencies) in a supply chain perspective. Collaboration and coordination are particularly complex activities as the scope of the planning process exceeds the individual company's boundaries and therefore must consider the entire network.

Performance measurement

As part of the demand driven and intelligent control concept, performance indicators should be defined to facilitate several applications. Firstly, performance measurement is the fundamental for monitoring operations, in such a way that presentations of performance indicators reveal whether the situation is within expected and accepted levels. Secondly, performance measurement should enable analysis applications. This means that historical and current data can be used to analyse data across multiple dimensions, revealing trends, explanations, problems and so on. Thirdly, performance indicators should have a management application, fostering communication among executives, managers and staff.

In intelligent and demand driven control concept, the performance measurement system will enable these applications, through an ICT based performance measurement system that is used to realise real time measurements and decision making with a collaborative perspective.

Proposed realisation of intelligent and demand driven control concept: Planning studios

The concept described in this paper argues that future control concept will be increasingly intelligent and demand driven. Important fundamentals for such concepts is utilisation of ICT-technology (including RFID) and development of unified and shared control models throughout a network, whereas important building blocks in the concept are demand driven control, integrated decision support, innovative solutions for roles and collaboration models and performance measurement. The actual realisation of this concept will differ based on the requirements and condition in each case. In this paper we propose a planning studio as a possible approach to realise this concept, and this approach is further described in this section.

The supply chain perspective in the intelligent and demand driven control concept implies an increased need for orchestrating a broad set of activities, resources and companies, often with decentralised geographical structure and high complexity. This requires collaborative environments where groups/teams can be involved to execute the activities of a network according to different demands. A key element in such environments is the visualisation of information through the use of e.g. planning studio. The main purpose of the planning studio is to meet the needs of members of distributed and complex supply chains by enabling holistic and integrated planning and decision making through a team-based collaborative environment. The distributed and linked planning studios in a supply chain will serve as information and communication nodes that enable integration of operations activities and distributed and interactive planning in the supply chain, across various geographical locations and organisational levels. The studios will provide members with access to network-wide real time information (Wang and Wei, 2007), enable visualisation of the available information (Boyson et al., 2003), secure the interaction between advanced ICT based decision support tools and human decision making (Barthélemy et al.,2003), and create a coordinated and collaborative environment (Deek et al., 2003) for planning and decision making.

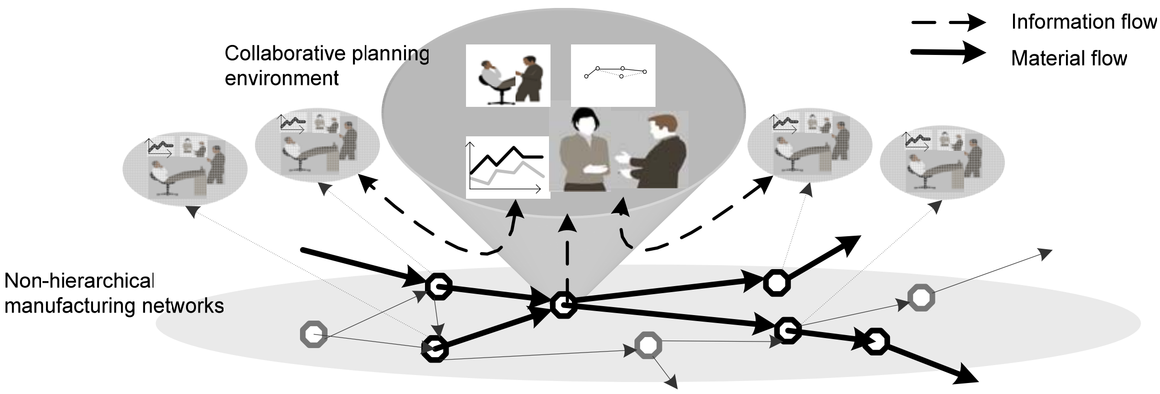

Figure 5: Planning studio

Figure 5 illustrates such a conceptual planning studio, for simplicity illustrated for one participant in the network. Each company is a member of several networks, and thus both network coordination and internal manufacturing planning have to accommodate a broad range of often conflicting and changing interests. Also, each member will be influenced by changes in parts of the network to which they are only indirectly connected. The illustrated collaborative environment presents real time information and provides decision support, thus enabling distributed collaborative planning. Figure 6 describes the planning studio as a collaborative environment, and exemplifies the underlying logic of such a studio. Possible conflicts in networks occur daily, and through the planning studio decision makers are able to collaboratively make decisions regarding these conflicts, with support from and interaction with advanced ICT decision support tool, in real time. In addition, the studio will monitor and handle a wide set of events related to shop floor, equipment status, maintenance – enabling proactive decision making.

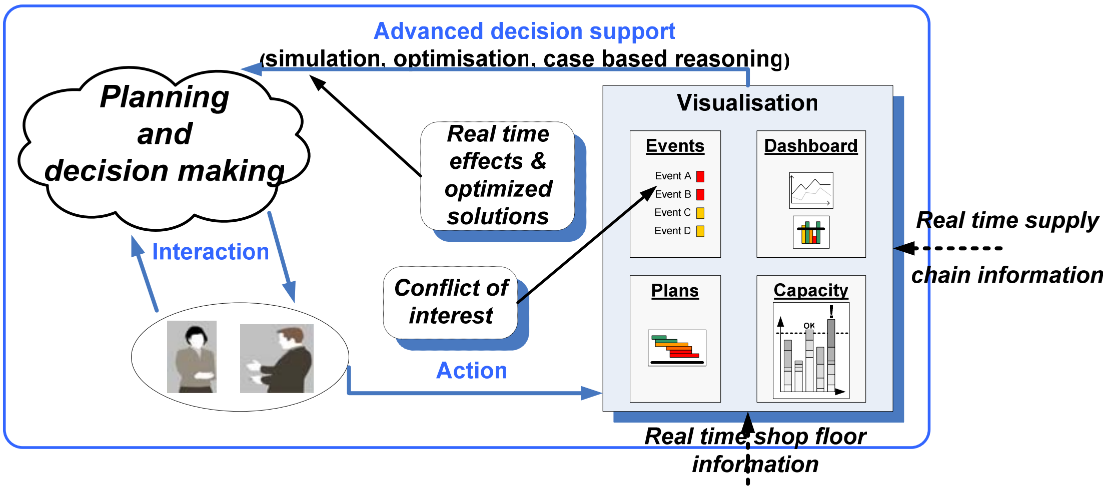

Figure 6: Collaborative environment planning studio

CONCLUSIONS AND FURTHER WORK

This paper has described the current trends in manufacturing illustrated bye the research project Smart Flow. Through this case project the need to improve performance in each supply chain by increasing speed, responsiveness and precision of flows in combination with reduction of total cost has been identified. Supply chains needs to be coordinated, collaborated and integrated, supporting the perspective of the entire manufacturing network, based on a shared and unified view of how the supply chains and the network is operated and controlled, enabled by ICT.

The paper proposes a concept of intelligent and demand driven control based on enabling ICT technology, and with the following main elements:

- Network unified and shared control model
- Demand driven control principles
- Integrated decision support
- Roles and collaboration models
- Performance measurement

A possible realisation of intelligent demand driven control concept is the development of Planning studios.

The main areas of future research is now in development of the detailed rules and algorithms of demand driven control, integration of control and decision support facilities in a real time environment, and integrating all ICT elements into a complete ICT architecture.

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