Enterprise Design for Mass Customization

The Control Model Methodology

By Erlend Alfnes and Jan Ola Strandhagen

Abstract

Demand for standard products has fragmented in many markets, and niche markets are becoming smaller - even down to the individual customer. Price, precision, and speed will still be major competitiveness determinants, but competition for manufacturing companies will increasingly require greater product variety and customer focus. The challenge is therefore to achieve *mass customization* – the ability to provide variety, and individual customization, at prices comparable to standard goods and services. Existing manufacturing approaches like ERP investments or lean production seldom provides the performance for mass customization. The Control Model methodology was developed at SINTEF/NTNU to design enterprises for mass customization. The major principles of this methodology include differentiation of manufacturing principles, simplification of material flow, strategic positioning of stocks, decentralized decision making in clearly defined control areas, and flow-orientated information. The Control Model methodology has been successfully applied in more than twenty manufacturing companies.

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Introduction

Demand for standard products has fragmented in many markets, and niche markets are becoming smaller - even down to the individual customer. This is one of the conclusions from a trend study carried out by Strandhagen et al (1999). The trend study showed that price, precision, and speed still will be major competitiveness determinants, but competition for manufacturing companies will increasingly require greater product variety and customer focus (Strandhagen et al 1999).

In their desire to become customer focused, many companies implement new programs and procedures to meet customer's request, but as customers and their needs grow increasingly diverse, such an approach adds unnecessary cost and complexity to operations (Gilmore & Pine 1997). The challenge is therefore to achieve *mass customization* – the production and distribution of customized goods and services on a mass basis (Pine II 1999). Mass customization involves responsiveness to customers' changing demands, and will require performance and flexibility improvements.

To meet these challenges, companies are spending millions of dollars to upgrade their Material Planning and Control systems to Enterprise Resource Planning (ERP) systems (Volmann 1996). However, ERP investments alone seldom provide the desired improvements. In many cases, a better approach is to achieve mass customization through redesign that reduces internal uncertainty, and provide the speed and flexibility that is necessary to handle variations and market uncertainty. This article describes how mass customization can be achieved by a design approach named the Control Model (CM) methodology.

The CM methodology is a design tool for high-performance industrial production and logistics. CM design was developed at SINTEF/NTNU, and is described by Quistgaard et al (1989) and Strandhagen & Skarlo (1995). The approach involves an analysis of the enterprise, and the design and implementation of a Control Model. The Control Model is *a description of how enterprises are organized and controlled*. The CM consists of text, figures and charts, and is used to communicate and explain how the enterprise should be re-designed. The CM methodology is based on a mixture of techniques and methods from manufacturing strategies like *lean production* and *socio-technical system design*, and aims to develop companies' control of production and logistic processes into a competitive advantage.

Time compression – a core idea in Control Model design

Mass production is still the dominant production form in most industries (Skorstad, 1999). Mass production is characterized by centralized hierarchical control, scientific management and function oriented layout, and was developed by scholars like Frederic Taylor (1911) at the beginning of the 20th century. Mass production focuses on productivity and capacity-utilization, and presupposes detailed information and standard products with predictable demand. This strategy was appropriate for the relatively stable market situation. However, the demand for standard products has fragmented, and the markets for products with predictable demand, long lifetime, low product variety, and high degree of standardization are declining. Mass production principles, although developed and refined, are insufficient to handle the low volumes and dynamic that characterize many of the current markets.

A major cause for the poor performance of the mass production approach is the unnecessarily long throughput times that characterize supply processes designed by this model. A typical product supply process is carried out by suppliers, manufacturing units and distributors, and involves activities like production, assembly and transport. Such activities add value for a customer. However, value-adding activities often constitute a minor share of product throughput-time in traditional enterprises. This is illustrated in figure 1.

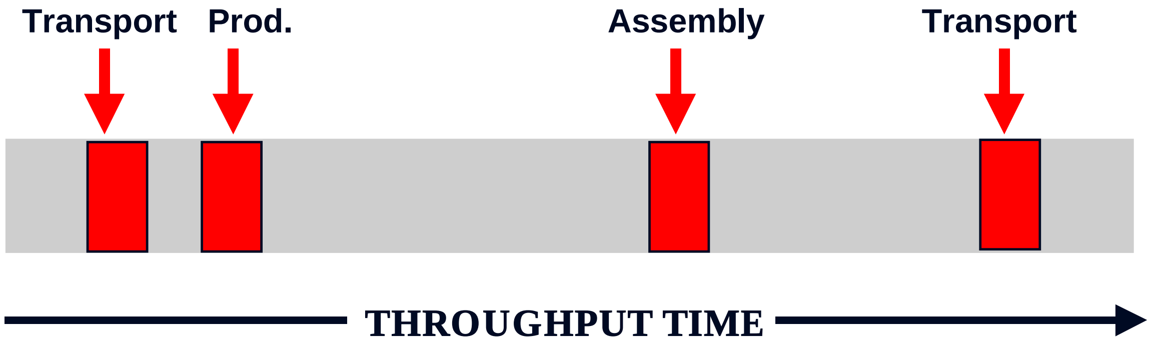

Figure 1 The time compression potential. Adapted from Quistgaard et al (1989)

The CM methodology holds time-compression as the central competitiveness enabler. Unnecessarily long throughput-times are often created by delays in queues and stocks, and non-value-adding activities like planning, document handling, quality inspections etc. Compression of throughput times provide lower Work-In-Process, shorter delivery time and improved delivery performance (Quistgaard et al 1989).

Long through-put times create uncertainty in manufacturing processes, and inhibit performance and flexibility. Moreover, a Forrester-effect might be facilitated if such delays are combined with long information-times. The Forrester-effect refers to situations where slight variations in end-customer-demand amplify when passed up a supply chain and cause high stocks and large fluctuations in factory orders (Forrester 1958). Burbidge (1987) has called this the “Law of Industrial Dynamics”: *If demand for products is transmitted along a series of inventories using stock control ordering, then the demand variation will increase with each transfer*. This law is not only valid for inventories in supply chains. The functional division of work-organization and resources in an enterprise may also create artificial barriers and thereby delays, uncertainty and inflexibility to demand variations.

Delays create reduced liquidity, high costs and low delivery performance. This situation is typical in many manufacturing companies and provides a potential for improvements through time compression. A simulation study on Foresters supply chain by Towill et al (1992) shows that there are three effective strategies to improve performance:

- To remove intermediate levels (as Forrester originally suggested).
- To integrate the information flow through the supply process (to compress information time) so that end consumer demand is passed upstream without distortion.
- To compress throughput-time so that time delays are minimized.

Time-compression is a major enabler for cost efficiency, responsiveness and flexibility, and is embedded in major manufacturing strategies like the ERP-approach, lean production and socio-technical system design. These manufacturing strategies form the backdrop of the CM methodology and are outlined in the next section.

Design Strategies

Three manufacturing strategies are outlined in this section, the implementation of ERP systems, lean production, socio-technical design. All strategies provide ideas and principles that have inspired the CM methodology, both for enterprise design and for managing the design process.

Enterprise Resource Planning (ERP) systems

The implementation of (or upgrading to) Enterprise Resource Planning (ERP) systems results in some improvements. ERP systems provide the facilities for Enterprise Modeling (Vernadat 1996) and Business Process Reengineering (Hammer & Champy 1995) and enable companies to compress information-time and minimize delays caused by functional silos. ERP-systems provide information about material flow, utilization of people and equipment, and future demand. This information aids managers in making decisions and control operations, and enables centralized hierarchical control.

However, manufacturing resource planning (MRPII[1]) is still the planning engine in most ERP systems (Bartholomew 1999). MRPII has been a well-known planning principle in the last decades and base the calculation of stock- and production-levels on sales forecasts. The logic of MRPII is based on assumed future requirements for final products, and presupposes an exact match between computer records and reality:

- Future requirements must be known with sufficient accuracy
- Production processes and Bill Of Materials (BOM) must be known for every product
- All databases (stock levels, BOM, customer orders etc) must be correct and updated
- Lead-times and lot-sizes are fixed (Andersen et al 1998)

These presumptions require discipline. The implementation of ERP systems require data discipline, exact rules, and procedures to ensure that plans are punctually followed. If the plans matches real demand and the required discipline is obtained, radical improvements can be achieved. The implementation of a working MRP planning system can result in inventory reductions of 40 percent and similar improvements in lead times, meeting promises to customers, and productivity Vollman (1996).

Manufacturing planning and control systems should support the strategy and tactics pursued by the company in which they are implemented (Vollman et al 1997). However, ERP systems are hard to apply in many of the current markets. Firstly, the dependency on accurate forecasts in ERP is very high. As demand variety increases (e.g. due to higher degree of customization), it is likely that demand variants and combinations would be too difficult to pre-define and forecast, especially when broken down to each product type. Secondly, the MRP/MRPII model of the real world is too simple (Euwe & Wortmann 1997). Simplifications like fixed lot sizes, fixed lead times, assembly oriented product-structures, and lack of capacity constrains, result in delays and material requirement plans that seldom match the actual situation.

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[1] Earlier versions were named Material Requirement Planning (MRP) systems

Thirdly, MRPII plans lack specifications of order sequence or priority within a time bucket, and provide no guidance for detail control. A possible solution to this problem is to integrate ERP systems with scheduling systems, but such systems are often complex and hard to run. Fourthly, the ERP logic represents a view on people, organization and control that follows the mass production approach. Centralized control, unnecessary data-collection, tight procedures, and management by "command and control" create inflexibility and inhibit effective control and coordination in dynamic environments.

ERP systems may not provide the desired improvements, but they still constitute a important element in most companies' infrastructure and must be integrated in a improvement strategy. In the CM methodology, ERP systems can be applied to manage order acceptance, stock levels, invoicing, purchasing, accounting and corporate-level planning.

Lean Production

The ERP based approach follows a traditional mass production strategy, and are seldom sufficient to handle the low volumes and demand variety that characterize current markets. An alternative approach is "*lean production*". During the last decade, several enterprises have achieved flexibility and increased competitiveness by implementing the "lean" or "just-in-time" principles developed at Toyota (Womack & Jones 1996). The basic purpose of lean production is to increase profits by reducing costs through completely eliminating waste such as excessive stocks or work force. To achieve cost reduction, production must promptly and flexibly adapt to changes in market demand without having wasteful slack time. Such an ideal is accomplished by the concept of JIT: producing the necessary items in the necessary time (Monden 1998).

Lean/JIT manufacturing is based on simplified fast flows that are coordinated by shop floor people to meet real demand. Supply on real demand requires that work-in-progress and throughput times are minimized to ensure responsiveness. Certain operational improvements are necessary to enable JIT manufacturing:

- Production smoothing to adapt to demand changes
  - pull-scheduling to determine tact time and production sequence
  - adapting to product variety by general purpose machines
- Shortening set up time – for increased flexibility and reduced throughput time
- Autonomous defects control (Jidoka) - never allowing defective units from a preceding process to flow into and disrupt a subsequent process
- Process layout for fast flows and multi-function workers
- Standardization of operations to attain workforce balancing

Visual control through Kanban, and close cooperation with suppliers are also key characteristics of the lean enterprise.

In lean production, teams are tightly linked in customer-supplier connections, that typically interact with each other in a predictable sequential manner, and the focus is turned towards process improvement. Activities, connections, and production flows are standardized and rigidly specified to provide the necessary performance and flexibility to supply a wide range of standardized products at low costs. The lean design approach can be described by four basic rules:

1. All work shall be highly specified as to content, sequence, timing and outcome

2. Every customer-supplier connection must be direct and there must be an unambiguous yes-or-no way to send requests and receive responses
3. The pathway for every product and service must be simple and direct
4. Any improvement must be made in accordance with a rigorous problem solving process, under the guidance of a teacher, at the lowest possible level in the organization (Spear & Bowen 1999).

As customers and their needs grow increasingly diverse, such an approach is not flexible enough. Pull scheduling and rigid specification of processes creates inflexibility. Mass customization requires workers and systems that master variations and uncertainty, and which focus on customers, not processes (Pine et al 1993).

The standardization, specification and improvement of processes still provide a flexibility to balance number of workers and to increase the manufacturing bandwidth. This makes JIT systems capable of handling a fairly mixed set of products and some variations in demand for the products as well (Vollman 1997). In the CM methodology, lean production constitutes a platform for mass customization.

Socio-Technical System Design

Socio-technical system design has traditionally focused on the work-organization in manufacturing systems, and has long traditions in Norway. Several socio-technical projects were carried out in the 60's and 70's under the label "the Norwegian Industrial Democracy project" (Herbst 1977). Since then, socio-technical system design has been developed and established as a comprehensive approach to design that meets the logistic requirements modern manufacturing companies have to cope with: i.e. flexibility, learning capacity and innovation (Dekker & Poutsma 1999). The "socio-technical" concept reflects a focus on joint optimization of technology and social systems indicating that really effective systems can only be generated when technology and people are properly matched (Trist 1981). In a socio-technical system, activities are no longer separated into narrow areas of responsibility. Teams of multi-skilled and empowered workers replace the conventional hierarchy (Taylor & Felten 1993). Major socio-technical principles are outlined below:

Semi-autonomous groups. Variance that can not be eliminated should be controlled as near the point of origin as possible. Effective control relies on actual, complete information and judgement. The best decisions are based on the decision makers practical knowledge and insight in a specific situation, and information must be provided at the place where decision and actions will be taken. Change and uncertainty require *multifunctionality*, it is easier to achieve the necessary variety of responses when the workers/teams are multifunctional. The more key variables can be controlled by the group, the better the results and the higher the member satisfaction (Herbst 1977)

Boundary management. The degree of self-regulation should be maximized throughout the enterprise. This is enabled though a design guided by the *minimum specification criteria* (Trist 1981), which is to specify no more than is absolutely necessary regarding tasks, jobs, roles etc. Boundaries should be designed around a complete flow of information, knowledge and material, so as to enable the sharing of all relevant data, information, knowledge and experience. The function of supervision is to manage the boundary conditions in the group's environment so that the group may be freed to manage its own activities (Trist 1981).

Participatory design. Technology (tools, information, machines, procedures etc) should be designed for competent worker performance, rather than for automation or command & control. This requires an extensive worker participation in design (Ehn 1992).

Design by socio-technical principles enables enterprises to handle variation and uncertainty, and provide solutions that improve peoples work quality and performance. In the CM methodology, these principles are combined with lean principles in order to design enterprises for mass customization.

Design for Mass Customization

The road towards mass customization requires a focus on time compression and flexibility, while costs are kept low. An emerging development of socio-technical design that claims to address the needs of market responsive processes is the concept of "agility".

Agility

Agility may be defined as the ability of an organization to thrive in a constant changing, unpredictable business environment. Agility adds the idea of time-compression to socio-technical systems design. Agile enterprises are capable of responding rapidly to changes in customers' demand (Kidd 1994). The major principles of agility are outlined by Goldman (1995):

- Enriching the customer
- Co-operating to enhance competitiveness
- Mastering change and uncertainty
- Leveraging people and information

The agility approach strives for flexibility and responsiveness and is well suited to handle the dynamic and uncertainty of mass-customization.

However, the focus of agility is too narrow. Flexibility requirements are not equally high for processes that not are customer specific. Mass customization requires a differentiated application of principles that provides speed, flexibility and cost efficiency. In CM design, Customer Order Decoupling Points (CODP) (Browne 1996) are central to meet these challenges.

Mass Customization and the Decoupling Point

The decoupling point separates the part of the enterprise where manufacturing is based on customers orders from the part that is based on planning and level control.
The decoupling point is also a point to stock components as a buffer that smoothens demand variety. In order to reduce number of components, such stocks should coincide with product T-points. T-points are points in product structures where a few standard components can be configured into a range of different products (Strandhagen & Skarlo 1995). Such strategic positioning of stocks enables the variant explosion, speed and cost efficiency required for mass customization. The decoupling point is often associated with the concept of postponement. It is favorable to postpone the decoupling point as close to product completion as possible. A postponing of the variant explosion enables shorter delivery times and higher delivery precision.

Figure 2 presents a family of manufacturing designs where the decoupling point also represents a stock holding point. Four different designs are represented by varying the position of the decoupling point. These designs range from providing unique products (Engineer to order) to providing standard products from a final stock (Make to stock).

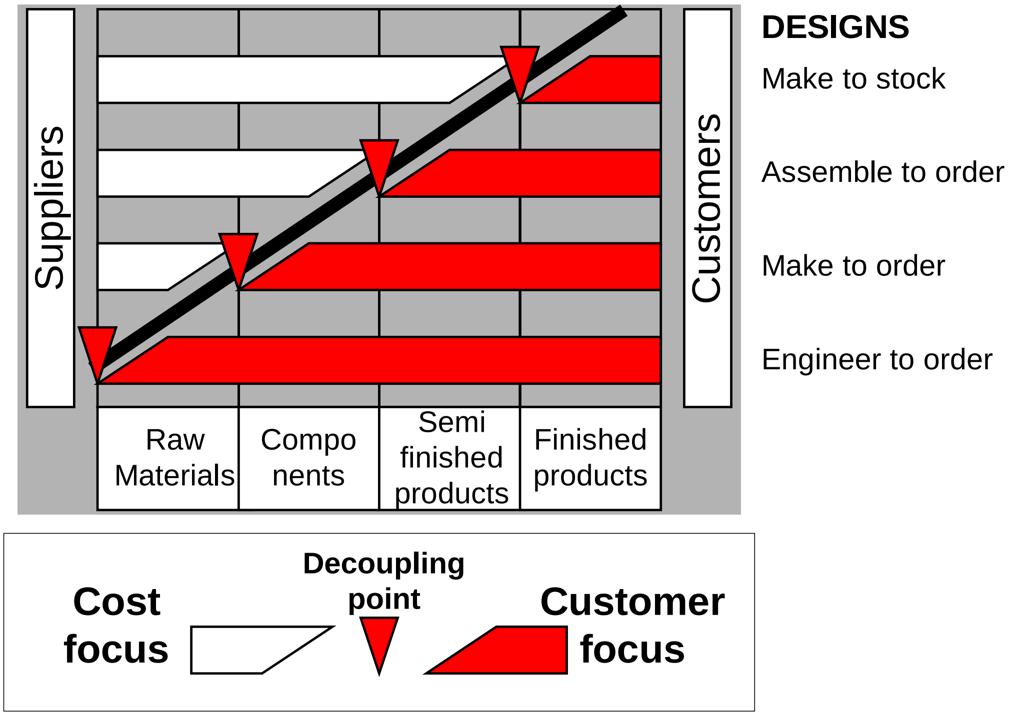

Figure 2 Enterprise design and the decoupling point (Adapted from Browne et al, 1996)

Figure 2 shows the degree of customer specification for the different manufacturing designs. Customer specific manufacturing is often time-critical and characterized by uncertainty and a high degree of demand variety. This kind of manufacturing requires fast and flexible processes that focus on due-dates, and is well suited for socio-technical principles like minimum specification and empowerment. The control of such processes may require customized Information and Communication Technology (ICT) that utilize principles like bottleneck control and cyclic production.

Manufacturing processes upstream from a decoupling point are not to the same extent time-critical. Such processes allow a focus on cost-efficiency and are well suited for lean principles like pull scheduling, standardization, and specification of processes. Several projects have showed that Kanban control is effective for these processes. A Kanban system provides the visualization of demand, clear responsibilities and customer/supplier rules that are necessary for decentralized control of processes. Material Requirement Planning can be applied for components with predictable demand and long lead times.

Material flow

The robustness and flexibility of an enterprise depend on a product-oriented and flow-oriented layout. Traditional solutions focus on resource-utilization, while the CM approach aims to:

- minimize handling and transport between different operations

- create a well-arranged and visible material flow that is easy to control
- group activities that are value-adding for a product

The design is carried out through Burbridge's material flow analysis and group technology (Burbidge 1979). Material flow is analyzed and resources are grouped into segments that form clusters of operations with joint input and output channels. This is illustrated in figure 3.

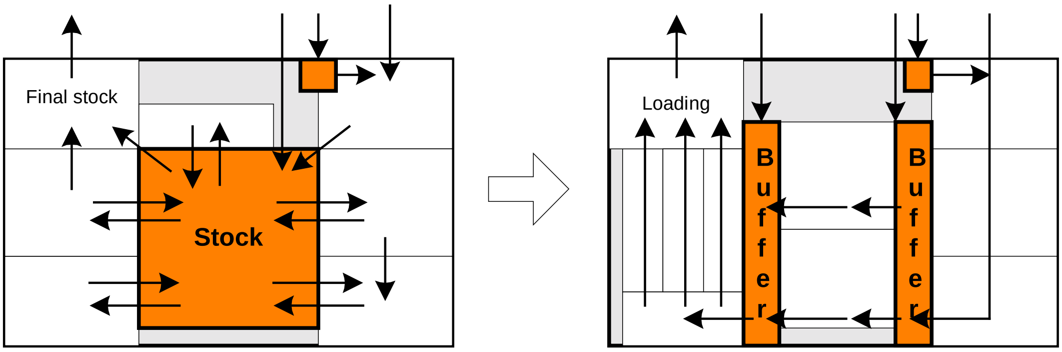

Figure 3 The design of a flow oriented layout

Burbridge's method does not only create a simple material flow: the flexibility to handle process variation is also improved. Processes may interfere with each other, or impede each other's due date. The grouping of functionally different resources in segments enables a more flexible order-sequence and better utilization of resources. The flexibility can further be increased by a reduction of set-up times. The placement of buffers is also central. Buffers are placed between segments to provide the necessary delays for flexible co-ordination of processes.

Control areas

The work force is reorganized to handle dynamic and changing environments. Semi-autonomous control areas that have clearly defined borders and responsibilities replace the conventional hierarchy. Each control area defines a group of resources or a group of activities that are linked and can be separated from the rest of the system. The detail planning and decision making are distributed to the leader of each control area, who manage the area in accordance to some clearly defined control principles. Effective co-ordination is ensured by manual or computerized tools, which provide a quick insight in the demand and capacity situation for each control area (Andersen et al 1998).

Information flow

Effective control requires technical solutions, software and manual systems, that support the communication of information along processes. Centralized generation and collection of operative information (orders, confirmations, invoice, available capacity) is therefore replaced or supplemented with flow-orientated information tools. The main principle is that operations only should be executed once, even across company borders. Effective management of production- and purchasing-orders are based on agreed, product differentiated delivery arrangements and supported by lean, customized Information and Communication Technology (ICT) tools. These tools are visual (like a Kanban) and provide a quick insight in the current demand and capacity situations. Lean, visual ICT tools are developed that:

- meet the requirements of a specific production and logistic environment
- enable effective communication and control

- are integrated with the company's existing ERP system.

The Control Model Design Process

A CM design process typically includes analysis, design, and implementation, and is carried out in line with socio-technical principles of participation and co-operation. Such design projects are rather creative and messy, and activities are carried out in parallel and in cycles, rather than in linear sequences. To clarify the process, activities are nevertheless described as three stages. The design process is illustrated in figure 4.

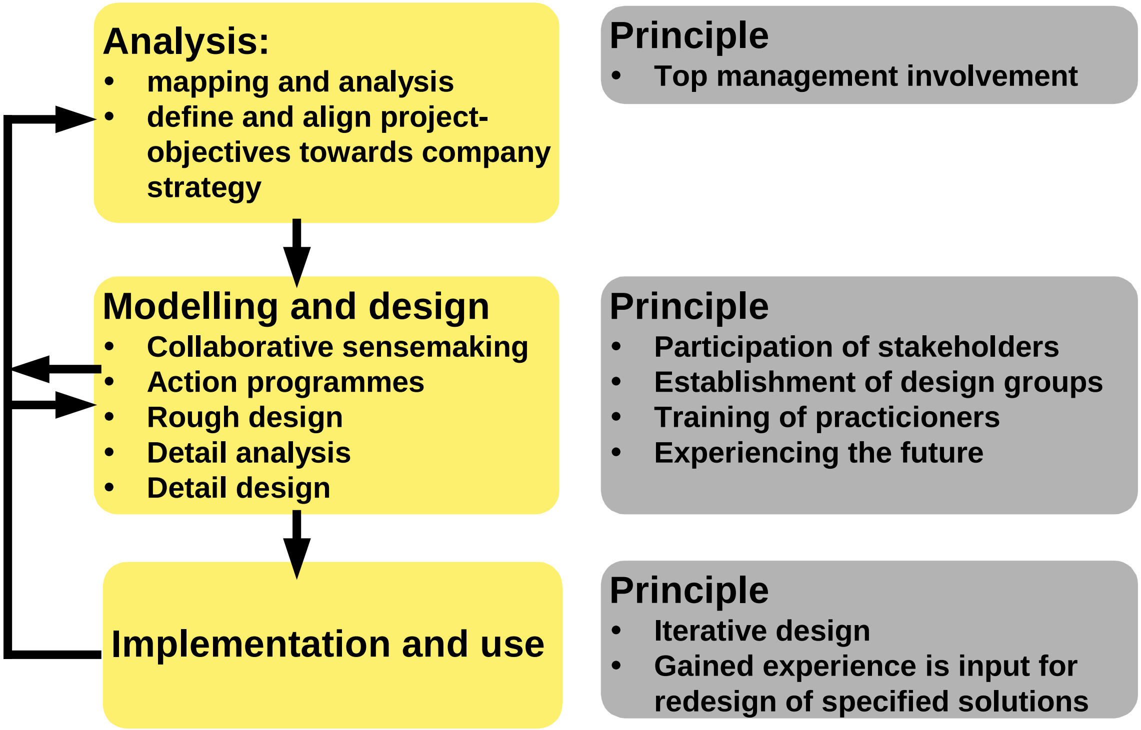

Figure 4: The enterprise design process

Analysis.

The project starts with a mapping and analysis of the company and its environment. This preliminary analysis focuses on production and logistics performance and covers company strategies, market requirements, product categories, business processes, and material flows. It is based on available information, interviews, and extracted information (e.g. corporate strategies) and is carried out in collaboration with practitioners. The result of this analysis is the designer's problem definitions and proposal for change areas. It will also propose objectives for improved performance or competitiveness. Secondly, project objectives are redefined and aligned towards organizational intention in collaboration with managers. This process should ensure managers commitment to the project. Thirdly, internal and external stakeholders are identified and representatives of different interest groups are invited to join a modeling and design process.

Modeling and Design.

The modeling and design process tries to enable active participation and knowledge creation. The process involves collaborative sense making, rough design of a control model, and detailed specification of tools, layout and business processes.

Sensemaking is a mutual learning process where researchers and stakeholders collaboratively revise the designer analysis, and agree upon a description of the company situation that makes sense to all participants (Greenwood & Levin 1998). To enhance knowledge-creation, different stakeholders should be allowed to tell their version of the company situation and their view on the underlying causes for insufficient competitiveness. The sensemaking process will continue until an aligned version of the company problems is achieved. This version, which should identify main areas for change and make sense to all participants, is the basis for the design project. Based on the revised company analysis, researchers and stakeholders develop and prioritize further action programs and analysis. Moreover, autonomous design groups are created. The design groups should consist of researchers and relevant practitioners, i.e. practitioners that have relevant experience and that represent the different interest groups involved in a change area. Secondly, researchers and stakeholders collaboratively design the main principles for a rough enterprise model. Based on the rough enterprise model, researchers and stakeholders specify and prioritize further action programs for the design groups. The most important action at this stage is to enable active participation and knowledge creation in the design process. This include training practitioners in logistics, control principles, and design methods, and letting practitioners experience the future through simulation games and work place visits. Thirdly, the design groups analyze the identified change areas in detail. Business processes are modeled and redesigned in detail, and requirements for ICT tools are specified. The new enterprise model may include the specification of layout, control areas, control principles, product range, processes, and supportive ICT tools.

Implementation.
Iterative design is a keyword at this stage. A new enterprise model is developed and implemented stepwise. The solutions are not complete, and are implemented stepwise to allow learning and habituation. This allows broader participation and makes it possible to change the course on the way. New solutions are tested in practice, and the gained experience is the input for new design solutions.

HÅG: A Swivel Chair Manufacturer

The applicability and principles of the CM methodology is here demonstrated by a illustrative example from HÅG, a Norwegian swivel chair manufacturer. HÅG customizes chairs on order, and is competing on the European swivel chair market. However, their location implies a competitive disadvantage. The factory is located at Røros, more than one thousand kilometres from their main markets, while the European competitors are located in or near the European markets. This was the point of departure for a redesign project, that aimed “to move HÅG to Europe”, i.e. to develop production and logistics processes that could compete with competitors’ delivery time and precision.

An analysis of the enterprise revealed poor performance: an inventory turnover at 6, delivery times at 15 – 20 days, and a delivery precision of 87%. The unsatisfactory situation was caused by several conditions. The factory was based on a make to stock production and was managed by an ERP system. This kind of control made it difficult to cope with the variety in demand and the variety of configurations (millions of variants) that is necessary to produce customized chairs. The plans generated by the ERP system seldom matched the actual sale, this lead to many express-orders that disturbed the plans and created co-ordination problems. The co-ordination problems were reinforced by a functional layout and work organization that created complex processes. Materials went back and forth between machining, welding, surface treatment, sub-assembly, sewing, gluing, assembly, packaging and stocks. Complex processes combined with mismatching plans created unintentional stockings and long throughput times. Measurement of some components showed an average throughput time of 45 days!

A new Control Model for mass customization was designed and implemented. The major principles in the new Control Model are illustrated in figure 5.

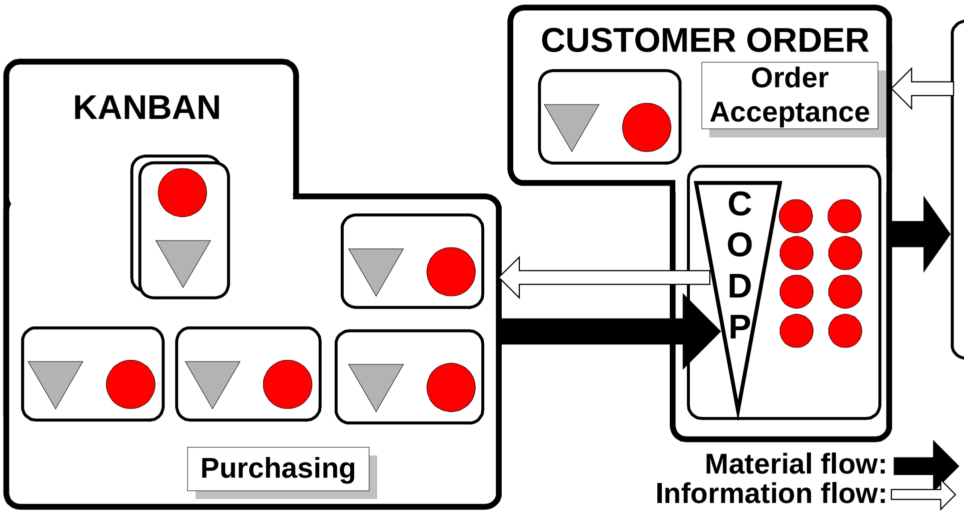

Figure 5 Major principles in a Control Model for Mass Customization

Figure 5 presents the principles of a Control Model for mass customization of chairs. A buffer before the assembly lines constitutes a CODP and enables assembly to order. Processes downstream from the decoupling point are controlled by customer orders, and Kanban controls processes upstream from the decoupling point.

The solution includes material and information flow-orientation, and control areas that are partly decoupled. A decentralized work-organization was designed where activities and responsibilities are grouped in 5 control areas. These control areas are semi-autonomous, only supported centrally for administrative activities like order acceptance, purchasing and the determination of Kanban levels (based on forecasts). Figure 6 present the solution in more detail.

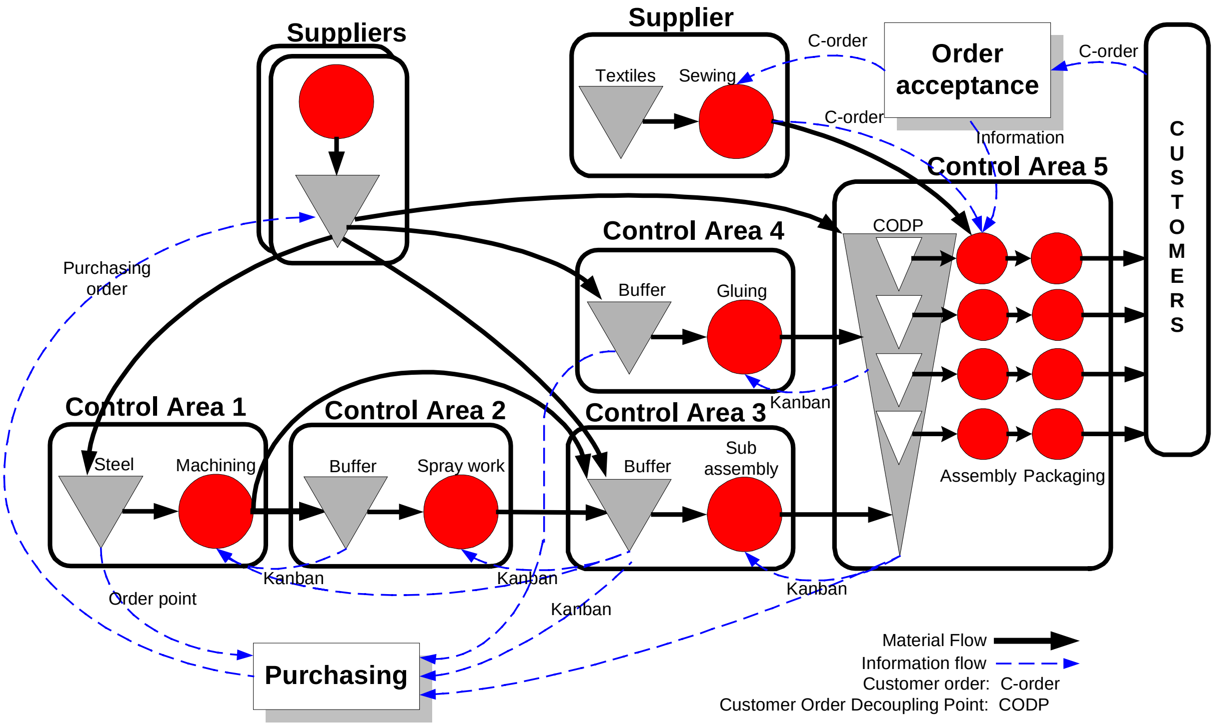

Figure 6 Details in a Control Model for Mass Customization

Control areas 1 – 4 are decoupled from customer orders, and Kanban controls the material flow, both internal flow and deliveries from suppliers. Control area 5 and the supply of seat-covers are controlled by customer orders. In fact, the supplier of seat-covers is integrated in the order process. Attached to a chair-cover is also the customer order that initiates assembly, packaging and loading of chairs.

The customer specific processes are controlled through a ICT tool which was developed through a collaborative design process. The ICT tool visualizes the capacity situation in the assembly lines (which also constitute the bottlenecks at HÅG), and new orders are adapted to the current capacity situation.

The result of this redesign was improved performance: the sale volume was more than doubled (from 100 000 to 240 000) with minor investments in resources. The inventory turnover was increased from 6 to 16, the delivery time was reduced to ca. 7 days for standard products, and the delivery precision is now higher than 98%.

Conclusion

During the last decade, more than twenty manufacturing companies have developed their manufacturing processes by the means of the Control Model methodology. They have radically changed their routines, layout, product design, control principles and information technology, and improved their performance. The experience from these cases is that the CM methodology is effective for creating flexible and competitive enterprises that provide mass customization.

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