Mass Customization with Configurable Products and Configurators: A Review of Benefits and Challenges

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ABSTRACT

Configurable products are an important way to achieve mass customization. A configurable product is designed once and this design is used repetitively in the sales-delivery process to produce specifications of product individuals meeting customer requirements. Configurators are information systems that support the specification of product individuals and creation and management of configuration knowledge, therefore being prime examples of information systems supporting mass customization. However, to the best of our knowledge, there is no systematic review of literature on how mass customization with configurable products and use of configurators affect companies. In this chapter we provide such a review. We focus on benefits that can be gained and challenges companies may face. A supplier can move to mass customization and configuration from mass production or from full customization – we keep the concerns separate. We also review benefits and challenges from the customer perspective. Finally, we identify future research directions and open challenges and problems.

KEYWORDS

Information systems; literature review; mass customization; configurable products; configurator

INTRODUCTION

Today, customers are demanding products that meet their increasingly diverse needs better. *Mass customization* (MC) has been proposed (Pine, 1993a) as a more cost-efficient solution to this challenge than *full customization* (FC), a term we use in this chapter for craft production of one-of-a-kind, bespoke products. MC is the ability to provide products tailored to individual customer needs on a large scale at, or close to, mass production (MP) efficiency, using flexible processes (Pine, 1993a; Hart, 1995; da Silveira et al., 2001). One way to implement MC is through *configurable products* (CP). The design of a configurable product specifies a set of predesigned elements and rules on how these can be combined into valid product individuals (Tiihonen & Soininen, 1997; Salvador & Forza, 2004). Such knowledge is called *configuration knowledge.* The design of a configurable product is used repetitively, in a routine manner without creative design, in the sales-delivery process to produce specifications of product individuals, meeting the requirements of particular customers. Defining a valid, error-free (sales) specification of a customer-specific product individual can be difficult because the product elements often manifest complex interdependencies and incompatibilities. Some companies have addressed this difficulty by employing information systems called *product configurators* (or *configurators* for short) as support in the task of defining a (sales) specification (Barker & O'Connor, 1990; Forza & Salvador, 2002a; 2002b). A configurator is an information system that supports the creation and management of configuration knowledge and the specification of product individuals (Tiihonen & Soininen, 1997; Sabin & Weigel, 1998).

However, to the best of our knowledge, there is no systematic review of literature on how configurators affect the operations and business of companies pursuing mass customization with configurable products. The majority of papers describe the introduction and use of a configurator in a single case company. A significant set of papers describes issues of MC, CP and configurators. This review aims to provide a summary.

The rest of this chapter is structured as follows. Next, the overall framework of the literature review is described. The following section then contemplates the benefits and challenges of MC and CP for the supplier and customer, first compared with MP and then compared with FC. This section is followed by the discussion of configurator benefits, how they may overcome or alleviate the MC and CP challenges and then moving on to the configurator challenges. Also in this section the supplier perspective is discussed before the customer perspective. Before suggestions for future research directions and discussion and conclusions end this chapter, the rationale for a company to move to MC are briefly discussed.

LITERATURE REVIEW METHODS AND FRAMEWORK

For the literature review we first identified the benefits and challenges attributed to MC, configurable products, and configurators. Second, we studied how configurators have been used to meet the challenges related to MC with configurable products. Third, we identified unmet challenges and remaining problems in configurator-supported MC and derived suggestions for future work. The framework for our literature review reflects this process and illustrates our viewpoints, see Figure 1. We classified benefits and challenges according to whom they concern (supplier or customer) and direction of move to MC. A supplier can move to MC (Lampel & Mintzberg, 1996; Duray, 2002; Svensson & Barfod, 2002) and CP (Tiihonen & Soininen, 1997) from either the direction of MP or FC. The latter classification is not visible in Figure 1.

We used electronic scientific databases with search terms such as mass customization, customization, product configuration, configurator, configurable products, benefits, challenges, opportunities, threats, limitations, problems, and drawbacks. From the yield of hundreds of articles, books and conference papers, we browsed the abstracts and selected about 75 publications for closer examination. Further selection left some of them out of this paper. For readability, we omit a full list of references to a benefit or challenge from the text. All references are shown in tables at the end of each subsection. The tables also show whether a reference belongs to MC or CP literature, when applicable.

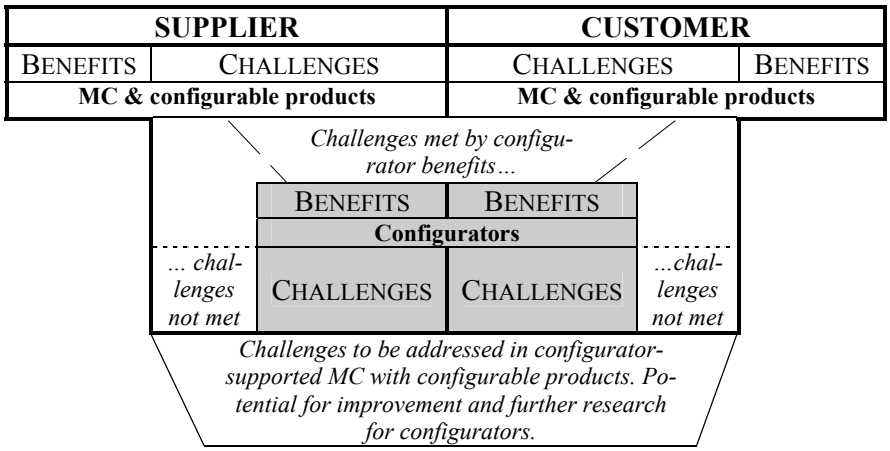

Figure 1 Framework for literature review

MASS CUSTOMIZATION AND CONFIGURABLE PRODUCTS

Supplier Benefits Compared with Mass Production

In this section we discuss the benefits for a supplier from MC or CP compared with MP. The benefits and references are summarized in Table 1.

In general, MC refers to the *ability to effectively fulfill a wider range of customer needs* than with MP (e.g. Pine, 1993a), an idea often incorporated into definitions of MC.

Perhaps the most cited benefit of MC and CP is the *reduction in inventories* of finished goods and work-in-progress, tying less capital compared to build-to-forecast MP (e.g. Pine, 1993a, p. 126). Less inventory handling and management is necessary (Broekhuizen & Alsem, 2002) and improvements in inventory turnover are implied (Beaty, 1996). Similarly, MC can eliminate or reduce the need to sell aging models and seasonal products by discount as MC *products are less subject to product obsolescence and fashion risk* (e.g. Kotha, 1995). MC often involves modular products. An inventory of modules is less subject to fashion and technological obsolescence than differentiated inventory (Berman 2002). As a result, the supplier does not have to include markdowns or high inventory accumulation in its pricing (Berman, 2002).

In MC and also with CP, the customer participates in the specification of the product. *Customers may enjoy the participation in design* and it can *increase customer satisfaction in the finished good* as well (e.g. Huffman & Kahn, 1998). Further, the *effort spent and information accumulated and stored* in the specification process *can become a switching cost for the customer* (e.g. Pine et al., 1995). Switching to competition would mean spending the effort again. However, this benefit can be realized fully only if the interactions or repurchases with the customers are frequent enough (Pine et al. 1995; Broekhuizen & Alsem 2002). As customers need to express their needs, the supplier has an opportunity to gather *more accurate customer information* (e.g. Pine et al. 1995) and develop a deep understanding of the customer's needs (Berman, 2002). This and engaging the customer in a continuous dialog (Berman, 2002) and learning relationship (Pine et al., 1995) makes it more difficult for competitors to accumulate the same depth of customer knowledge and entice customers away. Moreover, information on actual orders directly reflects current market information (Berman, 2002). This may enable quicker product development response to changes in overall customer needs (Slywotzky, 2000; Berman, 2002). However, Kakati (2002) argues that all customer needs cannot be captured with tracking choices on physical product elements. The customers must also be willing to share their preferences and purchase patterns with the supplier on an on-going basis if the supplier is to be able to use them for their own purposes (Wind & Rangaswamy, 2001).

MC can enable *premium pricing* (e.g. Kotha, 1995) due to the better fit of the product to customer needs and due to the difficulty of comparison-shopping of customized products (e.g. Agrawal et al., 2001, see Table 8). Ability to participate may also increase willingness to pay for the self-designed, customized final product (Franke & Piller, 2004).

Table 1 Summary of supplier benefits compared with mass production

Benefit	**References**	**MC/ CP**
Efficient way to fulfill a wider range of customer needs	E.g. Pine, 1993a; Hart, 1995; da Silveira et al., 2001. (*MC has been usually defined in a similar vein.)*	MC
	Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998; Bonehill & Slee-Smith, 1998	CP
Reduction in inventories	Pine 1993a, p. 126; Kay, 1993; Kotha, 1995; Ross, 1996; Beaty, 1996; Gilmore & Pine, 1997; Radder & Louw, 1999; Slywotzky, 2000; Zipkin, 2001;	MC

	Agrawal et al., 2001; Wind & Rangaswamy, 2001; Berman, 2002; Broekhuizen & Alsem, 2002; Svensson & Barfod 2002; Piller et al. 2004; Piller & Müller 2004	
	Tiihonen & Soininen, 1997; Tiihonen et al., 1998	CP
Reduction in product model obsolescence, fashion risk	Kotha, 1995; Agrawal et al., 2001; Zipkin, 2001; Berman, 2002; Piller et al., 2004; Piller & Müller, 2004	MC
Customer participation in design: satisfaction, effort spent a switching cost	*Satisfaction*: Huffman & Kahn, 1998; Wind & Rangaswamy, 2001; Bardacki & Whitelock, 2003. *Switching costs*: Pine et al., 1995; Broekhuizen & Alsem, 2002; Bardacki & Whitelock, 2003; Piller et al., 2004; Piller & Müller, 2004	MC
More accurate customer information	Pine et al., 1995; Hart, 1995; Ählström & Westbrook, 1999; Slywotzky, 2000; Agrawal et al., 2001; Kakati, 2002; Broekhuizen & Alsem, 2002; Berman, 2002; Brown & Bessant, 2003; Bardacki & Whitelock, 2003; Piller et al., 2004; Franke & Piller, 2004	MC
Potential for premium pricing	Kotha, 1995; Ross, 1996; Agrawal et al., 2001; Berman, 2002; Broekhuizen & Alsem, 2002; MacCarthy & Brabazon, 2003; Piller & Müller, 2004; Piller et al., 2004; Franke & Piller, 2004	MC

Supplier Challenges Compared with Mass Production

In the following, we discuss the supplier challenges from MC or CP compared with MP from a number of viewpoints.

Business

See Table 2 for a summary of the supplier business challenges we discuss in this section.

MP products have to be developed or adjusted to be suitable for MC. *MC tends to be more costly than MP* (e.g. Kotha, 1995). One of they key challenges for MC with CP for the supplier is to *find the right amount of customization to offer* that balances the costs of added complexity and increased customer value (e.g. Beaty, 1996). The offered customization range has to be matched to customer needs of the targeted segment(s). A mismatch reduces sales potential and can lead to excessive one-of-a-kind design (Tiihonen & Soininen, 1997; Tiihonen et al., 1998). Excessive customization increases the specification complexity both for the supplier and the customer and may strain the production process too far (Berman, 2002). Further, development of a product to be easy to configure ("design for configuration") can be a significant effort (Tiihonen & Soininen, 1997; Tiihonen et al., 1998).

MC products often are modular and possibly share components across product lines or families. *Component sharing may cause customers to see the products as overly similar* (Pine, 1993b) and create confusion over the 'true' customization level of the product (Berman, 2002; Kakati, 2002).

MC may cause *channel conflicts* (Wind & Rangaswamy, 2001; Broekhuizen & Alsem, 2002) as retailers may be unwilling to participate in fear of the supplier bypassing them in the future and they may also be reluctant to take on more specification tasks. *Difficulties of eliciting* customer needs *and creating sales specifications* (discussed in section Specification process below) *can cause severe challenges*. These include loss of confidence from customers (Fohn et al., 1995), lost sales, customers, and repeat business (Fohn et al., 1995; Heatley et al., 1995), and decreased customer satisfaction (Heatley et al., 1995; Forza & Salvador, 2002a). Further, the problems and complexity of specifying, and dissatisfaction in the shopping process are often attrib-

uted to the retailer (Huffman & Kahn, 1998). Elicitation difficulties, resulting order errors and delays may also lower dealer loyalty (Yu & Skovgaard, 1998).

Table 2 Summary of supplier business challenges compared with mass production

Challenge	References	MC/CP
Producing customized products often costs more than MP	Kotha, 1995; Åhlström & Westbrook, 1999; Zipkin, 2001; Berman, 2002; Broekhuizen & Alsem, 2002; Kakati, 2002; Bardacki & Whitelock, 2003; Piller et al., 2004; Piller & Müller 2004	MC
Finding right amount, balance of offered customization	Beaty 1996; Svensson & Barfod 2002; Berman 2002; MacCarthy & Brabazon 2003; Piller & Müller 2004	MC
	Tiihonen & Soininen, 1997; Tiihonen et al., 1998	CP
Component sharing across product lines may cause customer to see the products as overly similar	Pine, 1993b; Berman, 2002; Kakati, 2002	MC
Possible channel conflicts with retailers	Wind & Rangaswamy, 2001; Broekhuizen & Alsem, 2002	MC
Elicitation difficulties can cause lost business, image, and lower customer and dealer loyalty and satisfaction.	Huffman & Kahn, 1998	MC
	Fohn et al., 1995; Heatley et al., 1995; Yu & Skovgaard, 1998; Forza & Salvador, 2002a	CP

Organization and operations

The organizational and operational challenges for the supplier we contemplate here are summarized in Table 3. The *extent of operational changes required is large* (e.g. Pine et al., 1993). Sales and marketing has to increase interaction with the customers (Kakati, 2002) and learn new specification tasks (Tiihonen & Soininen, 1997). MC requires more manufacturing and logistics flexibility (discussed in section Manufacturing below).

A commonly cited challenge in MC is that it *increases the need for information management* (e.g. Åhlström & Westbrook, 1999). What an MC supplier basically does is that it takes the customer requirements, i.e. information, and translates them to a manufactured product (da Silveira et al., 2001). The information about the customer requirements flows through the supplier organization from sales to manufacturing and distribution, crossing organizational boundaries, until the customer-specific product is finally delivered to the customer. This increases both the amount of information transferred and the information flows (or paths) in the supplier organization. Both operations flow and customer information needs to be managed by the supplier (Broekhuizen & Alsem, 2002). MC also increases the need for product data and variant handling (Comstock et al., 2004).

The *extent of required organizational and cultural changes is large* (e.g. Pine et al., 1993). Functional silos are a hindrance to MC (Pine et al., 1993). It can be difficult to create company-wide understanding of the benefits of MC with CP. Effort spent and effects felt may occur at different places. Developing well managed and documented configuration knowledge takes effort in the product process but helps sales. Producing error-free and complete sales specifications takes extra effort at sales but helps to reduce fire-fighting in manufacturing (Tiihonen & Soininen, 1997). Highly-skilled, more costly sales staff and increased training may be required for eliciting customer needs, specification tasks and verification of specifications (Berman, 2002). Achieving

the required skills is more difficult if the supplier does not own the sales companies (Tiihonen et al., 1996; Broekhuizen & Alsem, 2002) or if the turnover in sales is high (Berman, 2002).

Table 3 Summary of supplier organizational and operational challenges compared with mass production

Challenge	References	MC/CP
Extent of operational changes large	Pine et al., 1993; Hart 1995; Kotha 1995; Ross 1996; Agrawal et al. 2001; Zipkin 2001; Berman 2002; Broekhuizen & Alsem 2002	MC
	Tiihonen & Soininen, 1997	CP
Increased information management	Åhlström & Westbrook, 1999; da Silveira et al., 2001; Zipkin, 2001; Berman, 2002; Broekhuizen & Alsem, 2002; Kakati, 2002; MacCarthy & Brabazon, 2003; Brown & Bessant, 2003; Piller et al., 2004; Comstock et al., 2004	MC
	Forza & Salvador, 2002a; Salvador & Forza, 2004	CP
Extent of organizational and cultural changes large	Pine et al., 1993; Kay, 1993; Ross, 1996; Åhlström & Westbrook, 1999; Slywotzky, 2000; Agrawal et al., 2001; Kakati, 2002; Berman, 2002	MC
	Tiihonen & Soininen, 1997	CP

Specification process

In this section we discuss the supplier challenges related to the specification process, for a summary, see Table 4. The most often cited challenge with MC and CP is the *difficulty of customer needs elicitation and defining a corresponding, valid sales specification* (e.g. Ross, 1996) as customization adds complexity and increases the amount of required information. Sales often have incomplete or out-of-date configuration knowledge, which is one contributing factor to the specification errors. This issue is discussed in detail in section Long term management of configuration knowledge below.

Several specification error types have been identified. 1) The *specified product individual cannot be produced at all or it would not work properly* (Aldanondo et al., 1999; 2000). Such *errors cause iterations in the sales-delivery process* (e.g. Wright et al., 1993) between the customer and supplier or sales and manufacturing because specifications have to be reconsidered. 2) The *specification might not meet customer needs optimally* (Aldanondo et al., 1999; Forza & Salvador, 2002a). One reason may be the different terminology or level of abstraction in expressing customer requirements and technical specifications (Tiihonen & Soininen, 1997; Tiihonen et al., 1998). Communicating customization possibilities of a very flexible product to the customer may also be hard (Tiihonen & Soininen, 1997). Technical experts consulted for specification feasibility may not communicate with the customer at all, which may be a cause for mismatch as well (Tiihonen & Soininen, 1997). Further, it is difficult to identify intangible preferences like the preferred fit of a shoe (tight/loose) (Wind & Rangaswamy, 2001). 3) Pricing errors: e.g., a specification might define a *smaller price than the effective cost of producing the product individual* (e.g. Wright et al., 1993). If pricing information is not available during the specification task the sales staff is not able to 'guide' the customer to more profitable options, nor inform the customer of costly options (Salvador & Forza, 2004). 4) An *erroneous delivery time* could also be specified (Salvador & Forza, 2004).

To avoid difficulties of specification, *sales staff may create repertoires of typical sales specifications that are valid but not necessarily optimal in fit with customer needs* (e.g. Sviokla, 1990). Therefore the full customization potential of the product is not offered to the customer (Salvador & Forza, 2004). Specification task complexity may also cause *sales persons to pro-*

duce different specifications for identical orders (Sviokla, 1990). To counter the difficulties of sales staff, *technical experts are often deeply involved in verifying specification validity* (e.g. Tiihonen et al., 1998), which detracts them from other tasks like product development (Forza & Salvador, 2002a), and also increases the lead-times in order processing (Wright et al., 1993). The validity checks are often bypassed under time pressure, which results in more errors (Forza & Salvador, 2002a; 2002b).

Table 4 Summary of the supplier challenges in the specification process compared with mass production

Challenge	References	MC/CP
Difficulty of customer needs elicitation and defining a corresponding, complete, and error-free sales specification	Ross, 1996; Huffman & Kahn, 1998; Åhlström & Westbrook, 1999; Zipkin, 2001; Wind & Rangaswamy, 2001; Berman, 2002; MacCarthy & Brabazon, 2003; Piller et al., 2004; Comstock et al., 2004	MC
	Sviokla, 1990; Wright et al., 1993; Heatley et al., 1995; Fohn et al., 1995; Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998; McGuinness & Wright, 1998; Sabin & Weigel, 1998; Yu & Skovgaard, 1998; Vanwelkenheysen, 1998; Aldanondo et al., 1999; Aldanondo et al., 2000; Forza & Salvador, 2002a; Forza & Salvador, 2002b; Salvador & Forza, 2004	CP
Can specified product individual be produced/ manufactured & will it work properly?	Aldanondo et al., 1999; Aldanondo et al., 2000	CP
Errors noticed after sales specification phase lead to iterations in sales-delivery process	Wright et al., 1993; Heatley et al., 1995; Fohn et al., 1995; Tiihonen & Soininen, 1997; Tiihonen et al., 1998; Sabin & Weigel, 1998; Aldanondo et al., 2000	CP
Does the specified product individual fit customer needs optimally?	Aldanondo et al., 1999; Forza & Salvador, 2002a	CP
Erroneous, smaller price than effective cost for the specified product individual.	Wright et al., 1993; Fohn et al., 1995; Aldanondo et al., 1999; Aldanondo et al., 2000; Salvador & Forza, 2004	CP
Erroneous delivery time	Salvador & Forza, 2004	CP
Sales staff create repertoires of typical specifications, valid but not optimal in fit with customer needs	Sviokla, 1990; Heatley et al., 1995; Salvador & Forza, 2004	CP
Two sales persons may produce different specifications for identical customer orders	Sviokla, 1990	CP
Technical experts deeply involved in verifying specifications	Tiihonen et al., 1998; Forza & Salvador, 2002a; Salvador & Forza, 2004	CP

Manufacturing

The manufacturing challenges for the supplier are summarized in Table 5. The manufacturing of customer-specific products *requires more manufacturing and logistics flexibility*, which can be difficult to achieve (e.g. Kotha, 1995). It is difficult to reach lead times (Åhlström & Westbrook, 1999; Svensson & Barfod, 2002; Comstock et al., 2004) and consistent quality

(Svensson & Barfod, 2002) comparable to MP. Further, the supplier has to handle variable costs instead of fixed costs (Hart, 1995). To operate efficiently, an MC supplier needs to produce, sort, ship, and deliver small quantities of highly differentiated products (Berman, 2002), which increase complexity of production planning and quality control (Piller et al., 2004). Achieving the flexibility can require *investments in expensive flexible machinery* (Piller & Müller, 2004) *and hiring and training highly skilled staff* (Kotha, 1995).

S*pecification errors that reach manufacturing cause fire-fighting* activities (e.g. Heatley et al., 1995) that can take up to even 80% of the order processing time (Tiihonen et al., 1996) to manage incorrect bills-of-materials (BOMs) and production orders, missing parts, rush deliveries from part suppliers at a extra cost, and missed delivery dates (Forza & Salvador, 2002a).

Table 5 Summary of supplier manufacturing challenges compared with mass production

Challenge	References	MC/CP
Difficulties in achieving the required production process flexibility	Kotha, 1995; Åhlström & Westbrook 1999; Slywotzky 2000; Zipkin, 2001; Kakati 2002; Berman 2002; Piller et al. 2004	MC
	Tiihonen & Soininen, 1997; Tiihonen et al., 1998; Forza & Salvador, 2002a	CP
May require expensive investments in flexible machinery and acquiring highly skilled staff.	*Machinery:* Piller & Müller, 2004 *Staff:* Kotha, 1995	MC
Fire-fighting in manufacturing from sales specification errors	Heatley et al., 1995; Tiihonen et al., 1996; Yu & Skovgaard, 1998; Forza & Salvador, 2002a; Salvador & Forza, 2004	CP

Long term management of configuration knowledge

For a summary of the challenges we discuss here, see Table 6. MC based on CP requires up-to-date configuration knowledge, stressing the importance of its management. The *long term management and maintenance of configuration knowledge is a major task and its level in companies often poor* (e.g. Wright et al., 1993). This contributes to the sales specification errors discussed earlier. Sales may not know the variation possibilities because configuration knowledge is not systematically documented (Tiihonen et al., 1996; Tiihonen et al., 1998). Product development rarely creates configuration knowledge and if it does, *extracting the knowledge to sales is problematic and the transfer rarely systemized* (Wright et al., 1993; Tiihonen et al., 1996). Knowledge transfer to retailers is even more challenging (Tiihonen et al., 1996). A compounding factor is that the configuration knowledge is often dispersed among a variety of sources across the supplier organization, like manufacturing, assembly, and marketing (Wright et al., 1993; Haag, 1998; McGuinness & Wright, 1998). This impedes knowledge acquisition in maintenance and update situations (McGuinness & Wright, 1998).

A further problem is that the *configuration knowledge often changes frequently* (e.g. Tiihonen & Soininen, 1997), which together with the transfer problems means that the configuration knowledge used in sales is often not up-to-date (Wright et al., 1993). The workarounds that sales staff sometimes invent to curb the elicitation complexity, like the aforementioned repertoires of typical specifications, are especially easily out-dated (McGuinness & Wright, 1998). Reasons for configuration knowledge changes can be shifts in customer requirements and marketing strategies (Tiihonen & Soininen, 1997; Fleischanderl et al., 1998), product and component evolvement (Tiihonen et al., 1996), and added or removed product functionalities (Tiihonen & Soininen, 1997).

Long term management of delivered product individuals (e.g. Tiihonen et al., 1996) is a related challenge. Information on product type and the product individual is needed when changes have to be made to an existing product individual for maintenance and servicing reasons, or when new or better functionality is added (Tiihonen & Soininen, 1997; Sabin & Weigel, 1998). This *reconfiguration* is problematic and prone to errors as it involves adding and removing components that may have complex interdependencies (Tiihonen & Soininen, 1997; Sabin & Weigel, 1998) and the required configuration knowledge may have to be retrieved from various sources and has to bridge temporally different versions of configuration knowledge base (Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998).

Table 6 Summary of supplier challenges in long term management of configuration knowledge compared with mass production

Challenge	References	MC/CP
Long term management of configuration knowledge	Wright et al., 1993; Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998; Yu & Skovgaard, 1998; McGuinness & Wright, 1998; Haag, 1998; Fleischhanderl et al., 1998	CP
Transferring (updated) configuration knowledge to sales force	Wright et al., 1993; Tiihonen et al., 1996	CP
Configuration knowledge changes frequently	Tiihonen & Soininen, 1997; Fleischanderl et al., 1998; McGuinness & Wright, 1998	CP
Long term management of delivered product individuals, reconfiguration	Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998; Yu & Skovgaard, 1998; Sabin & Weigel, 1998	CP

Customer Benefits Compared with Mass Production

This section presents the customer benefits as compared with MP, see Table 7 for a summary. The customer viewpoint has received relatively little attention in literature.

The main benefit from MC is the *better product fit with customer needs* (e.g. Pine, 1993a) which applies to CP as well. Customers may also find *participation in the design and specification enjoyable in itself* (e.g. Huffman & Kahn, 1998) and it can also increase satisfaction in the final product (Bardacki & Whitelock, 2003).

Table 7 Summary of customer benefits compared with mass production

Benefit	References	MC/CP
Improved fit with customer needs	Pine, 1993a, p. 127; Kotha, 1995; Radder & Louw, 1999; Agrawal et al., 2001; Wind & Rangaswamy, 2001; Berman, 2002; Broekhuizen & Alsem, 2002; Bardacki & Whitelock, 2003; MacCarthy & Brabazon, 2003	MC
Enjoyable participation in specification, design	Huffman & Kahn 1998; Wind & Rangaswamy 2001; Bardacki & Whitelock 2003; Piller & Müller 2004; Franke & Piller 2004	MC

Customer Challenges Compared with Mass Production

Next, the customer challenges from MC and CP compared with MP are discussed; a summary can be seen in Table 8. As for benefits, the customer viewpoint of the challenges appears to have received little attention in CP literature.

In MC, customers have to express their preferences for the product and may suffer from the *complexity of the specification* (e.g. Pine, 1993a). They may be overwhelmed by the number of

options, sometimes referred to as 'mass confusion' (Huffman & Kahn, 1998). Customers can be unsure of their needs and have trouble both in deciding what they want and in communicating their decisions precisely (Gilmore & Pine, 1997; Zipkin, 2001). Further, some needs are unarticulated (Gilmore & Pine, 1997). Customers may also feel uncertainty whether they have been exposed to all alternatives and have complete information about the options (Huffman & Kahn, 1998). Specification difficulties are compounded if the customers lack sufficient product expertise (Huffman & Kahn, 1998). Moreover, the *time and effort customers have to spend in specification,* expressing preferences is an added drawback (e.g. Gilmore & Pine, 1997) compared to picking a product 'off-the-shelf ' as in MP. Some *customers may feel that expressing preferences invades their privacy* (e.g. Pine, 1993a), especially in Internet (Wind & Rangaswamy, 2001).

In MC, the *customers usually have to wait for the finished product* (e.g. Radder & Louw, 1999) as it is produced for order. Moreover, *customers must trust the supplier to deliver exactly according to the specification* (Berman, 2002; Broekhuizen & Alsem, 2002). *Customized products tend to be more expensive* (e.g. Hart, 1995). The limited transparency of products, their complexity, and specificity of individual products make *comparison-shopping and judging whether the product is good value for money more difficult* (e.g. Wind & Rangaswamy, 2001). On the other hand, customization raises customer expectations, which can backfire as a more severe disappointment if the end product does not meet the expectations (Berman, 2002). Further, customers may fear that the customized products have more inconsistent quality (Svensson & Barfod, 2002).

Table 8 Summary of customer challenges compared with mass production

Challenge	References	MC/CP
Complexity of design, specification	Pine, 1993a, p. 246; Pine et al., 1993; Pine et al., 1995; Beaty, 1996; Gilmore & Pine, 1997; Huffman & Kahn, 1998; Berman, 2002; Wind & Rangaswamy, 2001; Zipkin, 2001; Svensson & Barfod, 2002; Broekhuizen & Alsem, 2002; Piller et al., 2004; Dellaert & Stremersch, 2005	MC
	Forza & Salvador, 2002a	CP
Time and effort spent in design, specification	Gilmore & Pine, 1997; Berman, 2002; Broekhuizen & Alsem, 2002; Kakati, 2002; Bardacki & Whitelock, 2003	MC
Feeling of invaded privacy	Pine, 1993a, p. 245; Pine et al., 1995; Wind & Rangaswamy, 2001; Broekhuizen & Alsem, 2002	MC
Waiting for the finished product	Radder & Louw, 1999; Agrawal et al., 2001; Zipkin, 2001; Svensson & Barfod, 2002; Bardacki & Whitelock, 2003; MacCarthy & Brabazon, 2003	MC
Need to trust supplier to deliver exactly as specified	Berman, 2002; Broekhuizen & Alsem, 2002	MC
Increased price of products	Hart, 1995; Radder & Louw, 1999; Wind & Rangaswamy, 2001; Zipkin, 2001; Agrawal et al., 2001; Broekhuizen & Alsem, 2002; Kakati, 2002; Svensson & Barfod, 2002; Bardacki & Whitelock, 2003; Piller & Müller, 2004	MC
More difficult comparison-shopping, limited transparency of product	Wind & Rangaswamy, 2001; Broekhuizen & Alsem, 2002; Piller et al., 2004	MC

Supplier Benefits Compared with Full Customization

This section discusses the supplier benefits (summarized in Table 9) from MC or CP compared with FC. Literature on moving to MC from FC and on associated benefits and challenges is limited to Svensson & Barfod (2002) while CP literature gives a bit more attention.

Svensson and Barfod (2002) mention several benefits that a FC supplier can gain from switching to MC. They all seem to stem from increased standardization. The benefits are *increased efficiency and more controlled production*, *improved and more uniform product quality*, *shorter lead-times*, and *lower costs*. These benefits are mentioned in CP literature as well. A reason for improved control of production is the use of a relatively small number of components to produce a large variety of end products (Tiihonen et al., 1996). A cause for quality improvements can be the use of a standard, modular design, which reduces incorrect assemblies (Bonehill & Slee-Smith, 1998). *Lead-time reductions* can result from quality improvements, and from the *reduced need for customer-specific design* of components or end products (e.g. Tiihonen et al., 1998). This also may *free expert engineering resources* to other tasks like product development (e.g. Tiihonen et al., 1998). Reduced effort also contributes to lower costs.

Lead-times may also be reduced by *easier selling*. For a configurable product, the sales options have been defined in advance. Choosing from existing options rather than beginning from scratch brings two benefits: it is *easier to arrive at a sales specification* (Tiihonen et al., 1998) *and to price the product* (Tiihonen et al., 1998). This may *allow retailers or even customers to do specification* themselves (Salvador & Forza, 2004). Customers who are engaged in the specification process may accept more responsibility for the product's fit to their needs (Salvador & Forza, 2004).

Table 9 Summary of supplier benefits compared with full customization

Benefit	References	MC/CP
Increased efficiency, more controlled production	Svensson & Barfod, 2002	MC
	Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998	CP
Improved, more uniform quality	Svensson & Barfod, 2002	MC
	Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998; Bonehill & Slee-Smith, 1998; Salvador & Forza, 2004	CP
Shorter lead-times, more accurate on-time delivery	Svensson & Barfod, 2002	MC
	Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998	CP
Lower costs	Svensson & Barfod, 2002	MC
	Bonehill & Slee-Smith, 1998	CP
Reduced design effort…	Tiihonen et al., 1998; Bonehill & Slee-Smith, 1998; Salvador & Forza, 2004	CP
…which freed expert engineering to other tasks like R&D		
Easier to do specifications, even by customers or retailers themselves, easier selling	Tiihonen et al., 1998; Salvador & Forza, 2004	CP
Easier pricing	Tiihonen et al., 1998	CP

Supplier Challenges Compared with Full Customization

Next, the supplier challenges from MC or CP compared with full customization are contemplated. The challenges are summarized in Table 10. It seems that MC has not been compared with FC in terms of benefits and challenges as often as with MP.

Compared to FC, MC with CP *requires changes in operations and organization* that can be significant (e.g. Tiihonen & Soininen, 1997). *Achieving more uniform quality and repeatable production may be a difficult challenge* (Svensson & Barfod, 2002). For FC suppliers, the main challenge in MC is the shift from managing the product and processing materials (which they master) to *systematically managing and processing information* involved in customer-specific orders, product documentation, etc., according to Svensson and Barfod (2002). This requires a cultural change that can be difficult to achieve. *Finding the right amount of offered customization* is equally important (e.g. Beaty, 1996), as when compared with MP. A balance must be found between the added standardization, uniform quality, and lowered costs and compromising the optimal fit of a fully customized product.

Customer needs elicitation and error-free specification is still a challenge (Svensson & Barfod, 2002). Sales specification errors cause similar problems in manufacturing, as when compared to MP. *Sales force must learn not to offer changes to the product that would require customer-specific design* (e.g. Tiihonen & Soininen, 1997).

For product development, it is a challenge and a *big effort to develop a design for the configurable product*, with a modular structure of reusable, replicable product components (e.g. Tiihonen & Soininen, 1997) and clearly defined module interfaces. On the other hand, Pine (1993a; 1993b) has expressed the fear that *modular designs are easier to reverse engineer and copy than unique designs*.

Table 10 Summary of supplier challenges compared with full customization

Challenge	References	MC/CP
Requires changes in operations and organization	Tiihonen & Soininen, 1997; Tiihonen et al., 1998	CP
Achieving uniform quality	Svensson & Barfod, 2002	MC
Systemizing information management	Svensson & Barfod, 2002	MC
Finding right amount, balance of offered customization	Beaty, 1996; Berman, 2002; Svensson & Barfod, 2002; MacCarthy & Brabazon, 2003	MC
	Tiihonen & Soininen, 1997; Tiihonen et al., 1998	CP
Customer needs elicitation, specification	Svensson & Barfod, 2002	MC
Sales staff must not offer changes outside pre-designed customization possibilities	Tiihonen & Soininen, 1997; Tiihonen et al., 1998	CP
Systemizing product design from configuration viewpoint a big effort	Tiihonen & Soininen, 1997; Tiihonen et al., 1998	CP
Reverse engineering of modular designs	Pine, 1993a, p. 212; Pine, 1993b	MC

Customer Benefits Compared with Full Customization

Here, the customer benefits compared with full customization are contemplated. However, the literature is scant. Nevertheless, the benefits for the supplier (see Table 9) could also generate benefits for the customers like *shorter delivery times, more predictable deliveries, better serviceability, more communicable product specifications, improved spare part stock management*, *better and more consistent quality*, *more affordable products*, *better accessibility to products*, and the like. Further, customers may prefer the *easier specification by choosing from existing options* and receive *better product documentation* than for a FC product.

Customer Challenges Compared with Full Customization

The literature we studied seems not to have examined the customer challenges compared with full customization. However, it is probable that *explicit specification is difficult for customers*, as it is a complex task nevertheless. C*ustomers may also have to compromise on the optimal fit* of the product and *the customer service experience may not feel personal enough* as with FC the customers are used to get exactly what they want.

CONFIGURATORS

Overview

A configurator checks the specification of a product individual, i.e. a *configuration,* for *completeness* (i.e. that all the necessary selections are made) and *consistency* (i.e. that no rules are violated) with respect to the configuration knowledge, stored in *configuration models* in configurators (Tiihonen & Soininen, 1997). Configurators also support the user in specifying a product individual, called a *configuration task*. Depending on the configurator, additional functionality such as price and delivery time calculation, layout drawing and document generation, etc. may be provided. Configurators are also used to create and manage the configuration models and configuration knowledge embedded in them.

In the rest of this section, the benefits and challenges related to configurators are discussed. The discussion is divided into supplier and customer viewpoints. The supplier perspective is further divided to issues concerning the business, organization, specification process, manufacturing, product development, and long-term management of configuration knowledge perspectives. The benefits are related to configurator use compared with MC with CP prior to configurator introduction. Challenges relate to configurator use. The benefits are also discussed in terms of whether they alleviate or overcome some challenges related to MC with CP.

Supplier Benefits

This section discusses the benefits configurators can bring to the supplier and if they overcome challenges related to MC with CP. The benefits are summarized in Table 14.

Business

In this section, we review the business benefits of configurators for the supplier. They are summarized in Table 11. *In some circumstances configurators can enable premium pricing*. Heatley et al. (1995) document a case where a sixfold shortening of the order throughput cycle brought a competitive advantage that enabled premium pricing. They also observed that configurator-supported sales engineers sold more complex products, often commanding a high premium. In a similar vein, Yu & Skovgaard (1998) claim *increased sales due to* (partially) configurator induced *shorter delivery times and product flexibility*. Heatley et al. (1995) report that *products that were at the borderline of profitability* prior to the configurator because of order delays, pricing errors, and rework costs *became attractive* as the configurator reduced these costly problems. Overall, avoidance of errors, related rework, and production problems seem to reduce costs. Fleischanderl et al. (1998) report of a case where configuration related costs were reduced 60% over the product life cycle.

Barker and O'Connor (1989) and Heatley et al. (1995) argue that customer satisfaction increases as many of the configurator induced benefits affect customers' perceptions positively. Giving the configurator to customers to use had the effect of *"tying" customers to the company*

in the case reported by Forza and Salvador (2002b). The configurator reduced the time customers needed for defining product specifications. *Dealer and retailer loyalty may be improved* by configurators (Heatley et al., 1995; Yu & Skovgaard, 1998) due to less errors and subsequent hassles and as configurators can enable selling products with a higher premium. Further, configurators can boost customer relationship management by enabling *storage and mining of customer orders and preferences for cues to future strategy*, forecasting, and supply chain management (Bramham & MacCarthy, 2004) and improve tracking of purchases and sales (McGuinness & Wright, 1998). This can be an enabling factor for realizing a benefit of MC, getting access to real-time, more accurate customer information (Table 10).

Table 11 Summary of business benefits for the supplier

Benefit	References	Challenges met?
Better price from products, in some situations	Heatley et al., 1995	Higher costs of producing customized products.
Increased sales from shorter delivery times, product flexibility.	Yu & Skovgaard, 1998	Higher costs of producing customized products.
Products at borderline of profitability can become more attractive	Heatley et al., 1995	Higher costs of producing customized products.
Reduction of costs in many areas	Fleischanderl et al., 1998	Higher costs of producing customized products.
Improved customers' satisfaction, perception	Barker & O'Connor, 1989; Heatley et al., 1995	Low customer satisfaction, lost image from elicitation difficulties.
Customer 'lock-in' from configurator usage; Dealer & retailer loyalty	*Lock-in:* Forza & Salvador, 2002b. *Loyalty:* Heatley et al., 1995; Yu & Skovgaard, 1998	Low dealer and customer loyalty from elicitation difficulties.
Improve tracking of purchases and sales. Mining of customer orders and preferences from configurator for future strategy.	McGuinness & Wright, 1998; Bramham & MacCarthy, 2004	

Organization

Next, we discuss the benefits from configurators to the organization, for a summary see Table 12. As configurators ensure the consistency of configurations and reduce manufacturing problems, they *allow for the use of less skilled workers in sales* (e.g. Bramham & MacCarthy, 2004) and in *production* (Sviokla, 1990). This probably lowers employment costs, as skilled labor tends to be more expensive. In similar vein, *customers* (Forza & Salvador, 2002b) or *retailers* (Yu & Skovgaard, 1998) *may do the specification themselves with configurators*. Further, *technical experts are no longer needed for consistency checks* (McGuinness & Wright, 1998) or *technical consulting during sales* (McGuinness & Wright, 1998), or *preparing customer-specific documentation* (Forza & Salvador 2002a), see also (Table 4). This frees them to other tasks like new product development (Bonehill & Slee-Smith, 1998; Forza & Salvador 2002a) or, less personnel may be necessary in general (Barker & O'Connor, 1989; Sviokla, 1990). *Work satisfaction increases as configurators obviate the need to working with mundane details*, like verifying specifications, *and more time may be devoted to intellectually challenging cases* (e.g. Heatley et al., 1995).

Table 12 Summary of supplier benefits in organization

Benefit	References for benefit	Challenges met?
Allows for less skilled workers in sales and production	*Sales:* Bramham & MacCarthy, 2004; Salvador & Forza, 2004. *Production:* Sviokla, 1990	Higher costs of producing customized products.
Allows for specification by retailers or even customers themselves	*Retailers:* Yu & Skovgaard, 1998. *Customers:* Forza & Salvador, 2002b	Technical experts deeply involved in verifying specifications
Technical experts needed less in specification → freed to other tasks, like R&D	Barker & O'Connor, 1989; Sviokla, 1990; McGuinness & Wright, 1998; Bonehill & Slee-Smith, 1998; Forza & Salvador 2002a	Technical experts deeply involved in verifying specifications
Configurators eliminate some tasks, even parts of organization related to consistency checks	McGuinness & Wright, 1998; Forza & Salvador, 2002b	
Work satisfaction increases as configurators reduce working with mundane details, and more time may be devoted to challenging cases	Heatley et al., 1995; Tiihonen & Soininen, 1997	

Specification Process

For a summary of the benefits, see Table 14 and Table 14. The ability of configurators to ensure the consistency and completeness of sales specifications by managing the complex interdependencies and incompatibilities between choices brings a number of benefits to the specification process. Configurators can *reduce or even eliminate the errors in sales specifications* (e.g. Barker & O'Connor, 1989) meaning also that the specified product individuals can be manufactured. Further, configurators also help to eradicate the errors noticed after sales, thus *reducing or eliminating the iterations between sales and manufacturing* (e.g. Wright et al., 1993), and *help sales staff to promptly give either correct or good estimates of delivery times* (e.g. Vanwelkenheysen, 1998) *and prices* (e.g. Barker & O'Connor, 1989). As configurators ensure the specifications are error-free, *sales staff can devote more time to actual selling* instead of doing consistency checks (e.g. Heatley et al., 1995) and *technical staff need not do consistency checks* anymore either (e.g. McGuinness & Wright, 1998).

Table 13 Summary of supplier benefits in the sales specification process (Part 1)

Benefit	References for benefit	Challenges met?
Reduce or eliminate errors in sales specifications	Barker & O'Connor, 1989; Sviokla, 1990; Fohn et al., 1995; Heatley et al., 1995; Ariano & Dagnino, 1996; Tiihonen & Soininen, 1997; Bonehill & Slee-Smith, 1998; Fleischhanderl et al., 1998; Vanwelkenheysen, 1998; Günter & Kühn, 1998; Yu & Skovgaard, 1998; Aldanondo et al., 1999; Aldanondo et al., 2000; Forza & Salvador, 2002a; Pedersen & Edwards, 2004	Difficulty, complexity of specification. Repertoires of typical specifications. Specified individuals that cannot be manufactured.
Reduce or eliminate iterations between sales and manufacturing	Wright et al., 1993; Heatley et al., 1995; Tiihonen & Soininen, 1997; Vanwelkenheysen, 1998; Aldanondo et al., 1999; Aldanondo et al., 2000	Errors noticed after sales lead to iterations in the sales-delivery process

Correct delivery time, or good estimate	Vanwelkenheysen, 1998; Forza & Salvador, 2002a	Incorrect delivery time
Correct price, or good estimate	Barker & O'Connor, 1989; Heatley et al., 1995; Ariano & Dagnino, 1996; Vanwelkenheysen, 1998; Forza & Salvador, 2002a	Incorrect, smaller price than effective cost
Sales can devote more time to selling	Heatley et al., 1995; Tiihonen & Soininen, 1997; Vanwelkenheysen, 1998	Difficulty, complexity of specification
Technical staff need not check consistency	McGuinness & Wright, 1998; Yu & Skovgaard, 1998; Forza & Salvador, 2002a; Forza & Salvador, 2002b	Technical experts deeply involved in verifying specifications

The support configurators lend to the specification process makes it less difficult and complex. Therefore, *sales staff can more freely and efficiently explore the alternatives, which can help to optimize the specification to customer needs* (e.g. Tiihonen & Soininen, 1997). This also enables sales staff to sell more complex products that often are more expensive as well (Heatley et al., 1995). Configurators also *reduce the effort needed in the specification* (e.g. Wright et al., 1993) by taking care of consistency checks and supporting the specification task, and often automatically generating documents that previously had to be produced manually. All this also results in *shorter lead-times in order-processing* before manufacturing (e.g. Barker & O'Connor, 1989) and in an *increase in the volume of processed quotations and orders without increasing sales staff* (e.g. Sviokla, 1990).

With configurator support, the repertoires of typical specifications sales staff invented to workaround the specification process complexity should become unnecessary. Further, as configuration knowledge and therefore the customization range of configurable products is "built-in" to *configurators,* they *standardize specification results*: it is not possible to specify product individuals outside the customization range nor to specify different product individuals for identical customer orders.

Overall, configurators improve the productivity of sales, quoting, and engineering for the aforementioned reasons. Moreover, customers may perceive the quality of operations higher as a single contact produces a manufacturable specification, often with a price and delivery time (or estimate), and promptly. Further, configurators lower the costs due to less effort required in specification, and the reduced rework and iterations due to elimination of specification errors (Wright et al., 1993; Vanwelkenheysen, 1998).

Table 14 Summary of supplier benefits in the sales specification process (Part 2)

Benefit	**References for benefit**	**Challenges met?**
More free exploration or product alternatives; helps to optimize to customer needs	Tiihonen & Soininen, 1997; Bonehill & Slee-Smith, 1998; McGuinness & Wright, 1998; Bonehill & Slee-Smith, 1998; Hvam et al., 2004; Pedersen & Edwards 2004	Does specified product individual meet customer needs optimally?
Reduce specification effort	Wright et al., 1993; Heatley et al., 1995; Ariano & Dagnino, 1996; McGuinness & Wright, 1998; Yu & Skovgaard, 1998; Aldanondo et al., 1999; Aldanondo et al., 2000; Forza & Salvador, 2002a; Hvam et al., 2004; Pedersen & Edwards, 2004	Customer has to spend time in specification and wait for the finished product.

Shorter lead-times in order-processing	Barker & O'Connor, 1989; Sviokla, 1990; Wright et al., 1993; Heatley et al., 1995; Fohn et al., 1995; Ariano & Dagnino, 1996; Tiihonen & Soininen, 1997; Bonehill & Slee-Smith, 1998; Günter & Kühn, 1998; Vanwelkenheysen, 1998; Aldanondo et al., 1999; Aldanondo et al., 2000; Forza & Salvador, 2002a; Forza & Salvador, 2002b; Hvam et al., 2004; Pedersen & Edwards, 2004	Customer has to spend time in specification and wait for the finished product.
Increases volume of quotations and orders processed, without increasing staff	Sviokla, 1990; Tiihonen & Soininen, 1997; Vanwelkenheysen, 1998; Pedersen & Edwards, 2004	
Standardize specification results	Sviokla, 1990; Tiihonen et al., 1996; Vanwelkenheysen, 1998; Forza & Salvador, 2002b	Sales force must not offer changes outside pre-designed customization options. Different specifications for identical customer order.

Manufacturing

This section discusses the benefits configurators can bring to manufacturing. Summary of the benefits can be found in Table 15. The main benefits for manufacturing stem from the *error-free, manufacturable sales specifications* (e.g. Heatley et al., 1995). Without errors there are *less production problems, stoppages, and firefighting* due to e.g. missing or wrong parts. Consequently, the *reliability of deliveries improves* (e.g. Forza & Salvador, 2002a) and *planning and scheduling of production become more accurate* (e.g. Heatley et al., 1995). Moreover, as *configurators guide customers to ordering within the supplier's normal product range there is less variation to handle, making production easier* overall (e.g. McGuinness & Wright, 1998). The aforementioned manufacturing benefits meet or alleviate the challenges of firefighting in manufacturing and achieving uniform quality. Finally, improved predictability of production and reduced order-processing time also allow *reduction of buffer inventories at the factory* (e.g. Barker & O'Connor, 1989).

Table 15 Summary of supplier benefits in manufacturing

Benefit	References for benefit	Challenges met?
Ordered products can be manufactured; less production problems, stoppages, fire-fighting	Heatley et al., 1995; McGuinness & Wright, 1998; Forza & Salvador, 2002a; Forza & Salvador, 2002b	Fire-fighting in manufacturing from specification errors. Achieving uniform quality.
More reliable and on-time delivery	Forza & Salvador, 2002a; Pedersen & Edvards, 2004	
More accurate planning and scheduling of production	Heatley et al., 1995; Bonehill & Slee-Smith, 1998; Yu & Skovgaard, 1998; McGuinness & Wright, 1998; Forza & Salvador, 2002a	
Configurators guide to more standard solutions → easier production	McGuinness & Wright, 1998; Forza & Salvador, 2002b; Pedersen & Edwards, 2004	
Lower (buffer) inventories	Barker & O'Connor, 1989; Yu & Skovgaard, 1998; McGuinness & Wright, 1998; Forza & Salvador,	Higher costs of producing customized products.

	2002a	

Product Development

The benefits from configurators to product development, summarized in Table 16, are discussed next. As configurators improve the complexity handling capabilities of the supplier in sales and production, more *complex products with competitive features can be developed* (Heatley et al., 1995) *and increased variety* can be offered (Sviokla, 1990).

Configurators require explicit definition, i.e. modeling, of the configuration knowledge. This *can initiate a better understanding of company's products* (Ariano & Dagnino, 1996) or *redefinition of the products to better suit the market and reduce unnecessary complexity*, according to Forza and Salvador (2002a). Forza & Salvador (2002a) also argue that *configuration modeling may provide ways to describe architectural product knowledge*. Further, *more resources may be available for product development* because configurators free the technical experts from doing consistency checks (e.g. Barker & O'Connor) and ongoing management of configuration knowledge (Yu & Skovgaard, 1998).

Table 16 Summary of supplier benefits in product development

Benefit	**References**
Increased complexity handling capability → products with a wider customization range can be developed	Sviokla, 1990; Heatley et al., 1995
Explicit configuration modeling may initiate better understanding of the products, or redefining them to meet markets better	Ariano & Dagnino, 1996; Forza & Salvador, 2002a
Configuration modeling may provide a way to represent architectural product knowledge	Forza & Salvador, 2002a
Configurators free resources to product development from consistency checks and ongoing management of configuration knowledge	*Checks:* Barker & O'Connor, 1989; Sviokla, 1990; McGuinness & Wright, 1998; Bonehill & Slee-Smith, 1998; Forza & Salvador 2002a *Management:* Yu & Skovgaard, 1998

Long term management of configuration knowledge

For a summary of the configurator benefits discussed here, see Table 17. *Configurators support centralized configuration knowledge maintenance and management* (e.g. Sviokla, 1990). Without a configurator, configuration knowledge can be dispersed in the supplier organization and transferring up-to-date configuration knowledge problematic. With configurators, *up-to-date configuration knowledge is easily available in the organization* (e.g. Barker & O'Connor, 1989), in sales and for customers as well.

Having systematic configuration knowledge embedded in the *configurator may help in training new employees to become productive* (e.g. Fleischanderl et al., 1998). Further, configuration knowledge managed centrally in a *configurator helps to turn individual knowledge into organizational knowledge,* reducing the need of the organization to rely on (few) knowledgeable individuals (e.g. Günter & Kühn, 1998) and supports systematic management of information.

Table 17 Summary of supplier benefits from configurator in long term maintenance of configuration knowledge

Benefit	**References for benefit**	**Challenges met?**
Support to maintain configuration knowl-	Sviokla, 1990; Tiihonen & Soininen, 1997; Yu & Skovgaard,	Long term management of configuration knowl-

edge, centrally	1998; McGuinness & Wright, 1998; Fleischhanderl et al., 1998; Forza & Salvador, 2002a	edge. Systemizing information management. Dispersed configuration knowledge in the organization.
Correct, up-to-date configuration knowledge available in the organization	Barker & O'Connor, 1989; Sviokla, 1990, Wright et al., 1993; Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Fleischanderl et al., 1998; Bonehill & Slee-Smith, 1998; McGuinness & Wright, 1998; Vanwelkenheysen, 1998; Yu & Skovgaard, 1998	Transferring updated configuration knowledge to sales force
Availability of systematic configuration knowledge helps in training new employees to become productive	Fleischanderl et al., 1998; Bonehill & Slee-Smith, 1998; Salvador & Forza, 2004; Pedersen & Edwards, 2004	
Centralized configuration knowledge in a configurator helps to turn individual knowledge into organizational	Günter & Kühn, 1998; Forza & Salvador, 2002a; Bramham & MacCarthy, 2004; Pedersen & Edwards, 2004	Systemizing information management.

Supplier Challenges

Business

The business challenges of the supplier, discussed next, are summarized in Table 18. Taking a configurator into use is a significant investment as developing, deploying and maintaining a configurator represents a *significant cost*, *requires a significant effort,* can take a *considerable time,* and can widely *affect the organization and its functions.* The cost may include software licenses, software development and integration, hardware, consultation, product modeling, and long-term maintenance (Tiihonen at al., 1997). Case experiences of costly configurator implementation and deployment projects taking a lot of effort and time have been reported in (Aldanondo et al., 2000; Forza & Salvador, 2002a; Forza & Salvador, 2002b; Hvam et al., 2004; Pedersen & Edwards, 2004). Investment into a configurator must be paid back in its repetitive use. Thus, a high enough volume is needed to justify the costs (Pedersen & Edwards, 2004).

Problems related to configurator introduction or long-term management might delay new product introductions or product improvements (Barker& O'Connor, 1989; Tiihonen et al., 1996). The supplier may end up *being over-dependent of the configurator* and the knowledge embedded in it (Sviokla, 1990). Thus the configurator becomes a mission-critical application.

A major challenge in configurator implementation is *aligning the business needs and processes* of the supplier *and the configurator*. It is necessary and challenging to integrate the configurator to the company's business processes (Bramham & MacCarthy, 2004). Business, not technologists, should guide the implementation (Barker & O'Connor, 1989). The scope of support provided by a configurator must be determined according to business needs. It may be feasible to leave the most complex products out to reduce the complexity of systemizing and managing configuration knowledge, as was done due to limited volume in a case reported by Forza and Salvador (2002a).

Aligning the processes with the configurator *may require business process re-engineering* to achieve full benefits (e.g. Tiihonen & Soininen, 1997). Especially the sales process may have

to be systemized or streamlined. The *need for different sales-delivery processes after the deployment of a configurator should be determined*. For example, separate processes may be needed for mass-produced products, configurable products, and products that require case-specific engineering in addition to configurable parts (Tiihonen et al., 1996). A manual configuration process may have to be retained even when a configurator is deployed. For example, in less developed areas the availability or price of computers and data communications or computer illiteracy of sales-persons may limit the use of a configurator (Tiihonen et al., 1996). Further, *multiple sales channels may have to be supported*, e.g. in-shop "offline" configuration, and on-line self-service in web (Reichwald et al., 2004).

Effective distribution of the configurator to the entire sales force, especially to retailers, *may be problematic* (e.g. Heatley et al., 1995). When the supplier does not own or control the sales channel, configurator use cannot be enforced (Tiihonen et al., 1996). Retailers, possibly having low volumes, may be unwilling to adopt a configurator due to cost of the system or training (Tiihonen & Soininen 1997).

Table 18 Summary of business challenges of the supplier

Challenge	References
Configurator development and maintenance takes considerable time and represents significant cost and effort.	*Cost:* Tiihonen at al., 1997; Pedersen & Edwards, 2004. *Effort:* Barker & O'Connor, 1989; Sviokla, 1990; Aldanondo et al., 2000; Forza & Salvador, 2002b. *Time:* Forza & Salvador, 2002a; Hvam et al., 2004
Challenges of long-term management may delay product introductions or improvements	Barker& O'Connor, 1989; Tiihonen et al., 1996
Risk of becoming over-dependent of configurator and knowledge in it.	Sviokla, 1990
The necessary alignment of business needs and processes, and scope of configurator-support is challenging.	Barker & O'Connor, 1989; Tiihonen et al., 1996; Forza & Salvador, 2002a; Bramham & MacCarthy, 2004; Hvam et al., 2004; Pedersen & Edwards, 2004
Business process re-engineering may be required	Tiihonen & Soininen, 1997; Tiihonen et al., 1998; Hvam et al., 2004
Multiple sales processes and channels may have to be supported	*Processes:* Tiihonen et al.1996; Tiihonen & Soininen, 1997; Reichwald et al., 2004. *Channels:* Reichwald et al., 2004
Effective distribution of the configurator to the sales force	Heatley et al., 1995; Tiihonen et al., 1996; Tiihonen & Soininen, 1997

Organization

Next, the supplier challenges involving the organization are reviewed. The challenges are outlined in Table 19.

Introducing a configurator can significantly *change an organization* (e.g. Barker & O'Connor, 1989), making it harder to implement than anticipated (Ariano & Dagnino, 1996). Configurator can reduce or eliminate the need for consistency checks, consulting technical staff during sales, part-list creation, and other tasks related to creating specifications. This *changes personnel roles* (e.g. Barker & O' Connor, 1989) and may make organizational units involved in the tasks redundant (Barker & O' Connor, 1989).

Co-operation between different parts of the organization is required to align the configurator with business needs (Barker & O'Connor, 1989), as well as for configuration knowledge acquisition and modeling (e.g. Sviokla, 1990). Configuration knowledge can be dispersed in the organization between different units and personnel. Some modeling decisions are business deci-

sions. It can be challenging to have prompt access to individuals who have the necessary authority and knowledge to make these decisions (Vanwelkenheysen, 1998). *The required work in implementing and maintaining a configurator and the challenges it alleviates may touch different parts of the organization* (Tiihonen & Soininen, 1997), which may hamper co-operation and cause resistance towards the configurator.

Resistance in the organization towards the configurator can also be caused by changes in personnel roles (Bonehill & Slee-Smith, 1998) and organization (Forza & Salvador, 2002a). Further, personnel may see the configurator as a menace to their position (Forza & Salvador, 2002a) or be unwilling to trust the decisions made by an automatic system (Tiihonen et al., 1996). In Heatley et al.'s (1995), 100% configurator usage had required an enforcing policy.

A *new function responsible for configurator development and maintenance may be introduced* (Sviokla, 1990; Ariano & Dagnino, 1996) as continuity in development and maintenance of the knowledge bases needs to be ensured (Vanwelkenheysen, 1998). This can cause subtle challenges. Configurator maintenance can be very critical (Sviokla, 1990) with configurator experts becoming vital to the company (Ariano & Dagnino, 1996; Forza & Salvador, 2002b). Expertise on configuration knowledge may shift to configurator development and maintenance organization who may not be not be good enough product experts (Sviokla, 1990). Management challenge may move from keeping staff up-to-date to keeping configurator software up-to-date (Sviokla, 1990).

Table 19 Summary of organizational challenges of the supplier

Challenge	References
Significant organizational changes may be necessary and harder to implement than anticipated.	Barker & O'Connor, 1989; Ariano & Dagnino, 1996; Aldanondo et al., 2000; Forza & Salvador, 2002b
Roles of individuals change, and some people delegate part of their tasks to configurator.	Barker & O' Connor, 1989; Bonehill & Slee-Smith, 1998; Forza & Salvador, 2002a
Organizational co-operation required to align configurator with business needs, and in configuration knowledge acquisition	Barker & O'Connor, 1989; Sviokla, 1990; Wright et al., 1993; Vanwelkenheysen, 1998; Forza & Salvador, 2002b
Benefits and challenges of the configurator and required work may touch different parts of the organization.	Tiihonen & Soininen, 1997
Potential for resistance towards configurator.	Heatley et al., 1995; Tiihonen et al., 1996; Bonehill & Slee-Smith, 1998; Forza & Salvador, 2002a
Configurator development and maintenance organization may be introduced, can become critical for company and individuals leaving a risk	Sviokla, 1990; Ariano & Dagnino, 1996; Vanwelkenheysen, 1998; Forza & Salvador, 2002b; Hvam et al., 2004.

Specification process

In this section, the challenges related to the specification process are discussed. The challenges are summarized in Table 20.

Even with configurators, *eliciting and understanding real customer needs may be difficult*. It is possible that customers do not know their real needs (Franke & Piller, 2003; Blecker et al., 2004), cannot express them (Blecker et al., 2004), or that the supplier may misinterpret customer requirements (Tiihonen & Soininen, 1997; Blecker et al., 2003). Customers may not want to part with all types of needed information (e.g. personal information affecting needs) during the speci-

fication task (Bramham & MacCarthy, 2004). These issues may be more serious in self-service settings where personal interaction with sales staff is not available. In some cases *customers may prefer consultative selling* where sales employees operate the configurator *over self-service* with web-based configurator (Reichwald et al., 2004).

Configurators may fix interaction with the customer in general (Bramham & MacCarthy, 2004) or at the level of fixing the order of selections (Fohn et al., 1995). The customer interaction which the configurator enables is easily imitated and may yield the same offering as competitors (Bramham & MacCarthy, 2004). Franke and Piller (2003) discussed the need to *support creative product specification* during configuration instead of simply choosing from pre-designed options. Configurators support partially configurable products, still involving some custom-design, poorly (Tiihonen et al., 1998).

It may be *difficult to modify created configurations* (Sviokla 1990). Most often reconfiguration is managed on a case-by-case basis, which cannot be efficiently supported by configurators (Männistö et al., 1999).

Table 20 Summary of supplier challenges in the specification process

Challenge	References
Obtaining and understanding real customer needs	Tiihonen & Soininen, 1997; Franke & Piller, 2003; Blecker et al., 2004
Personal service may remain preferable to self-service with a configurator.	Reichwald et al., 2004
Configurators may fix interaction with the customer	Fohn et al., 1995; Bramham & MacCarthy, 2004
Support for creative product specification	Franke & Piller, 2003
It may be difficult to modify created configurations	Sviokla 1990; Männistö et al., 1999

Long-term management of configuration knowledge

In the following we review the challenges related to configurators in long term management of configuration knowledge. For a summary of the challenges, see Table 21.

Configuration knowledge often changes frequently due to product changes and for business related reasons like shifting customer needs and marketing strategies (Fleischanderl et al., 1998) and pricing changes. If the sales rely on configuration support, *fast updating of configuration knowledge is important, even business-critical* (e.g. Barker & O'Connor, 1989). Over time, *configuration models grow and new ones are added to the configurator increasing the complexity* of management (Barker & O'Connor, 1989; Bramham & MacCarthy, 2004). More complexity arises from regional differences in products and prices (Tiihonen & Soininen, 1997) and if reconfiguration needs to be supported (Männistö et al., 1999).

There must be means for deploying the updated configurator and/or configuration knowledge bases to the entire sales force and/or to customers (Tiihonen et al., 1998). The related challenges are different in different architectural scenarios. Configurators based on a centralized, e.g. web-based architecture require updates only to the centralized system and knowledge base. Stand-alone configurators require either a synchronization mechanism (e.g. a docking station with appropriate software), or actions by the user and cannot therefore guarantee that configuration knowledge updates will be taken into use. *Ensuring the correctness of the configurator knowledge may be challenging after updates* (e.g. Tiihonen & Soininen, 1997).

The challenges of dispersed configuration knowledge and diverse expertise possibly required in implementing configurators play their role in long-term management as well. To reduce these burdens, Fohn et al. (1995) and Tiihonen and Soininen (1997) propose that *configuration*

modeling and maintaining the configurator knowledge-base *should not require any configurator expertise*. Rather, updates should be performable by product experts.

It can be concluded that *long-term management of configurators is both mission-critical and challenging* (e.g. Tiihonen & Soininen, 1997). Its failure may be a reason for many failed configurator projects. However, empirical evidence has not been published.

Table 21 Summary of supplier challenges in long-term management of configuration knowledge

Challenge	References
Fast updating and creating of configuration knowledge bases, configuration models	Barker & O'Connor, 1989; Wright et al., 1993; Tiihonen et al., 1996; Fleischanderl et al., 1998; Forza & Salvador, 2002b; Bramham & MacCarthy, 2004
Configuration models grow and new ones are introduced increasing complexity	Barker & O'Connor, 1989; Bramham & MacCarthy, 2004
There must be mechanisms that distribute and take configurator and/or knowledge base updates to use in entire sales force and/or customers.	Tiihonen et al., 1998
Ensuring correctness of the configurator knowledge base may be challenging after updates	Tiihonen & Soininen, 1997; Felfernig et al., 2004
Updates can require both product and configurator expertise. *Should need only product expertise*.	Fohn et al., 1995; Tiihonen & Soininen, 1997
Long-term management of configurators is both mission-critical and challenging.	Tiihonen & Soininen, 1997; Tiihonen et al., 1998

Development and initial introduction of a configurator

Here we discuss the challenges related to the development and initial introduction of a configurator. For a summary, see Table 22.

Fleischanderl et al. (1998) point out that the development and introduction of a configurator is a demanding task. Configuration modeling requires *knowledge acquisition* from different parts of the company, which is not always easy or frictionless (e.g. Wright et al., 1993). The people with the required knowledge may be different individuals, located in different parts of the organization, also geographically (e.g. Barker & O'Connor, 1989). The gathered *configuration knowledge must be systemized* and formalized (e.g. Tiihonen et al 1998) to make it coherent and usable in the configurator. Thus, *taking a configurator into use requires expertise both in the domain* (products and industry) and *in configurators* (e.g. modeling, possibly programming) and related IT. However, *validation and testing of configuration models is a challenge* due to combinatorial nature of configurable products (e.g. Barker & O'Connor, 1989). Regional differences increase the complexity of configuration models and related information systems. Often all product options are not available everywhere, prices differ from one area to another, and there may be several language versions to maintain (Tiihonen & Soininen 1996).

It may be necessary to improve product modularization to enable configuring (Hvam et al., 2004). Tiihonen & Soininen (1997) argue that good long-term results in using a configurator can be expected only when the product has been designed to be easily configurable as it simplifies the configuration models.

Integration of a configurator to other systems may be necessary (e.g. Barker & O'Connor, 1989). Integration can facilitate efficient and error-free transfer of configurations (e.g. parts lists, drawings, connection information, etc.), price, delivery time or capacity, and product model information. Systems that could be integrated include sales and CRM tools, ERP, PDM, and CAD.

However, the high cost and complexity of integrations calls for judgment. Integration to IT systems of retailers or customers may also be desirable (Tiihonen et al., 1998).

Developing an efficient, learnable user interface for a configurator can be a challenge. Determining "the best and most logical" sequence of user prompts can be challenging (Aldanondo et al., 2000). Additional concerns are the ability of the user interface to provide a satisfactory customer experience, which also provides integration into the company brand, and whether the configurator supports creative innovation by the customers (Franke & Piller, 2003).

Table 22 Summary of supplier challenges in configurator introduction

Challenge	References
Configuration knowledge acquisition	Wright et al., 1993, Tiihonen & Soininen, 1997; Forza & Salvador, 2002a
Configuration knowledge systemization and formalization	Tiihonen et al., 1998; Forza & Salvador, 2002a
Expertise in products and industry, in configurators, modeling and IT required	Barker & O'Connor, 1989; Fleischanderl et al., 1998; Aldanondo et al., 2000
Validation and testing of configuration models	Barker & O'Connor, 1989; Heatley et al., 1995; Tiihonen & Soininen, 1997; Felfernig et al., 2004
Integration to other IT systems	Barker & O'Connor, 1989; Tiihonen et al., 1996; Tiihonen & Soininen, 1997; Tiihonen et al., 1998; Franke & Piller, 2003
Developing a good and suitable user interface	Aldanondo et al., 2000, Franke & Piller, 2003

Customer Benefits

Next, we discuss the customer benefits from configurators, summarized in Table 23. Because configurators check the consistency and enable rapid specification, *it is possible to explore the alternatives and their impacts in a more thorough and free manner during sales* (e.g. McGuinness & Wright, 1998). This increases the possibility to find a good match with needs and probably lessens the complexity of specification to some extent. Moreover, as *sales staff* need not worry about consistency checks, they *can devote more time to the customer* (Vanwelkenheysen, 1998). This increased advice available to customers should help alleviate the complexity of specification in customers' mind and increase the possibility of finding a suitable product. Some *configurators can help to explain the incompatibilities and dependencies between product options to the customer* (Aldanondo et al., 1999), alleviating the complexity in specification. Forza and Salvador (2002b) argue that *communication may become easier as a configurator makes the company language available to customers*. The differences in terms used by the customer and supplier to describe the preferred product could be reduced, alleviating the difficulty of finding an optimal product to customer needs.

A configurator can enable the customers to do the specification task themselves (Salvador & Forza, 2004) *whenever they want* (Forza & Salvador, 2002b) if the configurator is available on the web or distributed to the customers. In general, configurators can *save customer time during specification* (Forza & Salvador, 2002b). Some configurators allow *using existing configurations as a basis for specification*, which also *saves customer time* (McGuinness & Wright, 1998). *The price and delivery time (or estimates) may be available immediately* (Vanwelkenheysen, 1998).

Table 23 Summary of customer benefits from configurators

Benefit	References for benefit	Challenges met?
More product alternatives and	McGuinness &	Optimal product individual

their impact can be more freely inspected during specification → increase possibility to find a good product fit.	Wright, 1998; Forza & Salvador, 2002b; Salvador & Forza, 2004	fit to customer needs. Complexity of specification.
Sales can devote more time for customer	Vanwelkenheysen, 1998	Complexity of specification. Optimal product individual fit to customer needs.
Configurator can help to explain to the customer why some alternative choices are not compatible	Aldanondo et al., 1999	Complexity of specification.
Configurator makes company product language available to customer, which may make communication easier	Forza & Salvador, 2002b	Optimal product individual fit to customer needs.
Customers can do the specification themselves, when they want (over web)	Forza & Salvador, 2002b; Salvador & Forza, 2004	
Save customer time in specification	Forza & Salvador, 2002b	Time and effort spent in specification.
Possibility to use existing specifications as basis saves customer time	McGuinness & Wright, 1998	Time and effort spent in specification.
Price and delivery time immediately	Vanwelkenheysen, 1998	

Customer Challenges

The challenges from the customer point-of-view have not been discussed much in literature. The challenges caused by configurators mostly relate to self-service configurators.

All customers may not want to use a self-service configurator. Selecting a suitable configurable product from the set of available products can be difficult, especially for non-expert customers typical to consumer e-commerce (Pargamin, 2002; Heiskala et al., 2003). Special product selection support may be needed (Heiskala et al., 2003). However, trusting recommendation(s) of a system can be a problem (Tiihonen et al., 1996). Self-service customers may find configurator user interfaces difficult, especially if the needs are not clear, or if there is a mismatch between configurator and customer logic for preferences. A configurator may also restrain the interaction, making it too rigid for customers' liking.

Several customer challenges discussed for MC and CP probably apply, even with configurator support. The number of options may overwhelm the customer (e.g. Huffman & Kahn, 1998) who may not be able accept the risk of making wrong decisions (e.g. Berman 2002). Additionally, the documentation of the customer's explicit preferences and personal information in the product specification process may feel as an invasion of privacy (e.g. Broekhuizen & Alsem, 2002). Even with a configurator, it may be difficult to judge whether the end product presents good value (e.g. Broekhuizen & Alsem 2002). Price in e-commerce is also an issue – it is difficult to know if personal contact could provide a better price. The challenges related to modifying created configurations, reconfiguration, and creative product specification are probably relevant as well.

RATIONALE FOR INTRODUCING MASS CUSTOMIZATION

In this section we briefly discuss under what kind of conditions it does make sense to introduce a MC strategy to the company and when it does not. Naturally, the benefits we have listed provide motivation for a company to introduce MC. Further, the company probably should have

capabilities in place to overcome or alleviate the challenges we have listed, at least to an extent that ensures that the benefits gained from MC outweigh the additional sacrifices, for both the company and its customers.

The necessary conditions and capabilities for MC have been discussed by several authors, again dominantly from a MP viewpoint (e.g. Pine, 1993a; Hart, 1995; Kotha, 1995; Pine et al., 1995; Radder & Louw, 1999; da Silveira et al., 2001; Zipkin, 2001; Berman, 2002; Broekhuizen & Alsem, 2002; Bardakci & Whitelock, 2003). Berman (2002) and Radder & Louw (1999) provide checklists for practitioners to assess the soundness of a MC switch. An integrative overview of the conditions is given by Blecker et al. (2005, pp. 23-41), which we summarize here.

Blecker et al. (2005) categorize the conditions to ones relevant before and after moving to MC. Before the move the company should assess the market conditions on a macro (demand and structural factors) and micro (customer demand for customization) levels. On the demand and structural factors, Blecker et al. (2005, p. 31) follow Pine's (1993a) market turbulence indicators, like unstable, unpredictable and heterogeneous demand, uncertain and quickly changing customer needs, low price consciousness but high quality and fashion/style consciousness and high level of pre- and postsale service. Customer demand for customization must truly exist and it is likely to be so only for a limited group of products (Blecker et al., 2005, p. 32; Svensson & Barfod, 2002). For luxury products (Pine, 1993a, p. 56) and business-to-business customers that arguably in many markets are more knowledgeable and demanding than consumers (MacCarthy & Brabazon, 2003) this might be more probable. The value of customization to customers must also overcome the challenges of possible higher prices, time to wait for the final product, effort spent in specification, and privacy concerns (Broekhuizen & Alsem, 2002; Bardakci & Whitelock, 2003). Blecker et al. (2005, p. 33) also state that possible first-mover advantages have to be taken into account. Pine et al. (1995) argue that frequent enough repeat business and interactions with the customer are positive conditions for MC to be a viable option. On the other hand, Spring & Dalrymple (2000) argue that on occasions that the price premium doesn't lead to increased profitability, there are still valid reasons to customize products: 1) to keep competition out, 2) to force the organization to learn and develop new capabilities and 3) to enhance the company's standing/brand in the industry.

In addition to the external conditions, before moving to MC the company must assess whether it has or can acquire the capabilities necessary to customize its products (Blecker et al. 2005, p. 33). The company's value chain must be responsive and flexible and willing and able to meet the added challenges of MC (Blecker et al., 2005) and connected with an efficiently linked information network (da Silveira et al., 2001). The production processes of the company must be flexible to be able to produce a variety of products and the products themselves customizable (Blecker et al., 2005, p. 35). A key ingredient for MC is customer needs elicitation capability of the company (Blecker et al., 2005, p. 35). MC with CP requires significant investment in product design, information management, and the like. Payback requires high enough a volume (Tiihonen & Soininen, 1997). This can be a challenge especially for those companies whose background is in FC with limited volumes.

When pursuing MC on a continuous basis, the company must maintain and improve its MC capabilities. These include the aforementioned customer needs elicitation, process flexibility, supply chain agility, and customer-oriented product design. Blecker et al. (2005, p.38) also emphasize the importance of having capabilities to manage the increased complexity and variety in products and production processes and of efficient knowledge sharing throughout the company.

SUGGESTIONS FOR FUTURE RESEARCH DIRECTIONS

The customer view on mass customization, configurable products and configurators is thin in the literature. Moving to MC with CP has been mainly documented from the direction of MP, especially in the MC literature. We call for research, especially empirical, on the customer benefits and challenges of MC with CP and on the move to MC from the direction of FC.

This review confirms the observation of da Silveira et al. (2001) and Paloheimo et al. (2004) that services have received little attention in MC literature, at least as regards the benefits and challenges. Literature on configurable service products and configurators is even scarcer. We therefore call for future research on MC, CP and configurators in service settings. We also find, as Franke and Piller (2003), that empirical findings on MC are limited.

Research on ways to overcome or alleviate the challenges, a collection of best practices, would probably be of interest to practitioners. A specific viewpoint could be avoiding the pitfalls in the initial move to MC with CP and in configurator introductions. The reviews of Broekhuizen and Alsem (2002) and da Silveira et al. (2001) provide a good starting point. We would expect to find different necessary conditions, success factors, enablers, and best practices when switching from MP vs. switching from FC. In literature, the configurator benefits are dominantly discussed with relation to the company not having a configurator. Comparative studies on what kinds of configurators are best for a given situation would be of interest.

Research on configurator introductions could benefit from literature on information system implementations and account for relevant differences. Is configuration knowledge acquisition different for technical knowledge and knowledge related to identifying optimal fit to customer needs? How tacit are these types of configuration knowledge? Is a configurator sufficient to transfer knowledge to sales? What are the challenges? In our view, especially empirical knowledge management research could provide interesting insights for MC and CP suppliers and configurator research. Further, empirical research on long-term management of modern configurators would be most welcome. How much effort is needed? What are the challenges? Can product experts do it? Cost vs. benefits?

We echo the notion of Franke and Piller (2003) that future research is needed on user interaction with configurators. This includes user interaction process patterns with configurators, user perception of 'mass confusion', user satisfaction drivers with configurators, and how configurators affect customers' valuation of individualization. We would like to extend the perspective from self-service configurator use over the Web in consumer markets towards business-to-business (B2B) environments. In some B2B scenarios, the need to support consultative selling may be more important than self-service.

Configurators presently fail to provide support for ensuring that the created configuration models correspond to the real customization possibilities of the configurable product. Configurator vendors e.g. SAP (Haag, 2005) and Tacton (Orsvärn, 2005) call for research on methods and techniques to debug and diagnose configuration models. Significant steps towards diagnosis have been provided e.g. by Felfernig et al. (2004) who present a method that applies knowledge-based diagnosis techniques with configuration test cases for locating errors in configuration models. On a more basic level, using capabilities of inference engines could provide semantic level configuration model checking without writing test cases. For example, it could be possible to check if e.g. any discrete configuration variable value can be present in a consistent configuration, or if any individual requirement that can be expressed can be satisfied. Future work on empirical evaluation on benefits versus sacrifices is required after such tools are in widespread use.

Another source of potential improvement is in user interfaces of configuration modeling tools that could apply ideas from Integrated Development Environments that are common in software development tools. This could provide model overview and navigation as well as immediate experimentation with the configuration model (Haag, 2005).

Although configurators do alleviate the complexity of specification, there is still room for improvement and future research. Configurators are not well-equipped to find optimal product fit with customer needs (Blecker et al., 2005, p. 92). Recommender or advisory system functionality could be included in configurators or they could be integrated with such systems. Reconfiguration is also still a challenge (Manhart, 2005, Männistö et al., 1999).

DISCUSSION AND CONCLUSIONS

MC literature has been reviewed from a general perspective (da Silveira et al., 2001), with the aim of recognizing the necessary conditions for successful MC (Broekhuizen & Alsem, 2002; Blecker et al., 2005, p. 23), and from the angle of customer sacrifices of MC (Bardakci & Whitelock, 2003). Franke & Piller (2003) have identified empirical research in the field of MC and discuss configurators among other user design toolkits for MC. The approaches to describe, model, and formalize configuration knowledge in configurators have been reviewed earlier (Stumptner, 1997; Günter & Kühn, 1999). Blecker et al. (2005, p. 80) have classified configurators to different categories. Our review has a different perspective and also synthesizes findings from MC, CP, and configurator literature. However, the scientific quality of the articles we have reviewed varies. We chose to aim for broad identification of issues instead of concentrating only on the papers of highest scientific quality. The amount of references discussing an issue may be an indicator of the level of its importance.

Judging from the benefits that configurators can bring and the challenges their use can overcome or alleviate configurators truly are key enablers for mass customization with configurable products. However, only individual cases with more efficient and streamlined business processes have been reported, and conclusive evidence on realized configurator benefits and whether the benefits outweigh the required sacrifices in a given situation is still lacking.

Configurator challenges remain. We believe our review, although by no means exhaustive, has been able to identify most of them, providing practitioners a useful checklist of issues that have to be taken into account when contemplating configurator-supported mass customization with configurable products.

Long-term management of configurators is claimed as one of the most significant challenges. The literature we examined does not provide a comprehensive answer on how difficult long-term management of configurators really is and to what extent it is easier with current configurators that do not require programming in configuration knowledge maintenance. Also, configurator introduction remains as a challenge and configurators represent significant cost over the whole lifecycle. Future opportunities and challenges remain in supporting customers in self-service settings - selecting a suitable product and appropriate technical specifications is a challenge, especially for customers who configure their products or services infrequently.

Applicability of the configurable products paradigm and configurators to services has received relatively little attention and remains a subject for future research.

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