IT SUPPORT FOR MASS CUSTOMIZATION

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ABSTRACT

Many authors have written about Mass Customization and its features and categories. Literature on the implementation of Mass Customization, and in particular the supporting information technology, is scant. This paper attempts to fill this gap by focusing on this subject. We determine the key functional requirements and identify possible implementations to show the existence of enabling information technologies for Mass Customization.

Keywords: mass customization; information technology

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INTRODUCTION

Mass Customization (Pine, 1993) has been the subject of extensive discussion in both scientific journals and trade magazines. It can be defined as tailoring mass-market products and services to the needs of each individual customer.

Customization has been a standard practice for many years in the services sector. Hairdressers, for example, ‘customize’ their service by cutting every customer’s hair in a different way or style. Thus, the principle of customization is very simple: adapt the product in such a way that it better satisfies the needs of the customer. The additional cost will be compensated by customer’s willingness to pay a premium price for a customized product or service.

Mass production is a characteristic of many large companies such as Ford and Unilever. Mass production of goods is characterized by cost-minimization using large production runs of identical products. Customers are willing to purchase these products due to the price advantage, even though they may not fulfill all their requirements.

Mass customization (MC) combines these two elements: adapting products or services to the needs of the individual customer and producing them efficiently. Pine (1993) describes a number of ways to accomplish this. A company can manufacture its products from modules, or adapt its production lines to allow for easy customization of each separate product. A company that can customize every product without extra costs is said to produce with lot sizes of one. Apart from this, a company can make a standard product that customers can adapt themselves (by changing settings, for example), or adapt the services around the product instead of the product itself.

There has been a significant amount of research into the topic of MC. Many authors have made taxonomies of the modes of MC as they appear in practice. There has been a limited amount of research on the enabling technologies of MC, however. MacCarthy et al. (2003) underline the importance of correlating the MC strategy and supporting technology in order to create comprehensive configuration models (as in Duray et al. (2000)). In this paper, we will focus on the role of information technology to support MC.

Our aim is to determine whether the various operational processes of mass customization can be adequately supported using information technology (IT). We will first review the mass customization literature. Next, we will discuss the various forms of mass customization on the basis of a known taxonomy. Analysis of the operational processes for each form yields a list of functional requirements or key features for each form. These key features are then linked to possible IT implementations. We will not provide an exhaustive overview of all possible supporting technologies: our contribution is the identification of the key features and a proof-of-existence for the IT support.

LITERATURE REVIEW

There appears to be no generally accepted taxonomy of forms of MC. A number of models have been proposed. Pine and Gilmore (1997) have defined a conceptual model that distinguishes collaborative, adaptive, cosmetic, and transparent customization. The difference between these forms is mostly expressed in the way that the company satisfies the customer’s needs, and what the customer notices of this. Briefly, in collaborative customization the company works together with the customer to design the product. In adaptive customization on the other hand, a company produces a standard product that can be customized by the customers themselves. Cosmetic customizers only adapt the packaging, not the product itself; transparent customizers adapt the product without the customer’s involvement.

Duray et al. (2000) use the moment of customization and the type of modularity used for their categorization. They propose four categories: fabricators, involvers, modularizers, and assemblers. Fabricators and involvers bring customers into the customization process as early as the design or production phase. Modularizers and assemblers, on the other hand, do not involve customers until the assembly or usage phase. Fabricators and modularizers often design parts specifically for a product, while involvers and assemblers mostly use standard components.

Da Silveira, Borenstein, and Fogliatto (2001) provide a detailed review of the MC literature. They use a number of models from the literature to create their own taxonomy with eight categories of MC. They distinguish standardization, usage, package & distribution, additional services, additional custom work, assembly, fabrication, and finally design as different categories of MC. The authors, like Duray et al. (2000), Lampel and Mintzberg (1996), Pine (1993b), and Pine and Gilmore (1997) focus primarily on the moment of customization.

MacCarthy, Brabazon and Bramham (2003) work from a different perspective. They propose that it is important that companies that are in the same category should also benefit from the same technologies. They define three features:

- The *temporal relationship between activities:* the amount of time that passes between, for example, design and production for an order. If a product is designed specifically for a customer, less time passes between these two phases than with standard products.
- A company's willingness to adapt their processes or take on new suppliers or use new materials. MacCarthy et al. call this *fixed or flexible resources*.
- A company's willingness to design new products that will probably rarely, if ever, be sold again after the initial order. MacCarthy et al. call this producing on a *call-off* or *design-per-order* base. Call-off means a company will only accept orders for new products if it expects there is a potential market for the product. Design-per-order does not make this demand.

They apply these three features to define five operational modes of MC (we have added some acronyms to ease the discussion in this paper):

Catalogue MC (*CatMC*) — all product variations are developed beforehand and customers can only order products from the 'catalogue'.

Fixed Resource call-off MC (*FixCo*) — the company is willing to develop new products or variations for customers, if it can be realized with their current processes and suppliers, in anticipation of repeat orders.

Flexible Resource call-off MC (*FlexCo*) — the company is willing to develop new products or variations for customers, if they see a potential market for the product. It is also willing to change its processes or take on new suppliers to do this.

Fixed Resource design-per-order MC (*FixDpo*) — the company is willing to develop new products or variations for customers, if these can be realized with their current processes and suppliers. There is no expectation of repeat orders.

Flexible Resource design-per-order MC (*FlexDpo*) — the company is willing to develop new products or variations for customers, without requiring repeat orders. It is also willing to change its processes or take on new suppliers to do this.

By dividing the categories on the flexible/fixed resource and the call-off/design-per-order dichotomies, we can identify five levels of flexibility (Figure 1; a higher level implies a higher degree of flexibility). It is likely that a larger degree of flexibility will require more sophisticated supporting technology. We will therefore discuss the IT needs of these modes in this order.

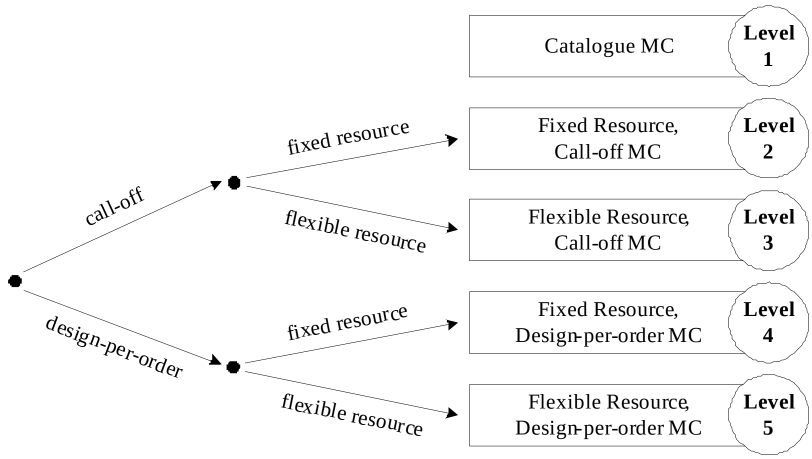

Figure 1: Levels of Mass Customization.

KEY FEATURES

The different levels of MC will have different functional requirements in terms of it support. In this paper, we will refer to these requirements as the key features of a mode. For each of these five modes defined by MacCarthy et al we will now outline the consequences for and identify the key features of the operational processes. The operational processes distinguished by MacCarthy et al are: order taking and coordination, product development and design, product validation and manufacturing engineering, order fulfillment management, order fulfillment realization, and the post-order process. In their paper, MacCarthy et al conclude that the post-order process does not significantly differ for the various modes and we will thus not consider it in this paper. We will then use these key features in the next section as the basis for determining enabling information technologies. The key features for each mode are summarized in Table 1 at the end of this section. Some of the examples are based on an online list of companies that implement mass customization (Managing Change, 2005).

Catalogue MC (CatMC)

Catalogue MC companies are often hard to recognize as being a mass customizer. They offer little to no options, a fixed assortment of products, and no willingness to accept special orders. The intention to offer variety and the number of product variations differentiate mass customization from the mass production strategy. This is most often found in companies that produce one product in multiple levels, differing in for example speed or comfort.

Two prime examples are Internet Service Providers (ISPs) and football clubs. An ISP has a network of cables that, depending on the subscription of the customer, can deliver 1Mb, 2Mb, 4Mb or 8 Mb DSL connections. A football club might have a stadium of 10.000 places where a customer can buy a ticket for the terraces, seating, or covered seating.

As stated before, CatMC is a mode in which a company limits the possible variations of its products to a predefined standard set. The difference with mass production without customization is in the company’s intention. A company that adheres to this strategy wants to offer variation to its customers but does not offer customers direct influence on the variation. A company with a mass production strategy, on the other hand, wants to avoid variation as much as possible in order to reduce cost.

We will now discuss the requirements for each of the operational processes for this mode.

Order taking and Coordination. Per order the dialog with the customer is tracked, the appropriate product is determined and the order is entered into the order database. Although this process differs little among the five modes, there are certainly differences between mass customization and mass production. The number of products and options on offer means that the dialog with the customer is more elaborate. Here, an interactive channel with a rich user interface will be very helpful to present the full range of options available to the customer. This interface can provide support for the customer to express his/her needs and to match products from the catalogue to those needs. For the purposes of this paper, we assume that a web-based sales channel best supports this.

Product development and design. This process is performed before orders are received. There is no need for systems to involve customers in the process. It is necessary to have information on customer needs, which can come from experience from previous sales, or from marketing research among potential customers.

Product validation and manufacturing engineering is also done before orders are received. There are therefore no special requirements for this process.

Order fulfillment management is done per order. It can be useful to keep a direct link with suppliers to enable just-in-time (JIT) deliveries of parts and materials. This could save costs and reduce lead times, but is not considered essential from the perspective of customization.

Order fulfillment realization is done per order. For the CatMC mode, production processes are considered fixed – the company will not adapt them for a customer.

The key features have been summarized in Table 1 (displayed after the discussion of the five modes, at the end of this section).

Fixed Resource Call-off MC (FixCo)

German contractor Streif can be considered an example of this mode. The website of Streif allows clients to design a personalized house by selecting a number of preferences on style, number of rooms, type of roof, etc. Customer selections are reflected in a two dimensional representation of the customized design (see Figure 2).

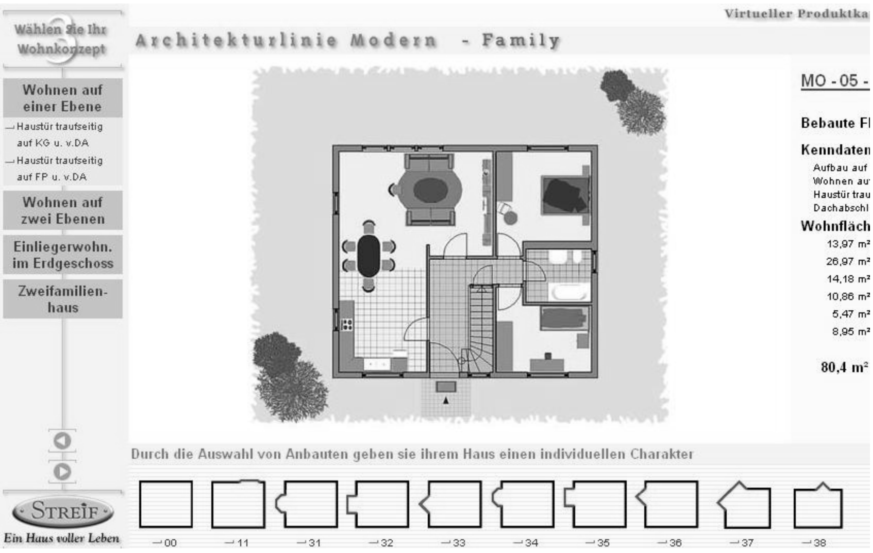

Figure 2: On Streif's website, customers can pick from a number of options (source: www.streif.de).

Another example is Dell. On their website www.dell.com, a customer can indicate what base model he wants. Dell will then list a number of other options for most of the components of the computer, and compute a price based on the options the customer picked. Further customization is possible when ordering over the phone: using this channel it is possible to request additional components that are not listed on the website.

In this mode, a company is willing to develop new products for a customer if it anticipates repeat orders. However, it is only willing to do this if no changes to current processes and suppliers are needed. The consequences for the key processes are as follows.

Order taking and coordination is done per order. There is, however, a small difference with CatMC, because the customer can, in some cases, have a say in the development process. A company could therefore choose to, for example, allow customers access to their own design systems via the website. Customers could then fill in a request for a new product, including a (partly) finished design.

Most sales will be from the catalogue: only a small proportion of sales will require this type of customization. We assume that this proportion will not require separate support systems and can be handled relatively ad hoc. A limited form of support, such as an option on the website to indicate this type of custom work, is required. We will therefore not consider this a key feature for this category.

Product development and design and *Product validation and manufacturing engineering* are usually done before an order is received. The exception is when a customer orders a new product that is yet to be developed. Again, we consider this to be an infrequent event that will not significantly influence the processes.

Order fulfillment management is basically done in the same way as with CatMC: production based on orders. To enable the production of new products based on specific customer needs, the company must be able to respond quickly and order the required parts and/or materials from suppliers. It might thus be useful to establish a direct link with suppliers to enable just-in-time (JIT) deliveries. This can reduce inventory costs and lead times.

Order fulfillment realization is done per order and is fixed.

Flexible Resource call-off MC (FlexCo)

Motorola's Bandit Pager division is often quoted as an example (Da Silveira, Borenstein and Fogliatto (2001) cite this as an example for their Fabrication category which is similar to FlexCo). This division was one of the first to realize a true "lot sizes of one" setup. Pine (1993), who also cites this example, reports that the Bandit line could produce 29 million different variations of the pager without delay or setup-costs.

FlexCo only differs from FixCo on one point: a FlexCo-company is willing to adapt its production processes or to use new materials to make new products for its customers.

Order taking and Coordination and *Product development and design* are unchanged with respect to FixCo.

Product validation and manufacturing engineering is the first process that shows the consequences of the flexible resource approach. First it must be determined whether a design can be produced with the current resources. If the current systems can not produce a design, then the additional resources that are required must be identified. The design must also be validated, for example on safety criteria.

Order fulfillment management is, again, done per order. This process must be able to adapt to changing configurations as a consequence of custom designs.

Order fulfillment realization is done per order and is flexible. The realization systems have to be aimed towards allowing changes within the process. This might be done by modularizing the production line.

Fixed Resource design-per-order MC (FixDpo)

FixDpo is a frequently adopted strategy for information services. Information can easily be customized using software: the additional cost of customizing is very low. This allows companies in this line of business to fulfill almost any order. Morningstar (www.morningstar.com) advises customers on retirement investments. Customers input their data using the website, and Morningstar computes the best portfolio for the customer, along with a few different possible scenarios for the future. This is all done in real-time by their software, which is accessible via their website (see Figure 3).

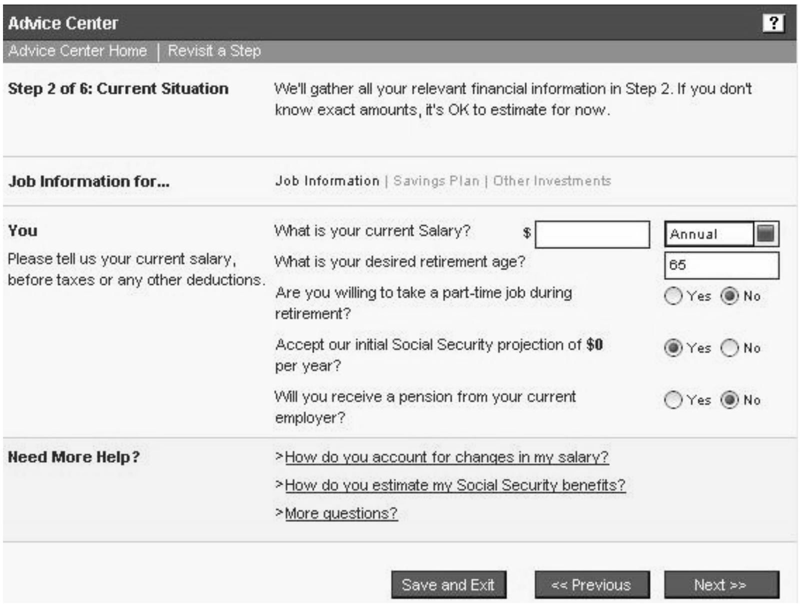

Figure 3: Morning Star's advice is calculated in real-time, based on the data provided by the customer (source: www.morningstar.com).

Lightning Source (www.lightningsource.com) uses information technology to deliver a tangible product: digital printing technology allows Lightning Source to print custom-made books. By digitally feeding the printers, Lightning Source enables their production systems to produce in lot sizes of one. The consequence is that it doesn't matter whether they print a single copy or ten thousand copies of a book.

A company that operates in this mode is willing to accept special orders from a customer, regardless of the expectation of repeat orders. They do this to, for example, create loyalty with the customer, so he will become a return customer and thus contribute to profitability. Companies in this category could have a production line capable of producing lot sizes of one, allowing the company to profitably produce these special orders.

Order taking and Coordination is done per order again. The major strength of a company in this mode is its willingness to take on special orders. This implies that these special orders will make up a significant proportion of the revenue. For these special orders, the next step (design) starts with the customer's input at the time of order taking.

Product development and design. Many customers will order yet-to-be-designed products. To supply them with information about and control over the design process, product development systems should be made (partially) accessible to customers. The large number of these special developments implies that decreasing the development time of a product can be very rewarding. The design process could be based on re-using (parts of) known designs, perhaps in an adapted form.

Product validation and manufacturing engineering will take on the same role as with FixCo.

Order fulfillment management is the same as with FixCo. However, new products may lead to new suppliers for parts and materials. For this mode, the focus will not exclusively be on reducing inventory but also on creating and maintaining flexibility.

The *order fulfillment realization* process will not need to change often. Instead, it will often have to produce new designs, and be able to produce many designs. The production process must thus be capable of switching between the various designs quickly and seamlessly.

Flexible Resource design-per-order MC (FlexDpo)

This type of mass customization is not very common. One example is ic3D (www.ic3d.com), a clothing manufacturer that lets a customer create their own jeans by choosing from a great number of options. However, the customer is not limited to the options defined by ic3D: he can also request additional options. The customer can select from fabrics such as denim and suede: additionally, a special option on the website allows the customer to contact the company to request a different fabric. (see Figure 4).

Figure 4: ic3d offers customers a lot of options, and a facility to request additional options (source: www.ic3d.com).

A company that employs a flexible resource, design-per-order mass customization strategy is willing to accept any realistic order for a new product, irrespective of the consequences for the key processes. The potential market for the product is not a primary consideration.

Order taking and Coordination and *Product development and design* work the same way in FLEXDPO as they do in FIXDPO. *Product validation and manufacturing engineering* is similar to the FLEXCO mode. The *Order fulfillment management* process must identify the changes to current processes that may be required – as in FLEXCO. Additionally, a good link with suppliers, as in FIXDPO, is necessary to order the parts and materials required. *Order fulfillment realization* has to allow for changes with the process and produce many different designs.

KEY FEATURES OVERVIEW

Table 1 summarizes the features we have identified in the previous section. The number of features increases with the amount of flexibility per mode. This implies that the more flexible modes will require a more complex configuration. In the next section we will discuss the information technologies that can be used to support those configurations.

Mode	Operational Process	Features
CATMC	Order Taking	Web-based sales channel
	Product Development	Supported by customer database
	Product Validation	Before order
	Order Fulfillment Management	
	Order Fulfillment Realization	
FIXCO	Order Taking	Web-based sales channel
	Product Development	Supported by customer database
	Product Validation	Usually before order
	Order Fulfillment Management	Links with suppliers for JIT delivery
	Order Fulfillment Realization	
FLEXCO	Order Taking	Web-based sales channel
	Product Development	Supported by customer database; Identify additional resources
	Product Validation	Validation of many different designs

	Order Fulfillment Management	Adaptable to changing configurations; Links with suppliers for JIT delivery
	Order Fulfillment Realization	Adaptable to changing configurations; Flexibility of production processes
FixDpo	Order Taking	Web-based sales channel
	Product Development	Integrated systems with customer access; Re-use of known solutions
	Product Validation	Usually before order; per order for custom work
	Order Fulfillment Management	Links with suppliers for JIT delivery and flexibility
	Order Fulfillment Realization	Flexible order realization systems that can quickly switch among various designs
FlexDpo	Order Taking	Web-based sales channel
	Product Development	Integrated systems with customer access; Re-use of known solutions
	Product Validation	Validation of many different designs and production processes
	Order Fulfillment Management	Adaptable to changing configurations and production processes; Links with suppliers for JIT delivery and flexibility
	Order Fulfillment Realization	Flexible order realization systems that can quickly switch among various designs, parts and production processes

Table 1: Features of the modes.

INFORMATION TECHNOLOGY

In this section, we will use the key features that have been determined in the previous section to identify the information technology that can support the various forms of mass customization. We will again focus on the operational processes: order taking and coordination, product development and design, product validation and manufacturing engineering, order fulfillment management and order fulfillment realization.

Catalogue MC (CatMC)

The first feature that was identified for this mode is the web-based sales channel. Ease of use is paramount given the usually large number of products and options. The system must then be able to determine the price of a selected product, including any options that have been selected, in real-time. Once an order has been configured, a link to the company back-end systems is required to immediately store the order and initiate fulfillment. This link should also support a realistic estimate of delivery time and price. Customer data must be stored for customer-relationship management and as a basis for future product development.

Frutos and Borenstein (2004) describe a prototype system that satisfies these demands. Their Mass Customization Information System or MCIS is a web-based object-oriented system that has three main components: a customer interface, a database, and a database management system. The system offers customers access to all the required information and is capable of updating prices for a customer's choices in real-time. It supports storage of customer data as well. The customer interface is written in Java, which guarantees the accessibility for customers with a PC with a Java-enabled browser. Future product development is supported by MCIS's ability to store customer data.

Order fulfillment management as well as order fulfillment realization on a per-order basis can be supported by a link between the sales channel and the production system. We assume that the MCIS database can be accessed by the production systems. When an order is placed, it can immediately be retrieved from the database by all the processes involved with order realization. The required parts can be ordered or taken from the inventory, production planning can be updated, delivery planned, etcetera.

Thus, a possible technology to support this mode of MC is MCIS, a web-based sales channel that links customers and companies, maintains an order database, and supplies customers with all the information they need.

Fixed resource call-off MC (FixCo)

The web-based sales channel should in principle satisfy the same demands as with CatMC. Because there are so few differences between FixCo and CatMC, we select Frutos and Borenstein's MCIS.

Product development and design can be done mostly in the same way as with CatMC, on the basis of MCIS. In this category, however, a company will occasionally develop a new product as a consequence of a customer order.

Parts and materials that are required to fulfill an order are identified during the order fulfillment management process. Once the parts and materials have been determined, they have to be sourced from suppliers. An electronic link with suppliers can support rapid sourcing. There are a number of possible solutions for this problem. Many organizations have implemented enterprise resource planning (ERP) systems; inventory management and supply chain management (SCM) modules are either already present or can be added to those systems.

Turowski (2002) describes a different type solution: an agent-based e-commerce system. With this system, all involved parties have a set of agents (programmed in Java) installed on their systems. Together these agents are capable of retrieving data from the ERP-system (or another database), contact the agents of suppliers, requesting quotes, negotiating about the price and other dimensions such as speed of delivery, and closing a deal. Wang and Shu (2005) describe an SCM system that can give an order-up-to level for inventories based on a set of user-defined preferences and information about the production line and suppliers. This value minimizes (according to their paper) the costs of keeping an inventory, given a desired amount of end product. Chen, Lin and Huan (2005) describe an SCM-system that is capable of ranking suppliers in order of preference with a fuzzy logic system. This system creates a list of recommended suppliers based on user-entered (linguistic) characteristics and demands.

Thus, possible enabling key IT technologies for FixCo are:

- MCIS**:** The web-based sales channel that is the link between customer and company, keeps the database up to date, and supplies customers with all the information they need.
- SCM-module in ERP-system: the link between company, suppliers and buyers that ensures flexibility in the supply chain. Alternatives: Turowski's agent-based e-commerce system; Wang and Shu's fuzzy-based SCM-system;, Ling and Huan's fuzzy-based SCM-system.

Flexible resource call-off MC (FlexCo)

In addition to the support required for the FixCo mode, the FlexCo mode requires additional support in the areas of flexible production and product validation.

Product Development and Design and Product Validation and Manufacturing Engineering are comparable to the FixCo mode. The only difference is in the willingness to develop products outside the current capacity: any additional resources that are required for the new design must be determined during this process. However, these are special orders from clients, and would not be initiated by the company. This does not require special IT support; future product development does not significantly differ from future product development in companies where future needs are gathered using different means.

Flexibility of production processes is needed if the company wants to regularly change product designs or production processes. The systems have to be able to switch to a new design easily and with minimal delays. We can look at the area of Agile Manufacturing or AM (Cao and Dowlatshahi, 2005) for support for these features. AM systems are information systems that allow a company to adapt processes and enter new designs quickly. These systems, when correctly implemented and aligned with the rest of the organization, can provide a significant benefit, either in reducing the time required to switch the system to new products, or in reducing the time required to adapt the system.

Cheng, Harrison and Pan (1998) describe an implementation of an AM system that uses the Internet, fuzzy logic and neural networks. Their system could also be accessed directly by customers, allowing them to specify their wishes, after which the system would pick the most fitting product and schedule it for production. In this sense, it could be an alternative for MCIS.

AM systems are obviously limited to the current physical characteristics of a production facility: AM systems merely support rapid changes in product design and production processes. AM systems also do not, like CAD/CAM systems, produce production schedules and designs for new products. (They can however benefit from the output of CAM systems.)

Thus, in addition to the technologies identified for the FixCo mode, the FlexCo mode will benefit from systems that support Agile Manufacturing such as the prototype described by Cao and Dowlatshahi (2005).

Fixed resource design-per-order MC (FixDpo)

The solutions that have already been presented for the web-based sales channel and the link with suppliers and buyers can also be used for this mode. Additionally, design-per-order could be supported by customer-access to the company’s design systems (see below). As the customer user-interface gains in functionality, additional client-side technology such as Macromedia Flash or Java may be required. This decreases the accessibility of the website.

A key feature for this mode is the need for flexible order realization systems. This mode features a large number of new product developments that are often produced in small amounts. To achieve this, the company must be able to quickly translate new designs into production schematics. Systems can then produce different new products quickly using the schematics. Rapid design and translation into production plan can be implemented using Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) systems respectively. Ito, Shinno and Saito (1988) as well as Srinivasan and Fischer (1996) describe ways to interface the CAD and CAM systems in order to integrate these processes.

Design time can also be reduced by reuse of known designs or parts thereof. In a design environment with a large number of previous designs and an even larger number of components, merely knowing that a previous design exists, fits the new requirements, and locating the details of that previous design becomes a challenge. Lee et al (2004) propose to support reuse of known designs with DDIS (Dynamic Data Interchange Scheme). Ddis is a case-based reasoning system capable of extracting (among other things) product designs, production schemas, and past orders and organize these into a set of cases. Here, a case is defined as a combination of a question or problem, and a solution. By searching for a certain problem, a product development team can check if the problem has already been solved previously, and possibly reuse a known solution. In a single case study, Lee et al. state that DDIS can indeed reduce design time; the effects on product engineering are, however, minor. Therefore, DDIS can be seen as an improvement to the competitive position of a FixDpo company.

Process integration & links between systems. It is likely that new products will often be developed specifically for customers. Thus, companies that employ the FixDpo strategy may gain a competitive edge by offering the customer a role in the development process. Companies with a FixCo or FlexCo, category, on the other hand, mostly sell from the catalogue unless a customer wants to order a new product and the company judges this product to have great potential. A FixDpo company is willing to engineer any products that satisfy its customer’s needs, given the standard order fulfillment processes. In such a setting, it is beneficial to give the customer insight into and even control over development process.

Figure 5: Streif supplies their customers with a render of their future home (source: www.streif.de)

To accomplish this, several solutions can be used. First of all, MCIS could be adapted in such a way that the customer has the ability to access information from the development process, like product designs, through the website. If necessary (and possible), the system could even allow the customer to use a company's development tools, like CAD systems. A customer could then, for example, develop a part of the product themselves - like drawing a part of your future home on Streif's website (Figure 5). This type of customer involvement in the product design process may make the product validation (such as verifying that a product meets safety requirements) more difficult. This type of solution then is mostly useful for products with few safety risks, and possibly only for the cosmetic options. In this case, adapting MCIS could be sufficient.

An alternative solution is to provide consulting services to customers by means of company representatives that can collaborate with the customer to create a design. This can be supported using both offline design software such a CAD system on a laptop computer and online access to company systems. The obvious disadvantage to this approach is the high cost per transaction, which will limit this solution to premium products.

In addition to the MCIS and SCM-integration systems that have already been identified for other modes, the FIXDPO mode will benefit from systems that support the reuse of known designs such as DDIS and from CAD/CAM systems that support rapid product design and production planning .

Flexible resource design-per-order MC (FLEXDPO)

In this mode products are engineered per order and produced using modified order fulfillment processes. The supporting information technologies are a combination of the supporting technologies for the FLEXCO and FIXDPO strategies. MCIS can be used as the web-based sales channel, DDIS supports reuse of known solutions, and SCM-modules in ERP-systems can be used to support links with suppliers and buyers. CAD/CAM systems are used to enable flexible order realization systems. The required flexibility of processes can be supported by Agile Manufacturing systems. The FLEXDPO strategy means that the customer is often deeply involved in the product development process and will need access to the information systems; this need can be fulfilled using an adapted version of MCIS, similar to the requirement for FIXDPO.

CONCLUSION

In this paper, we have examined the relationship between a number of mass customization strategies and the information technology required to support these strategies. We have shown that the operational processes for the modes of mass customization defined by MacCarthy et al (2003) can be supported by specific types of information technology. Table 2 below summarizes the key supporting technologies for each mode.

		Supporting Information Technology					
Level	*Mode*	MCIS	SCM-module	CAD/CAM	AM	DDIS	Process Integration
1	CatMC	●					
2	FixCo	●	●				
3	FlexCo	●	●		●		
4	FixDpo	●	●	●		●	●
5	FlexDpo	●	●	●	●	●	●

Table 2: Enabling technologies for modes of mass customization.

Higher levels of mass customization (cf Figure 1) demand increased flexibility. This increase in flexibility in turn requires additional supporting information technology. In this sense, IT is an enabler of flexible mass customization. The obvious basic feature for all categories is MCIS, a web-based sales channel. Supply chain integration is required for both call-off and design-per-order strategies. Agile Manufacturing systems are needed to deal with the complexities of using flexible resources. CAD/CAM systems and DDIS are essential for engineering customer specific products.

The categories that have been analyzed in this paper have been described as clearly separated modes of mass customization. In reality, multiple modes may co-exist within a single company or division. The implication is that a company that employs multiple modes of mass customization will face an additional challenge to combine the requirements of the modes and integrate the various systems.

The implementations of enabling technologies described in this paper are, in the case of MCIS and DDIS, academic prototypes that have been used as examples. These prototype systems are not commercial-grade software: they are proof-of-concepts and should be considered as such. The aim of this paper is to identify key features and show the existence of IT systems suitable for supporting the various modes of mass customization, not to present an overview of available commercial software packages.

Given the prototypical nature of the existing systems there is still a long way to go before the ultimate goal of commercially available, seamlessly integrated IT-support for mass customization across all processes will be achieved. It is even doubtful whether an integrated solution will ever appear. Whereas replacement of previously fragmented systems by integrated systems has been successful in other areas, such as ERP, the diverse requirements and broad scope of the supporting technologies may well enforce a best-of-breed strategy. In this case, integration of these systems presents a major challenge to the successful support of mass customization in which hurdles like defining data entities, communication standards and clear separation of responsibilities will have to be overcome, presenting interesting research challenges.

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