The Impact of Modular Production on the Dynamics of Supply Chains

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The principle of modular production has been applied internally by companies since the 1960's. Innovative companies in various industries are now experimenting with application of the concept in a supply chain setting. Modular production makes it possible to further involve distributors and suppliers in the manufacturing process and create a new tier of suppliers in the automotive industry; that of the "zero-level suppliers". Expected benefits of the increased integration in the inbound and outbound flow of goods are improved responsiveness to customers and increased efficiency. It can be questioned, however to what extent manufacturers can increase the amount of control over operational activities based on networking, as opposed to control based on ownership, without becoming an empty design and marketing company. This paper assesses the impact of the new model of modular production on the dynamics in supply chains as a whole and the consequences for individual players, based on innovative cases such as that of the SMART car.

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Implementing modular production in a supply chain setting involves extensive reconfiguration of the chain, including functional spin-off of activities in the inbound and outbound flow of goods.

The purpose of modular production is to decrease product complexity, while raising product variety offered to the customer. This principle can be traced back to the 1960's [1]. The underlying production concept is the use of generic modules interchangeable in a number of different finished products. This can contribute to more efficient differentiation of products in response to customer orders which goes beyond the apparent differentiation provided by marketing efforts. Pine [2] states, "Increased variety must come from manufacturing;" and, that modular production is the best way to achieve the mass customization of products and services. Lampel and Mintzberg [3] state that, increasingly companies are looking for ways to combine standardization and customization within one supply chain. This is opposed to focusing on either full standardization and transforming heterogeneous markets into unified industries or focusing on, one-time-only, customized products.

Figure 1 graphically displays this evolution. The horizontal axis displays the shift from traditional mass production and mass marketing approaches to mass customization. The vertical axis indicates that companies increasingly structure organizations around processes, as opposed to traditional product, geographical or functional organizations. These evolutions are not only driven by market requirements, but is also facilitated by regional integration such as in the European Union (enabling a move away from geographical structures) and information and communication technologies (enabling a move away from product and functional structures). Within this framework the general move from hierarchical organizations, based on the principle of command and control or control by ownership, towards supply chain management organization based on networking, or control by networking, not ownership, can be expected.

Within this framework, modular production may be the method to achieve mass customization of goods and services. Modular production is taken beyond its original principle, introduced in the 60's and is implemented in a supply chain-wide setting by a number of companies, such as in the SMART case. Thus, modular production may contribute very well to the overall evolution displayed in Figure 1. However, as the Vice President of Manufacturing and Logistics of Whirlpool Corporation [4], stated: "The strategic intent to strive for mass customization is one thing, the process and systems to accomplish it are another."

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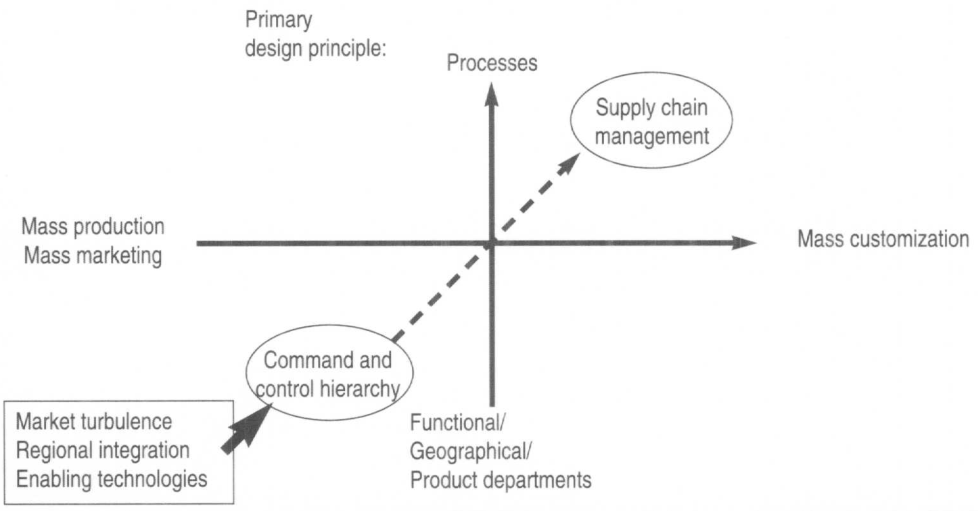
Figure 1
From a Command and Control Hierarchy to Supply Chain Management



reconfiguration of the chain, including functional spin-off of activities in the inbound and outbound flow of goods. Modular production allows manufacturers to further involve suppliers and distributors in the supply, assembly and distribution of products. At a modular level suppliers can start to perform supply and assembly, which is an extension of their existing involvement in the supply chain. This extension of supplier involvement is only possible based on the modularity of a product. Further involving a lead supplier would otherwise imply that one supplier would have to take over the entire supply and assembly task of the manufacturer, as opposed to various suppliers performing the assembly of specific modules only. Modularity also allows for rapid and easy final modification performed in the distribution channel. The involved reconfiguration of the supply chain results in an increased integration of supply and assembly, and assembly and distribution. Also, physical integration of parties in a manufacturing site is involved. Under this concept the manufacturer/OEM decreases the scope of activities that it performs itself, but expands its grip on the overall supply chain, including the commercial distribution channel as suggested by Ealey and Troyano-Bermudez [5].

The purpose of this paper is to develop insights into how modular production can be implemented in a supply chain setting. The aim is to give insight into the dynamics within supply chains. Managers have to deal with using the supply chain management perspective from Figure 1 (involving cross-company, cross-functional and cross-border issues). Case material of companies that are pioneering in this area will be introduced and used to assess the impact that the concept may have on the strategies of the various individual players in the supply chain. The modular production concept as applied to the SMART car, the Mercedes-Benz and Swatch joint venture project, will be used as a case study. Additionally, cases from Volkswagen and companies from other industries, such as the software and electronics industry, will be used as a comparison of the findings across supply chains. The impact on the supply chain as a whole will be discussed and possible strategic consequences for individual players in the chain will be assessed. These consequences are not limited to the manufacturer, but also include suppliers, such as LEAR and Autoliv and dealers and distributors.

Modular Production: Roots and Applications

Anderson and Narus [6] state that to tailor one's offerings to the specific needs of each customer while still maintaining low cost, companies "...have created modular components that can be assembled in a wide variety of configurations and designed platforms that can be shared by a family of products..."

Feitzinger and Lee [7] specify three advantages of a modular product design, which relate to the citation from Cooper [8]:

- Standardization of parts combined with postponed differentiation of products.
- Total lead-time can be shortened because modules can be manufactured simultaneously.
- A company can easily isolate potential quality problems.

Before further explaining the principle of modular production, the first question that may be raised is, where is modular production most viable?

One aspect relevant for determining the applicability of modular production is the type of product platform or chassis used.

One aspect relevant for determining the applicability of modular production is the type of product platform or chassis used. Kuhlmeijer [9] explains that there are three types of platforms used in industry:

- Launching platforms or design centers where multi-functional engineering teams work together in developing platforms or concepts of products (like the basic lay-out of a PC), which can be further developed as a second stage in multiple products (like various types of PC products or upgrades of models).
- Technology platforms that engineers use to develop new breakthroughs. For example, the internet is increasingly used as a platform for experimenting with direct marketing methods and developing a new context for commerce.
- Product platforms like a TV or car chassis or a computer motherboard can be used in producing a multitude of finished products by simply adding different modules and components to the platform. These modules will give the final product its unique features and appearance.

Modular production is based on product platforms and a product architecture, which can be used in the production of differentiated final products using a variety of modules, while maintaining commonality and interchangeability of components. Launching platforms may be used in developing product platforms.

A second element, which helps determine the viability of modular production is the type of product. Hoekstra and Romme [10] categorize finished products into three generic categories that can help in determining the area where modular production is feasible. The three categories are:

- Standard products without variants are undifferentiated products. These can be manufactured in mass-production environments.
- Standard products with variants: Standard products can be differentiated into an assortment of products with technical or country variants (different voltage or plugs, etc.) and commercial or customer variants to be sold to a variety of consumers and markets. Products within a product family can be modified to differentiate their functionality and features. Differentiation may be based on peripherals and modules. Various components will be common in various products (commonality).
- Systems and projects: Systems are collections of finished products that interactively operate. Projects result in products that are unique not through exclusive use of components, but through sales and design. The design and technology used may be specified in a unique customer-specific combination as a complete "once in a lifetime" product.

Raw materials and primary products are not included in this categorization. The manufacturing and distribution organizations of these products differ because the design may be less modular. The number of manufacturing stages is limited and the differentiation of distribution channels may be even less than in standard products.

The focus will be on standard products with variants or category two. Modularizing the components of these products contributes to the interchangeability or commonality of those components. According to Pine [11] modularizing products contributes to economies of scale in component manufacturing and to economies of scope in using modular components over and over again in a wide variety of products, most relevant for category two.

Levels of Modular Production

Prior research and published literature indicate that modular production can be applied at three levels: at a product level, at a product group level, and at a process level.

The first level, based on the modularity of products, has a strong logistics aspect attached to it, that of design for logistics. Saving in inventory costs (storage space and interest costs) and transportation costs associated with work in progress can be lowered by modularizing product, while product customization can be increased.

Figure 2 displays work in progress in a hypothetical flow of goods, from purchase/input through transformation to assembly and delivery. The number of parts/products in progress may decrease through transformation and increase through assembly and distribution, including the assignment of products to specific markets in the distribution process. It is logistics friendly to design products and processes to decrease inputs as soon as possible and to increase them into outputs, as late as possible. Modular production can enable just that by transforming inputs and materials into parts with a high commonality and assembling them into a wide variety of products. The commonality index C from Collier [12] is often used to assess commonality at a product level. C is calculated as the number of components per product multiplied by the number of products and divided by the total number of components. The higher C, the higher the inventory savings that can be realized with modular production [13].

The mentioned advantages of design for logistics can be expanded by using modular production at the second level, that of modularity in product-groups. Ford and Mazda for example, are sharing a car-platform. Sheu and Wacker [14] state that in addition to the C-index a further consideration can be the difference in the effect of commonality between and within products. Thus, the effect of commonality at a product-group level may differ from that on a product level.

The reasoning behind modularization as outlined above, can be traced back to Starr [15], who already pointed to the growing customer demand for maximum product variety that can be achieved by modular production; the capacity to combine parts in numerous ways as well as the compatible (process-)managerial abilities. With increasing customer demand for variety, conventional mass production facilities were unable to generate as many variants as demanded. Starr [16] attributes this to a lack of technological capability and managerial ability to control the production of diverse outputs. The system of mass production transforms various inputs and raw materials into standardized outputs by use of standardized processes. Marketing may create some variety based on marketing activities such as place, promotion and price differences (see Figure 3A). Lampel and Mintzberg [17] state that the history of most (U.S.) businesses over the past 100 years has been one of fortunes built on the transformation of fragmented and heterogeneous markets into unified industries. Standardization of taste allowing for the standardization of design and mechanized mass production of standard products is distributed through mass channels.

Starr [18] reasoned that variety based on marketing solely is not enough in demanding markets and real variety needs a production involvement. Modular production separates the production process into a primary transformation process of

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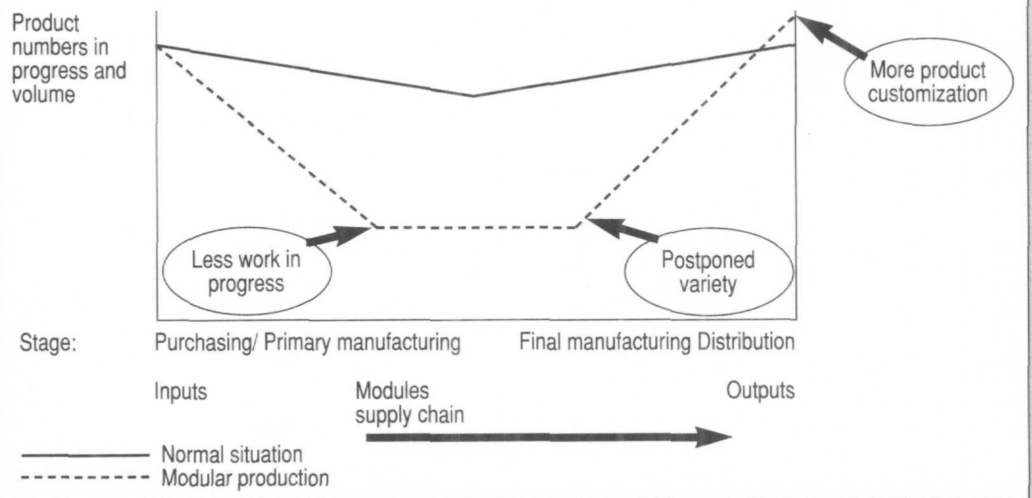
Figure 2
Design for Logistics



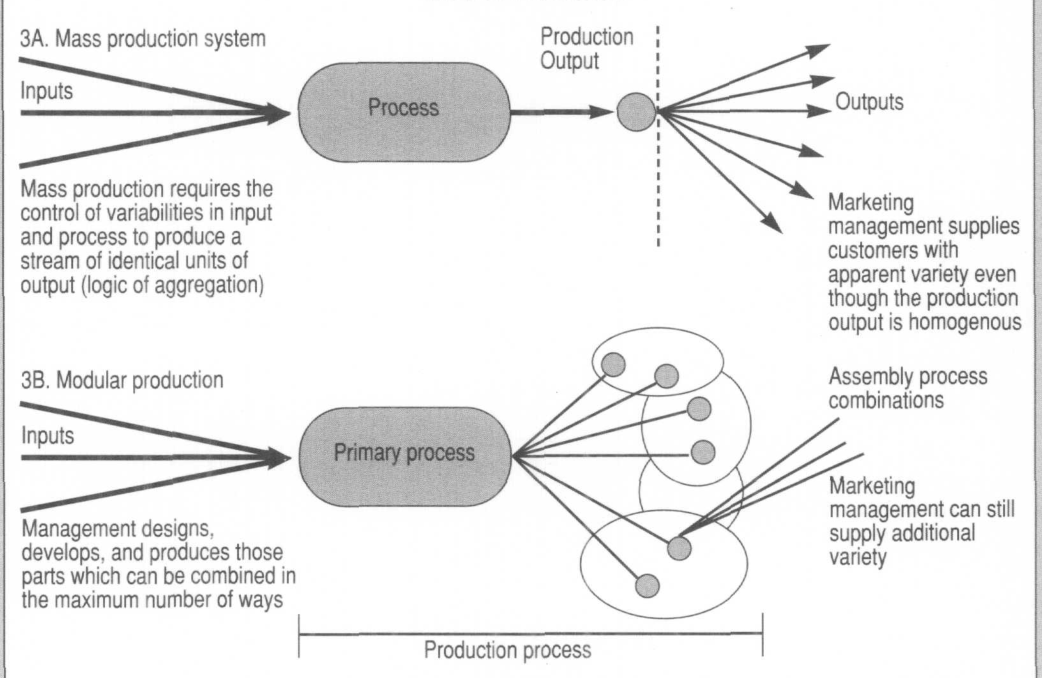
inputs and raw materials into generic modules and components; and, a secondary assembly process that combines generic parts in a maximum number of ways into finished goods (Figure 3B). In this manner a wide assortment of products can be created, in response to demands for variety. In a case study of National Pen outlined by Kotha [19], it is explained how bicycles can be ordered in eight million possible customer-specific variations based on model types, color, frame size and other features. Integrating marketing management's differentiation capabilities in the system can further customize products. Starr [20] stated that industries with short life cycles will react earlier to possibilities for modular production. In that respect, the current shrinking of product life cycles may be a reason for the increased attention being given to the principle of modular production, as confirmed by Feitzinger and Lee [21].

In summary, the application of modular production may not only be driven by logistics costs considerations, but also by lead time [22] and customization considerations [23]. The implementation of modular production at the levels mentioned above requires:

- The modularization of products to contribute to the commonality of components in products and product-groups.
- The integration of various functions inside the company; the input from R&D to (re-) design products in order to achieve efficiency based on design for logistics; the input from manufacturing to contribute to the responsiveness of marketing based on product variety and customization, etc.

It seems reasonable to experiment with the implementation of modular production on a supply chain level. Modular production at a process level involves cross-functional and cross-product aspects and may provide a step up to a cross-company application. The next section will outline how the implementation of modular production in a supply chain setting moves beyond the internal integration by expanding the application of the concept to include parties in the inbound and the outbound flow of goods.

Figure 3
Modular Production



Source: Starr, Martin K., "Modular Production, a New Concept," *Harvard Business Review*, Vol. 43, No. 6 (November - December, 1965), pp. 131-142.

The SMART Car

The SMART Case and the Volkswagen truck and bus plant in Brazil are examples of companies that are presently experimenting with the implementation of modular production in a supply chain setting.

In 1997/1998 Micro Compact Car AG (MCC), a joint-venture of Mercedes-Benz and SMH (Swatch), introduced a new vehicle concept, named SMART. Together these manufacturers have developed a new mobility concept that reduces the heavy environmental damages caused by present traffic, but still ensures continuity of individual mobility. The mobility system goes beyond the actual car, as it also includes space saving parking systems, networking with public transport systems and pool leasing. This case study will concentrate on the car itself and on the production and distribution system.

The car is a two seater mini car (smaller than Fiat 500), mainly developed for in city use. Both the car and the processes needed for production and distribution are focused on increasing the responsiveness to customer demands. In general, three stages in the supply chain are involved in achieving responsiveness.

First, the generic car is assembled in a highly automated plant in Hambach in Elzas-Lothringen in France, referred to as SMART Ville. The car is based on an integral body-frame called "TRIDION" in which modules are attached and assembled. The car consists of five main modules: the platform, the powertrain, doors and roof, electronics and the cockpit, containing sub-modules and components. The modules are supplied in sequence for final assembly, by a small number of first tier suppliers of which seven suppliers are fully integrated in the final assembly plant. These seven companies, are located at the same site as MCC and supply "super modules" based on a postponed purchasing approach. Modules are bought by the OEM only when they are needed in the final assembly process. For example, a complete rear including wheels, suspension and engine is pre-assembled by one supplier, who maintains the module in its possession until it is needed on the assembly line. The same is true for the doors and for the dashboard system. Together these seven suppliers supply 50% of the total value of the purchased goods.

In order to enable a smooth flow of goods within the plant, the car is moved along the work stations of the assembly line, which has a lay-out in the form of a cross (see Figure 4). This way the "integrated suppliers" are able to supply their finished products directly to the final assembly line. The effect of this enlarged role for the "super module" suppliers is that MCC is able to assemble the car in 4.5 hours. Apart from short lead-times, the benefits of the product design and flexible manufacturing system are that modules can be combined into a wide variety of products.

On top of these integrated companies, 16 non-integrated suppliers supply sub-modules and parts to both MCC and the integrated suppliers. It is interesting that seats and other voluminous components like exhaust systems are supplied from a distance by non-integrated suppliers. These products are often supplied from doorstep plants located in the immediate proximity of the OEM. It might indicate that for super modules, further integration into the plant of the OEM is needed, which is different from the levels of integration achieved in supply chains to date. Table 1 lists integrated and non-integrated suppliers of MCC.

The system differs from previous supply chains with respect to the activities that are outsourced. Even activities, traditionally considered core activities of the OEM, like pressing of body-parts and the painting process and the co-ordination of internal logistics, are no longer performed by MCC. Not only is there a close participation of the suppliers in the final assembly of the car, the suppliers are strongly involved in the development, planning and launching of the

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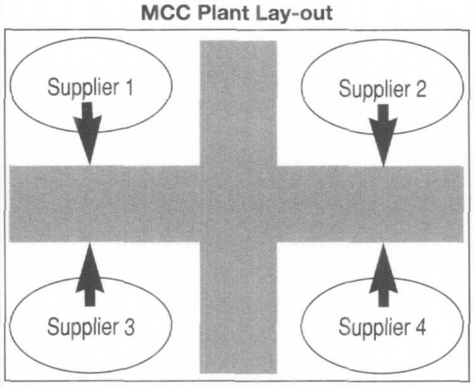
Figure 4
MCC Plant Lay-out



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product. What can be said about the outsourcing of component and module manufacturing, is also true for supporting services. The whole information system supporting the processes of MCC in manufacturing, logistics and distribution is outsourced to Andersen Consulting, who owns the hardware and the software. The same is true for the ownership of the production buildings and site management.

As a second stage of the supply chain, the distribution system is totally geared towards responding quickly to ever changing customer needs. The car will be sold at life style centers, located in shopping centers and other highly frequented places in urbanized areas. These franchise organizations will use multi-media systems to enable clients to build their car in the showroom and for forwarding the order for the car to the distribution centers. Within an order to delivery lead-time of less than one day, five interregional distribution centers in Europe, supply the dealer with the requested car. Some of the final assembling tasks, like adding special features or light final assembly, are performed at these distribution centers as a form of postponed manufacturing. Postponed manufacturing aims at delaying the customization until actual orders have been received, and performing the necessary manufacturing activities close to the customer in the distribution channel to assure short lead-times. In order to perform final finishing, the distribution center stores cars and changeable modules.

Finally, the modular concept of the car enables the customer completely to renew and upgrade the product during its lifetime, based on adding product-features and rapid replacing of body-parts. As a result, the car is more of a consumption product than a fixed capital good. And SMART can target a lasting customer relation, as well as, repeat business.

Whereas MCC applies modular production in a consumer market, Volkswagen applies modular production in an experimental factory in Brazil, where buses and trucks are assembled for the business-to-business market. As in the SMART factory, also for Volkswagen, modular production is the basis of a new supply chain configuration. In order to simplify final assembly as much as possible, VW divided the truck into seven modules, with a supplier responsible for each [24]. VW named this concept, in which all final assembly operations are transferred to suppliers, "Modular Consortium" [25]. In this plant, all direct workers are on the supplier's payroll. VW only employs 140 engineers, designers, supervisors and administrators, who supervise the 450 employees of in total seven suppliers [26]. Suppliers are responsible not only for the supply of a major module of the truck, but also for performing the final assembly together with

Table 1
Suppliers of MCC

Integrated suppliers					
1.	Bosch	Front module (Front wheel suspension, brake system, steering-system, etc.)			
2.	Dynamit Nobel	Synthetic body-panels			
3.	Eisenmann	Paint and surface protection			
4.	Krupp Hoesch	Rear module (Rear wheel suspension, integration of engine, etc.)			
5.	Magna	Safety body work			
6.	VDO	Dashboard			
7.	Ymos	Doors			
Non integrated main-suppliers					
8.	Behr	Heating system	16.	Mercedes	Engine
9.	Bertrand Faure	Seats	17.	PPG	Windows
10.	Continental	Tires	18.	SMH	Electro-/micro-motor
11.	Eberspächer	Exhaust-system	19.	Rockwell-Golde	Roof-module
12.	Freudenberg	Engine-struts	20.	Schenk	Control-/stability system
13.	Getrag	Transmission	21.	STMP	Fuel tanks
14.	Hella	Head lights	22.	TRW	Belts, airbags
15.	Magneti Marelli	Dynamo/starter/relays			

other suppliers, which goes even further than the role of suppliers in the MCC case. Suppliers even invested in the buildings and plant infrastructure.

It should be noted that, VW's concept for modular truck building, focuses largely on a reduction of production cost and throughput time by transferring work to suppliers. There is no evidence that improving the ultimate responsiveness to customers is of major importance for VW's initiative. This could well be another distinction between this example and the MCC case.

Application in Other Supply Chains

Table 2 compares the application of modular production in the SMART/MCC case with the application of modular production as found in other cases. The cases are:

- A manufacturer in the electronics industry who uses modular production for printer-products and is now implementing the system in its PC-business.
- A manufacturer of conveyors for industrial use.
- A software manufacturer.

When comparing the cases, differences can be found in the particular application of modular production. Whereas the application at MCC is based on the delaying of purchasing and final manufacturing (the next section will return to these applications of postponement), the other cases tend to concentrate slightly more on postponed manufacturing. The electronics company assembles its printers based on customer orders, as does the transport equipment company with its conveyors. The software company has postponed the packaging of products and the adding of documentation and promotion material. This application is less complex and can be explained based on the different product characteristics of a software package; this product can only be modularized to a modest extent, when compared to printers and cars. As a result, the possibility to apply modular production is limited.

Table 2 focuses on the reconfiguration needed for the implementation of modular production in a supply chain setting. The general reconfiguration tendencies found are listed and cross-company reconfiguration tendencies, most relevant with respect to the supply chain perspective, are detailed. The supply chain aspects involved in the electronics case are that the company decentralized final assembly into the market to raise responsiveness and shorten lead-times. Another important consideration was to maintain technological leadership by not outsourcing the final assembly to a competitor, who would gain access to the company's technology and printer software. The company has outsourced logistics operations in its postponed manufacturing operation to a logistics service supplier and uses temporary labor for final assembly operations. As a result, the manufacturer's head-count is lowered and only includes management-staff. These cross-company reconfiguration tendencies are even more drastic in the other two cases; both companies have fully outsourced the final manufacturing operation, the software company has only one manager stationed at the operation.

In both cases the implementation of modular production also involved a reconfiguration of the supply-base; the software company developed a European operating base with local suppliers and only sourced copies of software from its U.S. headquarters. The transport company delayed the finalization of conveyor belts and re-aligned the supply of parts. Parts are directly shipped to the postponed manufacturing operation and parts are increasingly sourced from multiple suppliers around the world. These three cases involved reconfiguration in the dealer channel, dealers are increasingly encouraged to specify desired product variants and can start selling on a consultive basis. The reconfigurations are not as extensive however, as in the MCC case, where the distributors also finalize products.

In summary, although the application at MCC may be most far-reaching, involving both postponed purchasing and postponed manufacturing, modular production in a supply chain setting is not limited to automotive supply chains and can be applied in other supply chains, such as software, hardware and conveyor belts. Because of differences in operating environment, cross-functional and cross-company relations, the specific applications and implementation paths may differ between cases. The next section describes the impact of modular production on the supply chain structure.

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Table 2
Modular Production Across Supply Chains

	MCC	Electronics	Transport equipment	Software
Product	Cars	Printers (& PC's)	Conveyors for industrial use	Graphical software packages
Application of modular production	In a postponed purchasing and manufacturing setting	Postponed final assembly and shipment	Customer specific assembly of conveyors	Postponed packaging, adding promotion material, shipment
Reconfiguration of chain needed	Zero-level suppliers in-house, finalization in distribution channel	Decentral final assembly followed by direct delivery from postponed manufacturing operation	Global sourcing of parts, decentralization of assembly into postponed manufacturing operation	Local supply base of parts, global supply of software, establishment of postponed manufacturing operation
Cross-company reconfiguration:				
OEM/ Manufacturer	Coordination/ integrating chain	Technological ownership	Delayed final assembly	One man operation in the market
Suppliers	Zero-level suppliers and main-suppliers	Outsourced warehousing and distribution operations	Fully outsourced warehouse, shipment and final assembly operation	Fully outsourced warehouse, shipment and final assembly operation
Dealers	Final configuration/ adding parts	Specification of orders	Direct selling and shipment	Specification of orders/order generation

Impact on Supply Chain Structure

Based on the first examples of modular production implemented in a supply chain setting, a number of important considerations can be identified.

Product Redesign Allows for Supply Chain Redesign

First of all, modular production requires a further product redesign, involving not only the internal production process, but aiming at a further involvement of players in the inbound and outbound flow of goods. Modules are used in both segments of the supply chain, resulting in a stage-wise increase of volume and differentiation of products (see Figure 5). Thus, postponed purchasing is combined with postponed manufacturing. Postponed purchasing of modules, which leaves suppliers in possession of goods until they are actually needed in the assembly process, is now combined with postponed final manufacturing in the distribution channel, which further increases responsiveness to customers on an efficient basis. Of course, the two types of postponement differ. Table 3 offers a comparison.

By having the supplier take over much of the inbound flow of goods, complexity of the inbound flow of goods can be lowered, offering manufacturers the benefit of one-stop shopping for modules.

Postponed purchasing involves the postponement of upstream stages of the supply chain, involving the inbound flow of goods and sourcing of goods. Whereas, postponed manufacturing is applied in the final stages of the chain involving the final transformation of products and the outbound flow of goods. By having the supplier take over much of the inbound flow of goods, complexity of the inbound flow of goods can be lowered, offering manufacturers the benefit of one-stop shopping for modules. Whereas, postponed purchasing is operated in the factory with suppliers pulled towards the factory location, postponed manufacturing is applied close to the market. Being close to the market allows for rapid delivery and customer responsiveness seems to pull companies closer to the market. The benefits of postponed purchasing are that delaying ownership allows for more accurate sourcing and lowered inventory risks based on feeding the customer order (or a last minute projection of orders) all the way to purchasing. The OEM may even decide to have the supplier take over the full inbound flow of goods based on the one-stop-shopping concept. Postponed manufacturing is aimed at responding to the customer order more accurately in finalizing the product. A joint benefit of both applications of postponement is avoiding obsolescence risks resulting from the sourcing, producing and storing of products, which the company is not sure whether or not a customer will actually buy. Both involve aligning players in the chain more closely to the market by using a pull-approach. Suppliers ship modules directly to the manufacturer and manufacturers or distributors ship directly to customers, avoiding a slow distribution process with many inventory hubs and warehouses causing even more inventory costs. Thus, it seems very powerful to combine the two, generating a new operating format, which goes beyond the traditional (product or process level) approach of modular production and the categorization of chains by Lampel and Mintzberg [27]. The categorization for example, assumes that customer orders are entered at only one point in the chain, as opposed to two points. Nor does it include specific application of postponement such as postponed packaging in the case of the software company.

Figure 5
Stage-wise Evolution Through Postponed Purchasing and Postponed Manufacturing

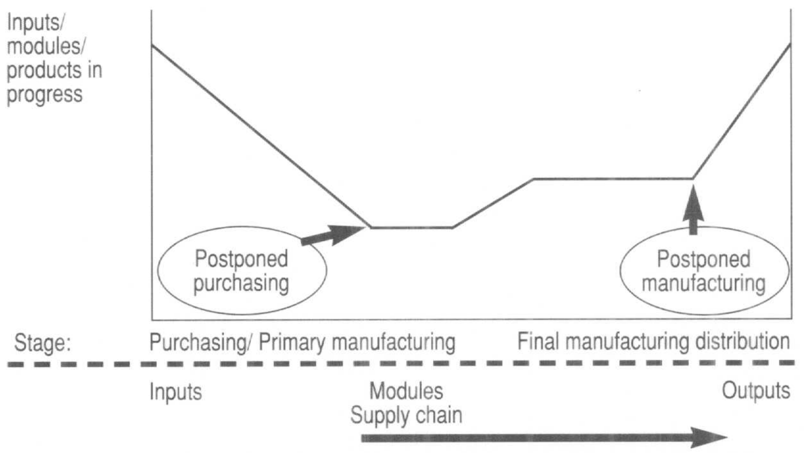


Table 3
Postponed Purchasing and Postponed Manufacturing Compared

	Postponed purchasing	Postponed manufacturing
Position in the supply chain	Upstream from the OEM	Downstream from the OEM
Location	Factory	Close to the market
Postponed activities	Sourcing and (converging) inbound flow of goods	Final transformation and (diverging) outbound flow of goods
Main targeted benefits	Delay ownership until orders have been received allowing suppliers to take over management of supply	Tuning products based on customer orders allowing the company to respond directly to market signals.

Impact of Modular Production on Upstream and Downstream Integration

Returning to the issue of raising responsiveness to customers, Feitzinger and Lee [28] rightfully stated that it is not only necessary to rethink and integrate the design of products and processes, but also the configuration of the entire supply network. Thus, modular production in a supply chain setting moves beyond traditional in-house applications of modular production. In the SMART car's supply chain, main suppliers work inside the OEM's factory and final modifications are done in the distribution outlet and the dealer channel and at the VW plant suppliers even perform the assembly themselves. Thus, suppliers integrate forward in the supply chain. A new tier of super-module suppliers is formed. Manufacturers are at present striving to further increase the complexity, value and size of the sub-assemblies sourced from their suppliers. At the same time, ever more supplier door-step plants are being opened next to the sites of OEMs, involving suppliers in the final assembly seems a logical next step.

Manufacturers are at present striving to further increase the complexity, value and size of the sub-assemblies sourced from their suppliers.

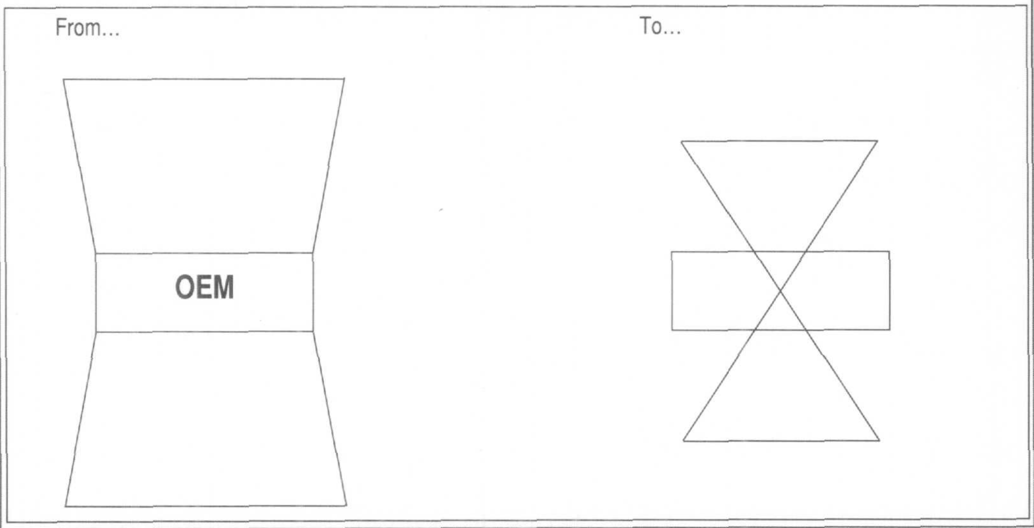
The extension of the assembly-line via distribution centers into the showroom, furthermore, leads to an improved grip of the OEM on the downstream part of the supply chain. Thus, the supply chain is further integrated through the realignment of inbound and outbound logistics.

Shifting Basis and Balance of Power

Additional critical factors in the application of modular production in a supply chain setting, are that the creation of a super module supplier tier may accelerate the battle among the system automotive suppliers for the position closest to the OEM. As an indication of the increased competitive conditions, the door-step JIT suppliers of today may not be (physically) close enough anymore to the OEM as indicated by the MCC case. In fact, the new first tier suppliers created may be called zero-level suppliers instead of first tier. As the boundaries between supply and assembly activities and functions are blurred and the supplier moves into the OEMs factory, the supplier no longer is an outside player; he becomes an integral partner that controls a significant part of the value adding process.

In that respect, a point should be made in relation to the role of suppliers in the modular production concept. It is interesting to see that a number of supplier conglomerates, after following the initiatives of the vehicle manufacturers for years, are now beginning to take the lead in defining their future role in the industry. A good example is the Lear Corporation. The company presently supplies interior components and modules, for example seats and interior panels. According to Lear, the development of interior systems can best take place in two stages. In the next few years a

Figure 6
The Impact of Modular Production on Supply Chain Integration



development is expected towards more integrated interior systems assembled into the car through the front-window and side doors. Although the complexity and size of the modules supplied will increase, the concept is basically the same as the present concept in which dashboards are pre-assembled and are mounted into the car. According to Lear Corporation, the next stage could be one in which the complete interior will be supplied as one module. Dashboards, seats, roof-panels and steering-column can be integrated to one super-module. Before the car platform and body are put together, this complete interior system will be placed on the bare platform, followed by assembly on the platform. This way the OEM saves significant amounts of time at the final assembly line. However, will it be possible for OEMs to keep their lead in design and development, when they increase the share of activities performed by third parties and suppliers? Will the OEM be able to create learning effects from the assembly processes, to keep on developing cars, based on merely doing project management in-house? For years the vehicle manufacturers maintained an extremely powerful position in relation to their suppliers. In the last decade, while OEMs in the automotive industry were under severe competitive pressures, suppliers have become more involved in producing and developing cars. A higher mutual dependency based upon longer relationships has become more common.

Figure 7 illustrates the integration of the inbound and the outbound logistics flows by the OEM based on the forward integration of the zero-level suppliers into the factory and backward integration of distributors and dealers into the final manufacturing process. This results in a decrease of OEM operational added value and direct control over activities.

The integration achieved is not based on OEM ownership, but based on network relations with parties in the supply chain. This has to do with two effects of modular production on the supply chain, that of dis-integration and re-integration. Initially, when implementing modular production in the supply chain the product is dis-integrated into separate modules. These are engineered by different teams of engineers and spread across companies leaving co-designers and super-suppliers to take care of the manufacturing and supply. Furthermore, the final transformation is spread across regional distribution centers and various distributors. Thus, looking at the flow of goods in the supply chain, the role of the OEM decreases and the flow is spread across parties and modules. However, the OEM aims to re-integrate the supply chain, into the modular consortium, based on the closer grip on the flow of information in the chain.

A critical reflection on this approach is how effective the re-integration will be as it is based on only the flow of information. Rayport and Sviokla [29] reason that it is very important for companies to develop a fully integrated "virtual value chain". However, they should do this along the integrated physical value chain, and assure a continued integration of this chain. The ideal use of the virtual value chain or integrated flow of information they describe is one in which the virtual and physical chains are used in a synergistic way to create new markets and products. This suggests that OEMs are approaching the end of further possible integration based on networking, as they are almost entirely excluded from actual operations. The OEMs begin to look like empty design and marketing companies. Examples from the clothing industry, an industry that has moved towards complete outsourcing and subcontracting of manufacturing to outside companies, indicates the risks involved. Due to its lack of operational experience, one company we studied had to ask its suppliers for a factory tour and for information about the manufacturing process before being able to design a new line of jeans. Of course, a related risk is that zero-level suppliers, will by-pass the OEM and move directly to super-distributors that have developed the capability to very effectively service customers based on their experience with postponed manufacturing.

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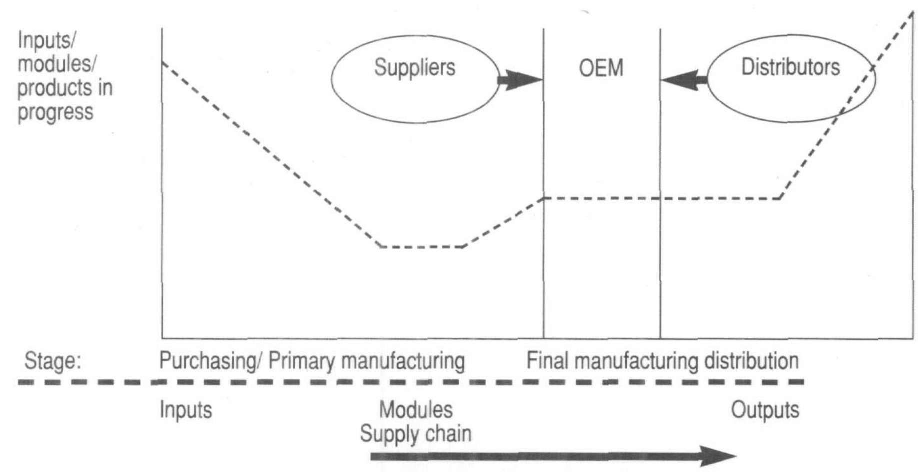
Strategy Implications for The Players in The Chain

The previous section raised a number of issues relevant for the various players in the supply chain. This section details strategy implications of the modular production concept for the strategies of the three players along the chain that were included in case studies; zero-level suppliers, the manufacturer/OEM and the distributors/ dealers.

Table 4 outlines some of the most

Figure 7
The Decreasing Role of the OEM in a Supply Chain Operations



prominent strategy consequences of the modular production concept for the players in the MCC case. This case was used because it was found to be the most far-reaching of the cases presented in Table 2. Starting with the super-module or zero-level supplier positioned upstream in the chain, this player increasingly becomes an extension of the OEM. Not only does this supplier organize the supply network consisting of lower level suppliers, he co-engineers and may even co-own the assembly factory, but has to assure proximity to the OEM facility to assure short lead-time windows. The benefit of this development for the supplier is that increasing shares of the added value created in the chain are under its responsibility based on forward integration into more and more operational tasks. Also, the supplier can contribute to product development based on advancing modules, as long as the proper interfaces are used with the overall product architecture, specified by the OEM. The risk is that the supplier becomes increasingly dependent on a few customers. Autoliv, for example, invested in an airbag assembly operation in order to supply GM. The facility is located fairly close to the GM operations and initially operated for GM only. In order to lower dependence, Autoliv is now supplying airbags to multiple customers located within acceptable distance from the facility. In this process, knowledge co-developed with GM is used to win new customers and allows Autoliv to strengthen its position as an innovative and leading supplier. This approach supplements the Lear-strategy, which more aggressively targets independence of the OEM.

For the OEM, positioned intermediately in the supply chain, the challenge is to assure its leading position in the chain while being dependent on outside suppliers that perform most of the operational tasks in the supply chain. In order to assure and improve its position and the overall chain performance OEM's like Mercedes focus on the coordination and integration of the players in the chain using its overview of technologies, the overall production process and the specification of the overall product architecture. Its operational contribution increasingly reflects that of a project-manager, as less assembly and logistics activities are performed in-house. When well-coordinated, the modular production concept can be used to achieve mass customization with the ultimate purpose of raising market-share or even creating new market-segments of, for example, supermarket buyers.

Most logically this involves downstream players, the distributors and dealers. They operate regional distribution centers in important market-areas and also perform product finalizing activities. Whereas the dealer might have been perceived as an instrumental player in the past, this does not reflect the pull-reasoning of postponement and modular production. One of the central elements of supply chain management is that the final customer determines what value is [30]. Applying such reasoning makes the dealer critical in feeding market-signals and customer orders into the chain, the dealer thereby directs many upstream players. Of course, this is not without challenges. Dealer development programs are assisting dealers in the implementation of intelligent datasystems. Those involve point-of-sale data systems to rapidly transfer market-signals upstream, to multiple players. Customer information systems are used to increase turn-over and strengthen customer relations through direct marketing efforts, such as sending letters reminding customers that it has been six months since the last technical check-up. Also the sales-force has to be upgraded as sales become more consultative and the sales-force has to design a unique car together with the customer. In doing so, new marketing channels are developed; supermarkets will be used as sales-outlets, thereby creating new market-segments.

Most important may be that the distributor and dealer have to expand their operational role beyond distribution and sales activities into product finalization and other upstream activities, in order to assure market-orientation of manufacturing, to specify design requirements in engineering teams and to co-develop distribution

Table 4
Changing Strategies of Players in a Modular Supply Chain

	Super module supplier	OEM/Manufacturer	Distributor/Retailer
Position in the chain	Upstream	Intermediate	Downstream
Geographic position	At the assembly plant	Global/continental operations	RDC's in market-area, sales outlets locally, some in supermarkets
Role in the chain	Zero-level supplier; extension of the OEM	Coordinator/integrator; most value created outside the OEM	Setting the chain in motion based on sales and product finalization
Dominant activities in the chain	Assembly, logistics, co-design and integrating supply	Some assembly and logistics activities still done, concentration on project management	Some assembly, sales and distribution activities
Dominant contribution to the chain, in general	Increasing share of operational added value	Technological, process knowledge, integration of chain	Market contact, feedback of customer information, consultative sales
Specific knowledge contribution in the chain	Technological lead at module level	Overall-product architecture and integration of flow of information	Market knowledge generation
Main challenges	Assure independence and use lead customers in developing broader customer base in multiple geographical markets (involving globalization)	Coordinating and developing supply chain format. Using mass customization to increase market-share and create new market-segments	Improving responsiveness to customers and aligning chain to pace of the market

structures and service-levels. For one thing, this will mean that lead-times of six months or longer for new cars, resulting from the optimization of production in massive production-batches, will no longer be the case. Based on such strategies the automotive supply chain can be increasingly geared to the pace of the market, or rather, to individual customers. Providing rapid customization at competitive price-levels to customers will not only assure the position of the dealer/distributor, it will raise the competitiveness of the entire chain.

Conclusion

This paper outlines how the concept of modular production, when applied in an extended supply chain setting, can impact the structure of the supply chain and the relations among parties involved in the inbound and outbound flow of goods. The combined application of postponed purchasing and postponed manufacturing is expected to contribute to an increased responsiveness to customer demands on a cost-efficient basis, that is, the mass customization of goods. Based on a comparison of four cases it was found that, despite differences in operating format and content, modular production can be applied in a variety of different supply chains and industries.

A number of issues were identified which impact the implementation process. In general, attention shifts towards supply chain relationship considerations when management takes a supply chain-wide approach of modular production. As a consequence, roles, positions and contributions to knowledge and added value are dynamic and complex. We will learn more about these "chains in change" in the near future. For the time being it is clear that modular production is becoming one of the practical business concepts that provide input to realizing the vision of a truly integrated supply chain.

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References

[1] Starr, Martin K.,"Modular Production, a New Concept," *Harvard Business Review*, Vol. 43, No. 6 (November - December, 1965), pp. 131-142.

[2] Pine II, Joseph P., *Mass Customization*, Boston, MA: Harvard Business School Press, 1993.

[3] Lampel, Joseph, and Henry Mintzberg, "Customizing Customization," *Sloan Management Review*, Vol. 38, No. 1 (Fall, 1996), pp. 21- 30.

[4] Dittmann, Paul, Presentation at the CLM Annual Conference reproduced in the Conference Proceedings, Oak Brook, IL: Council of Logistics Management, October 20-23, 1996.

[5] Ealey, Lance, and Luis Troyano-Bermudez, "Are Automobiles the Next commodity?" *McKinsey Quarterly*, No. 4 (1996), pp. 63-75.

[6] Anderson, James C., and James A. Narus, "Capturing the Value of Supplementary Services," *Harvard Business Review*, Vol. 73, No. 1 (January - February, 1995), pp. 75-83.

[7] Feitzinger, Ed, and Hau L. Lee, "Mass Customization at Hewlett-Packard: The Power of Postponement," *Harvard Business Review*, Vol. 75, No. 1 (January - February, 1997), pp. 116-121.

[8] Cooper, James C., "Logistics Strategies for Global Business," *International Journal of Physical Distribution & Logistics Management*, Vol. 23, No. 2 (1993), pp. 12-23.

[9] Kuhlmeijer, Hein J., "Platforms voor Produktinnovatie en -Variatie," *Markeur, Marketing Associatie*, Erasmus Universiteit Rotterdam, No. 3 (1997), pp. 50-51 [in Dutch; "Platforms for product innovation and variety"].

[10] Hoekstra, Sjoerd, and Jacques H.J.M. Romme, *Op weg naar Integrale Logistieke Structuren*, Deventer: Kluwer bedrijfswetenschappen, 1985 [in Dutch].

[11] Pine II, Joseph P., *Mass Customization*, Boston, MA: Harvard Business School Press, 1993.

[12] Collier, David A., "Aggregate Safety Stock Levels and Component Part Commonality," *Management Science*, Vol. 28, No. 11 (1982), pp. 1296-1303.

[13] Collier, David A., "Aggregate Safety Stock Levels and Component Part Commonality," *Management Science*, Vol. 28, No. 11 (1982), pp. 1296-1303.

[14] Sheu, Chwen, and John G. Wacker, "The Effects of Purchased Parts Commonality on Manufacturing Lead-Time," *International Journal*

of *Operations & Production Management*, Vol 17, No. 8 (1997), pp. 725-745.

[15] Starr, Martin K.,"Modular Production, a New Concept," *Harvard Business Review*, Vol. 43, No. 6 (November - December, 1965), pp. 131-142.

[16] Starr, Martin K.,"Modular Production, a New Concept," *Harvard Business Review*, Vol. 43, No. 6 (November - December, 1965), pp. 131-142.

[17] Lampel, Joseph, and Henry Mintzberg, "Customizing Customization," *Sloan Management Review*, Vol. 38, No. 1 (Fall, 1996), pp. 21- 30.

[18] Starr, Martin K.,"Modular Production, a New Concept," *Harvard Business Review*, Vol. 43, No. 6 (November - December, 1965), pp. 131-142.

[19] Kotha, Suresh, "Mass Customization: Implementing the Emerging Paradigm for Competitive Advantage," *Strategic Management Journal*, Vol. 16 (1995), pp. 21-42.

[20] Starr, Martin K.,"Modular Production, a New Concept," *Harvard Business Review*, Vol. 43, No. 6 (November - December, 1965), pp. 131-142.

[21] Feitzinger, Ed, and Hau L. Lee, "Mass Customization at Hewlett-Packard: The Power of Postponement," *Harvard Business Review*, (January - February, 1997), pp. 116-121.

[22] Sheu, Chwen, and John G. Wacker, "The Effects of Purchased Parts Commonality on Manufacturing Lead-Time" *International Journal of Operations & Production Management*, Vol. 17, No. 8 (1997), pp. 725-745.

[23] Starr, Martin K.,"Modular Production, a New Concept," *Harvard Business Review*, Vol. 43, No. 6 (November - December, 1965), pp. 131-142.

[24] Sedgwick, Dave "Suppliers Build Trucks for VW Plant B", *Automotive News Europe*, 1997.

[25] Salerno, Mario S., Mauro Zilbovicius, and Roberto Marx, "The Modular Consortium," at the new VW's truck plant in Brazil: a case study of a "Virtual Factory," *Proceedings from the 3rd EurOMA Conference*, London: London Business School, 1996.

[26] Sedgwick, Dave "Suppliers Build Trucks for VW Plant B", *Automotive News* Europe, 1997.

[27] Lampel, Joseph, and Henry Mintzberg, "Customizing Customization," *Sloan Management Review*, Vol. 38, No. 1 (Fall, 1996), pp. 21- 30.

[28] Feitzinger, Ed, and Hau L. Lee, "Mass Customization at Hewlett-Packard: The Power of Postponement," in: *Harvard Business Review*, Vol. 75, No.1 (January - February, 1997), pp. 116-121.

[29] Rayport, Jeffrey F., and John J. Sviokla, "Explioting the Virtual Value Chain," *Harvard Business Review*, Vol. 73, No. 6 (November-December, 1995), pp. 75-85.

[30] Womack, James P., and Daniel T. Jones, *Lean Thinking*, London: Simon & Schuster Ltd., 1996.

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