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Distributed mini-factory networks as a form of real-time enterprise: concept, flexibility potential and case studies*

Competition in the real-time economy

The dynamics of market demands require manufacturers to be flexible. Currently, however, more flexibility can only be achieved with a considerable trade-off in resource utilization. Under-utilization of resources in many companies presently lies at between 20–50%, resulting in massive cost disadvantages.

This particularly applies to the field of machine and plant engineering. The main reason for poor resource utilization is that today's value-added chains are geared toward product and unit quantities. To a large extent, flexibility and efficiency have only been optimized at the level of the individual enterprise. In part, this is due to product complexity and the shortening of delivery times in recent years by almost 50% (Eggers/Kinkel 2002).

Since the potential within companies for rationalization and flexibility has largely been exhausted, the most promising avenue for responding to the need for further dynamics in the creation of value today is considered to be the reorganization of the entire value-added chain across company boundaries. At the center of attention is production that takes place in dynamic, quickly adaptable networks. Complementary and partially overlapping production competencies in a value-added network permit the metamorphosis from rigid value-added chains to highly dynamic networks (Zahn/Foschiani 2002). Interaction within dynamic production networks

* This article draws largely on the initial results of Collaborative Research Center 582, "Production of individualised products close to the market" (http://www.sfb582.de/), advanced by the Deutsche Forschungsgemeinschaft (DFG - German Research Foundation) in Bonn.

stabilizes and improves utilization of existing production capacities. As a direct consequence, this permits a reduction in investments in the plant and equipment.

The buzz word "real-time economy" describes management and planning practices of the company as a direct response to customer wishes, market demands and to the circumstances of external value partners (Reichwald/Piller 2003, p. 515f; The Economist 2002). Traditionally, supply and demand have been decoupled, an approach that leads to efficiency benefits from an internal point of view, but that from the perspective of value-added chains causes mounting adaptation costs due to the increased dynamics of demand. Thus, instead of decoupling supply and demand, output generation is to be triggered within a network in direct response to a specific market demand.

An organizational form that is able to ideally adapt to a "real-time economy" is the "real-time enterprise". An important feature of the real-time enterprise is its ability to flexibly link output generation to existing customer wishes. Specifically, this means: Large parts of the value-added chain are not activated until after a customer order has actually come in. Until now, lead times have at best been unaffected in an order handling network, although such networks typically tend to extend lead times because of the additional interfaces. The market, of course, is unwilling to accept the associated delivery delays and demands "real time". Therefore, a further goal is implementing competency network structures that would make it possible to substantially reduce lead times to as little as one tenth of today's values. This in turn would result in a dramatic reduction in the level of non-fixed assets in the network (see figure).

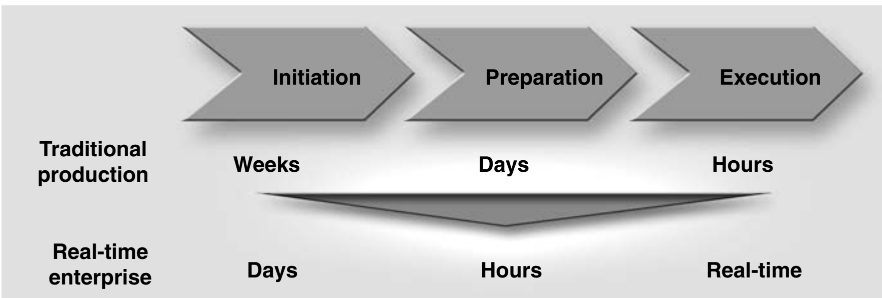

Figure 87: Goals of the real-time enterprise (source: WZL, RWTH Aachen)

This type of modern management gives rise to new cost structures and cost reduction potential generated by a customer-specific and customer-integrated creation of value (Piller/Möslein 2002; Reichwald/Piller 2002a). Where up to now discussion has primarily centered around procurement-related approaches to supply chain management or "efficient consumer response", which are likewise based on the potential offered by an intensive, informative and up-to-date network of interdependent value partners in real-time, this article will focus on the "real-time" inclusion of customers.

The basis for efficient and effective management in real-time is the improvement of the knowledge base, both from a procurement-related and customer-related perspective. In this regard, intensive discussions under the heading of "Customer Knowledge Management" have recently dealt with the broadening of information and knowledge management to include knowledge about customers and knowledge contributed by customers. While "knowledge about customers" tends to aim at the familiar approaches of market research and the evaluation of customer data by means of CRM activities (purchase histories, customer account cards, scanner data, etc.), "knowledge contributed by customers" refers to new techniques that actively include the customer in knowledge acquisition (see Piller/Stotko 2003; 2004). The approach is to directly involve customers in corporate output generation. The customer becomes an integral part of the dynamic value-added network.

Mass customization is a comprehensive concept for the efficient integration of customers in flexible, inter-company value creation (for basic information, see Piller 2003; Pine 1993; Pine 1997; Victor et al. 1996; for current developments, see, e. g. Reichwald/Piller 2002b; Reichwald et al. 2003 and in particular the articles in Tseng/Piller 2003). The goal of mass customization is to create customized products and services at an efficiency equal to that of mass production. While scientific discussion and practical implementations of the concept initially focused on enhancing production flexibility by introducing modular product structures, the emphasis has now shifted to accessing customer knowledge through customer integration. Customer interaction, which automatically becomes necessary when customizing products or services (during the configuration phase), is a very valuable source of information on the customer and from the customer. Thus, this information is used not only in the creation of the respective customized product or service, but is also a contributing factor in the long-term improvement of output potential.

In this regard, the necessity for and increased significance of customer knowledge have led to a fundamental discussion of existing organizational structures for output generation (Reichwald/Piller 2003). Access to customer knowledge demands close customer relations. Dealing in real-time demands new organizational structures. Therefore, the focus of this article will be on a new organizational approach, namely that the prevailing division of tasks between centralized production and distributed sales is to be replaced by distributed mini-factory structures in the form of integrated sales, innovation, customer interaction and production units that are in close proximity to the customer. The aim is to achieve a more efficient customized production (efficient flexibility) in addition to improving access to customer knowledge. The mini-factory is where customer integration occurs, and it is here that real-time management takes place.

Thus, the mini-factory network represents the ideal model of a real-time enterprise. In fact, futurologists have already projected the implementation of this organizational form. “Instead of new factories overseas, there will be an increase in independent mini-factories in an urban context thanks to innovative production engineering such as real-time manufacturing,” was the forecast that appeared in a current article for the year 2020 made by Burrmeister et al. (2003, p. 119). In the course of the present article we will show that mini-factories are not merely an idea for the future, but are already coming into existence today and have begun to develop their potential.

After a short description of mass customization, we will elaborate on the concept of the mini-factory as a specific form of the new organizational structure required for mass customization. Then we will examine the advantages of such a structure with regard to increased flexibility and efficiency in the context of a real-time enterprise. To demonstrate that these mini-factories are not merely a vision of the future but have already become reality, we will then present several case studies that clearly illustrate the theory underlying the concepts and demonstrate that they are founded in reality.

Mass customization as a response to the real-time economy

The term “mass customization” coined by Davis combines the inherently contradictory concepts of “mass production” and “customization”. Its objective is: “[...] the same large number of customers can be reached as in mass markets of the industrial economy, and simultaneously they can be treated individually as in the customized markets of pre-industrial economies" (Davis 1987, p. 169). To this end, the production of products and services must to meet the following conditions (Pine 1993, 1997; Piller 2003; Tseng/Piller 2003):

- Customized products on offer answer to the differing needs of each individual customer. However, from the perspective of the product policy, the selection options are limited (unless the digitization of individual components or production processes permits a virtually unlimited adaptation without efficiency losses). The goal of production is to use stable processes to produce customized products.
- A (relatively) large market is targeted that corresponds to the market segments that would have been targeted with traditional mass-produced goods.
- The price for the customized goods is not so high as to lead to a change in the market segment, i.e. the same customers that previously would have purchased a comparable mass-produced article would now decide for the individualized mass customization article. There is no shift to a higher market segment as is usually the case for customized production.
- The information that is acquired in the course of the customization process is used to build a lasting individual relationship with each and every customer.

Until now, mass customization has usually been implemented centrally on the basis of mass production processes. This is in accordance with recommendations stemming from research and practical experience from the time when the production of customized products first became an issue at the beginning of the 1990's. "Pine 1993 and Kotha 1995 both explore standard product producers integrating mass customization into their product lines. Pine states that mass production is the counter point for mass customization and that standardization of products is a starting point for the development of mass customization. Kotha explores the learning relationship between mass customized and standard product production at the same plant" (Duray 2002, p. 319).

However, an examination of failed pioneers of mass customization has led to a rethinking of the concept of a centralized production of customized products (Piller/Ihl 2002). Traditionally, mass customization was considered to lie in value-added functions that were subject to great change within the individual functions, but that left the inter-functional division of tasks largely untouched. This meant, for example, that production would implement new technologies, production planning approaches and conveyor systems; sales would change a salesperson's image to that of a consultant who responds to customer needs using highly complex configuration systems. The division of tasks between production and sales, however, remained traditional. The only advancement was to be the use of new information systems to improve the interfaces for the purpose of meeting increased information-related demands.

With all its advantages, mass customization nevertheless is subject to a number of problems (Piller/Ihl 2002) that, in our opinion, can at least in part be ascribed to existing organizational structures. For example, the abundance of information that must be exchanged between the customer and the provider for the purpose of customization often brings on uneasiness and frustration in the customer, a situation that could end in the discontinuation of the customer relationship (Franke/Piller 2003; Huffmann/Kahn 1998). Another weak spot of many concepts has turned out to be the poor market proximity exhibited by many companies. For too many goods, customization is based on cultural and regional distinctions or on certain sector structures. Many manufacturers of mass-produced and series-produced goods long ago relinquished the notion of being globally active with a single product program. However, the same applies to modular product systems and selection options offered by mass customization companies, who generally need to become more market-oriented than they now are. Other points are excessive delivery times, high logistics costs and inadequate information for customers on order status.

This analysis prompted the idea of abandoning the prevailing concept of a centralized production model and replacing it with a distributed model. The outcome is a vision of a market-oriented, efficient production of customized products in mini-factory structures. These structures are the focus of the Collaborative Research Center SFB 582, advanced by the Deutsch Forschungsgemeinschaft (DFG – German Research Foundation) at the Technical University of Munich (see www.sfb582.de), on whose initial results this article is based.

Below follows a discussion of the economic potential of the real-time production of customized products and services in mini-factory structures. As a comprehensive example, we have selected the customization of a cleaning robot, a choice that is also the development scenario at SFB 582. The robot can be customized either with regard to its physical characteristics (design, functionality, quality, etc.) or with respect to the accompanying services (e. g. cleaning services). For example, customers can fashion the cleaning robot according to their personal design preferences (e. g. "to match the color of the furnishings"), to the available space (e. g. "device is to be stored in a narrow space beneath the stairs") or, above all, to functional requirements (e. g. type of floor, climate, cleaning program). The device can also be customized by selecting specific services, such as a cleaning crew responsible for the infrequent and strenuous task of cleaning difficult to reach areas (e.g. windows). In this way, a comprehensive cleaning solution (product service system) can be created by combining customized hardware and additional services.

Mini-factories as a real-time enterprise

Definition

In contrast to large factories with a 'Tayloristic' style, mini-factories are able to respond flexibly to sales and production tasks because of the aggregation of a number of functions "under one roof". Mini-factories perform independently on the market and must be able to manage customer interaction both before and after the purchase while also producing customized solutions. To be able to accomplish these core tasks, a mini-factory is designed as a scalable, modular, geographically distributed unit that is networked with other units of this type. A mini-factory performs the entire scope of activities necessary to effectively serve the customer. This particularly includes designing the product with heavy customer involvement, supplying the product and providing customer service after the purchase. This means: mini-factories must be located in their customers' vicinity and, in addition to sales activities, must also carry out repair and maintenance work on the purchased products and offer supplementary services (e. g. complementary cleaning services). In the operative area, i. e. when involving customers in the value-added process, a mini-factory must handle the following process steps (Figure 88):

- Recording of customer specifications by sales personnel using tool kits (configurators),
- Translation of customer specifications to customized product features (this may include a complete redesign of the product),
- Customized production of the product requested by the customer and
- Delivery of the product, customer service over the product life and initiation of a repeat sale.

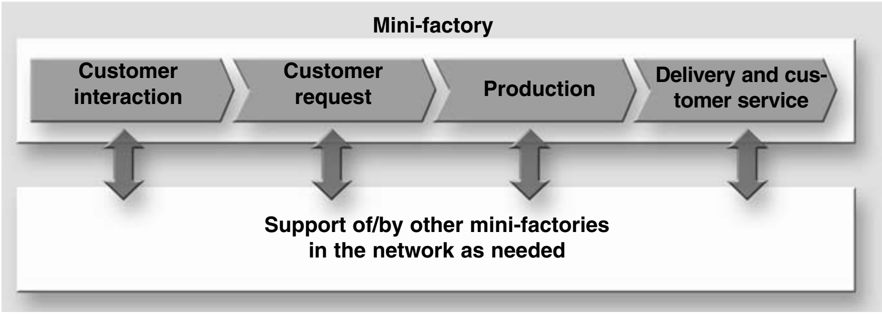

Figure 88: Operative processes handled by a mini-factory

However, the range of tasks handled by a mini-factory goes still further: In addition to the operative activities involving the customer, the mini-factory is responsible for structuring potentials, an area that is unconnected with the customer (see Figure 89). "Structuring of potentials" refers to the designing of company workflows that are not related to customer requests (e. g. the design of modeling and analysis techniques used for customer integration). By contrast, "operative activities" refers to the execution of processes for the purpose of meeting individual customer requirements. A mini-factory has the capability of quickly reacting to customer feedback by adjusting strategic, tactical and operative potentials. In this way, it is able to modify the process design of production and interaction systems and the architecture of product and service design in order to gain a strong position in its particular market. In this regard, mass customization in mini-factory structures is primarily intended to improve access to customer knowledge and to use it purposefully, both for a current order and for improving overall company potential in the long-term.

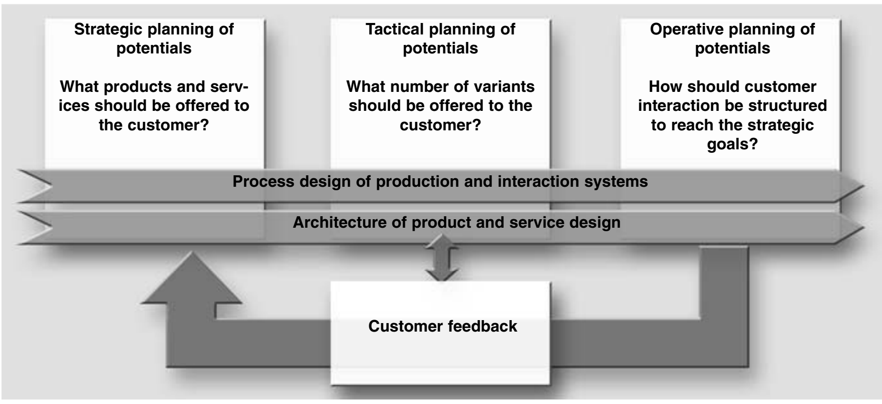

Figure 89: Potenzialplanung in der Minifabrik

Differentiation from similar organizational forms

Unlike businesses in the skilled trades, which also feature many of the above-mentioned characteristics, the mini-factory is part of an enterprise that consists of a network of mini-factories. The individual mini-factories within this network interact intensively with one another. The network between the mini-factories serves the purpose of exchanging knowledge, a process that is just as important for configuring customized products and services as it is for marketing and production. The exchanged information relates to the feasibility of the customer request, the ensuing costs, technical details, general experience and customer profiles (Reichwald et al. 2003, p. 56). If a customer requests an unusual specification, an inquiry within the mini-factory network for similar specifications can significantly increase solution efficiency. A conceivable situation would be a customer who contacts a mini-factory in Germany to design a cleaning robot for hot and humid environments (e. g. for cleaning saunas). An inquiry in the mini-factory network might reveal that a similar order had once been filled in a Swedish mini-factory. Instead of "reinventing the wheel", the mini-factory designer can present the German customer with the Swedish solution and quickly fulfill the customer's request. Production specifications for the solution could likewise be passed along. Ideally, the Swedish mini-factory would already have gathered suggestions for improvement in the course of customer care following sale of the product, and these suggestions could flow directly into the German product. Mini-factories also differ from traditional businesses in the skilled trades in that they have a central support unit. It supplies all mini-factories with standard components, basic product developments and employee training.

Our mini-factory concept also differs from applications discussed in literature that come fairly close to our concept and are based on similar principles, usually at the production level (for an overview, see the table below. The first three concepts listed there, MIRS, PLUTO and Küche Direkt, will be described in detail in the last section of this article). The U. S. military's concept of the mobile parts hospital (MPH) shares with our concept the principle of an efficient production of small batches and the transferability of solutions between different "markets". The MPH aims to accelerate the supply of replacement parts in the field by manufacturing parts on location in a mini-factory: "The overall approach is to develop a mini-factory that can be deployed to the field to manufacture replacement parts so that military equipment can be quickly returned to fully operational combat ready status" (no author, 2003b).

This approach differs from our mini-factory primarily in that it doesn't require involved customer interaction for product specification. All data required for replacement parts are transmitted to the mini-factory in the field via satellite from a database that contains the technical specifications for all parts in the deployed military apparatus. Thus, this version of a mini-factory plainly shows the flexibility of this kind of production unit. Almost any replacement part can be promptly produced nearly anywhere in the world. This type of flexibility is also of great significance to replacement part businesses in the civil sector: it is precisely the quick supply of rarely needed replacement parts (e. g. ventilation fans for 20-year-old car models) that is the strength of mass customization in a mini-factory (Suomala et al. 2002). However, this production-related aspect will not be discussed further in this article since it deals with an order-based production of standard and not customized parts.

Table 6: Defining characteristics of the SFB 582 mini-factory

Concept of...	SFB 582	MIRS	PLUTO	Küche Direkt	MPH	IPA
...tools with which customers can construct their own designs	Customers can design a customized product from the ground up using CAD tool kits.	Not a main focus, but individual volume specifications can be made, such as replacement part requirements.	Not a main focus, but the entire range of variants can be produced.	Selection of a customized kitchen with the support of a salesperson.	Not a main focus	Not a main focus
...production facilities that permit the efficient production of batches of size 1	Development of several techniques (e.g. computer-supported drive, droplet pressure, etc.).	Robot production. Complete break with existing production procedures.	Completely new procedure that eliminates the requirement for uninterrupted production.	Comprehensive implementation of customized production.	Agile manufacturing on location.	Not a main focus, possible for some applications.
...processes that allow the use of mass customization as a CRM instrument	The mini-factory provides after-sales customer care (economies of relationship).	Not a main focus	Not a main focus	Not a main focus	Not a main focus	Not a main focus
...structures for easy transfer to new markets and scales.	Modular structure at the process level permits scaling and installation at other locations.	Modular structure permits scaling and installation at other locations.	Not a main focus, but possible in principle.	Modular structure permits scaling and installation at other locations.	Main focus on mobile implementation, possible in principle.	Not a main focus, possible for some applications.

Another example of a mini-factory is that designed by the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), the "Advanced Modular Micro-Production System" (AMMS), which meets the requirements for system components with a modular and miniaturized design. Using standardized interfaces, small handling and process modules are mounting on a desktop platform in plug-and-play mode and combined to form a manufacturing system. From the range of modules available, the user can select the modules required for his or her specific application and assemble an AMMS production structure. The module interfaces have been simply designed so as to permit a rapid alteration of the manufacturing concept (Dobler/Malthan, no year).

However, this type of mini-factory does not allow for the changed economic situation described above, but addresses the challenges in manufacturing that arise from the miniaturization of components. The increased miniaturization of mechanical and electronic components demands suitable manufacturing technologies characterized by the efficient manufacture of small series in a large number of variations, high changeover flexibility, low investment costs and small space and infrastructure requirements. However, this has no effect on customer interaction, an aspect that is essential to our concept of a mini-factory. Nevertheless, there is one feature that may prove interesting and could be implemented as a building block in the mini-factory for mass customization. The ability of the AMMS to generate a modular production design could be used to create a structure that enables the transfer of the potential of the mini-factory into new markets by scaling and copying mini-factory modules.

Mini-factory structures as we envision them have already been realized at Schott Zwiesel, Pirelli and Küche Direkt (see also "Mini-factories for market-oriented production"). These case studies are evidence of the efficiency advantages that can be gained from the production of customized products in distributed locations. For example, offering customized goods is more costly on account of the greater flexibility. This can be counterbalanced by the improved efficiency brought on by customer interaction and production. The MPG and AMMS examples described above will not be discussed in further detail, since they do not generate specific efficiency benefits in the production of customized products. They were included here merely to demonstrate the existence of smaller production plants.

Economic potential of a mini-factory

Applying the mini-factory concept

A network of mini-factories is only one method of combining efficiency and flexibility in a real-time enterprise. There will continue to be tasks that are more suited to a traditional system in which there is a delay between production and the customer request. Using a situation-based approach, we will now identify the situations in which a mini-factory structure is advantageous over a centralized production. As situation variables, we will use the mini-factory tasks shown in Figure 5. The task characteristics will be the same as those selected in Picot et al. (2003): variability, specificity, frequency, structuring and similarity. Plotting the degree of these task characteristics against the functions involved in processing a mass customization order results in the structure shown in Figure 90.

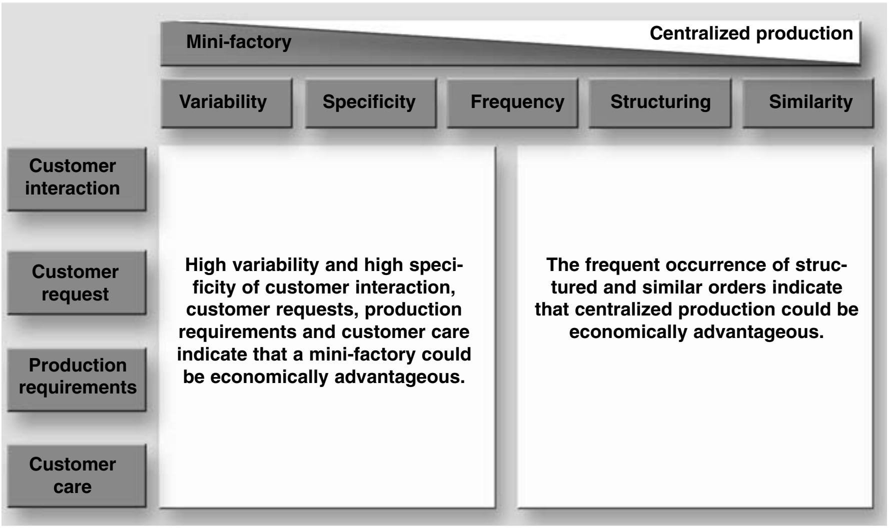

Figure 90: Dimensions of customized production

This analysis demonstrates that a mini-factory is suitable for creating customized products and services if a company's situation is characterized by a high degree of variability and specificity. This would cause the company to be highly insecure about being able to fulfill customer requests and its products would undergo significant depreciation if rejected by the customer. These are important requirements that arise in the environment of a real-time economy. When producing customized products, this situation usually arises when a company offers an unrestricted customization of its products that goes beyond a simple combination of modules. In the example of the customized cleaning robot, this would be the case if the housing style were to be designed entirely according to customer request without any module restrictions. In contrast, a strictly modular offer of customized products on the basis of fixed components would tend to favor production in a centralized factory.

We will elaborate on this argumentation in the following two paragraphs, in which we discuss the specific potential benefits offered by outsourcing production into mini-factories. These advantages must balance out the additional cost of mass customization resulting from increased flexibility if one is to meet the objective defined for the concept (i. e. a level of efficiency comparable to that of mass production). Figure 91 provides an overview of the following argumentation.

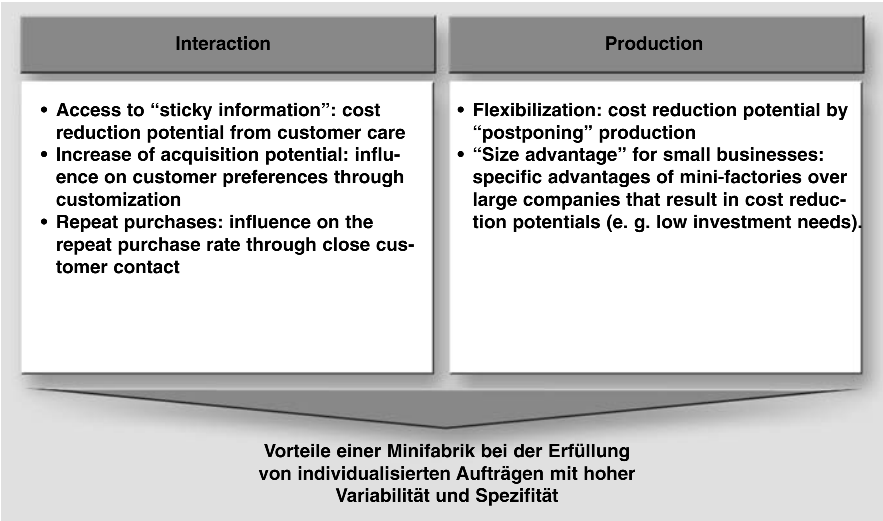

Figure 91: Advantages of a mini-factory with regard to interaction and production

Customer interaction in the real-time enterprise

Access to "sticky information": cost reduction potential from customer care through "customer interaction"

The starting point of our argumentation is the necessity for better access to knowledge about customers and to knowledge contributed by customers as the basis for running a company in real-time. In this context, the proximity of a mini-factory to the market offers a cost reduction potential resulting from better access to customer knowledge. Customer interaction in a mini-factory generates better access to "sticky information". The stickiness of information is defined as follows: "We define the stickiness of a given unit of information in a given instance as the incremental expenditure required to transfer that unit of information to a specified locus in a form usable by a given information seeker. When this cost is low, information stickiness is low; when it is high, stickiness is high" (from Hippel 1994, p. 430). One possibility of receiving information on what the customer really wants is to employ the instruments of market research. However, especially in the area of customized products, these methods are usually inadequate. "Need information is very complex, and conventional market research techniques only skim the surface" (from Hippel 2001, p. 247). Traditional market research methods commonly only assess the current situation and often do not contribute to the correct assessment of future customer requirements. The resulting strategic gap between built-up output potential and requested output and the ad hoc measures needed for closing this gap are a significant cost driver in companies that simply are not able to collect the right customer information in real-time.

Customer interaction in a mini-factory offers a new approach to understanding customers and recognizing their future needs. Access to this information during order handling lowers access costs to "sticky information" and thus contributes to efficiency improvements in market research. This can lead to a reduction in transaction costs in a mini-factory in the areas of initiation, negotiation and handling of subsequent orders. What's more, costs arising from the multiple iteration loops necessary to accurately record customer wishes and translate them into customized product features are lowered through the greater accessibility to "sticky information" in a mini-factory. "Sticky information" is used at the various levels at which the potential benefits of mass customization are planned, as introduced above in Figure 91.

In our view, the cost of access to "sticky information" is easier to reduce in a mini-factory than in a centralized production with distributed sales. The reason for this lies in the nearness of sales (e. g. show rooms) and production, which makes it easier to reduce the number of iteration loops mentioned above by clearing up questions of feasibility directly with production, which is also located within the mini-factory. In addition, customers will be more likely to come up with additional requests if they have a better understanding of the mini-factory's output potential (see "Repeat purchases").

Increasing the acquisitive potential: influence on customer preferences through customization

A fundamental advantage of mass customization is that, in the eyes of the customer, customized products are always of better quality than comparable ready-made products. This leads to greater willingness to pay a higher price, an advantage the suppliers can skim off of customized solutions (Chamberlin 1962). A company that is in the position of offering customized products is in a "near monopolistic" (Weigand/Lehmann 1997) state since the offered products, at least on the surface, cannot be compared with products from the competition.

The customer is willing to reimburse this uniqueness by paying a higher price, and in the extreme case, the supplier is able to skim off this benefit from each individual customer (see e. g. Skiera 2003). However, to be able to take advantage of this potential, any insecurities remaining with the customer must first be overcome. From the customer's point of view, mass customization is completely different from purchasing a mass product. Mass customization is complex, obscure and risky (Huffmann/Kahn 1998; Zipkin 2001). Many customers do not have sufficient knowledge to define a product specification that meets their requirements. The result is not only a considerable amount of time spent by the provider in defining the specification, but also increased insecurity on the part of the customer. The situation is more pronounced the newer and the more customized the product is. This puts companies to the difficult task of offering their customers a large variety of options while at the same time taking suitable measures to offer assistance in selecting the correct customized product. Only then will it be likely that the offer of customized products will lead to a profitable business model. "If customers become frustrated or dissatisfied with the complexity, a [...] customization strategy obviously would not be a competitive advantage [...]" (Huffmann/Kahn 1998, p. 492).

We argue that a mini-factory is better suited to overcoming customer insecurity than comparable sales concepts from a supplier with a centralized production. Firstly, there is the emotional attachment that customers feel toward a mini-factory in their own surroundings. Secondly, a mini-factory makes it possible to assist customers with the configuration procedure to the extent that each customer requires. But the tour through the configuration system not only provides technical support in finding an appropriate specification, it also represents a special shopping experience. Empirical studies have shown that the perceived product satisfaction in mass customization is strongly correlated to the satisfaction experienced during the purchasing process (Franke/Piller 2003). For many customers, their participation in designing a customized product is a special experience. This experience is further enhanced in a mini-factory through its direct access to the customer and the customer's active participation in product development and production. This can markedly increase customer identification and involvement with the final product. Consequently, it is the main sales task of the mini-factory to convey features that generate enthusiasm, thereby helping to fully tap the acquisition potential in customized products. In this way, the mini-factory differs greatly from a dealer, for example, who only sells customized products. Even a professionally organized "event shopping concept" cannot, in our view, generate the enthusiasm experienced by customers through active on-the-spot participation in the value-added chain. Finally, a mini-factory makes it possible to exercise influence on customer preferences. For example, customized products can be supplemented with customized services such as maintenance and repair work or training sessions.

Repeat purchases: influence on the repeat purchase rate through close customer care

Another method by which the mini-factory takes advantage of customer interaction to reduce costs is the use of mass customization as an instrument of relationship marketing. Many approaches of relationship marketing fail on account of the unwillingness of customers to allow themselves to be "milked" for information without receiving an adequate service in return. "Relationship Marketing as practiced today has not brought companies any closer to their customers. On the contrary, the gap has only widened" (Fournier et al. 1998, p. 108). Offering customized products to customers in mini-factories is an effective alternative, since the customized product represents a tangible motivation for the customer to participate in the measures used to promote customer loyalty. In this way, mass customization comes close to meeting the requirement for a value-generating reciprocal exchange. After all, by creating a customized design through mutual interaction (communication), relationship marketing aims to "[...] integrate buyers into an exchange that is value-generating and lasting for both sides [...]" (Wehrli/Krick 1998, p. 63).

Using the knowledge gained during the customer relationship and the willingness of the customer to interact with the mini-factory even after the purchase has been completed (e. g. by giving feedback on whether the product meets expectations), a mini-factory is able to capitalize on the customer relationship to sell several products to the customer in repeat purchases. In the end, then, mini-factories meet the following frequent requirement: "[...] to abandon the one-sided focus on gaining new customers (and losing regular customers in the meantime) in favor of fostering a stronger loyalty of existing customers to the company" (Diller/Müllner 1998, p. 1220). Collection and comparison of information on individual customers increase the information density mini-factories have on their market and promote targeted and successful market development (see also Peppers/Rogers 1997). New customers can be given better and more efficient assistance. For example, customers may be recommended a customized product variant that other customers with a similar profile had purchased in the past ("profiling"). In a mini-factory network, profiling can span across many mini-factories (see also the example of the cleaning robot for a sauna), thus raising its success rate.

This close proximity to customers can in the end help realize the cost reduction potentials that we refer to as "economies of relationship". Economies of relationship are the cost reduction potentials that lie in the additional opportunities that a mini-factory offers for building customer loyalty. Greater customer loyalty leads to increased sales to existing customers and to cost reductions in meeting these customers' wishes. For example, new sales can be generated by offering existing customers other products for purchase or by bridging the time between purchases with "intermediate sales" (e. g. repair, maintenance, replacement parts, etc....). The recommendations made to the customer are based on profile information stemming from customer interaction during previous mass customization purchases. This generates cost reduction potential because acquisition, configuration and customer retention costs for that customer are lower when repeat purchases are made (Piller/Stotko 2003, p. 215). Overall, this is how a real-time enterprise in the form of a mini-factory network can compensate the additional costs that result from greater flexibility and more intensive customer interaction (see figure).

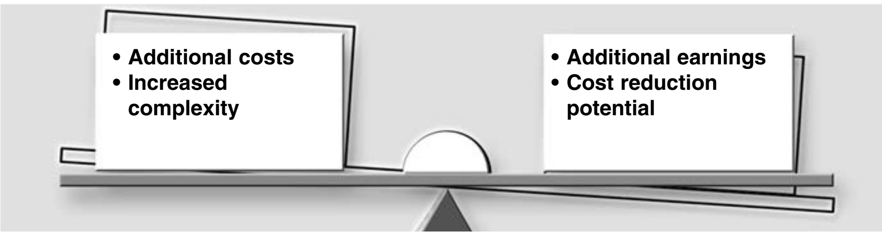

Figure 92: Economic potential of a mini-factory

Production in the real-time enterprise

Flexibilization: cost reduction potential by "postponing" production

The ability to postpone the adaptation of products to specific customer requirements as long as possible is considered to be one of the most important prerequisites for the successful implementation of mass customization. "The key to mass-customizing effectively is postponing the task of differentiating a product for a specific customer until the latest possible point in the supply network (a company's supply, manufacturing, and distribution chain)" (Feitzinger/Lee 1997, p. 116). The postponement of the final specifications can be with regard to aspects of design, time or location. In a mini-factory structure, postponement occurs by delaying the final product design. "Form [Design] postponement means that companies delay production, assembly, or even design until after customer orders have been received, which increases the ability to fine tune products to specific customer wishes." (Hoeck van et al. 1998, p. 33). Postponement with regard to time and location concerns the movement of finished products in the distribution chain or of supplier parts in the supply chain. These two aspects of delay are not well-suited to increasing a company's ability to offer customized products since they primarily relate to functions of commerce (bridging distance and time). Therefore, they will not be included in the discussion below.

A mini-factory, however, provides a good opportunity for putting the design delay approach into practice. Particularly useful is the local aggregation of development, sales and production units, since cooperation of these departments is essential for the success of a mass customization strategy. "Customization involves an intimate connection between product design and manufacture [...]" (Spring/Dalrymple 2000, p. 445).

To be precise, even product development is postponed in a mini-factory until the customer has asked for a product. With the mini-factory's expertise in defining product concepts (e. g. the cleaning robot should be able to climb stairs) and implementing them in concrete product features (e. g. the cleaning robot will be equipped with a chain drive), product development can be delayed until the customer walks into the mini-factory, sits down with the construction engineer and begins constructing the product. With respect to development expertise, the only thing that will already have been defined in a mini-factory before the customer is involved is the "solution space", i.e. the scope within which customers may realize their individual preferences (von Hippel 2001, p. 251f). From this perspective, a mini-factory offers the best possible flexibility for responding to customer requests, in some cases even adapting the output potential of the mini-factory to fulfill customer wishes. In other words, if a "solution space" turns out to be insufficient, a mini-factory has the capability of adjusting it to match actual customer requests.

This clearly distinguishes a mini-factory from a centralized production model whose output potential is difficult to adapt to individual customer requirements. Because centralized production is oriented toward frequent orders that are highly similar and highly structured (see Figure 90), adjusting workflows to the requirements of individual customers it more difficult than it is in a mini-factory. In our view, cost efficiency in the completion of orders with high variability and specificity is therefore easier to achieve in a mini-factory than via centralized production.

Specific advantages of mini-factories over large companies that result in cost reduction potentials

In addition to the advantages arising from the implementation of postponement, a mini-factory offers benefits that are a direct result of its small size: "All business is local. And that must include production. This is the only way that individualization can be managed on the many world markets." (Reuther 2000). This statement is based on the (dramatic) changes that general production conditions that have undergone in the last years. They have resulted in a liberalized world trade that gives manufacturers the opportunity of building up proximity to the market and customers in terms of location, time and social aspects, leading to further competitive advantages that Porter summarizes as follows: "Paradoxically, the enduring competitive advantages in a global economy lie increasingly in local things – knowledge, relationships, and motivation that distant rivals cannot match" (Porter 1998, p. 77).

In striving for market proximity, smaller businesses can capitalize on specific advantages they have over large companies. One important means of realizing these potentials is modern information and communication technology (IaC). By employing such technologies, small companies can flexibly generate customer benefits across the globe. Traditionally, the implementation of new IaC technologies, especially of high-speed networks with high data volumes, was limited to large concerns. Only these large enterprises were capable of carrying the fixed installation and training costs – costs that were prohibitively high for small businesses with relatively small capital stock.

However, recent technical advancements that are reflected in the rise of the World Wide Web (WWW), compatible standards for exchanging (CAD) data (e. g. STEP, XML, etc. ...) and sharp drops in hardware prices now also make it economically feasible for smaller businesses to employ IaC technologies for worldwide collaboration. The improved IaC technologies permit a physical-geographic relocation of flexible production cells from the central production location into the vicinity of the customer. This effectively lowers the entry barriers into new domestic and international markets faced by small businesses in the form of a mini-factory, since customized goods can now be economically produced in small batch sizes outside of niche markets. It essentially heightens the competitive capacity of small businesses in a market environment that requires proximity to the customer and distributed decision-making structures. “The adaptation of information technology tends to decentralize the economy and to reduce the average firm size, even if the information technology lowers both internal and external coordination costs” (Jonscher 1994, p. 38). It is precisely this demand that a networked mini-factory structure can meet.

Examples of mini-factories for market-oriented production in practice

Below, the concept of a mini-factory will be described in further detail using several practical examples. The case studies presented here are based on on-site investigations by the authors in each of the companies, on interviews with management and on the evaluation of literature and other sources. Due to the very small number of real examples, these cases were selected on the basis of being able to access the necessary information.

Schott-Zwiesel AG: Pluto (Production Logistics Under Target Group Optimization aspects)

A case study that comes very close to our vision of a mini-factory is the PLUTO project of Schott Zwiesel AG. Schott Zwiesel is a world leader in crystal drinking glasses for the gourmet dining establishment, bulk quantity and lifestyle markets. The motivation for Schott Zwiesel to begin its mini-factory project arose due to highly fluctuating sales figures among its wide product spectrum, which encompasses some 2,500 models. By implementing a network of mini-factories, the response to specific customer demands was moved as far downstream as possible.

While worldwide sales of water, wine and champagne glasses as well as burgundy and bordeaux goblets are fairly high at 100,000 units per year, sales of "exotic glasses" such as liqueur and sherry glasses lie at less than 10,000 units per year (Kreiß 2001, p. 128). In particular, these wide variations in sales figures for individual models prohibits the economical production of less popular models by mass production, which can only take advantage of economies of scale at a minimum volume of approx 30 to 50 thousand pieces. The PLUTO project is intended to improve this situation by shifting production to customer-oriented "satellites".

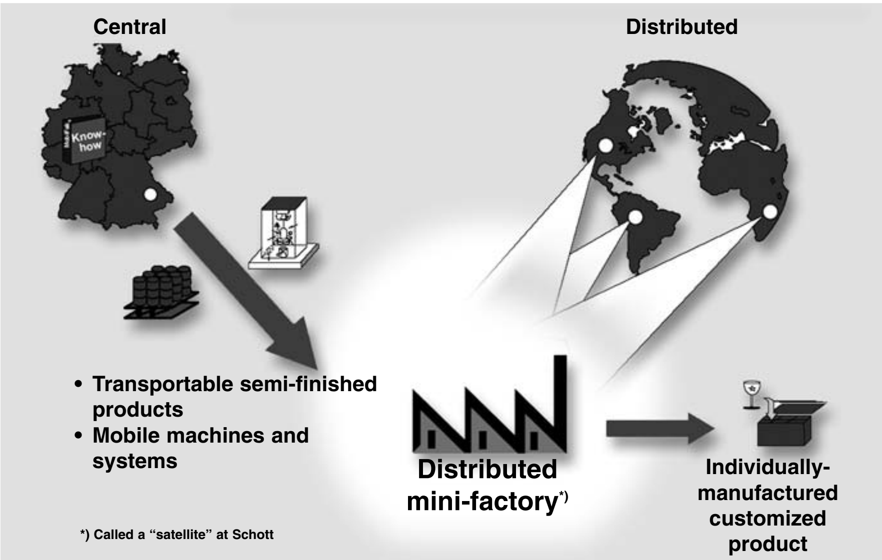

Figure 93: Overall concept at Schott-Zwiesel-Pluto (source: Schott-Zwiesel)

At the root of the PLUTO project is a fundamental rethinking of the premises of the production line as it exists today. A glass production line consists of several consecutive process steps that build on each other to produce the final glass product and that add value to the glass melt without interruption until it the final product is completed (Figure 94). The finished glasses are transported to storage, sometimes in the vicinity of the customer, and remain there until an order from a distributor triggers shipping of the required glasses.

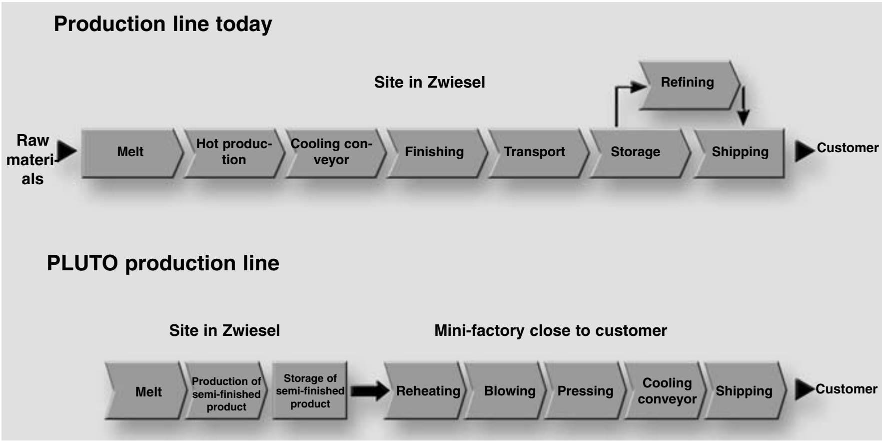

Figure 94: Production line today and as envisioned by PLUTO (source: Kreiß 2001, p. 128f)

The production model envisioned by the PLUTO project breaks with the traditional concepts of glass production. Thanks to new manufacturing technologies and innovations in the glass melt, the requirement for uninterrupted processing through to completion of the final product no longer applies. Instead, production at the central location is limited to the manufacture of semi-finished products (small disks the size of a hockey puck), which are then reheated in a mini-factory close to the customer and further processed to create the final product. This means, firstly, that production can respond flexibly to customer requests as they arise (sherry goblet or bordeaux glass). Secondly, transport costs are reduced significantly. Since shipping finished glasses to a warehouse close to the customer means "shipping air", cargo space can be much more effectively used by shipping semi-finished products. The cost reduction potentials this brings about are easy to appreciate. At the same cost, significantly more semi-finished products can be shipped to distributed mini-factories than finished glasses can be shipped to distributed warehouses. Also, the cost of storing semi-finished products lies well below that of storing glasses.

In addition, the value of semi-finished products lies well below that of finished glasses. This means that the opportunity costs for stock of finished products will be lower due to lost interest income. This aspect is of particular importance when serving overseas markets. Besides the positive aspect of reduced transportation costs, there is the added advantage of lower initial investments in a mini-factory. This ultimately permits an economical development of markets that previously lay outside of the company's own business radius.

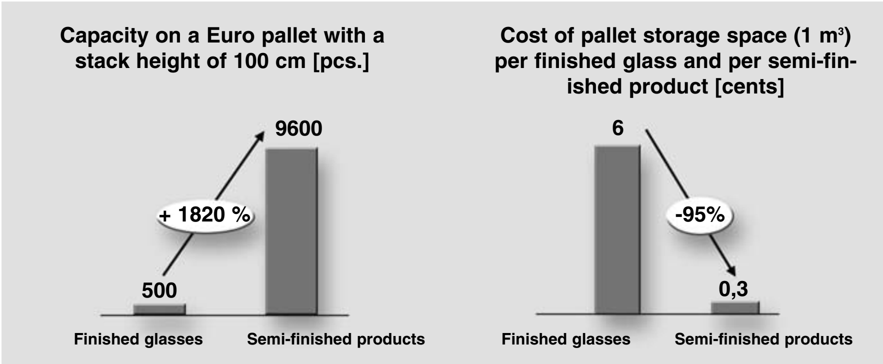

Figure 95: Comparison of warehousing and transport of finished glasses and semi-finished products (source: Kreiß 2001, p. 129)

The vision of Schott Zwiesel also permits a postponement in the design, which earlier in this article was described as an important condition for the implementation of a mass customization strategy. This case study deviates from the vision of a mini-factory in only a few points. Probably the most important one is that customers cannot (yet) design the glass themselves, since the PLUTO mini-factory needs exactly the same tools for each glass model as are used in the central production plant. Small production volumes could, for example, become feasible by employing wooden tools.
Generative procedures in tooling making, as are being researched in SFB 582, may be able to close this gap. As for customer participation in designing the glass, this is easy to achieve using suitable tool kits for calculating volumes and stability.

Pirelli: MIRS (Modular Integrated Robotized System)

While the PLUTO project is still in the conceptual phase and has not yet been introduced on the market, the following concept for a mini-factory has already proved its worth. Pirelli is a globally-active, international concern involved in the business areas of tires, energy and telecommunication cables. Pirelli concentrates on these key markets and is a leader in the industry and a prime innovator. It is one of the largest global suppliers of tires to major car manufacturers. The MIRS system used by Pirelli makes the production of a single tire economical. A robot-supported factory of this type can be accommodated in a space of approx. 350 m^2.

For Pirelli, the necessity of implementing a strategy of this nature arose from the fact that the prices that customers were willing to pay for tires in the replacement parts and accessories markets (after market) had fallen considerably over the last several years (original equipment manufacturers had never been very willing to pay). This low willingness to pay is accompanied by the markedly increased lifetime for today's tires, which results in still another loss in turnover. While the average tire performance in the 1980's was approx. 45,000 km, today's tires reach almost 70,000 km. In this type of market environment, a cost-minimizing production is needed to remain competitive. That is exactly what Pirelli managed to accomplish with the MIRS program.

Often, the cornerstone for the implementation of a mini-factory is innovative manufacturing technology that breaks with the old familiar premises and makes customized production economically viable. This, too, Pirelli has accomplished. At a heretofore unknown speed, MIRS robots perform the entire production cycle of a tire. In contrast to traditional tire production, the robots accomplish this without interruption and without the intermediate transportation of semi-finished products and tires. Integrated software controls every production phase, such as robot motion, automatic material loading, selection of the tire size, selection of a ready-made drum, manufacturing of the tire, vulcanization of the tire and transport of the finished product.

Thanks to this technological support of production, tires of greatly differing sizes can be manufactured in any sequence. This method of tire production is more efficient than in a comparable mass production plant, since a number of steps that add no value to the final product can be eliminated. Thus, for example, preparation time is well below that for mass production, as is the changeover time before manufacturing a different tire size.

In addition, this system achieves entirely new levels of product quality, since circumstances that are detrimental to quality, such as process interruptions, human intervention and temperature fluctuations of the semi-finished products during transport and storage can be avoided, otherwise often leading to vulcanization defects due to an inhomogeneous temperature distribution.

MIRS is also suitable for implementing a mass customization strategy because tire dimensions of any size can be manufactured consecutively. Thus, tire manufacture is no longer bound to the planning of large batches in the millions, but can now produce tires according to demand, with sizes ranging from those for small vehicles (e. g. Fiat Punto) to sports utility vehicles (e. g. Ford F-series). Like the mobile parts hospital described above, the Pirelli system is suitable for the production of replacement parts. Instead of manufacturing tire models that are seldom required in large batches and warehousing them, these slow-moving items can be economically manufactured in the MIRS system after a customer order comes in.

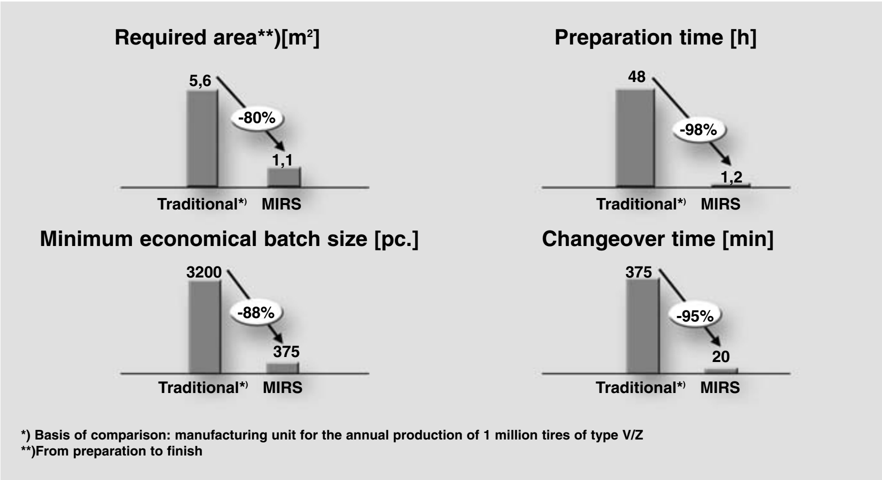

Figure 96: Characteristic values of the MIRS system (no author, 2003a)

The market for replacement tires is enormous. In Germany alone, some 40 million tires are replaced every year (average tire lifetime of 4.5 years at 45 million passenger cars and wagons (Federal Motoring Authority of Germany, status 1.1.03)). The replacement tire market extends to literally thousands of tire sizes, a number that is due to the specifications of car manufacturers, who require new tires with special characteristics (with respect to the speed and load index) for every new vehicle model. All this requires is a customer interaction facility that is suited for querying tire data. In the extreme case, this could even take place on an automatic interface into which the customer enters the vehicle data found on the registration document and can then view a selection of suitable, legally approved tires. A click on the required tire followed by the entry of the number of tires required, and the order is placed and quickly filled in the MIRS module (the manufacture of one tire takes three minutes.)

The MIRS system at Pirelli exhibits the features of a mini-factory as we have defined it, since it is possible to scale the facilities at the existing location and copy them to another site. For example, in Breuberg, Hessia, Pirelli has a facility for manufacturing the tires mounted on the BMW Mini Cooper S. Since construction of this MIRS facility began in December 2000, 12 of the 13 planned modules have been put into operation. With this equipment, the plant in Breuberg will be able to produce 2 million tires annually. Breuberg is a copy of the first MIRS facility that Pirelli put into operation in the Bicocca plant close to Milan in July 2000 (Pirola 2001, p. 15).

Küche Direkt

Another example for the implementation of the mini-factory concept is provided by Küche Direkt (Kornacher/Suwelack 2003). With respect to customer interaction and mass customization, this example comes closest to the mini-factory concept we have presented in this article. It takes advantage of direct customer interaction to configure customized kitchens, and makes use of innovative manufacturing methods that permit the production of customized kitchens at costs comparable to those of mass production.

The business goal of Küche Direkt, a joint project of the Rudolf Systemmöbel furniture company, IMA engineering company and Suwelack business consultancy, is to offer customized kitchen furniture on the basis of a fully parameterized furniture program at a bulk price (Ikea price). Together with a trained consultant, customers design their own dream kitchen. To ensure that kitchens would be available quickly while still being affordable, a completely new process chain was developed. The kitchen is manufactured within just a few days and assembled on location. Küche Direkt was designed as a "production franchise system" and encompasses the production and sales systems. The intention is for the franchisee to be able to concentrate on his or her strengths – planning, selling, producing and assembly – without having to have actually system know-how. Data maintenance, continued development of organization software, comprehensive marketing, procurement, product development, etc., are all carried out and advanced at the system headquarters. This division of tasks corresponds to the basic mini-factory structure presented in this article. A central unit performs the core support functions, while the mini-factory handles customers and customized production on location.

The approach used by Küche Direkt makes use of the following principles of mass customization:

- The kitchen fulfills customer wishes with regard to its appearance. In addition, the height of counter can be adjusted to suit the customer and the width and depth of the standard cabinets can be fit to the space available. Also, compared to the classical range of options, there is now a much larger selection of colors, grips and styles without extra charge.
- Because the product architecture is fully parameterized, parts lists and production information can be generated at the touch of a button

notwithstanding the large number of variants.
- Currently, plastic-coated particleboard still dominates production. This has the advantage that it does not require additional surface treatment. The production methods used (see below) are suitable for all other materials as well (solid wood, three-layered plywood, veneered board, etc.). In standard models, the exterior design is also found in the cabinet interiors.

Küche Direkt also follows the mini-factory approach described above when it comes to customer interaction:

- A configurator is not only used to plan the kitchen but also to visualize the desired models.
- Information flow from the laptop of the salesperson to the flexible production system is fully linked. Thus the manufacturer has direct access to the customer, i.e. the usual interface between retailer and manufacturer is eliminated. This has the advantage that there is no duplicate handling of orders, permitting a fast response time.

In production, Küche Direkt also follows the principles recommended for a mini-factory:

- Production is designed as a scalable mini-factory that encompasses the entire scope of production engineering from unfinished board to finished kitchen in only a few integrated workstations. Production costs are lowered considerably by using a highly automated, flexible production system and a consistently simple and clearly structured basic product architecture. Moreover, the absence of warehousing and elimination of the risk of not being able to sell the product avoid additional cost drivers that are usual for mass production (for warehousing). Only two employees control and carry out the entire production (from initial cutting to final assembly).
- Paperless production begins after the customer requirements have been defined and does away with intermediate storage. Lead times are therefore extremely short. The finished product can be delivered within 2 days (without appliances) if the customer selects a decor for which raw material is already present.
- The "upgrading" of materials leads to a significant reduction in complexity. The furniture design was tailored to suit the machine concept with a view to making production as efficient as possible. For example, all parts are constructed from the same 19 mm particleboard – even for

back panels. This increases material costs but greatly reduces the complexity of production planning and cutting. In part, scraps can be used for production of the next order.
- A customized production that begins with the raw materials results in enormous savings in logistics costs. Vendors are integrated in the customized manufacture of the product since they deliver the kitchen counter made to measure. The price of the individually produced kitchen is therefore not higher than that of an average kitchen sold by large furniture stores.

What has not yet been fully implemented and up to now has only been implicitly used is the opportunity of gaining customer knowledge and the systematic use of such knowledge in the overall network of the mini-factory. Missing are systems suitable for accomplishing this and organization guidelines. Thus, essential potential benefits are not being utilized, especially since the participating companies and franchisees often continue to offer "mass-like" series products. An information transfer of aggregated knowledge from the customized orders to the series products could provide those products with important information relevant to gaining a competitive advantage.

Summary

The mini-factory model presented here is a concrete example for the concept a real-time enterprise and opens up interesting perspectives for the efficient and flexible production of customized products. Due to their small investment volume, mini-factories bear fewer risks when entering new markets or experimenting with new organizational forms. Entering and exiting markets is easier to accomplish than with a large, centralized production structure. This is because the processes within a mini-factory – from order acceptance to order processing – are all modularly structured. Since such processes are scalable, the capacities of existing mini-factories are easier to adapt to market requirements in "real-time". Thus, the mini-factory is in accordance with the view that a factory should be "living and breathing". As well, modular processes make it possible to transfer (copy) proven concepts to other markets and to thereby gain access to new markets with low initial investments.

The mini-factory is particularly well suited for the production and sale of customized products, since the sales and production units in a mini-factory are all joined together "under one roof". This serves to raise customer confidence and enthusiasm, and to meet in real-time even those individual requests that require a complete reconstruction of the product. The mini-factory concept is made possible by technical innovations in the area of production that permit a break with the batch-based manufacturing technologies employed until now. The case studies of Schott Zwiesel, Pirelli and Küche Direkt demonstrate that the overall vision of the mini-factory is a viable alternative even today under the right economic conditions. The future of the real-time enterprise has already begun.

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