

**ORGANISING AND COORDINATING
ACTIVITY STRUCTURES IN BUILD-TO-ORDER PRODUCTION**

Competitive paper for the IMP Conference 2004

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Abstract

This paper deals with customisation, i.e. firms' abilities to tailor their products to the individual customer's needs within reasonable cost and time limits. The aim of the paper is to explore the characteristics of the evolving activity structures for customisation and build-to-order production. The paper begins with a framework for analysing activity structures in networks. This framework is applied on the production and logistics network of the build-to-order production at Volvo Cars' plant in Gothenburg. This activity structure is then compared with traditional means of making products available to customers. It is concluded that efficient organisation of activity structures for build-to-order production requires extensive coordination in terms of information exchange and interaction across the boundaries of firms. The analysis also leads to the conclusion that efficient structures for build-to-order production require flexibility in some dimensions, while in others they have to rely on rigidity.

Introduction

A flood of recent publications attests to the widespread belief that we are in the midst of a fundamental technological change in manufacturing, communication, distribution and retailing – a virtual renaissance of customization. (Lampel and Mintzberg, 1996:28)

The above conclusion is formed on the basis of a substantial literature review where the authors found that 234 articles on customisation appeared between 1981 and 1990, while the corresponding figure for the period 1991-1995 amounted at 2,324 (ibid. p. 28). The increasing attention to customisation has continued according to recent reviews (for example, da Silveira et al 2001, Jiao et al 2003) and Salvador *et al.* (2002) conclude that even if customisation has not “completely swept away the remains of mass production”, there are clear signs that it is “becoming more and more a widespread concern” (ibid. p. 62).

The enhanced attention to ‘customisation’ is explained on one hand by the fact that customers are “demanding highly customized products and services” (Feitzinger and Lee 1997:116). At the same time customisation has been marketing driven and provided selling firms with an approach that is suggested to improve the competitive position of the company (e.g. Pine 1993, Kotha 1995, Stump et al 2002). Implementation of the new approach was made possible primarily through the development of more flexible manufacturing systems (e.g. da Silveira et al, 2001) and enhancements in information technology (e.g. Jiao et al, 2003). Other important prerequisites for increasing customisation were improvements in supply chain coordination (Lancioni *et al.* 2000), and greater differentiation of distribution networks (Ford et al 2003). The literature indicates that ‘customisation’ covers a wide range of approaches with quite different extent of attention to the individual customer. These approaches stretch from solutions that are uniquely tailored to an individual user to those being “slight variations of standard configurations” (Ulrich and Eppinger 1995:22). Most texts deal with what is identified as ‘mass customisation’ (originally coined by Davis, 1987) interpreted as “a new paradigm for industries to provide products and services that best serve customer needs while maintaining near mass production efficiency” (Jiao et al 2003:810). In this paper the distinction concerning the level of individualisation is no crucial issue. Our main concern deals with the characteristics and conditions of supply networks where manufacturing and distribution operations are directed by orders from end-users, i.e. when ‘build-to-order production’ rules the game (Svensson and Barfood (2002).

The increasing attention to build-to-order production has required considerable reorganisation of the activity structures in supply networks. Van Hoek et al (1999) analyse the transformation processes towards ‘new structures’ during the implementation of customization strategies in four firms. Lampel and Mintzberg (1996) argue that suppliers increasingly have to adapt ‘the logic of individualisation’ as a complement to ‘the logic of standardisation’. Gadde (2004) discusses changes in the activity structure of distribution networks in general with a particular attention to the requirements from the buying side. Berman (2002) concludes that mass customising firms rely on small production lot sizes, seek very low levels of inventory and attempt to cut costs by small production runs by both set-up and change-over times. Such activity structures contrast traditional approaches where firms

tended to rely on “large inventory levels through the channel and seek to cut costs through long and continuous production runs” (Berman 2002:53).

Aim and scope of the paper

The aim of this paper is to explore the characteristics of the evolving activity structures for customisation and build-to-order production. We begin the paper by developing a framework for analysing activity structures in networks. The concepts in the framework then are illustrated with a case study of the production and logistics network of the build-to-order production at Volvo Cars’ plant in Gothenburg. The car industry is used as the empirical setting because it constitutes a complex setting where customisation is increasingly applied (Agrawal et al 2001, 3DayCar Project 2002). 75% of British customers now buy customised cars, while the corresponding figure in the beginning of the 1990s was 25% (Svensson and Barfood 2002). In the description of Volvo’s activity structure we pay particular attention to the operational consequences for manufacturing related to increasing customisation. These issues have been given only scant attention in the literature (Åhlström and Westbroke 1998, Selladurai 2004), while other areas have been more carefully scrutinized, for example, Internet applications (Ghiassi and Spera, 2003), inventory reorganisation (Tibben-Lembke and Bassok 2004), product configuration modifications (Salvador and Forza 2004), and spare parts operations (Suomala et al 2003). In the final sections we compare the activity structure for build-to-order production with traditional means of making products available to customers and finalise the paper with a concluding discussion.

Analytical framework

Customisation implies adaptations towards individual customers. Customising offerings in relation to single buyers is not a big problem per se. Tailor-made solutions were the common norm before the establishment of mass production systems and craft manufacturing continued to be so in some industry sectors even in the era of mass production (Piore and Sabel 1984). What is problematic, however, is to customise at reasonable cost and

time (Pine 1993). Adaptations are always costly because they undermine the possibilities to standardise operations which increases complexity and reduces the scale of the operations. These characteristics make customisation a challenge because buyers tend to require individualised solutions at the same time as they demand orders to be fulfilled more quickly (Feitzinger and Lee 1997) and at lower costs (Oswald and Boulton 1995).

Our framework for exploring activity structures for customization and build-to-order production consists of two main parts: the first deals with the principles of modularity and postponement, the second with efficiency in activity structures.

Modularity and postponement

Increasing customisation requires reorganisation of the activity structures in production and distribution in order to enhance process flexibility. It seems a shared understanding that the main components in this restructuring are the implementation of modular product design and postponement of product differentiation (for example, Feitzinger and Lee 1997, van Hoek et al 1999, Berman 2002). One of the best known examples of this combined approach is a case study of Hewlett Packard (Feitzinger and Lee 1997). Through the reorganisation of its activity structure the company managed to improve three processes: they dramatically increased the product variety, they slashed the time required to fulfil customers' orders, and they were able to reduce costs. The main key to achieve these effects was to postpone the differentiation of the product for a specific customer until the latest possible point in time. These changes, in turn, built on the principle of modularity (ibid. p. 117):

- modular product architecture; implying that a product is designed so it consists of independent modules that can be quickly assembled into different product variants.
- modular process architecture; implying that manufacturing processes should be designed so that they consist of independent activities that can be rearranged.
- modular logistics and supplier configuration with the capability of taking individual customer orders as the starting point for the operations.

Van Hoek et al (1999) argue that these benefits stem from the rediscovery of the virtues of the principle of postponement. Alderson (1950) identified postponement (i.e. when suppliers take customer orders as the starting point for their operations) as one strategic approach for selling firms, complementing the principle of speculation where operations are based on forecasts. Van Hoek et al (1999) makes a distinction between three types of postponement. Form postponement (or postponed manufacturing) means that companies delay manufacturing, assembly or even design activities until after customer orders have been received. Place postponement and time postponement (in combination labelled logistics postponement) relates to the forward directed movement of goods that can be based either on orders or forecasts.

Speculation and postponement are characterised by two different principles for activity structuring, both aiming at exploiting the economies of the activity structure in the most appropriate way. Exploring the benefits associated with customisation and build-to-order production therefore requires some concepts for analysis of the efficiency in activity structures.

Efficiency in activity structures

For this analysis we rely on two concepts developed by Richardson (1972): similarity and complementarity. Richardson makes a distinction between similar and dissimilar activities implying that activities are similar when they require the same capabilities and resources for their undertaking. For example, the manufacturing operations needed for two different products may use the same machining equipment or require the same skilled work force. Increasing activity similarity is thus related to standardization, economies of scale, and specialization of actors. The main rationale behind mass production is to increase the similarity among activities.

The second concept is complementarity. According to Richardson, activities are complementary when they have to be undertaken in a specific sequence, such as in supply chains. Some activities are closely complementary, implying that it is necessary “to match not the aggregate output of a general-purpose input with the aggregate output for which it is needed, but with particular activities” (ibid. p. 891). Sequential activities thus become closely

complementary at the point where a product is customised to a particular user. Postponement of product differentiation thus changes the extent of complementarity in activity structures.

When activities are closely complementary across boundaries of firms it is necessary that “two or more independent organizations agree to match their related plans in advance” (ibid. p. 890). Inter-firm matching of plans is thus a prerequisite for customisation in supply networks and involves two dimensions. The first is the joint organisation of the activity structure on the basis of the principles discussed above. Establishing systems for just-in-time deliveries between buyer and supplier is an example of joint organising of closely complementary activities. The second dimension is the coordination of activities within single firms and across boundaries of firms.

Coordination of activities that are interdependent across firm boundaries cannot take place through market mechanisms, but requires extensive interaction among the companies (Dubois 1998). These conditions are at hand also in customisation and build-to-order systems where van Hoek et al (1999:517) found that for efficient coordination of these processes “close cooperation with both internal and external supply chain partners is required”. One important prerequisite for coordination of customised processes is the exchange of information among the parties in the supply network (see for example, da Silveira et al 2001, MacCarthy et al 2003).

The framework for analysis of the activity structures in supply networks based on build-to-order production is now complete. Before providing the empirical illustration through the case study of Volvo Cars we present some characteristics of these processes in the car industry in general.

Customisation and building to order in the car industry

Using the principle of modularity as a means for customisation is a prime concern in the car industry (Alford *et al.* 2000, Agrawal *et al.* 2001). Car manufacturers apply modularity to increase the flexibility of both their internal operations and their supply networks, aiming at reduced cost and lead time in manufacturing and assembly (Sako and Warburton 1999). Modularity is also suggested as a means of enhancing the car design process (Salerno 2001),

which showed to be important for both high volume manufacturers who pre-define the variety offered and for the low-volume manufacturers who let individual customers influence the design of their specific cars (Alford *et al.* 2000). Modularity is further considered a way to enhance supplier involvement in product development and supply chain efficiency and flexibility (Doran 2004).

Although most literature dealing with customisation and modularity emphasises the importance of supply chain coordination (see Alford *et al.* 2000, Salvador *et al.* 2002, MacCarthy *et al.* 2003), few researchers have actually studied how the logistics and production activities along the whole chain are coordinated (Doran 2002). In the following sections we describe these conditions at Volvo Cars on the basis of the findings of a five year case study.

Production and logistics activities at Volvo Cars

Volvo reorganised the structure of its production and logistics activities when the S80-model was introduced in 1998. In the following four years four new models based on the same product platform were launched. In spite of the common platform the number of product variants increased dramatically. These five models are now available in 14 colours, and a car buyer can choose from 9 engine and 5 transmission alternatives. A buyer can also choose between left- and right-hand steering, which altogether sums up to 6300 variants. Many other options are available, e.g. 22 types of interior trim and 9 wheel variants. In the end, Volvo can offer more than one million car variants and therefore tailoring each car in accordance with individual customer demands requires a flexible and well-organised activity structure.

The cornerstones of Volvo's production and logistics activities are its two main assembly plants in Torslanda, Sweden, and Gent in Belgium. In this paper we focus on the operations related to the Torslanda plant where about 160,000 cars were produced in 2003. Volvo's in-house production units account for approximately 25% of the value of the components and systems in a car, while external vendors supply 75%. For the car models based on the present platform, the plant in Torslanda uses about 170 suppliers, which is a substantial reduction compared with previous platforms. Some of these vendors are involved in pre-assembly of components and supply Volvo's final assembly line with product modules

that are ready to install. These suppliers deliver their modules in the same sequence as car bodies are put on Volvo’s assembly line. While this sequence is finally determined first when the car bodies are actually put on the line, the module suppliers have only a few hours available to perform their respective activities. They have therefore established module assembly units (MAUs) very close to Volvo’s plant. In total 15 MAUs are related to the Torslanda plant delivering 26 different modules such as seats, cockpits and exhaust systems. The structure of the Volvo network including 2,400 dealers is illustrated in figure 1.

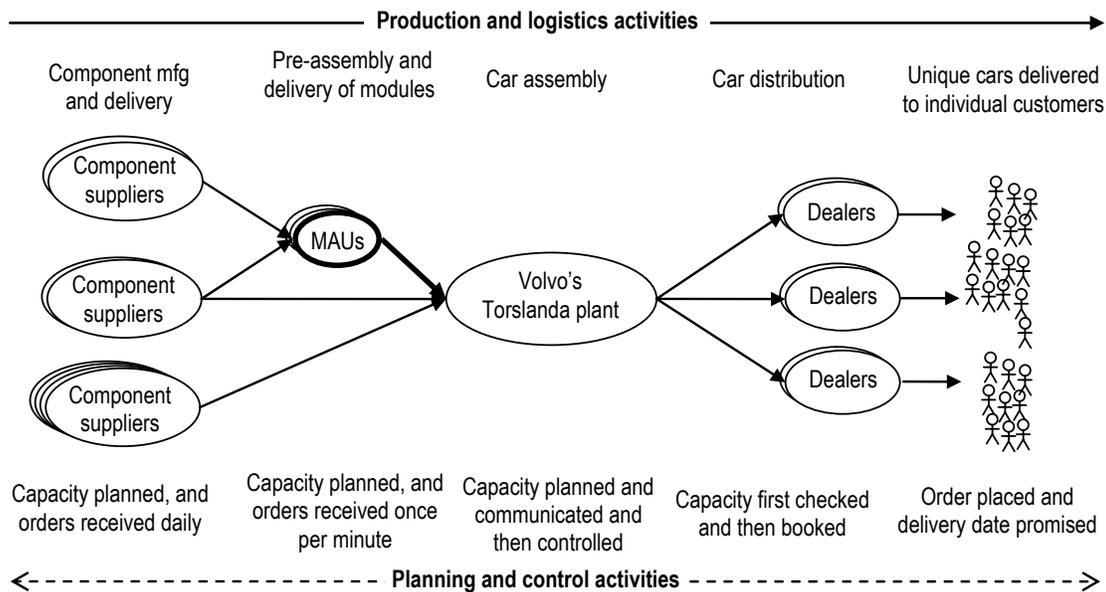


Figure 1. Volvo’s production and logistics network.

The modular supply and sequencing principle is illustrated in figure 2. When a car body is put on the final assembly line, it has been dedicated to a specific car buyer’s order and given a unique identity. All the options chosen by the car buyer in terms of exterior colour, engine and transmission types, interior trim, etc are linked to this identity. Variant specific modules must therefore be available at each station on the assembly line when the specific car body arrives. The suppliers delivering to the first assembly station has about four hours at disposal, whereas those delivering to the end of the line can use about ten hours. To be able to pre-assemble and deliver modules in this short time, all MAUs are located at maximum 15 minutes driving distance from Volvo’s plant.

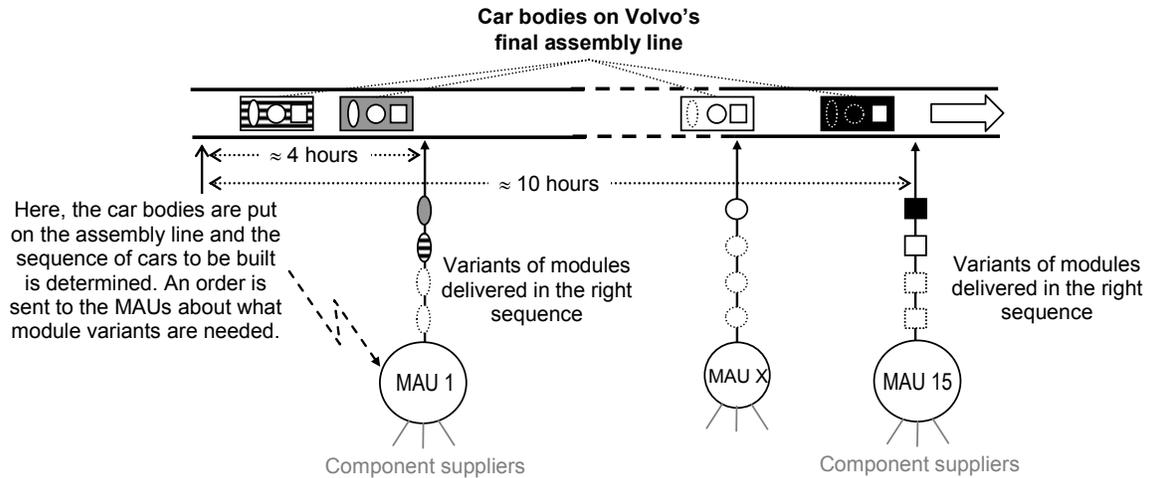


Figure 2. Pre-assembly and delivery of module variants.

Transportation of modules between the MAUs and the final assembly line is handled by Volvo and trucks drive 'milk rounds' and pick-ups are made between one and two times per hour at each supplier. The pick-up frequency fluctuates in accordance with Volvo's line pace and the packaging density for each module type. The packaging density is in general quite low since the modules require special carriers to be protected from transport damages and to make access easy for the operators. While the modules constitute a large part of each car they contain many of the components that differentiate car variants from each other, for example in terms of exterior colour and engine. The modules are therefore available in different variants, and so there are more than 3,500 types of seats and more than 10,000 power-pack combinations. Furthermore, most modules are physically large and represent considerable capital investment. The cost of buffering all the potential modules thus would be extremely high in terms of both capital and space. The current activity structure in production and logistics allows Volvo to deliver a huge number of product variants to its customers in an efficient way. The prerequisite for this capability is the coordination and 'matching of plans' across the boundaries of firms.

Coordination across firm boundaries

Centralised planning and control relying on information transparency through the whole supply network is the hallmark of Volvo's customisation strategy. Forecasts and orders

from dealers make up the basis for Volvo's production planning. This information then is related to the production capacity of Volvo and its suppliers. It is the Logistics department at the Torslanda plant that is responsible for the planning process, which results in (i) a production forecast showing what cars to assemble on a monthly basis and (ii) a production plan with two time horizons. The production forecast is generated by the production planning system without any human involvement. It is based on the current order queue, capacity restrictions in the system, and Volvo's priorities concerning the different markets. This production forecast is updated on a monthly basis and distributed to departments within Volvo and to suppliers about six weeks in advance. It is primarily used for giving the first delivery promises to dealers when they place orders and for assisting suppliers in the component production planning process.

The second output of the planning process is the production plan that outlines what car variants to assemble in what sequence, covering the coming 62 weeks. It is updated on a weekly basis and complements the production forecasts and improves the planning conditions for Volvo's assembly department and its suppliers since it is based on both orders and forecasts. A more short-term production plan called the Call-off is also generated in the planning process. It is updated every day and covers the next 12 weeks. These production plans are based on both the restrictions in the automatic planning system and hands-on involvement of the Logistics engineers who are able to consider far more restrictions than those fed into the system.

Volvo's huge product variety and the subsequent numbers of component and module variants make the planning process complicated. The production forecasts and plans generated must ensure a relatively smooth workload on Volvo's final assembly line. Otherwise, costly line set-ups have to be made and personnel hired and withdrawn. The restrictions in Volvo's production planning system protect the final assembly line from too large variations in workload. Although the loads at the line and in the MAUs are important from a cost perspective, it is the economies of scale of the component suppliers that are most sensitive to variations in demand for different car models and variants. In order to limit the variations experienced by the component suppliers, Volvo's Logistics engineers consider more than one hundred restrictions when production plans are decided upon. Volvo's centralized planning system thus coordinates the chain of production and logistics activities in

order to balance customer service levels and costs. The outcome of these efforts is strongly dependent on the information exchange between the actors in the network.

Information exchange

Volvo's production planning is heavily dependent on information from the customer side in terms of sales forecasts and orders. The sales forecasts come from Volvo's market organization and are based on estimations of each geographical market's expected sales of different car models and variants. The forecasts build on sales trends of Volvo and other car manufacturers, launches of new and refined products, and more general socio-economic factors of each region. These forecasts cover several years, with a reduced level of detail as the time span increases. They are updated on a regular basis to reflect changes in total and for specific markets. The forecasts form the basis of Volvo's production planning on a long-term basis, including planning of the internal assembly capacity and the agreements made with suppliers regarding future component volumes.

On a short-term basis, the production plans are based on orders. To avoid building stocks of finished cars, Volvo's ambition is to build cars only when orders are placed by dealers. This principle is fully adhered to for the European market accounting for almost 60% of the total sales involving about 1500 dealers. Dealers, in turn, only order cars when they have received orders from final customers who then have to wait a few weeks for delivery. The production planning and assembly of cars are thus entirely dependent on the final customers' actual ordering.

European dealers communicate directly with Volvo's production planning system. The dealer feeds the full specification of the car into the system that determines when the car can be assembled. Based on these calculations, the dealer gets a first delivery promise. A second, and final, delivery promise is given when the Logistics department has analysed the specific order in relation to the many restrictions not included in the automatic planning system. The orders that Volvo receives from the North American market accounting for about 30% of total sales, are handled differently. These car buyers are not willing to wait for a car for several weeks. Instead, they want to get the new car more or less the same day as they place the order. Volvo's sales organization in North America therefore orders car variants in

accordance with its own and the local dealers' forecasts. The cars are then stored at three central warehouses and immediately shipped to dealers when these receive a customer order. Most dealers also store a limited number of Volvo cars with different features that are instantly available to customers. The lead-time from order to delivery is therefore shorter on this market, while the number of available car variants is limited compared to the European market.

The information in Volvo's planning system for build-to-order production is transferred to suppliers. Suppliers use this information for planning their replenishment and production processes, thereby ensuring that they can deliver the different component variants as requested by Volvo. The production forecast forms the basis for the suppliers' planning since Volvo's actual ordering is allowed to deviate from the forecast only within limits specified in the contracts. Each supplier also receives the two production plans with different time horizons and levels of detail. The Call-off is updated and sent out every day and covers the coming 12 weeks. The first eight days of the Call-off are fixed in the sense that Volvo is committed to assemble the specified car variants in a certain sequence. From the ninth day the Call-off is a forecast and Volvo can change it within the limits specified by the agreement. The long-term aggregate plan is primarily based on Volvo's sales forecasts. Although it is uncertain, this plan complements the production forecast for the suppliers' long-term planning.

Underlying the exchange of plans and forecasts is Volvo and each supplier's capacity agreement. Based on its long-term sales forecasts, Volvo has signed contracts with all suppliers regarding price and expected volumes that varies over the life cycle of a car model. The expected volume peaks then form the basis for an agreement on the maximum capacity the supplier must have available for its Volvo-business. Volvo also owns the dedicated tools and equipment that suppliers use for producing Volvo-specific components.

The MAUs are imposed with particular planning problems. If one of these module flows stops, so will also Volvo's line and all the other module flows, because some modules can only be assembled into the car bodies at the designated assembly station. The most important MAUs are therefore invited to participate in the planning process. MAUs are also allowed to set temporary restrictions in Volvo's production plan. If a MAU faces sudden

problems and cannot deliver a module variant for a limited period of time, it can set a restriction and Volvo will adjust its assembly of car variants and its ordering of module variants. Disturbances in Volvo's internal manufacturing processes may also underlie such changes, e.g. if the paint shop cannot deliver blue car bodies to the assembly line. Although this means that the ordering deviates from the fixed plan, the alternative would be an expensive line stop and delayed deliveries to customers.

The need for interaction

The above discussion illustrates that continuous interaction between the actors in the network is a necessary complement to the information exchange mediated through the centralised planning system. It is the interaction and negotiations between Volvo and the actors on its supply and demand sides that coordinates the activity structure. Volvo and its suppliers, distributors, sales companies, and dealers discuss capacity constraints, product range, expected sales volumes, and so on in order to achieve a balance between production and logistics costs, and customer service. Basically, the operations of the actors are based on long-term sales forecasts for the product range as a whole and for the different variants. However, when actual sales deviate from the forecast the plans must be revised. The uncertainty of the forecast for individual product variants may be substantial implying that firms involved in customisation are more dependent on interaction than companies that mass-produce items on speculation. Continuous interaction between the involved actors is therefore an important means for balancing customer service and costs.

Interaction is required also between the customising firm and the demand side both when an order is placed and after. When activities in production and logistics are directed by orders, the time required for delivering the product varies in relation to the capacity constraints and the order queue for that particular variant. If the delivery time is considered too long the buyer may prefer to choose a product variant that can be produced earlier. Interaction is also required if the customer wants to change an order and select another variant. The change desired is then discussed between Volvo's production planning department, the dealer and/or the sales company, and the car buyer. Interaction between the

customisation firm and the actors on its demand side is thus an important means for generating and updating production plans that enhance customer service.

Volvo also interacts intensively with actors on its supply side. Especially the MAUs constitute important counterparts for interaction both when production plans are generated and after. The capacity situations of the most important MAUs are considered in the planning process, and, as discussed above, they are allowed to set temporary restriction in Volvo's plans. The MAUs play a crucial role in the interaction process representing both themselves with their internal constraints and their component suppliers. Volvo's interaction with the supply side is thus primarily focused upon limiting the costs and handling disturbances in the production and logistics activities. In order to balance customer service and costs, centralized planning and information transparency thus need to be complemented with tight interaction among the actors to handle situations when planning assumptions are not realised.

Analysis

As discussed in the Introduction it is a common view that the establishment of systems for customization requires transformation of the activity structures in the supply networks. To understand the prerequisites and effects of this transformation we begin the analysis with a discussion of the characteristics of the systems for mass production that were replaced in this transformation, identified as the shift from the 'logic of aggregation' to the 'logic of individualization' (Lampel and Mintzberg 1996).

Activity structures based on the logic of aggregation

The activity structures in the regime of mass production aimed primarily at exploiting the potential benefits related to increasing similarity among activities. Economies of scale then were captured through massive standardization: "standardization of taste that allowed for standardized design, standardization of design that allowed for mechanical mass production, and a resulting standardization of products that allowed for mass distribution" (Lampel and Mintzberg, 1996:21). The sequential dependence among the activities showed different patterns in this activity structure. Some of the components used by car producers were

completely standardized thus implying minimum interdependence concerning product form. Other components and systems delivered by suppliers were adapted to the particular requirements of the specific car producer, in turn meaning that these activities were closely complementary between supplier and assembler. In the downstream operations in the supply chain there were no closely complementary activities as cars were intended for a mass market. In general, therefore, most activities in this network structure were complementary. Inventories, both on the input and output sides of the producing firms, functioned as buffers, thus minimizing the need for coordination across firm boundaries (see figure 3). Car buyers had no opportunity to affect the characteristics of the cars – they had to take what was available.

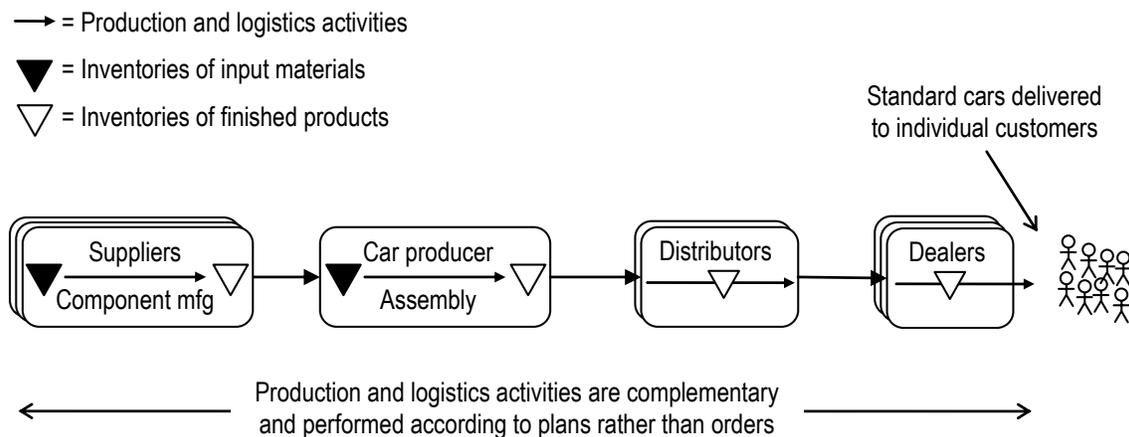


Figure 3. The activity structure building on speculation and the logic of aggregation

The first steps in the transformation of this type of activity structure were taken when car producers began to reorganise their manufacturing operations in the late 1980s. Inspired by experiences from the Japanese motor industry European and American car manufacturers began to require just-in-time deliveries from their suppliers (Gadde and Håkansson 1993, Lamming 1993). This change was supposed to provide the same benefits as in the Japanese systems: reduced inventories, in turn leading to lower costs and improved delivery performance. However, when car assemblers cut their inventories, supplier inventories had to be increased substantially to secure availability of components. In cases where suppliers were located far away from assemblers intermediate inventories were established close to the car manufacturer. The warehouse business in Detroit flourished and one company even picked

the name 'JIT-warehousing'. Obtaining the desired effects thus required further modifications of the activity structures which are discussed later.

JIT-deliveries increased the complementarity among the activities on the input side of car producers. Handling these interdependencies at reasonable costs required manufacturing techniques with reduced lead times. Otherwise the economies of manufacturing would have suffered severely owing to the shortening of production runs. Moreover, reduced inventories and increasing variety called for enhanced coordination of the production and logistics activities of both component suppliers and car assemblers. These effects were made possible through developments in information technology (Dubois *et al.* 1999).

From the output side of the car assembler and further downstream the supply chain, however, these changes had little impact on the activity structure and car buyers still had to buy what was available in terms of product features.

Activity structures based on the logic of individualisation

Volvo's current activity structure in production and logistics illustrates perfectly what Lampel and Mintzberg (1996) identify as 'the logic of individualisation' making it possible for consumers to affect the features of the cars they buy. As discussed above developments in manufacturing, logistics and information technology made it possible for producers to exploit the differentiation in consumers' tastes and from the time customisation was first offered standardisation of products was no longer a viable approach and mass distribution became increasingly supplemented with tailor made delivery systems. These distribution and logistics systems were developed because customisation starts with the downstream activities closest to the marketplace (*ibid.* p.25). The individualisation efforts in logistics are known under various acronyms, such as JIT (just-in-time) see for example White and Pearson (2001), ECR (efficient consumer response), e.g. Kurnia and Johnston (2001), and QR (quick response), e.g. Perry and Sohal (2000). These types of delivery systems rely on other principles than those based on buffers and inventories that made products available in time and place during the mass production regime. In this section we analyse the characteristics of this structure and make a comparison with the previous way of making cars available to customers, which relied on the logic of aggregation.

User involvement in the specification of the car features impacts on the complementarity among activities by increasing the sequential interdependence. In the current Volvo system all activities between the buyer and the assembly operations are closely complementary. Many of these interdependencies run all the way back to the MAUs thus increasing the complexity of the activity structure (see figure 4).

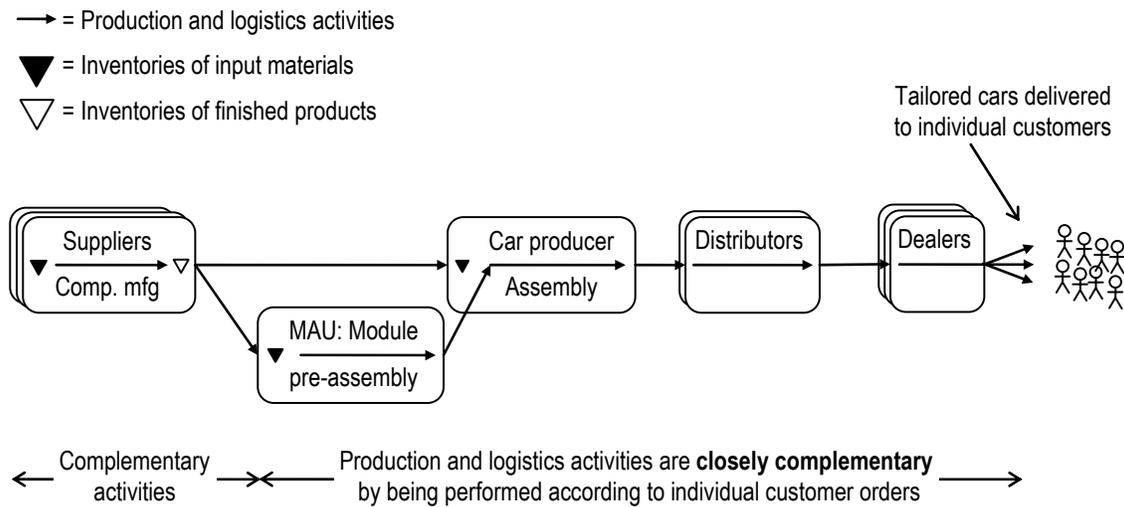


Figure 4. Activity structure building on postponement and the logic of individualisation

Applying the logic of individualisation impacts on the potential for standardisation and reduces the similarity among activities in turn decreasing economies of scale in the assembly operations and for the MAUs. However, in the activity structure designed by Volvo, component production is decoupled from the close complementarity stemming from the customers' ordering of build-to-order cars. Component production may thus benefit from similarities and economies of scale in the operations, although the component level is characterised by variants as well.

The main difference between the structures based on the logics of aggregation and individualisations relates to inventories and buffers. In the activity structure based on the logic of individualisation inventories and buffers are minimised. Activity structures with these characteristics need more coordination and planning than those building on aggregation. Volvo's activity structure showed to be strongly dependent on massive matching of plans and continuous interaction among actors.

Concluding discussion

This paper explores the characteristics of activity structures developed to realize the type of customisation where production and distribution activities are directed by customer orders and performed differently depending on the product variant demanded. The case study illustrates that such systems require a transformation of previous activity structures relying on mass production and the principle of speculation. The main feature of build-to-order production is an increasing complementarity among activities based on the principles of modularity and postponement. . In such activity structures production and logistics operations are coordinated through extensive information exchange and interaction. Through these coordinative efforts across the boundaries of firms variant flexibility can be created at reasonable cost.

Build-to-order production seems to be more complex in the car industry than in most other settings. Previous studies have mostly dealt with home appliance products, computer hardware and electronics, which allow for ‘simpler’ means of customisation (Henke 2000). For example, a PC consists of seven basic standardised and interchangeable components that are readily available for assembly (Curry and Kenney 1999). Accordingly, assembly operations may take place at various positions in the network, such as manufacturing, distribution, retailing, and even final consumption (Hulthén 2002). Moreover, computers can be delivered directly to end-users, for example like the distribution system of Dell Computers. These characteristics are quite different from the conditions in this case study.

Economies in the operations of build-to-order systems stem from the decoupling of customised activities downstream from component manufacturing upstream. In the case study the MAUs showed to be very significant for this decoupling. The role of MAUs are in some respects similar to that of inventories, because both buffer parts of the production system from variations downstream. In this way the close complementarity required in the supply chain running from the MAU can be combined with increasing similarity in upstream operations.

Even more important are the similarities a component manufacturer may capture by combining orders from different customers. The module suppliers operating the MAUs produce many of the components included in the modules and other components and

subsystems as well. Their component manufacturing is centralised to the large plants of the suppliers, which supply other car assemblers as well. Even if all activities performed for various customers are not identical, suppliers can utilize some of their resources in relation to different customers. If the volumes ordered by Volvo vary over time, suppliers may be able to fully utilize their resources through directing them to other customers. Efficiency in activity structures thus needs to be considered in a network context, because the performance in one particular supply chain depends on how it is combined with other supply chains (Gadde and Håkansson 2001). Accordingly, the product variety that can be allowed for within specific cost and time limits is dependent on each supplier's possibilities to coordinate its use of resources among different customer orders. The single company's potential to realize volume and variant flexibility in a particular supply chain is thus dependent on how the activities in this chain can be linked to other supply chains.

Finally, our study leads to the conclusion that customisation through the logic of individualisation is based on flexibility in some dimensions, but also dependent on rigidity in other dimensions. Firstly, there are certain limitations in what variants a car buyer actually can choose between. When the new options for build-to-order production became available car manufacturers' ambitions to individualise were considerable. For example, Toyota launched an all-out effort to offer buyers individually customized automobiles and Nissan at the same time boasted that customization meant it could produce "any volume, anywhere, anytime, of anything for anybody" (Lampel and Mintzberg 1996:24). These efforts had to be abandoned because they lead to dramatically increasing production costs.

Secondly, the MAUs are important in providing variant flexibility at reasonable cost by decoupling component production from the customised activities that are closely complementary. At the same time the MAUs imply constraints for what changes in the system are feasible because of the large investments they represent. Other investments in the networks include the relationships between the firms and the adjustments undertaken. The firms involved thus have reduced their strategic flexibility in terms of the possibility to change business partners without incurring too much cost. Therefore, customisation in terms of offering a wide product range at reasonable cost and lead-time thus is dependent on the way in which a company combines flexibility and rigidity in different dimensions in long-term cooperation with actors on its demand and supply sides.

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