

# Implementing Sustainable Mass Customization in Real Industrial Environments

THE USE OF AN OPERATIVE REFERENCE FRAMEWORK

Master Thesis

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### **Abstract**

This thesis aims at developing guidelines for manufacturers for the adoption and implementation of a sustainable mass customization system framework. A framework that has previously been developed as to help companies in adapting to global competitive pressures by better plan and utilize resources and manufacturing for a sustainable production in mass customized order. The framework was developed as part of a bigger project, S-MC-S – Sustainable Mass Customization – Mass Customization for Sustainability, which involved organizations and companies over the world, mainly in Europe.

The S-MC-S framework provides means for Data Models harmonization defining a coherent data infrastructure where the Extended Product, Sustainable Factory and Supply Chain Data Models developed are plugged. This thesis is focused on two companies in particular as two case studies, to develop guidelines for the implementation of the framework.

The reference framework considers the integration of sustainability strategy and mass customization strategy for a new product development process and considering the whole life cycle of the product. It is taking into consideration the main required activities for product, manufacturing system and the whole supply chain considering the above-mentioned strategies.

This thesis presents guidelines for two companies in particular, described in case studies, and from those experiences draws conclusions about the framework's implementation possibilities and adaptability to different types of companies and industries.

## 1 Introduction

This thesis is related to the project Sustainable Mass Customization – Mass Customization for Sustainability – S-MC-S, which is a collaborative project among various institutions and organizations around the world, with the aim to ‘support European manufacturing enterprises to adapt to global competitive pressures by developing methods and innovative enabling technologies towards a personalized, customer oriented and eco-efficient manufacturing, across a broad range of sectors’.

The fact is that manufacturing is growing beyond the economic context, into a social and ecological phenomenon, both from the side of the end-user as from the side of governments whom, guided by increased customer eco-consciousness, are expected to further introduce eco-taxes, motivating companies to move towards sustainable manufacturing, to be reactive towards customer needs and wishes, and proactive towards ecological and environmental impact. S-MC-S will work for European industries to meet the increasing demand for greener more customized and higher quality products, fostering the necessary transition to a demand-driven industry (mass customized) with lower waste generation, energy consumption and increased social attention (sustainable).

Sustainability and Mass Customization are two concepts that are gaining more and more importance to customers, institutions and firms across a broad range of sectors. By developing guidelines for companies to implement the previously developed reference framework, as a first step in the S-MC-S project, better and faster transition into this paradigm can be achieved. Providing companies with a good source of competitive advantage in today’s volatile and very requiring markets. By looking at two case studies, and two different companies in particular, generic guidelines will be outlined, as well as the reference framework tested and validated.

A broad literature review on sustainability and mass customization, with the focus on requirements, and implementation strategies has been conducted in order to better and in a more holistic manner develop generic guidelines. These guidelines are meant to help companies strengthening their manufacturing abilities, as to better compete on the market in

terms of added value coming from strong customer-orientation, concern for sustainability and technical innovation.

## 2 Literature Review

### **Mass Customization**

#### **Definition**

In the book “The Third Wave”, Robert H. Anderson, former Head of Information Systems of RAND Corporation, predicted that

*“the most creative thing a person will do twenty years from now is to be a very creative consumer... Namely, you’ll be sitting there doing things like designing a suit of clothes for yourself or making modifications to a standard design, so the computers can cut one for you by laser and sew it together for you by NC machine”*

-Toffler, 1980, p. 274

The term *Mass Customization* was coined by Davis, seven years later in 1987, with explicit reference to Anderson (Piller, Schubert, Koch, & Möslin, *Overcoming Mass Confusion: Collaborative Customer Co-Design in Online Communities*, 2005). Today Mass customization is defined as ‘the technologies and systems to deliver goods and services that meet individual customers’ needs with near mass production efficiency’(Piller F. T., *Mass Customization: Reflections on the State of the Concept* , 2005)(Tseng & Jiao, 2001). What one needs, when one needs it, mass customization aims at producing goods and services catering to individual customers’ needs. The first definition, which was first introduced by Joseph Pine 1993, is that mass customization is ‘developing, producing, marketing and delivering affordable goods, and services with enough variety and customization that nearly everyone finds exactly what they want’(Piller & Tseng, *Mass Customization Thinking: Moving from Pilot Stage to an Established Business Strategy*, 2010). This means mass customization is the production with low unit cost as characterizes mass production but with flexibility, using computer-aided systems, to individual customization.

Mass Customization is a relatively new production strategy for both manufacturing and service industries, stemming from the increased demands for variety from customers and requirements for production efficiency as well as developing technologies enabling more flexible systems. According to Fabrizio Salvador, Pablo Martin de Holan and Frank Piller in ‘Cracking the Code of Mass Customization’ this style of production can be

applied to most businesses as long as it is done in the right way and the impacts are completely comprehended. The starting point is to understand Mass Customization as a process, not as an end state, understanding and incorporate customers' need and aligning them into the production capabilities (Salvador, de Holan, & Piller, 2009). Through this process not only a high variety of customized products and services to mass production costs can be obtained but also strategic business advantage and economic value.

*"It's important to realize that mass customization is a business strategy first  
and a technology direction second"*

- Milan Kratochvíl, Growing Modular: Mass Customization of Complex Products,  
Services and Software

### **Evolution of Mass Customization**

Mass Customization as term was later into a business approach by Pine (1993) and many other authors (e.g. Duray, Piller, and Wind & Rangaswamy). It became popular in academia and was adapted as an e-business approach or a strategy of supply-chain management. Research on mass customization is dealing with different issues around developing, producing, and selling individualized products and services for rather large customer segments. Within a mass customization business, customers are integrated into value creation by defining, configuring, matching, or modifying their individual solution from of a list of options and pre-defined components (Piller, Schubert, Koch, & Möslein, Overcoming Mass Confusion: Collaborative Customer Co-Design in Online Communities, 2005).

In 2005, Piller refined the term Mass Customization for a final time stating that mass customization refers to *'Customer co-design process of products and services, which meet the needs of each individual customer with regard to certain product features. All operations are performed within a fixed solution space, characterized by stable but still flexible and responsive processes. As a result, the costs associated with customization allow for a price level that does not imply a switch in an upper market segment.*

Now, when economic and political changes have led to de-regulation in many industries and the removal of trade barriers in many others. The global market is becoming saturated and the customer's knowledge and discernment is increasing. Improved education and access to information is producing customers that are both cost-conscious and demanding. An increased awareness and greater access to similar products is leading to increased competition and price sensitivity. Companies must compete on the basis of giving the customer exactly what he or she needs, where and when he or she wants it – but profitably and at a price the customer is prepared to pay. The fundamental principle of the solution is to combine components and increasingly intelligent software tools. Custom-tailored mass production can in fact sound as an own contradiction and indeed, prior to recent technology developments and e-commerce, only a few companies were able to deliver Mass Customization (Kratohvil & Carson, 2005).

### **Content, Concepts and Terminology**

Mass customization needs involvement from the customers. This can be obtained through communication techniques and information systems where the customer-specific information will be stored. The goal is to create a space for interaction with each customer in order to learn about customer needs and to form a long lasting relationship. This is different both from traditional customization and mass production.

Piller states a few concepts to what Mass Customization really is and what distinguishes it different from similar concepts.

- *Customer co-design*

A process that allows customers to express their product requirements and carry out product realization processes by mapping the requirements into the physical domain of the product. As a result, the customer chooses an individualized combination of product specifications from a set of options. During this process of elicitation, the customer is being integrated into the value creation of the supplier. The customer becomes a co-producer or “prosumer”. However, as the main part of the interaction with the customer takes place during the configuration and therefore the design of a customer specific product, hence the customer is rather a co-designer than a co-producer.

The genus of mass customization is customer co-design. Customers are integrated into



value creation by defining, configuring, matching, or modifying an individual solution. Customization demands that the recipients of the customized good transfer their needs and desires into a concrete product specification. Different than a do-it-yourself (DIY) setting (i.e., autonomous creation activities of consumers), this is done in a mode of interaction with the manufacturer who is responsible for providing the custom solution (“co-creation,” Ramirez, 1999). Co-design activities are performed in an act of company-to-customer interaction and cooperation (Franke and Piller, 2003a, 2004; Khalid and Helander, 2003; Toffler, 1980; Tseng, Kjellberg, and Lu, 2003; von Hippel, 1998; Wikström, 1996). This is the core element that differentiates mass customization from other strategies like lean management or agile manufacturing. Customer co-design also establishes an individual contact between the manufacturer and customer, which offers possibilities for building up a lasting relationship. Once the customer has successfully purchased an individual item, the knowledge acquired by the manufacturer represents a considerable barrier against switching suppliers. Reorders are much easier (Pine, Peppers, and Rogers, 1995; Wayland and Cole, 1997).

These *co-design activities* are performed in an arena where vendors use so-called toolkits for customer co-design. Von Hippel (2001) defines these toolkits as a technology that: allows users to design a novel product by trial-and-error experimentation, and delivers immediate (simulated) feedback on the potential outcome of their design ideas. Today, most of these toolkits are internet-based. Co-design activities are the necessary prerequisite of mass customization in order to fulfill the needs of individual customers. However, these activities are also a major driver for complexity, effort, and perceived risk from the customers’ perspective, limiting the success of a mass customization strategy.

- *Meeting the needs of individual customer*

From a strategic management perspective, mass customization is a strategy of differentiation. Referring to Chamberlin’s (1950, 1962) theory of monopolistic competition, customers gain from customization, the increment of utility of a good that fits their needs better than the best standard product attainable. The larger the heterogeneity of all customers’ preferences, the larger is this gain in utility. From a managerial point of view, customization can be carried out with regard to fit, style, and functionality.

To match the level of customization offered with customers' needs is a major success factor of mass customization.

- *Stable solution space*

The space within which a mass customization offering is able to satisfy a customer's need is finite. The term solution space represents "the pre-existing capability and degrees of freedom built into a given manufacturer's production system" (von Hippel, 2001). Correspondingly, a successful mass customization system is characterized by stable but still flexible and responsive processes that provide a dynamic flow of products (Pine, 1995). Value creation within a stable solution space is the major differentiation of mass customization versus conventional (craft) customization. A traditional (craft) customizer re-invents not only its products but also its processes for each individual customer. But a mass customizer uses stable processes to deliver high variety goods (Pine, Victor, and Boynton, 1993). This allows a mass customizer to achieve "near mass production efficiency," but also implies that the customization options are limited to certain product features. Customers perform co-design activities within a list of options and pre-defined components. This space determines the universe of benefits that an offer intends to provide to customers, and then within that universe, the specific permutations of functionality that can be provided (Pine, 1995). Mass customization does not mean to offer limitless choice, but choice that is restricted to options which are already represented in the fulfillment system. In the case of digital goods (or components), customization possibilities may be infinite. In the case of physical goods they are, however, limited and may be represented by a modular product architecture (Tseng and Du, 1998; Tseng and Jiao, 2001). Setting the solution space becomes one of the foremost competitive challenges of a mass customization company.

- *Adequate price and cost levels*

Often, the definition of mass customization is supplemented in the literature by the requirement that individualized goods do not carry the price premiums connected traditionally with (craft) customization (Davis, 1987; Hart, 1995; Pine, 1993b; Victor and Boynton, 1998; Westbrook and Williamson, 1993). However, mass customization practice shows that consumers are frequently willing to pay a price premium for customization to reflect the increment of utility they gain from a product that better fits their needs than the best standard product attainable (see Franke and Piller, 2004;

Levin, Schreiber, Lauriola, and Gaeth, 2002; Piller, Honigschmid, and Muller, 2002). The mass customization definition is not to be restricted to “mass production prices”. To distinguish mass customization from craft customization, the fact that mass customized goods are targeting the same market segment that was purchasing the standard goods before is pointed out.

- *No switch in an upper market segment*

Traditionally, craft customization is related to price premium to such an extent that it targets a completely different market segment. Premium of mass customization offerings may be substantial, but still has to be affordable.

From the manufacturer’s perspective, this price level demands for a cost level that allows such affordable premium. Piller, Moslein, and Stotko (2004) discuss the value creation mechanism of mass customization. They show that customized production can allow for *economies of integration*, cost saving potentials resulting from better planning conditions, a reduction of fashion risks, a drop in distribution stock-keeping, or higher customer loyalty.

The information acquired during the co-design process allows the firms to cut back on pools of fixed costs that came about due to the necessity of maintaining a high level of operational flexibility. Economies of integration are substantially based on better access to knowledge about the needs and demands of the customer base (see also Kotha, 1995; Piller, 2003a; Rangaswamy and Pal, 2003; Squire et al., 2004; von Hippel, 1998)(Piller F. T., Mass Customization: Reflections on the State of the Concept , 2005).

### **Levels of customization and customer involvement**

The level of customer involvement can vary; on the basic level is letting the customers only choose colors and outer design for their products, like Nike’s NikeiD where the customer can personalize their shoe with colors and id numbers ([www.nikeid.com](http://www.nikeid.com)) (Boer & Dulio, 2007). A next level is to let customer choose from pre-design modules, like Dell computers where customers can build their own computer choosing from the made available components ([www.dell.com](http://www.dell.com)). An even further level of involvement from the customers is when the customer is allowed to co-creation the product, not only outer design and aesthetics but also characteristics and functionalities of the product. An example of this is Adidas Salomon, the customer chooses functions and best fit and

all shoes are made-to-order ([www.miadidas.com](http://www.miadidas.com)) (Berger & Piller, 2003). Many different classifications of the types of mass customization have been presented, one of them is by Duray who classified mass customization into four types, depending on customer involvement; fabricators, involvers, 'modularizers' and assemblers (Duray, 2000). Another division, related to the automotive industry was made by Alford et al. who classified the strategies of mass customization into; core, optional and form customization.

On the production side of mass customization, the specific characteristics are flexible manufacturing systems, modularity and postponement. By postponing the production, assembly and even design of products down the line until orders have been received, standard parts and modules can be manufactured in the traditional ways of mass production (Piller, Moeslein, & Stotko, 2004).

Determining the level of individualization characterizing truly mass-customized products seems to be a major point of contention in the debate concerning mass customization. Some attribute the mass customization concept to only products that contemplate all requirements made by individual customers. Others suggest mass customization to be simply about delivering products following customer options, independent of the number of options actually offered. According to Hart (Hart, 1995) the solution for this contention lies in careful determination of the range in which a product or service can be meaningfully customized, and how individuals make options upon this range. To Westbrook and Williamson (Westbrook & Williamson, 1993) successful mass customization systems should be able to mix true individualization with high part variety and standardized processes. There are many propositions of a *continuous framework* upon which mass customization may be developed; namely, mass customization can occur at various points along the value chain, ranging from the simple 'adaptation' of delivered products by customers themselves, up to the total customization of product sale, design, fabrication, assembly, and delivery. Gilmore and Pine (Gilmore & Pine, 1997) identify four customization levels based mostly on empirical observation: *collaborative* (designers dialogue with customers), *adaptive* (standard products can be altered by customers during use), *cosmetic* (standard products are packaged specially for each customer), and *transparent* (products are adapted to individual needs). Lampel and Mintzberg define a continuum of five mass

customization strategies (and therefore levels) involving different configurations of process (from standard to customized), product (from commodities to unique) and customer transaction (from generic to personalized)(Lampel & H, 1996). Pine suggests five stages of modular production: customized services (standard products are tailored by people in marketing and delivery before they reach customers), embedded customization (standard products can be altered by customers during use), point-of-delivery customization (additional custom work can be done at the point of sale), providing quick response (short time delivery of products), and modular production (standard components can be configured in a wide variety of products and services). Spira developed a similar framework with four types of customization: customized packaging, customized services, additional custom work, and modular assembly (Spira, 1998).

The combination of these frameworks leads to eight generic levels of Mass Customization, ranging from pure customization (individually designed products) to pure standardization; these levels are presented in Table 1.

<i>MC generic levels</i>	<i>MC approaches</i>	<i>MC strategies</i>	<i>Stages of MC</i>	<i>Types of customization</i>
8. Design	Collaborative transparent	Pure customization		
7. Fabrication		Tailored customization		
6. Assembly		Customized standardization	Modular production	Assembling standard components into unique configurations
5. Additional custom work			Point of delivery customization	Performing additional custom work
4. Additional services			Customized services, providing quick response	Providing additional services
3. Package and distribution		Segmented standardization		Customized packaging
2. Usage	Cosmetic		Embedded customization	
1. Standardization	Adaptive	Pure standardization		

**Table 1 Generic levels of mass customization**

Design is the top level in Table 1 and refers to collaborative project, manufacturing and delivery of products according to individual customer preferences (e.g. residential

architecture).

- Level 7 (fabrication) refers to manufacturing of customer-tailored products following basic, predefined designs (e.g. Motorola's Bandit pager).
- Level 6 (assembly) deals with the arranging of modular components into different configurations according to customer orders (e.g. Dell products).
- Levels 5 and 4, mass customization is achieved by simply adding custom work (e.g. IKEA's furniture) to standard products, often at the point of delivery.
- Level 3, mass customization is provided by distributing or packaging similar products in different ways using, for example, different box sizes according to specific market segments (e.g. Wal-Mart's peanuts).
- Level 2, mass customization occurs only after delivery, through products that can be adapted to different functions or situations (e.g. Lutron's lighting systems).
- Level 1 refers to Lampel and Mintzberg's pure standardization, a strategy that can still be useful in many industrial segments (Da Silveira, Borenstein, & Fogliatto, Mass Customization: literature review and research directions, 2001).

### **Benefits from Mass Customization and incentives for implementation**

Customer co-design is a distinctive principle of mass customization (Piller, 2003) and the source of its competitive advantage. Co-design can also lead to a complex, risky and uncertain buying situation that could deter customers from participating in this process. For customers, the decision to buy a customized product is basically the result of a simple economic equation (Franke & Piller, 2003): The higher the perceived (expected) benefit (returns) from the product compared to the (expected) cost, the higher the likelihood of a customer employing mass customization. *Returns* are twofold: Firstly, the value of a customized product, i.e. the increment of utility that a customer gains from a product that fits better to her needs than the best standard product attainable (Tseng & Jiao, 2001), and secondly possible rewards from the design process such as flow experience or satisfaction with the fulfillment of a co-design task (Novak, Hoffman & Yung, 2000).

The current literature present many benefits from implementing mass customization, it

says almost every type of business can implement and gain from mass customization – as long as it is performed correctly (Salvador, de Holan, & Piller, 2009).

When the customer is involved in the value creation he or she is more likely to remain loyal to the company, the information sharing process and the knowledge acquired develops into a switching costs for the customer. When a good relationship with is build up from start, it is probable that the relationships become long lasting.

Piller, Moeslein & Stotko also present, in the article 'Does mass customization pay? An economic approach to evaluate customer integration' the concept of 'sticky information'. Sticky information is another benefit derived from attaining personal customer, or customer-specific, information. It is the knowledge gained from transferring the information about customer needs and wants into products and then aggregating the information into better marketing research and forecasting about future customer needs (Piller, Moeslein, & Stotko, 2004). This is possible because customer do not always know what they want. Tastes, desirable designs and functionalities are not always possible to describe, but by letting the customer be a part of the creation these wishes can be captured and transferred into the product.

More benefits are presented by Christoph Berger and Frank Piller in the article 'Customers as Co-designers', where they explain how sports goods manufacturer Adidas Salomon succeeded in mass customization. These include; increase in flexibility and scalability, open innovation, innovation leadership and also the concept of postponement. By postponing production until customer orders are received, there is less risk of forecasting as when products are made-to-stock. Increase in flexibility and scalability refers to the possibility of faster respond to market trends. Open innovation can be achieved through the fact that customers are integrated in the creation of the product and not only being asked about their preferences and likes in extensive market researches. Innovation leadership, in the case of Adidas Salomon – that still is mainly a mass producer, which came with the customization program, has allowed new flexible technologies to be introduced, and incorporated throughout the whole company (Berger & Piller, 2003).

General benefits that mass customization also brings along are that customers are willing to pay more for personal products, than for mass produced products. Researches have shown that customer would pay up to 100 percent more for at customized product



(SAP Info, 2004). Margins should therefore be greater and mass customized products will not be affected by price wars. Also, producing on demand allows for cost savings by not having any inventory and no forecasting errors, the storage costs become lower and there is no risk for obsolescence.

In the book, *Growing Modular - Mass Customization of Complex Products, Services and Software*, more benefits resulting from mass customization implementation are presented (Kratochvíl & Carson, 2005). It is said that Mass Customization *delivers a constant process innovation push*, resulting in lean quick processes, increasingly generalized components, and powerful, fit-for-purpose IT. The improved order processes associated with Mass Customization result in:

- *Lower costs*

By automating or eliminating unnecessary steps in a business process (for example inspections, checks, handovers etc.) and by fine-tuning an order-driven just-in-time supply system and production. Several SMEs have shown that some 80% of the old process steps can be omitted; among many good examples, the Lundkvist Interior Equipment office-furniture company in the Silicon belt of Kista outside Stockholm, who quickly and successfully configures bids from furniture components. The subsequent time saving can then be *reinvested* – as time spent with customers to increase sales and in new product and process development.

- *Minimization of losses*

By eradicating misunderstandings and misinterpretations in the order process through use of intelligent software that requires precise, hard facts as input – pushing for improvements in data and processing quality. In complex products, this category of losses could recently become rather extreme. PDMG's studies of Finnish companies (Tiihonen et al., 1995) showed that traditional bids and orders for complex products used to be swamped with ambiguities and errors. Up to 65% of time could be spent changing orders, 17% correcting errors in orders, leaving just 18% to be spent in normal sales & marketing work. Thus, Mass Customization *minimizes losses by delivering better quality of customer contact*.

- *Increased loyalty and life-cycle revenue*

Through an improved dialog with customers. Customer Relationship Management (CRM) is a current approach emphasizing the benefits of focusing on “share of customer”



rather than “share of market”. In reality nonetheless, many CRM related initiatives are really aimed at reducing operational costs for the business in customer communications and service – often with no improvement in *quality* of contact or increase in customer loyalty. Mass Customization in contrast, truly does “treat different customers differently” with each customer having their needs met individually rather than homogenously.

- *Easier service and upgrade over time*

In addition to the loyalty induced by more personalized customer response. The modular nature of mass customized products such as personal computers, telecommunication switches or industrial machinery facilitates having their use extended, modified or their capacity increased by simply “swapping out” one modular component for another. As to loyalty, risk and cost, this can be contrasted with the expensive need to perhaps strip down and refurbish, or potentially totally replace (i.e. opening up to competition), traditional equipment that is non-modular and has a limited life span. Thus, Mass Customization *increases customer loyalty* (and revenue) by responding to customer needs and by providing the customer with flexible products with extendable life cycles.

Conclusively, it can be said that mass customization, if implemented correctly, can become a competitive advantage factor, the increased costs of dealing with customer interaction can be overcome by the increased value created by the same.

Mass customization also allows for a concept called ‘economies of integration’, coined by Berger and Piller, which is exactly the economical benefits gained from integrating customers into the design and production of goods. How the value is created is described through a model in the figure below (Piller, Moeslein, & Stotko, 2004).

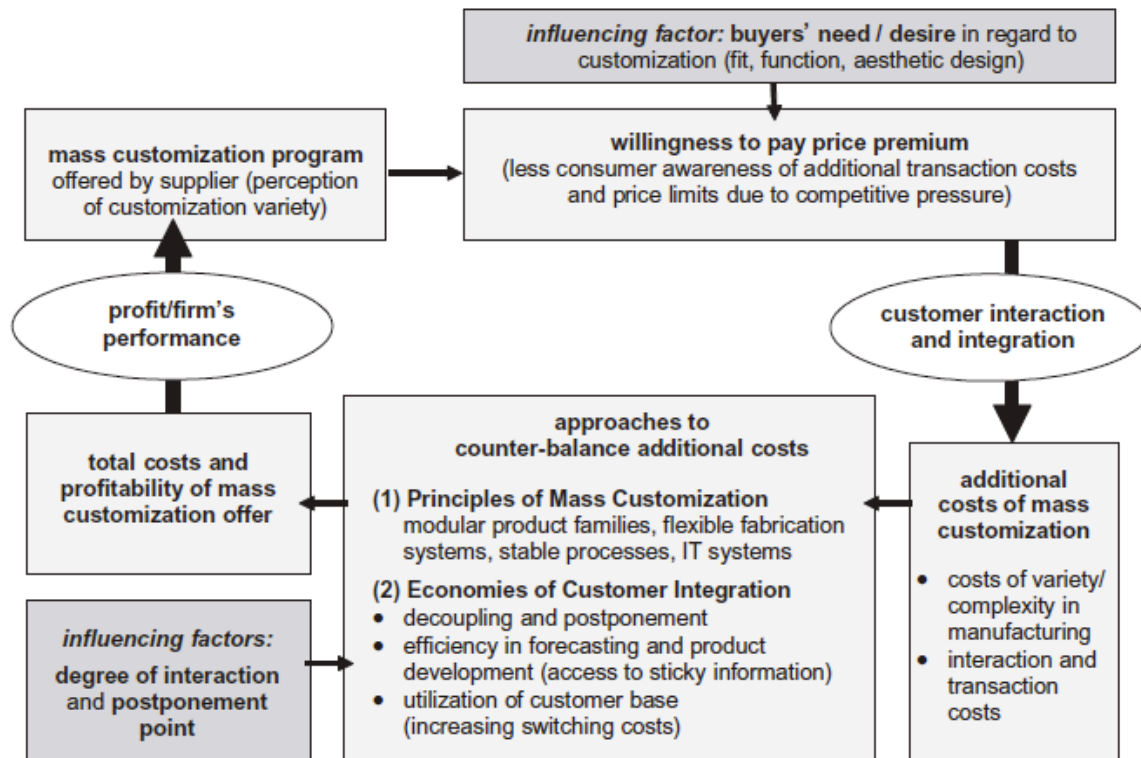


Figure 1 - A model of value creation in mass customization systems (Piller, Moeslein, & Stotko, Does mass customization pay? An economic approach to evaluate customer integration, 2004)

### Drawbacks, Barriers and Costs of Mass Customization

There are, however, some drawbacks and challenges with mass customization. The literature presents some issues that are related to the benefits and somehow resulting from them. For example:

- *Speed and lead-time*: are longer than in mass production. This should be taken into consideration when managing customer expectations.
- *Customer's needs*: customers do not always know exactly what they need – or want. Also lack of knowledge, about production capabilities and feasibility (for the products)
- *Economies of scale*: can be, partly overcome, by modularization and postponement
- *Value*: at some point too many choices only confuse the customers, they do not provide additional value
- *Complexity*: require good IT solutions to manage. Managing different modules, designs and products together with customers' needs and production processes (Piller & Tseng, 2010).

Moreover, Pine coined the term “*mass confusion*” (in Teresko, 1994) as a metaphor to describe the burdens and drawbacks for the consumer as a result of the mass customization interaction processes. Mass confusion can be seen as one major explanatory factor for the delay in adoption of mass customization technologies in business practice. Discussions with managers from different companies about mass confusion have given a first indication that interactions between customers could become a means to reduce mass confusion. Case study research then provided additional evidence that customers are able to support each other in a co-design process by jointly performing the design process or giving each other feedback and inspiration during this process. This notion of collaboration in customer groups, however, challenges an implicit assumption raised in most of the literature on personalization and customization: (mass) customization and personalization is about offering individual customers a customized product or service according to their personal needs (e.g. Rieck, 2003; Squire, Brown & Cousins, 2003; Wind & Rangaswamy, 2001) (Piller, Schubert, Koch, & Möslein, 2005).

Three sources can be identified of ‘mass confusion’: the burden of choice of finding the right option from a large number of customization options; the difficulty of addressing individual needs and of transferring them into concrete product specifications; and uncertainties, based on missing information, about the behavior of the provider (Piller, Schubert, Koch, & Möslein, 2005).

*Burden of choice:*

Marketing research has demonstrated since decades that customers strive to minimize time and effort, and value convenience by a higher willingness-to-pay (Anderson, 1972). When the purchasing act becomes too time consuming, customers regularly stop it and relocate their purchasing budget to another offering or product category (Babin, Darden, and Griffin, 1994; Simon, 1976). One limit of mass customization often quoted is that *excess variety* may result in an external complexity. Customers might be overwhelmed by the number of possibilities at their disposal (Franke and Piller, 2004; Huffman and Kahn, 1998; Kamali and Loker, 2002; Stump, Athaide, and Joshi, 2002; Wind and Rangaswamy, 2001). Anyone who has been forced to choose from a fairly wide selection—for example, in a restaurant that offers 500 entrees—knows that equating a large number of possibilities with high customer satisfaction would be blind optimism.

The human capacity to process information is limited (Miller, 1956). The burden of having to choose from too many options may simply lead to information overload (Maes, 1994; Neumann, 1955). Consequently, users may turn away from the liberty to choose and decide for the standard (or starting) solution offered by a toolkit (Dellaert and Stremersch, 2005; Hill, 2003)—or they may even frown and turn their backs completely (Piller F. T., *Mass Customization: Reflections on the State of the Concept*, 2005).

#### *Matching needs with product specifications:*

In addition to large variety and the burden of choice, customers often simply lack the knowledge and skills to make a “fitting” selection, i.e. to transfer their personal needs and desires into a concrete product specification (Dellaert, 2001; Huffman & Kahn, 1998). Even a standard and rather simple product like a pair of Adidas sport shoes becomes a rather complex product if one has to decide explicitly between different widths, cushioning options for the insole, patterns for the outsole, and color options. In the case of miAdidas, consumers regularly reported in customer surveys that they are not sure if they have chosen the right specifications. Also, customers of American Eagle are not sure if their own designs match the latest fashion trend (Piller, Schubert, Koch, & Möslein, *Overcoming Mass Confusion: Collaborative Customer Co-Design in Online Communities*, 2005).

#### *Information gap regarding the behavior of the manufacturer:*

For many consumers, customizing a product is still an unfamiliar process. In this regard, uncertainty also exists in connection with the potential behavior of the provider (Kamali and Loker, 2002; Terwiesch and Loch, 2004). The cooperative character of the configuration results in an asymmetrical distribution of information—a typical principal agent problem: The customer (principal) orders (and pays) a product she has never seen. Additionally, she may have to wait some days or even weeks to get the product. This problem is common for catalog order or online retailers. However, compared to distance shopping of standard goods, customers of customized goods often have much higher problems to claim that they do not like a product after receiving it. Without a clear reference point for the definition of an optimal performance, it is difficult to judge whether a case of warranty arises compared to purchasing standard mass-produced goods.

These three sources of uncertainties can be interpreted as additional transaction costs

for customers looking for a customized product. Interviews have shown that often consumers perceive these cognitive costs higher than the actual price premium asked for the customized product. One of the most important tasks of a mass customizer is to ensure that the customers' perceived expenditure is kept as low as possible, while the additional benefits of getting a customized solution have to be clearly perceptible. This requires a careful planning of the co-design process as well as the co-design environment in order to successfully reduce the complexity and risk of the configuration process. Only if customers do not experience 'mass confusion', they are likely to place an order within a mass customization environment – enabling firms to actually reap the benefits of this strategy. Note that the extent of the mass confusion problem, and the demand for a customized product per se, depends on a number of contingency factors such as the type of the product, socio-demographics of the users, previous user experience with both the product provider and customizing another product, and the possible customization options (Piller, Schubert, Koch, & Möslin, *Overcoming Mass Confusion: Collaborative Customer Co-Design in Online Communities*, 2005).

### The costs of Mass Customization

Customer co-design is a distinctive principle of mass customization (Piller, 2003) and the source of its competitive advantage. Co-design can also lead to a complex, risky and uncertain buying situation that could deter customers from participating in this process. For customers, the decision to buy a customized product is basically the result of a simple economic equation (Franke & Piller, 2003): The higher the perceived (expected) benefit (returns) from the product compared to the (expected) cost, the higher the likelihood of a customer employing mass customization. *Returns* are twofold: Firstly, the value of a customized product, i.e. the increment of utility that a customer gains from a product that fits better to her needs than the best standard product attainable (Tseng & Jiao, 2001), and secondly possible rewards from the design process such as flow experience or satisfaction with the fulfillment of a co-design task (Novak, Hoffman & Yung, 2000).

*Costs* of mass customization for consumers are: the premium a customer has to pay for the individualized product compared to a standard offering and the drawbacks of the customers' active participation in (integration into) value creation during the

configuration process. Researches show that consumers in many cases are willing to pay a high monetary premium for a customized product (Dellaert & Stremersch, 2005; Franke & Piller, 2004). Co-design activities can result in the perception of extended complexity and additional effort during the buying (configuration) process. Especially in consumer markets, customers often do not have sufficient knowledge for the definition of the product specification that corresponds to their needs (Huffman & Kahn, 1998; Liechty, Ramaswamy & Cohen, 2001).

The additional premiums of mass customization (compared to traditional mass-production) are challenged by additional costs associated with this system, also for the manufacturers. Basically, higher costs occur both in sales and customer interaction as well as in manufacturing. As mentioned before, higher costs in sales stem from the elicitation and interaction with the customers. This includes not only investments in configuration systems and other information-handling equipment, but a firm has also to establish mechanisms to minimize the burdens of customization from the customers' point of view. 'If customers become frustrated or dissatisfied with the complexity, a mass customization strategy obviously would not be a competitive advantage (Huffmann and Kahn, 1998). Corresponding actions demand investments in customer service centers, highly qualified staff, or trust-building promotion activities – leading to additional costs. Also, distribution costs are higher due to smaller lot sizes in delivery. In manufacturing, costs increase due to a loss of economies of scale (specialization and standardization) in comparison to mass manufacturing. Higher set-up costs, costs for better-qualified labor, an increased complexity in production planning and control, and more complex and detailed quality control are escalating the cost level. Additionally, inventory of components may rise, and higher capital investments in advanced flexible production units and appropriate information systems often result in additional machinery costs.

Concluding, from the firm's perspective, the costs of mass customization include two factors: the cost of providing high flexibility in manufacturing, and the cost of eliciting customer preferences. Till today, mass customization research and practice is closely connected to the first factor, i.e., the potential offered by new manufacturing technologies to reduce the trade-off between variety and productivity (Ahlström and Westbrook, 1999; Fogliatto, Da Silveira, and Royer, 2003; Kotha, 1995; Pine, 1993a;

Thoben, 2003; Victor and Boynton, 1998). But if a firm cannot transfer the customers' preferences cheaply into a fitting product design, the best available manufacturing technology is of no meaning (Reichwald, Piller, and Moeslein, 2000).

### **Implementing Mass Customization**

Mass customization is a strategic mechanism that is applicable to most businesses, provided that it is appropriately understood and deployed. The key is to view it basically as a *process* for aligning an organization with its customers' needs. That is, mass customization is not about achieving some idealized state in which a company knows exactly what its customers want and can manufacture specific, individualized goods to satisfy those demands - all at mass- production costs. Rather, it is about moving towards these goals by developing a set of organizational capabilities that will, over time, supplement and enrich an existing business.

In order to implement mass customization, it has been suggested that a company must develop three different capabilities. These are: *solution space development, robust process design, and choice navigation* (Salvador, de Holan, & Piller, 2009). Admittedly, the development of these capabilities mandates for organizational changes that are often difficult because of powerful inertial forces within a company, but that makes the argument more compelling: those who are able to develop these capabilities will be able to enjoy long-lasting competitive advantages.

*Solution space development* is the development of a system to understand and capture the customers' particular needs and to present the products or services offered by the company. The solution space has to be defined in the context of diverse customer needs and it has to enable for various selection possibilities in a way that is easy for the customer to understand and use. The most common tool used here is computer-aided design, CAD, systems, which can present the modules and product offered with an easy-to-use interface. From the information collected the company can interpret differentiation characteristics and desired product attributes, as well as unwanted



features, when the customer is allowed to, by themselves, translate their needs directly into product designs. The interface should also allow tracking of customer behavior in order to collect information from customers that also do not order the final product designed. In this way the company can evaluate and incorporate trends in customer preferences into a refined solution space. When the information is collected a prototype has to be developed by the company, the prototype can either be physical or virtual. In the case of Adidas Salomon – miAdidas mentioned above, most of the prototypes developed are only made virtual, this allows for massive savings for the company (Berger & Piller, 2003).

A subsequent capability to develop is *robust process design*, which is defined as:

*“The capability to reuse or re-combine existing organizational and value chain resources to fulfill differentiated customers needs.”*

(Piller & Tseng, Mass Customization Thinking: Moving from Pilot Stage to an Established Business Strategy, 2010)

With robust process design the customized product can be produced with near mass production efficiency. It can be achieved through three different approaches; *process modularity*, *flexible automation* and *adaptive human capital*. Flexible automation means the usage of modern digital technology to allow for variations in manufacturing without high switching costs. Process modularity can be obtained by breaking down the processes into segments and modules that can be performed individually when required for specific customer needs. Adaptive human capital is also required to attain robust process design; employees have to be able to deal with unclear and unstable tasks to support the technology (Salvador, de Holan, & Piller, 2009).

The third capability through which the mass customization implementation process should go is *choice navigation*. Choice navigation is required for helping and directing customers through the various options offered. If the choices are too many the value gained from a customized product might not be worth deciding among excessive amounts of options, in fact, the choices may even reduce customer value. This is called



the “paradox of choice” (Salvador, de Holan, & Piller, 2009). A company must therefore minimize the complexity of the choices offered. *Assortment matching*, *fast-cycle trial-and-error learning in co-design toolkits* and *embedded configuration* are methods proposed for the simplification of choice.

Assortment matching means matching the available choices through software that automatically proposes the solution most similar to by the customer desired attributes; configurations can subsequently be made by adding or removing parts or functionalities. Through fast-cycle trial-and-error learning the customer is given the possibility to on by themselves design and build solutions and later test the configurations to match available offers.

Embedded configuration is a system that automatically changes the attributes of product to adapt to customer preferences. The products re-configure automatically in accordance to the users.

Most consumers have a general idea of what they want but by adapting the technologies described above the customers are allowed to try, design and combine different styles, colors, fits and functionalities until they find exactly what they want. Through an iterative practice they also learn about their own preferences and can see how the configurations look, in real time. Examples of self-configuration products are products that adjust themselves to the customer’s size, weight and shape as on My Virtual Model™ ([www.mvm.com](http://www.mvm.com)), where the customer can create a virtual model of themselves and ‘try on’ different types and styles of clothing.

A summary of the three capabilities to develop to move towards mass customization is presented in the table below:

<b>Mass customization capability</b>	<b>Examples of approaches to develop Mass customization capabilities</b>
<p><b>Solution Space Development:</b>  <i>Capability to identify the product attributes along which customer needs mostly diverge</i></p>	<p><b>Innovation toolkits:</b> Software applications that can empower large pools of customers to translate their preferences into unique product variants by themselves, enabling each of them to highlight possibly unsatisfied needs</p> <p><b>Outcome-driven innovation:</b> Methods to identify latent customer needs in an analytic way and to transfer those into product functionalities.</p> <p><b>Customers experience intelligence:</b> Definition of adequate processes to continuously collect data on past customer transactions/ behaviors/ experiences and to translate this data into information on customer preferences</p>
<p><b>Robust Process Design:</b>  <i>Capability to reuse or re-combine existing organizational and value chain resources to fulfill a stream of differentiated customers needs</i></p>	<p><b>Flexible automation:</b> Using modern "digital" manufacturing technologies that enable high variance in operations at low switching cost.</p> <p><b>Process modularity:</b> Reusing and recombining existing organizational and value-chain resources to fulfill differentiated customers' needs</p> <p><b>Adaptive human capital:</b> People are a necessary element of a mass customization strategy, especially for their capacity to deal with new and ambiguous task.</p>
<p><b>Choice Navigation:</b>  <i>Support the customers in identifying their own solutions, while minimizing complexity and burden of choice</i></p>	<p><b>Assortment matching:</b> Negotiating the characteristics of an existing assortment with a model of the customers' needs in order to propose possible solutions to the customers without requiring significant effort and time in the search process</p> <p><b>Fast-cycle trial-and-error learning in co-design toolkits:</b> Empower customers to build models of their own needs and to learn about appropriate solutions to their needs by interactively testing the match between these models and the available options.</p> <p><b>Embedded configuration:</b> Developing smart products that "understand" how they should adapt to usage conditions and re-configure itself accordingly to a user profile.</p>

**Table 2 - Mass Customization Capabilities (Handbook of Research in Mass Customization & Personalization)**

Modularization

(Re)assembly and disassembly of suitable designed module interfaces allow a postponement of the final assembly step thus contributing to Mass Customization and increase the efficiency of manufacturing, maintenance, modification, and remanufacturing processes. Module interfaces should be standardized to allow an efficient adaptation of a product as well as a module reuse in different products, product variants and generations. In order to assure the functionality of module interfaces, a definition early in the design process is crucial. Module interfaces have to be designed simple and in a way that they safely allow the transfer of energy, signal, and material flows. Thereby, the disassembly and reassembly frequency has to be considered.

#### Product platform

Modules have to be based on a product platform, which should be the starting point of designing the product and processes for mass customization. Coordination of product and process variety conduces to the planning of both product and process platforms. Consequently, a well-structured product and process platform can enable manufacturing organizations to respond quickly to unpredictable and continuously changing markets and, thus, to realize mass customization with less efforts and expenditure.

In conclusion, the process of implementing mass customization can be described, and has until now usually been as follow.

Mass customization starts with a segment of the market that has not been served well. Certain types of products are needed to fulfill this market gap. Companies then design not a single product, but a platform that can be configured to address the requirements of this potential market. The marketing department will then come up with a campaign to communicate the unique differentiation of the products, which have been perceived as market needs. The sales department interacts with customers to translate customers' needs with machine specification and to configure a product that fits well with the customers' requirements and can be delivered when the customers need it. At the same time, and often more importantly, the total cost has to be within the budgets available to the customer.

Next, production and distribution have to figure out a way to produce and to manage the logistics for the necessary components and assemblies and to complete machine efficiently. However, uniqueness of components often translates into set up time and additional cost. This may run against the required budget limitation and lead-time. To address these challenges, techniques like flexible scheduling, modularity, commonality and others are applied to counterbalance the additional cost.

In a final step, often years after product modularity and flexible processes in manufacturing and logistics have been established, the firm starts to increase the efficiency of the customer interaction process when taking the order. A product configuration system is introduced to better communicate to customers what is available and to match customer requirements with existing solutions of the

manufacturer (Kratovich & Carson, 2005).

### **Strategy and success factors for mass customization**

Companies that master mass customization successfully have found an integrated way to address the challenges coming with a mass customization system. This requires them to gain competences around a set of three core capabilities, mentioned earlier (*solution space development, robust process design, and choice navigation*), that are driving a sustainable mass customization business. The key to profiting from mass customization is to see it as a set of organizational capabilities that can supplement and enrich an existing system. While specific answers on the nature and characteristics of these capabilities are clearly dependent from industry context or product characteristics, three fundamental groups of capabilities determine the ability of a firm to mass customize.

Findings show that companies that have found individual means to implement methods and approaches to match the three previously mentioned capabilities are succeeding in their mass customization endeavor. Other companies are just working along one of these capabilities. This is a good strategy as well. It is argued that mass customization has to be seen as a process rather than a destination. It is not about achieving a "perfect" state of mass customization. What matters to most companies instead is to continuously increase their overall capabilities to define the solutions space, to design robust processes, and to help customers navigate available choices. A company may already profit tremendously from just implementing better, for example, choice navigation capabilities to match diverse requests of customers not familiar with the product category. This is called understanding "*mass customization thinking*". It provides a way to profit from heterogeneities of a firm's customers. Mass customization thinking means to build the three capabilities outlined before and to apply them for designing a value chain that creates value from serving different customers differently (Moser & Piller, 2006).

The success of mass customization systems depends on a series of external and internal factors. The existence of these factors justifies the use of mass customization as a

competitive strategy and supports the development of the systems. The six factors most commonly emphasized in the literature are as follow below. Factors 1 and 2 are primarily market-related factors. Factors 3-6 are primarily organization-based factors.

- *Customer demand for variety and customization must exist.*

The need to deal with increasing customer demand for innovative and customized products is the fundamental justification for mass customization (Pine, Victor, & Boyton, 1993)(Lau, 1995)(Kotha, From mass production to mass customization: The case of the National Industry Bicycle Company of Japan, 1996). The success of mass customization depends on the balance between, on the one hand, the potential sacrifice that customers make for mass customization products (i.e. how much they will pay and wait for the delivery of mass-customized products(Kotha, From mass production to mass customization: The case of the National Industry Bicycle Company of Japan, 1996)(Lau, 1995)) and, on the other hand, the company's ability to produce and deliver individualized products within an acceptable time and cost frame.

- *Market conditions must be appropriate*

According to Kotha, a company's ability to transform mass customization potential into actual competitive advantage greatly depends on the timing of this development. In other words, being the first to develop a mass customization system can provide substantial advantage over competitors, since the company may get well entrenched in this position, and start being seen by people as innovative and customer-driven.

- *Value chain should be ready*

Mass customization is a value chain-based concept. Its success depends on the willingness and readiness of suppliers, distributors, and retailers to attend to the system's demands. The supply network must be at close proximity to the company to deliver raw materials efficiently(Feitzinger & Lee, 1997)(Kotha, From mass production to mass customization: The case of the National Industry Bicycle Company of Japan, 1996) Most important, manufacturers, retailers, and other value chain entities must be part of an efficiently linked information network (Haglund & Helander, 1999)(Kotha, From mass production to mass customization: The case of the National Industry Bicycle Company of Japan, 1996).

- *Technology must be available*

The implementation of advanced manufacturing technologies (AMTs) is fundamental to enable the development of mass customization systems (Pine, Victor, & Boyton, 1993) (Lau, 1995). One could argue that the very concept of mass customization appeared only after some companies were able to successfully integrate a series of information and process flexibility technologies. Mass customization is one of the best opportunities offered by coordinated implementation of AMTs and information technology (IT) across the value chain.

- *Products should be customizable*

Independent units that can be assembled into different forms compose a modular product (Feitzinger & Lee, 1997). Successful mass customization products must be modularized, versatile, and constantly renewed.

It enables simpler and lower-cost manufacturing of products with similar effectiveness if compared to true customization. Also, mass customization processes need rapid product development and innovation capabilities due to typical short life cycles presented by mass customization products (Pine, Victor, & Boyton, 1993).

- *Knowledge must be shared*

Mass customization is a dynamic strategy and depends on the ability to translate new customer demands into new products and services. To achieve that, companies must pursue a culture that emphasizes knowledge creation and distribution across the value chain. That requires the development of dynamic networks along with manufacturing and engineering expertise, and in-house development of new product and process technologies (Kotha, Mass customization: Implementing the emerging paradigm for competitive advantage, 1995).

These factors have direct practical implications. First, they corroborate the idea that mass customization is not every company's best strategy, for it must conform to specific market and customer types. Second, they assert the complexity involved in mass customization implementation. In other words, mass customization implementation involves major aspects of operations including product configuration, value chain network, process and information technology, and the development of a knowledge-based organizational structure.

<i>Enablers</i>	<i>Related success factors (organization-based)</i>
<i>Processes and methodologies</i>	
Agile manufacturing	Knowledge
Supply chain management	Value chain
Customer-driven design and manufacturing	Customizable products
Lean manufacturing	Value chain
<i>Enabling technologies</i>	
Advanced manufacturing technologies	Technology, customizable products
Communication and networks	Technology, knowledge

**Table 3 - MC Enablers and their related success factors (Da Silveira, Borenstein, & Fogliatto, 2000)**

### Enablers

Mass customization enablers are the methodologies and technologies that support the development of the organization-based factors described above (Table 2).

This section is divided in three subsections discussing: *processes and methodologies* enabling mass customization; *technologies enabling* mass customization; and, how technologies support information transfer, that is perhaps the major implementation problem with mass customization.

- *Mass customization processes and methodologies*

Mass customization processes and methodologies address the organizational and cultural aspects of implementing a mass customization system. They concern the main elements of a manufacturing strategy supporting the development of successful systems, capable of providing the elements cited in the previous section. Literature points to the existence of at least four main business practices relating to the mass customization concept: *agile manufacturing*, *supply-chain management*, *customer-driven design and manufacture*, and *lean manufacturing* (Da Silveira, Borenstein, & Fogliatto, 2000).

Agile manufacturing has been defined as the ability to thrive and prosper in a competitive environment of continuous and unanticipated change to respond quickly to rapidly changing markets driven by customer-based valuing of products. Agile manufacturing is characterized by the conscious usage of a changing environment as a means to be profitable. While a flexible manufacturer is characterized by a reactive adaptation behavior (waiting for a change to occur to act), an agile manufacturer has a



proactive behavior. DeVor et al. identify the main strategic dimensions of agile manufacturing as: value based strategies that enrich customers; focusing on delivering value; cooperating to enhance competitiveness; organizing to master change and uncertainty; and, leveraging the impact of people and information.

Supply chain management concerns the co-ordination of resources and the optimization of activities across the value chain to obtain competitive advantages. Efficient supply chain management is one of the key success factors in systems. Eastwood, Feitzinger and Lee, Lau, Kotha, and Moad describe how improving supply management provides organizational coordination required in MC systems. Such conditions include: development of an interconnected information network involving a selected group of trained suppliers; successful balance of low stocks with high delivery service; design of innovative products with active collaboration of suppliers; and cost effective delivery of the right product to the right customer at the right time.

Customer-driven design and manufacture is in the core of mass customization systems. Jagdev and Browne define this business practice as 'to actively consider the market trends in general and individual customer requirements in particular during the design, manufacturing and delivery of the product. Some authors call this practice 'One-of-a-Kind-Production'. The application of customer-driven practices in mass customization systems aims fundamentally at: providing conditions for the customer to initiate the design process of a product; and building an infrastructure to develop new products driven by the market.

Lean manufacturing is an efficient way to satisfy customer needs while giving producers a competitive edge. The mass customization production addresses four elements of lean production: product development; the chain of supply; shop floor management; and after-sales services.

- *Enabling technologies*

Main enabling technologies supporting MC are AMTs, such as computer numeric control (CNC) and flexible manufacturing systems (FMS), and communication and network technologies such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer integrated manufacturing (CIM), and electronic data interchange (EDI) [26,27,49].(Hirsch, Thoben, & Hoheisel, 1998);(Kanchanasevee, Biswas, Kawamura, &



Tamura, 1999);(King, 1998). Many researchers consider such technologies fundamental to mass customization implementation. The use of AMTs is justified by their inherent capability to alter the economies of manufacturing and remove barriers to product variety and flexibility. These technologies enable the development of factories that can exploit the benefits of such fundamental mass customization attributes as agility and flexibility.

#### Common failures

A repeating pattern of failure can be seen in unsuccessfully managing the change process from a product-focused, mass production firm to a customer centric mass customization organization. Shifting the locus of value creation towards customers requires no less than a radical change in the management mind-set (Piller, 2005; Ramirez, 1999). It is assumed that the expectation of a difficult change management process required to implement mass customization successfully may prevent managers from investments in this system. Already Pine (1993) mentioned that the transition from mass production to mass customization would often be gradually phased, given the complexity of this process. A senior management buy-in and a top-down implementation approach are essential to address the following subjects.

The genus of mass customization as a co-design process of collaborative value co-creation has to be deeply implemented into the cultural mindset of the organization. However, like all humans, business managers and their employees are socialized in a dominant logic, shaped by the attitudes, behaviors, and assumptions that they learn in their business environments (Huff and Möslin, 2004; Prahalad and Bettis, 1986; Prahalad and Ramaswamy, 2004). Their thinking is conditioned by managerial routines, systems, processes, budgets, and incentives created under the mass production framework. As a result, management concepts like buffering demand from supply, inventory management, forecasting, plant scheduling, cycle time, and seasonal product development cycles evolved and became the common ground for action. Unsurprisingly, interactions with customers are often approached in a similar fashion. In essence, a company that is including customers in product design in the course of the co-design process is outsourcing valuable activities that were once proprietary and have been a source of strategic advantage in the past (Prahalad and Ramaswamy, 2004). This calls

for a deep understanding and debate about mass customization on the top management level of an organization. Many mass customization initiatives, however, are regarded just as a marketing gimmick and nice PR tool, neglecting the needs and possibilities of dealing with single customer orders (Piller F. T., 2005).

### Mass Customization as a Continuous Process

In the article 'Cracking the code of mass customization' written by Salvador, de Holan and Piller (2009), Mass Customization is introduced as a continuous process for business and organizational strategy, rather than an end state. The authors argue that, Mass Customization is about moving towards knowledge about customer needs and wants through the development of organizational tools that will develop the business and create a competitive advantage (Salvador, de Holan, & Piller, 2009). They propose the process to be a move from mass production to mass customization as seen in the figure below. Through the development of three capabilities previously mentioned; solution space development, robust process design and choice navigation (described below), the organization can start moving from mass production state to mass customization.

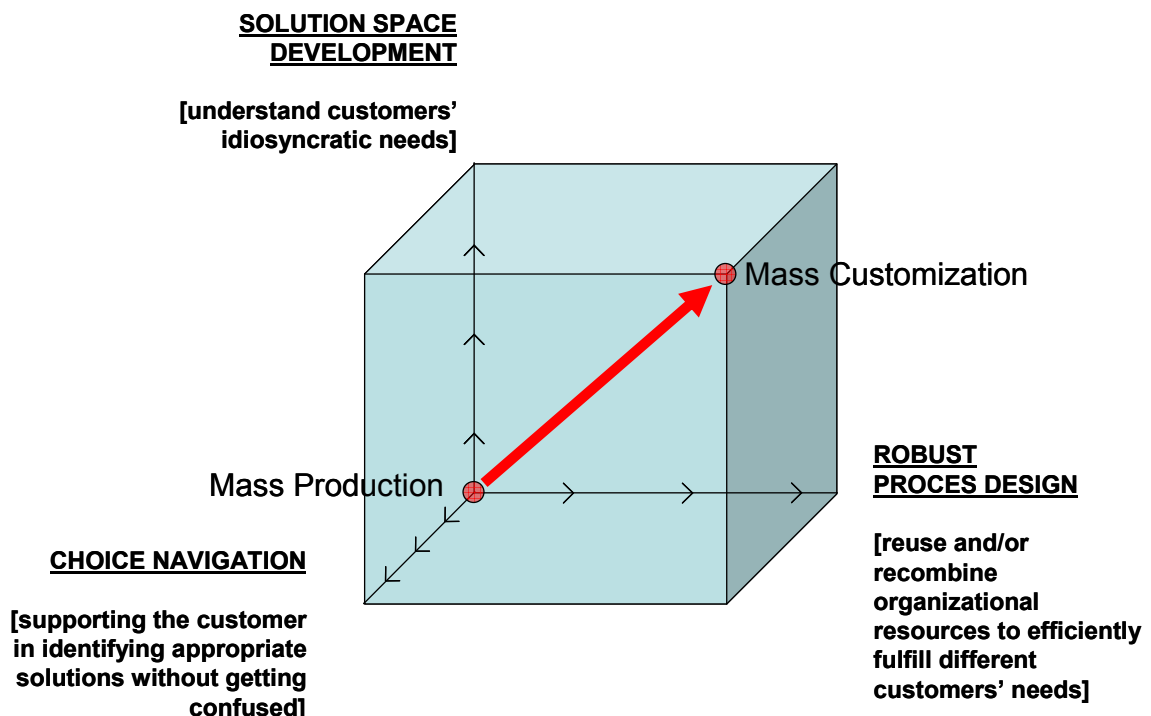


Figure 2 - The Mass Production - Mass Customization Continuum (Cracking the Code of Mass Customization)

## ***Sustainability***

### **Definition**

The concept of sustainability was first formulated in 1987 with the Brundtland Report stating that the goal of sustainability is to ‘meet the needs of the present generation without compromising the ability of future generations to meet their own needs’ (World Commission on Environment and Development (WCED), 1987). Later, in academic debates and business arenas, hundreds of definitions have been proposed referring to a more humane, more ethical and more transparent way of doing business (van Marrewijk, 2003). Several parties tried to poster sustainability proposing guidelines, theoretical models, standards, tools and monitoring instruments, tackling both private companies and public entities. They have been supported by a number of organization agencies and consulting firms. However, this variety also led to some confusion regarding the linkages and the differences between the various tools, as well as, how to apply them (Arena, Duque Ciceri, Terzi, Bengo, Azzone, & Garetti, 2009).

Other relevant definitions for the purpose of this thesis are definitions for sustainable engineering, and for sustainable development. Sustainable engineering is the ‘The application of scientific and technical knowledge to satisfy human needs in different societal frames without compromising the ability of future generations to meet their own needs’.

*Sustainability* is the capacity to endure. In ecology the word describes how biological systems remain diverse and productive over time. For humans it is the potential for long-term maintenance of wellbeing, which in turn depends on the wellbeing of the natural world and the responsible use of natural resources.

Sustainability has become a wide-ranging term that can be applied to almost every facet of life on Earth, from local to a global scale and over various time periods. Long-lived and healthy wetlands and forests are examples of sustainable biological systems. Invisible chemical cycles redistribute water, oxygen, nitrogen and carbon through the world's living and non-living systems, and have sustained life for millions of years. As the earth's human population has increased, natural ecosystems have declined and changes in the balance of natural cycles has had a negative impact on both humans and

other living systems.

There is abundant scientific evidence that humanity is living unsustainably, and returning human use of natural resources to within sustainable limits will require a major collective effort. Ways of living more sustainably can take many forms from reorganizing living conditions (e.g., ecovillages, eco-municipalities and sustainable cities), reappraising economic sectors (permaculture, green building, sustainable agriculture), or work practices (sustainable architecture), using science to develop new technologies (green technologies, renewable energy), to adjustments in individual lifestyles that conserve natural resources.

A definition of sustainability in engineering is given:

- 'The application of scientific and technical knowledge to satisfy human needs in different societal frames without compromising the ability of future generations to meet their own needs'  
- (Seliger, Kim, Kernbaum, & Zettl, 2008)

However, the authors point out that still there missing scientific basic principles, methods, procedures and tools for planning, development, adduction, and utilization of sustainable engineering.

### Content, concepts and terminology

Regardless of the many definitions, it is generally accepted that sustainability, and *sustainable development*, consist or is based on three fundamental pillars: environmental, economical, and social dimension.

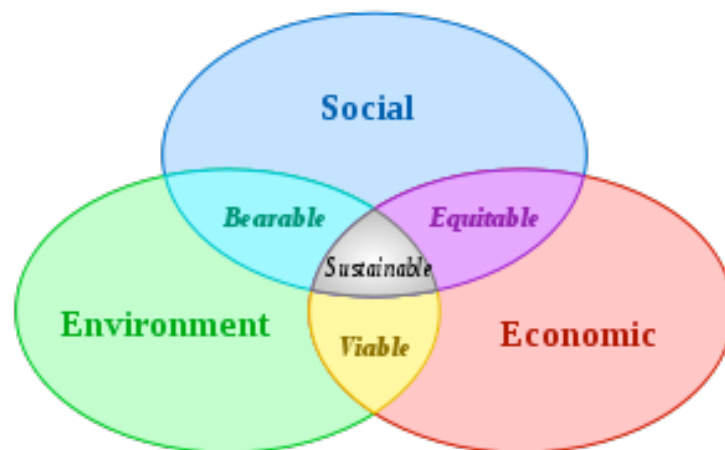


Figure 3 - Three pillars of sustainability

#### Environmental principles

Environmental principles denominate those terms that describe environmental performance, in order to minimize the use of hazardous or toxic substances, resources and energy. These terms are: renewable resources, resource minimization, source reduction (dematerialization), recycling, reuse, repair, regeneration, recovery, remanufacturing, purification, end-of-pipe, degradation, and are arranged from preventive to control principles.

- *Renewable resources*

Renewable resources are available in a continually renewing manner, supplying materials and energy in more or less continuous ways. In other words, renewable resources do not rely on fossil fuels of which there are finite stocks. The term emerged as a response to increased carbon dioxide emissions. It is fostered by the rise of the sustainability paradigm and includes energy resources such as solar, wind, tidal, wood, biomass, and hydroelectric. Of course food and feed are renewable resources as well.

- *Minimization of resource usage*

The fact that natural resources will not last forever is leading to widespread concerns about energy, raw materials and water supply. Therefore, a resource minimization principle has been developed. The definition of the term has not been proposed, yet.

Minimization of resource usage is understood as conservation of natural resources. It is an activity that can be applied to any reduction of usage of resources. Therefore, the term encompasses, not only raw materials, water, and energy, but also applies to natural resources such as forestry, watersheds, other habitats, hunting, fishing, etc. All these resources and processes, which enable ecosystems to survive and are essential for helping societies to make progress toward sustainability, must be addressed. Thus, resources can be conserved, their availability improved and maintained. Reduction in the usage of materials and energy can result in dramatic cost savings.

- *Source reduction (dematerialization)*

Source reduction is the practice that reduces the quantity of materials entering a waste stream from a specific source by redesigning products or patterns of production and consumption (US Environmental Protection Agency, 2004). Besides materials, this definition also encompasses energy. According to the EPA dematerialization refers to

quantitative reduction in the volume of material and energy used to meet user's demand, while maintaining a uniform quality of services and as introduced by Wernick et al., it refers to the absolute or relative reduction in the quantity of materials required to serve economic functions and matters for the environment (Wernick, Herman, Govind, & JH, 1998). This definition of materialization is more appropriate, because dematerialization is semantically not applicable to energy. Source reduction contributes to a lowering of disposal and handling costs, because it avoids the costs of recycling, municipal composting, land filling, and combustion. Source reduction also conserves resources and reduces pollution, including greenhouse gases that contribute to global warming (US Environmental Protection Agency, 2004).

- *Recycling, Reuse, Repair*

The recycling is defined as a resource recovery method involving the collection and treatment of waste products for use as raw material in the manufacture of the same or a similar product (European Environmental Agency, 2004). The EU waste strategy distinguishes between reuse and recycling. The reuse means using waste as a raw material in a different process without any structural changes and recycling refers to structural changes in materials within the same process. Repair means an improvement or complement of a product, in order to increase quality and usefulness before reuse; it decreases consumption, because the product's life is extended.

- *Regeneration, recovery, remanufacturing*

Regeneration is an activity of material renewal to return it in its primary form for usage in the same or a different process. This activity enables an internal restoration and, therefore, decreases the environmental impacts. Recovery is an activity applicable to materials, energy and waste. It is a process of restoring materials found in the waste stream to a beneficial use, which may be for purposes other than the original use (European Environmental Agency, 2004), e.g. resource recovery in which the organic part of the waste is converted into some form of usable energy. Recovery may be achieved by combustion of a waste material in order to produce steam and electricity, or by a pyrolysis of refuse to produce oil or gas, or by anaerobic digestion of organic wastes to produce methane gas and a fermentate that can be used as a soil-conditioner (European Environmental Agency, 2004). Remanufacturing is defined as substantial

rebuilding or refurbishment of machines, mechanical devices, or other objects to bring them to a reusable or almost new state. This prevents many reusable objects from becoming waste. The remanufacturing process usually involves disassembly, and frequently involves cleaning and rebuilding or replacing components. Remanufactured objects are sometimes referred to as rebuilt objects (remanugact, 2005).

- *Purification and end-of-pipe*

Purification is the removal of unwanted mechanical particles, organic compounds and other impurities. The process of removal could be mechanical, chemical or biological in order to improve the environment and quality of life. End-of-pipe is defined as a practice of treating polluting substances at the end of the production process when all products and waste products have been made and the waste products are being released (through a pipe, smokestack or other release point) (US Environmental Protection Agency, 2004).

This approach is designed to reduce the direct release of pollutants so as to achieve compliance with environmental regulations; sometimes it results in transmitting pollutants from one medium to another. Therefore, it can result in only a temporary delay of causing environmental problems.

- *Degradation*

Term degradation could be understood as a biological, chemical or physical process, which results in the loss of productive potential (European Environmental Agency, 2004). From the biological point of view, degradation can lead to the elimination and extinction of living organisms. It can also refer to biological degradation of plant and animal residues, thereby making their elemental components available for future generations of plants and animals.(Glavic & Lukman, 2007)

### Economic principles

Economic principles embrace terms like *Environmental Accounting*, *Eco-efficiency* (*Factor X*, *Factor 4*, and *Factor 10*), and *Ethical Investments*.

- *Environmental accounting*

Environmental accounting is designed to bring environmental costs to the attention of

the corporate stakeholders who may be able and motivated to identify ways of reducing or avoiding those costs while at the same time improving environmental quality and profitability of the organization (US Environmental Protection Agency, 2004). Environmental accounting can be applied at the national, regional and corporate levels. National accounting refers to physical and monetary accounts for environmental assets and the costs of their depletion and degradation. Corporate environmental accounting refers to environmental auditing, but may also include the costing of environmental impacts caused by the corporation (European Environmental Agency, 2004).

- *Eco-efficiency*

The term Eco-efficiency was perceived within numerous definitions of cleaner production (Conference, 2004).

Eco-efficiency is the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity (US Environmental Protection Agency, 2004) (DTIE), 2004).

It is based on the concept of "doing more with less" (Australian Government, 2004) representing the ratio between economy and environment, with the environment in the denominator. It is about more efficient use of materials and energy in order to provide profitability and the creation of added value. In the triangle, it could be located at the side between the economic and environmental dimensions. According to the usual usage, eco-efficiency specifically emphasizes production processes and services.

- *Factor X, Factor 4, and Factor 10*

Robert et al. (Robert, et al., 2002) defined Factor X as a 'direct way of utilizing metrics in various activities that can reduce the throughput of resources and energy in a given process'. The Factor X concept is a very useful and flexible approach for monitoring activities aimed at reducing the materials and energy usage of diverse industrial and societal processes (Robert, et al., 2002). The overall aim of Factor X is to enable society to achieve the same or even better quality of life improving human welfare, while using significantly less resource inputs and causing less ecosystem destruction. The Factor X concept proposes X times more efficient use of energy, water and materials in the future as compared to the usage today. In other words, Factor 4 refers to a fourfold increase in



resource productivity; Factor 10 refers to a tenfold increase in productivity(Conference, 2004).

- *Ethical investments*

Ethical investments or socially responsible investments are financial instruments (mortgages, bank accounts, investments, utilities, and pensions), favoring environmentally responsible corporate practices and those, supporting workforce diversity as well as increasing product safety and quality (advice, 2006).

#### Social principles

Societal principles are composed of terms such as *Social Responsibility, Health and Safety, "Polluter pays" principle (Taxation), and Reporting to the stakeholders*. Social responsibility refers to safe, respectful, liberal, equitable and equal human development, contributing to humanity and the environment. Furthermore, the term health and safety usually refers to the working environment and includes responsibilities and standards. The Polluter pays principle was defined by the EEA as a principle that those causing pollution should pay the costs it causes. Thus, the polluter pays for environmental damage in the form of a cleanup or taxation but usually, in practice, this principle is overlooked. Reporting to the stakeholders is about sharing the progress, results and planning with the general public. The leading role has been taken by Global Reporting Initiative, presenting global effort to create a framework for reporting on economic, environmental and social performance by all organizations (initiative, 2006).

#### Sustainable development

Sustainable production is a key component of sustainable development, with its environmental, social and economic dimensions. Sustainable development should not be confused with environmental management. Environmental management invariably seeks improvements in performance without reference to environmental limits, whereas, sustainable development fosters human activities within the carrying capacity or environmental limits of the planet, now and in the future, at all scales from local to global. Moreover, sustainable development has a social dimension, paying attention to the quality of life, defined by factors such as the quality of work and social cohesion. In

In addition, in sustainable development, various terms are used to describe different strategies, actions, effects, phenomena, etc. Sustainable development emphasizes the evolution of human society from the responsible economic point of view, in accordance with environmental and natural processes. Therefore, the political dimensions are central elements. Furthermore, in a sustainable development paradigm the limitations of economic, societal and environmental resources are considered in order to contribute to present and future generations' welfare and can be applied on local, regional, national and international levels, based on political will.

### **Evolution and Incentives for Sustainability**

The book *Design for Environment* (Fiksel, 2009) presents and discusses the many forces of change in the business environment that have converged during the late twentieth and early twenty-first centuries, resulting in a sort of 'tipping point' for adoption of corporate sustainability and sustainable development. The most quoted changes from the literature are summarized here:

- *Climate change anxiety*

Once climate change was finally acknowledged as a reality, governments, NGOs, and corporations began to seriously explore policies and technological solutions for mitigation of greenhouse gas emissions; and carbon offset schemes flourished.

- *Energy security*

Concerns over depletion of fossil fuels and dependence on imported petroleum, coupled with the problem of carbon emissions, drove investments in alternative fuels; this trend was further intensified by a sudden rise in oil prices in 2007.

- *Customer awareness*

Both retail and industrial customers became increasingly concerned about the environmental performance of products that they purchased. Major corporations began to systematically review the environmental performance of their suppliers, and many governments introduced environmentally preferred procurement policies.

- *Legislative requirements*

A series of government directives in the European Union forced global multinationals to change their practices with regard to product design and life-cycle management; similar measures were adopted in many other countries.

- *Voluntary codes and standards*

Voluntary codes of conduct such as the Ceres principles, as well as environmental management system standards such as ISO 14001, were widely adopted by the business community as a way to demonstrate environmental responsibility.

- *Eco-labeling programs*

A number of eco-labeling initiatives have gained acceptance by consumers around the world, and companies in the electronics, consumer products, food and beverage, and other industries are now compelled to qualify in order to remain competitive.

- *Sustainability-driven investing*

The financial investment community has begun to recognize sustainability as an indicator of overall superior management, as exemplified by the increasing interest in the Dow Jones Sustainability Indexes and other rating systems.

- *Globalization*

Rapid economic growth in emerging economies, such as Brazil, Russia, India, and China (known as BRIC), as well as globalization of supply chains, have forced multinational companies to grapple with the challenges of energy, environmental protection, human rights, poverty, and social responsibility.

- *Transparency*

Public expectations for information disclosure, as well as the explosive growth of electronic communication, have made it essential for global companies to increase their level of accountability, transparency, and stakeholder engagement.

The main incentives for DFE can also be summarized in this figure:



Figure 4 - Driving forces influencing the adoption of DFE

Drivers and Eco-innovation

Baroulaki and Veshagh presented the attempt to achieve sustainable development by strategies that *lower production costs* through *improved quality* and *product function* to be amongst the main drivers that motivate business to move towards eco-innovation. Another factor is the interest in the share of the *market value* rather than the actual share of the market. *Customers' power* is more important than the power of the actual product. Additionally, by *extending the transparency* and the *tools of corporate social responsibility* to embrace the whole innovation process, including the research and development, technology selection, product and service design, investment and employment policies, business is increasing the shareholder value (Baroulaki & Veshagh, 2007).

From the customer's point of view, green consumer organizations and other environmental organizations are drivers for environmental design. It is people's commitment and desire to fight for a better world that will bring the change. Increased pressures due to the waste disposal regulations as well as bans and taxes on certain materials also act as eco-innovation drivers [14], [15]. The eco-innovation driving forces can be summarized under the technology push (eco-efficient technologies) and the market pull factors (preferences for environmentally friendly products or better image). This is called the push/pull effect and is illustrated in Figure 4.

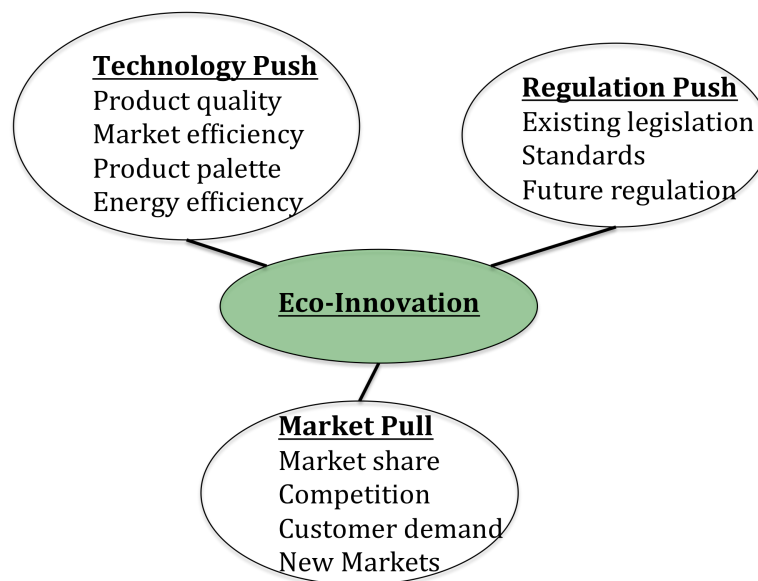


Figure 5 Drivers of Eco-Innovation

### Benefits

Based on Kemp and further literature research (Tischner & Charter, 2001), (Pfeiffer & Rennings, 2001), the main benefits of sustainable development can be increased competitiveness and creation of new markets for environmentally desirable products. By being proactive they gain the potentials of market leadership and greater customer satisfaction. Furthermore, sustainability is expected to offset burdens and costs incurred by environmental regulations, as - on average - 80% of a product's overall cost is due to its design. Therefore, sustainable design offers great opportunities to companies to improve their financial and environmental performance. Sustainable development definitely improves a company's image as well as relations with suppliers, customers and authorities. Employees are also informed on environmental and health and safety issues, and more capable of dealing with them. Finally, it seems that sustainability has a positive effect on unemployment, due to the creation of new jobs.

### **Barriers for sustainability**

Due to the fact that sustainability is a whole different way of thinking there are potential obstacles that might slow down or even inhibit the process. First of all, *lack of clear government policy framework* for environmental goals and long-term targets; governments need to provide more incentives and new policies to promote sustainable development. Other economic barriers, such as the cost of research and development as well as marketing to convince people to accept the new product or process is usually high, making it more difficult, especially for small businesses, to invest. Furthermore, the environmental technologies for controlling pollution and improving environmental performance often cause high expenses to businesses and therefore minimizing the potentials for competitiveness by cost leadership. Process inflexibility or inexistence of innovative technology can also inhibit sustainable development (World Business Council for Sustainable Development, 2000) (Organization for Economic Co-Operation and Development, 2001).

On the other hand, other *cultural and psychological issues*, such as inertia as well as the security of well-proven techniques and no or little environmental sensitivity hold sustainability back. Moreover demand is vital at certain points, as technology users have different needs at different times, as the time-to-market, the *cost pressures* and the *risk*

involved can be sustainability slow downs. Finally, *infrastructure difficulties*, such as reluctance to train or employ experienced engineers on environmental issues and a *lack of communication* between the departments can slow the sustainable development process remarkably. (Baroulaki & Veshagh, 2007)

### Approaches for implementation

Achieving sustainability: the role of technology as a fourth dimension

The question on whether technology can solve the catastrophic environmental and social threats have been formulated and explored in many ways by different scientists. For example, Chertow (2000) underscored that technology, although associated with both disease and cure for environmental harms, is a critical factor in environmental preservation (and is therefore included in the environmental dimension). The IPAT equation, formulated over 30 years ago, explicitly includes technology as a determinant of the environmental impact (I), which is actually function of population (P), affluence (A) and technology (T). The equation has taken various forms over the years, which is an evidence of a shift towards a more accepted view of the role that technology can play in sustainable development.

By its nature, sustainability has a global dimension and most of the major challenges cannot be solved in one isolated region of the world. As global sustainability indicators show clearly (e.g. Seliger et al., 2008), current patterns of mass production of cheap goods and over-consumption of products with a short use, cannot be indefinitely sustained for the future. However, as some foreseeing authors have already shown (e.g. Jovane et al., 2008; Lovins et al., 1999; McDonough and Braungart, 2002), some major shifts in business practices could help in moving towards a more sustainable approach to industrial production. These shifts are mainly related to technology-based improvements, such as (Lovins et al., 1999):

- *Shifting from overconsumption based to biologically inspired production models*

That is, investment in all techniques and organizational models that pursue a 'biological style' into the management of products during their life cycle (to maintain, repair, re-use, retrofit products during their active life phase and to disassemble, re-manufacture, recycle products during their active life and henceforth of involved materials/resources,

which are re-routed to a new life of to the natural environment when the end of life cycle is reached.

- *Moving from an ownership based to a solution-based business model*

This approach may have a strong impact on the current business model for manufacturing, which is based on the sale-of-goods principle (where value is given to the customer through a physical product). Value can be instead delivered through a flow of services and a shift is suggested (wherever possible) from an owner approach in product use to a 'user' one (i.e. products are not sold but are offered in a pay per use way)

- *Reinvesting in natural capital*

It means to restore, sustain and to expand the health of the natural ecosystem as a way to guarantee future support of the nature to the human life and to production of goods as an activity of the human being.

According to this view, technology – in its wider definition – can support sustainability, which can be physically achieved through the optimization of the use of resources along the whole product life cycle, while retaining the same quality of products and services. Thus, technology cannot be seen only as a mere tool to help in achieving a more sustainable world, instead technology should be seen as an unavoidable component of the world we live in and, as such, it would be considered the fourth dimension of the same concept of sustainability (Arena, Duque Ciceri, Terzi, Bengo, Azzone, & Garetti, 2009).

In this view, technology influences and interacts with the economic dimension (e.g. it allows new business solutions), with the environment (e.g. providing solutions to nature and resource conservation) and with the society (e.g. it supports new living models), besides acting as a powerful tool to give resources for 'meeting the needs of the present generation without compromising the ability of future generations to meet their own needs'.

### **Sustainable design**

Sustainable design, or Eco-design can be defined as design which addresses all environmental impacts of a product throughout its complete life cycle, without compromising other criteria like function, quality, cost and appearance' (Recchioni, Mandorli, Germani, Faraldi, & Polverini, 2007). It integrates the three pillars of sustainability but goes beyond and embraces how to meet consumer needs in a more holistic way (Crul et al, 2006).

According to Clark et al. (2009) companies incorporating sustainable design into long-term product innovation strategies strive to alleviate the negative environmental, social, and economic impacts along a product's supply chain and through its life cycle. This is called the *cradle-to-cradle* mentality. These newly designed products and services offer increased functionality and ease of use, longer life spans, easy disassembly or recyclability and lower environmental impacts.

Sustainable design must consider the product from its combining raw materials to end of its life. The approach incorporating this fact is called *life cycle assessment - LCA*. LCA is an objective process for evaluating the environmental burdens associated with a product, process, or activity through its lifespan. It identifies and quantifies the materials and energy used and wasted. Moreover, LCA assesses and implements different plans for improving environmental aspects. This assessment covers the entire life cycle of the product, process or activity, including extracting and processing of raw materials; manufacturing, transportation and distribution; reuse and maintenance; recycling and final disposal (Guinée 2002). Four main types of LCA methods are presented for different situations. *Cradle-to-Grave* is the most common LCA and is used for the analysis of materials used in making a product. This analysis covers the entire product life cycle. *Wheel-to-Wheel* determines the efficiency of transportation system fuel consumption. *Cradle-to-Gate* calculates the efficiency of product until it is delivered to the customers. Finally, *Cradle-to-Cradle* is a new way of designing which tries to make the grave of a product, into another product cradle.

The literature also presents another concept for sustainable design - *Design for Environment - DFE*, which is the systematic consideration of design performance with respect to environmental, health, safety, and sustainability objectives over the full



product and process life cycle. Over the years DFE has become a common theme in corporate environmental stewardship and pollution prevention programs. Typically, the scope of DFE includes the following objectives:

- *Environmental protection*

Assurance that air, water, soil, and ecological systems are not adversely affected due to the release of pollutants or toxic substances.

- *Human health and safety*

Assurance that people are not exposed to safety hazards or chronic disease agents in their workplace environments or personal lives.

- *Sustainability of natural resources*

Assurance that human consumption or use of natural resources does not threaten the availability of these resources for future generations.

Design for environment also incorporates the *design for green engineering*, which is commonly described through 12 principles. The principles are as follows:

1. Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible
2. It is better to prevent waste than to treat or clean up waste after it is formed
3. Separation and purification operations should be designed to minimize energy consumption and materials use
4. Products, processes and systems should be designed to maximize mass, energy, space, and time efficiency
5. Products, processes, and systems should be 'output pulled' rather than 'input pushed' through the use of energy and materials
6. Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition
7. Targeted durability, not immortality, should be a design goal
8. Design for unnecessary capacity or capability (e.g. 'one size fits all') solutions should be considered a design flaw
9. Material diversity in multi-component products should be minimized to promote disassembly and value retention
10. Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows

11. Products, processes, and systems should be designed for performance in a commercial 'afterlife'
12. Material and energy inputs should be renewable rather than depleting

### **Sustainable manufacturing**

The European Commission identifies a number of characteristics that must be satisfied in order to ensure that production processes and the use of products and materials operate within environmental limits (European Commission, 2001). These are:

- The sustainable use of renewable resources and renewable energy
- The management of non-renewable resources, for example in closed material loop systems
- The use of non-renewable energy in ways that maintain the integrity of natural cycles, such as the carbon cycle
- The maintenance or restoration of ecological and environmental systems that provide environmental sinks for wastes and pollution arising from production, products and materials in use and waste
- The minimization of transportation needs

These systems should:

- Operate in a competitive market framework
- Provide for social cohesion and quality of life, implying a satisfaction of human needs extended to all members of the population

Sustainable production is context dependent. It is defined and interpreted by different societies in line with:

- Economic trends, such as those related to growth and to market and pricing mechanisms, that may change ecological balances, social cohesion and determinants of economic welfare
- Socio-cultural trends changing the requirements for human satisfaction, including new life-styles or society's ecological concerns
- Political trends and priorities modifying the regulatory process that deal with

management of the environment, the economy and society

- Ecological conditions and environmental limits
- Our knowledge of those circumstances and limits
- International issues including the economic and physical transfer of materials, energy and products across boundaries, resources

The U.S. Department of Commerce provides the following definition: 'Sustainable manufacturing is defined as the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers.'

Until now, the scientific approaches have neglected to enhance sustainability in the use phase and have also focused on the design for environmental and material level recycling. However, it is pointed out that the potential of sustainability in engineering is not yet discovered. There are still missing scientific basic principles, methods, procedures and tools for planning, development, adduction, and utilization. The literature presents three approaches for sustainable manufacturing: *implementation of innovative technologies, improving the use-intensity, extension of product life span.*

- *Implementation of Innovative Technologies*

It is the usage for resource-saving applications and the technologies included, e.g. fuel cell, photovoltaic and laser technology. Other innovative technologies suggested are the application of modularity and standardization, which allow for more efficient production processes.

- *Improving the use-intensity*

Improving the use-intensity of products has the objective to increase the utilization ratio of a product or components. Two strategies are used for this, the first one is the development of a new business model, focused on the usage not the product itself, and the second is distribution of product and component usage to different applications. By leasing or renting products, instead of selling, the service provider is responsible for the availability of the product and can therefore influence the utilization ratio. Requirements on products within this business model are: modularity, integrability, customization, convertability and diagnosability to support customer-driven

adaptability. For the distribution of usage, the products need to be flexible and reconfigurable for various applications and this need to be decided upon in the design phase of the product. Requirements are, as mentioned before, modularity, compatibility, standardization of components and interfaces as well as high product and component quality. Examples are mobile phones (include also cameras, radios, MP3 players, navigation systems). Moreover, the authors emphasize that especially in the electronic industry this approach has a high potential to improve resource productivity.

- *Extension of Product Life Span*

Extension of product life span can be achieved by both expanding the use phase and by realizing different use phases. Maintenance preserves the product and different types of adaptation of the product (up-/down grading, rearrangement, enlargement, etc.) allows for more use phases. Another important alternative is remanufacturing. Here, again, the requirements are modularity, integrability, customization, convertibility, and diagnosability (Seliger, Kim, Kernbaum, & Zettl, 2008).

#### Drivers of sustainable production

Competitiveness is a pillar of sustainable production. However, competitiveness and environmental performance have traditionally been viewed in terms of trade-offs. The logic here is that environmental improvements [internalizing the externalities of production] are only achievable at a cost to competitiveness. Policy making by governments has focused on striking an acceptable balance between interests; industry, employees, consumers and citizens, and social interests in environmental quality and quantity. However, this logic really applies to remedial responses to production systems that were not designed with environmental impacts or limits in mind.

Synergistic innovations are possible because of trends in manufacturing and business. Together with growing environmental awareness, these are changing the way people think about business.

While many companies are still only concerned about environmental compliance, an increasing number are adopting approaches to environmental risk management. Other companies are beginning to pursue long-term sustainable development strategies.

Trends in the modernization of production support movement through the hierarchy, especially the levels beyond pollution control and compliance. For example, lean production, miniaturization, advances in the durability of materials, and, lower energy inputs in the manufacture of products are leading to efficiencies. Consequently, products are less material intensive. These gains in resource efficiency support competitiveness and reduce the environmental impact of production processes and products. The outcome is that the environmental burden, of each unit of product, is lowered (European Commission, 2001).

### ***S-MC-S Framework***

The reference framework has been developed in a way to create a link between mass customization and sustainability.

The Sustainable Mass-Customization (SMCS) reference framework is composed of three integrated entities: (1) product, (2) manufacturing process/manufacturing system, and (3) supply chain, where each entity plays an important role in a novel product development process for sustainable mass customized products. These three entities are placed as columns in the framework. On the other axis six sequential steps (phases) have been identified, which should be passed during a new product development process. All these steps belong to the beginning of the life (BOL) of the product. These steps are the same for all three entities of product, manufacturing system and supply chain. For this reason this steps have been placed as rows, creating a matrix. The columns of the matrix are three entities and the rows are six steps (phases). By crossing each column with each step the required major activities in that specific step (phase) have been recognized.

The reference framework consists of six phases. The process begins with a planning phase, which is the link to advanced research and technology development activities. The output of the planning phase is the project's mission statement, which is the input required to begin the concept development phase and serves as a guide to the development team. The conclusion of the product development process is the product

launch, at which time the product becomes available for purchase in the marketplace.

The six phases of the generic development process are:

- *Phase 0: Planning*

The planning activity is often referred to as 'phase zero' since it precedes the project approval and launch of the actual product development process. This phase begins with corporate strategy and includes assessment of technology developments and market objectives. The output of the planning phase is the project mission statement, which specifies the target market for the product, business goals, key assumptions, and constraints.

- *Phase 1: Concept development*

In this phase the needs of the target market are identified, alternative product concepts are generated and evaluated, and one or more concepts are selected for further development and testing. A concept is a description of the form, function, and features of a product and is usually accompanied by a set of specifications, an analysis of competitive products, and an economic justification of the project.

- *Phase 2: System-level design*

The system-level design phase includes the definition of the product architecture and the decomposition of the product into subsystems and components. The final assembly scheme for the production system is usually defined during this phase as well. The output of this phase usually includes a geometric layout of the product, a functional specification of each of the product's subsystems, and a preliminary process flow diagram for the final assembly process.

- *Phase 3: Design detail*

This phase includes the complete specification of the geometry, materials, and tolerances of all the unique parts in the product and the identification of all the standard parts to be purchased from suppliers. A process plan is established and tooling is designed for each part to be fabricated within the production system. The output of this phase is the drawings or computer files describing the geometry of each part and its production tooling, the specifications of purchased parts, and the process plans for the fabrication and assembly of the product.

- *Phase 4: Testing and refinement*

The testing and refinement phase involves the construction and evaluation of multiple preproduction versions of the product. Early prototypes are usually built with parts with the same geometry and material properties as the production version of the product but not necessarily fabricated with the actual processes to be used in production. Prototypes are tested to determine whether the product will work as designed and whether the product satisfies customer needs.

- *Phase 5: Production ramp-up*

In the production ramp-up phase, the product is made using the intended production system. The purpose of the ramp-up is to train the workforce and to work out any remaining problems in the production processes. Products produced during production ramp-up are sometimes supplied to preferred customers and are carefully evaluated to identify any remaining flaws. The transition from production ramp-up to ongoing production is usually gradual. At some point in the transition, the product is launched and becomes available for widespread distribution. Columns of the framework consist of three entities. Product entity represents all major activities, which should be done in a new product development process from a product perspective. Idea generation, Idea screening, concept development and testing are parts of these activities. Manufacturing entity represents all major activities, which should be done regarding manufacturing system while developing a new product. And Supply chain entity covers all major activities regarding supply chain strategy, management and policy that have to be specified while developing a new product. In order to reach to a sustainable mass customized (SMCS) version of the reference framework the below approach has been applied.

The SMCS reference framework aims to be a roadmap composed by set of guidelines to achieve sustainable mass customized products.

### 3 Research objectives

The project S-MC-S vision is to define and research *a new production paradigm, Sustainable Mass-Customization* and to present Customization as a driving force for the success of Sustainability. As is it today, companies face the pressures, from competitors, customers and unions, for the requirements of sustainable products. And, in a faster changing environment, the requirements for a wide product range high variety. Still, companies do not succeed in making profits out of Mass Customization and Mass Customization together with Sustainability. This, according to S-MC-S, because of the lack of a network environment build to support mass customization along the entire value chain and the fact that implementation of Mass Customization as it is, is mainly focused on economical impact, when it should be on the integration of sustainability – environmental and social consequences, into the assessment of the value chain. Hence, there are yet no companies successfully operating a Sustainable Mass Customization business. To combine sustainable or environmental friendly operation and products, together with mass customization of the same, still requires some research and work to develop methods and enabling technologies for models, procedures, implementation and operations across a broad range of sectors.

This research aims at supporting companies and manufacturers to adapt to global competitive pressures by developing methods and innovative enabling technologies towards a customer oriented and eco-efficient manufacturing. To this end, the research vision is to define and research a new production paradigm, Sustainable Mass-Customization System (Also known as SMCS), while also presenting Customization as one of the main driving forces behind the future success of Sustainability.

To help with the adoption of the S-MC-S paradigm, a reference framework has been developed, which also acts as a backbone for the integration of all four pillars in the S-MC-S solution.

At the Design Tools level, it will provide the means for Data Models harmonization defining a coherent data infrastructure (Reference Model) where the Extended Product, Sustainable Factory and Supply Chain Data Models developed will be plugged. Thus, the research objective is to translate Ecological, Economical and Social concepts and their relationships with Mass Customization into a set of three concrete Sustainability Data Libraries



constituting the shared foundation for the new extended models of Product, Sustainable MC Factory and Supply Chain of the Design Tools.

The research objective of this thesis solely is to, with previously developed reference framework for S-MC-S, develop guidelines for companies for the implementation of Sustainable Mass Customization. The research and guidelines are worked out for two companies in particular, which have been investigated and visited, and then presented in two separate case studies. Furthermore, objectives of this research are to make a comparison of the implementation and modifications of the framework for the two case studies. The comparison will be to see the framework's applicability to the two types of companies and industries, and from there, to draw general conclusions of its applicability in different environments and methods for implementation.

## 4 Case studies

### Co.FI.Plast

#### *The company*



Co.FI.Plast is a diamond wire-rod manufacturing company, located in Lessolo (TO), Italy. Together with diamond wire-rods the company also develops and produces machines for quarrying and cutting of different materials.

Co.FI.Plast was founded in 1984 by Emilio Brocco in Lessolo (TO), Italy. It started its production as a part in the Brocco group, which consists of Co.FI.Plast and Wires Engineering S.r.l. At this time Co.FI.Plast was the first company on the market to produce diamond wires with plastic assembly for granite. As being founded in the Brocco group, the company is able to develop its manufacturing and project, produce and test directly and jointly on location both the machines and the diamond wires. Wires Engineering S.r.l is a stone cutting company owned by the brother of Emilio Brocco, and is located just across the road from Co.FI.Plast. Together, the two companies were able to learn from each other and become the leading firms in their field on the market. Brocco group has worded a slogan that well describes the two companies missions: "Together for Stone Cutting". Working in this way together has given the companies profound experience in the industry and a unique know-how of stone cutting and moreover, a strong competitive advantage.

Co.FI.Plast came into business because the need of cutting marble, granite and other stones without the drawbacks of using traditional methods, such as the use of explosives. Using explosives gives a waste rate of about 80% and uses up to 25 people when the diamond wires machines would only need 3. Co.FI.Plast was formed because of this need and was able to grow by taking the opportunity and learning from the local businesses and industries in the area. Needs that needed to be fulfilled from wire cutting were those that traditional methods were not able to do, without having drawbacks of production and disposal of waste materials; high production costs and times and also mining problems and risk of accidents.

By working together with Wires Engineering S.r.l has allowed both companies, through common effort to increase levels of efficiency and customer satisfaction, to reach a unique offering basket (Machine and Tool) to maximize the advantages of the products provided by the companies. This exploitation of synergy and to the constant pursuing of quality and reliability of the product brought into the market two worldwide trademark leaders of the stone cutting technology. Now, after more than twenty years of experience in the field, the group Co.FI.Plast – Wires Engineering S.r.l, operates around the world through a network of representing actors, with production plants located in Italy, Brazil, USA, India, Poland, Norway and South Africa.

Co.FI.Plast as organization is divided into several departments, which are:

- Beads production
- Wires Production
- Diamond wire assemble
- Marketing
- Administration
- R&D

Co.FI.Plast currently employs about 20 to 30 people with specialized skills for their particular work, within these departments.

### ***Customers and the market***

Co.FI.Plast is currently producing different typologies of wire-rod in order to be able to respond to any kind of customer request. Keeping a record of past sales gives the company ability to on a firm base forecast the future customer needs and request, as well as the amount of requests. Co.FI.Plast sales are depending on the customer needs, depending on the type of machine - a multi-wire machine uses from 5 to 84 wires - usually each wire is 15.15 meters long, which means a regular customer can require from 75.75 to 1272.2 meters of diamond wire. Wire consumption is strictly correlated with cutting parameters; a correct usage of the wire prolongs the life of the wire and hence reduces the supply need. However, Co.FI.Plast offers to replace wires at the end of life and the mounting of beads on a new wire, which leads to customers being loyal to the company for a long time, rather than just a one-time purchase. On an average, Co.FI.Plast sells about 350 000 meters of diamond wires per year, to its more than 200 customers, of which, a big majority are company-loyal and regular.

The customers of Co.FI.Plast are mainly based in the US, Canada, Brazil, Russia, Europe – France, Italy, Spain, Iceland, Norway, Asia – China, India Pakistan and since recent in Saudi Arabia. The customers are mainly quarries and sawmills that would use diamond wires cut (in quarries blocks are extracted from the ground and cut in blocks; in sawmills blocks are cut into slabs, in some cases blocks are also cut directly into slabs in the quarries). The type of customer varies depending on the location and area; for example, in northern Europe customers are mainly purchasing machines and wires for caves, and in the south, most are machines to final customers.

The customers are usually owners of quarry or sawmill that use the technology of diamond wires cut and have therefore in most cases great experience and deep knowledge of the different stones and minerals. However, they need Co.FI.Plast and their knowledge about mechanics and physics to help with better fitting the cutting tools for their specific needs.

### ***The market***

There is no specific environment in which particularly diamond wires are used; cutting tools are employed all over the world, and specifically where the presence of mineral repository is high.

Currently, the bigger part of the market is in Brazil, where a majority of quarries are located and the request for slab production is high. Brazil is also producer of many of the finest stone materials to be found. At the moment, other markets in regions like China are obstructed by the low prices. Since Co.FI.Plast's products are of high quality, and consequently more expensive, the company does not have much market opportunities in areas where price is more important than quality. Nevertheless, Co.FI.Plast is attempting to improve opportunities and reach those markets, mainly by working on reducing costs. This is thus one of the reasons for Co.FI.Plast to implement the Mass Customization framework and system for production.

Co.FI.Plast occupies currently 20% of the total market. The main competitors, in terms of wire quality, are:

- Diamant Boart
  - A North American enterprise established in 1937. It was originally formed to develop tools and machines for industrial use, using boart, which is a low quality diamond found in diamond mines in the Congo. The diamond was later replaced by synthetic diamond when it was developed in the 1960's, synthetic diamonds taking up 95% of the world's consumption of diamonds. Together with Dimas, Diamant Boart and Partner, form Husqvarna Construction Products, and now claim to be the world leader in diamond tools and equipment. Their product range encompasses diamond blades, diamond core bits, diamond wore, wall saws, flat saw, core drills, masonry saws, tile saws, power cutters, gang saw blades and equipment for the construction industry. A complete range of tools necessary for working natural stone from extraction up to final polishing. Its stone business is concentrated in the European market.
- Tyrolit
  - A part of the worldwide active Swarovski Group. Was founded in 1919, in Tyrol in Austria, as the part of Swarovski that marketed grinding and dressing tools. Supplies now innovative solutions in grinding, cutting, drilling, honing, dressing and polishing. The company offers over 80.000 products, with distribution in 65 countries, and has 4.618 employees in 28

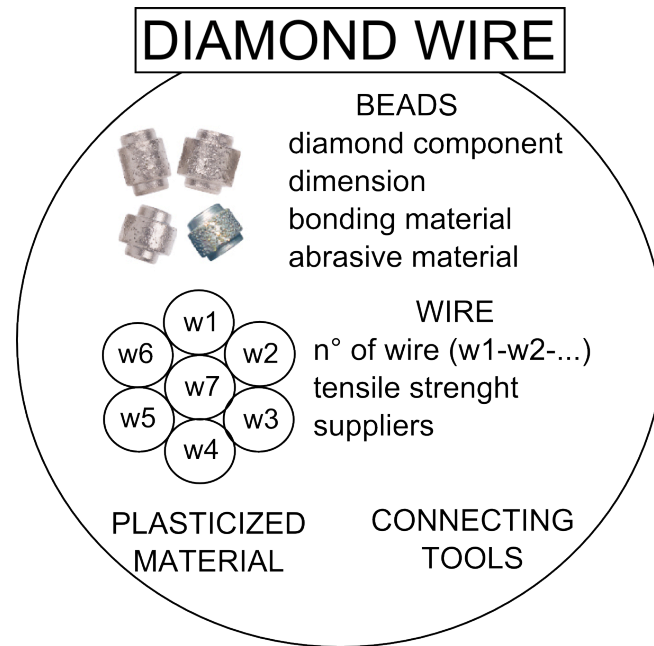
production facilities in 13 countries. The Tyrolit Group belongs to the worldwide leading suppliers of cutting tools. The company offers its customers extensive advices in how to work out economic and ecological solutions. The turnover of Tyrolit was in 2009 392 million Euros. In June 1994, Tyrolit became the first European manufacturer of grinding tools to receive the ISO certificate for its Quality Management system.

- Winter Diamant
  - A German company established in 1847 in a workshop in Brachstedt. Was the first company to, in 2006, deliver diamond circular saw blade with a diameter of 4.000 mm. In 2003 Winter Diamant – Winterstone was integrated into the group Wheelabrator Alleward and was in 2007 the worldwide leading company in diamond tools. The company has five production facilities, six sales companies and more than thirty representative offices worldwide.

### ***Product***

Compared to traditional methods, quarrying can be performed more efficiently and effectively as regard quality and varied needs, using diamond wire-rods. In the squaring of blocks, diamond wires can make full use of frames to improve overall production and moreover, save energy and costs. Co.FI.Plant produces diamond wires to cut marbles, granite, concrete and other materials, such as fiberglass and ferrous material. The diamond wires can be used in quarries or in sawmills on mono- or multi-wires machines, to cut, profile and square blocks.

The composing parts of a diamond wire, are the following:



**Figure 6 - Composing parts of a diamond wire**

As can be seen in the picture, different parts assemble each diamond wire. Each part plays a fundamental role for the final performance characteristics of the wire; beads represent, however, the key component.

Co.FI.Plast produces all the composing parts in-house; only raw material is brought in by suppliers. At the moment, all applications are made to work on the ground, but it is possible to also consider undersea application, beside chemical, nuclear or underground.

A diamond wire vary mainly depending on what material they will cut. The different dimensions of the product are as follow:

- Diameter
- Assembling
- Number of beads
- Material
- Cutting speed
- Production

For each wire there is also a specific code and notes, regarding the performances.

Co.FI.Plast produces, at this time, 80 different types of beads, in 7 different sizes, which are all later mounted on wires, which differ also in length, strength, diameter and number of composing wires.

#### Beads

Diamond beads can have a diameter of 9-10 or 11 mm, for the usage in quarries and on sparing block machines. On profiling machines and on mono-wire/multi-wire machines the beads have a diameter of 6-7 or 8mm. Diamond beads are either sintered or electroplated. Co.FI.Plast has recently introduced the electroplated bead for dry cutting in the quarry. In appendix 1 can be seen the different types of beads and their names.

All of the beads are standard, meaning they are offered and produced regularly. When needed, tailored and customized solutions are studied to suit the particular client.

The wires produced are classified as follows:

- Granite – a sintered wire for cutting with fixed machinery
- Marble – a plasticized wire for quarry cutting and with fixed machinery
- Concrete – diamond wires for cutting concrete
- Shape cutting – diamond wires for shape cutting
- Special multiwire saw – diamond wires for multiple diamond wire saw
- Special dry cutting – diamond wires for marble dry cutting

Co.FI.Plast also offer other tools for diamond wires and beads. These tools are:

- Press
- Cable cutting piler
- Crimping dies
- Joints
- Plasticized d. wire for assemblage
- Rubberized cable for quarry
- Holefinder – Hydro bag
- Hydraulic Jacking

Besides the cutting tools and accessories, Co.FI.Plast, together with Wires Engineering S.r.l also produces the cutting machines on site.



### ***Production processes***

The production of wire-rods is based on the common use criteria of MTO production. Distribution of the production is made depending on the orders received. The company holds therefore no stock merchandise of finished products. Yet, beads are manufactured for warehousing but the final diamond wire is assembled only when customer specific orders are received. In this way a wire that best fit the customer needs can be produced, although a clear customization system is not yet arranged.

The product design process at Co.FI.Plast stems from the now great background and experience of cutting tools, and errors and successes of the past. Any modification of the product is a form of starting point for a new design project and the use of past knowledge is the most common method for an efficient implementation. Information from the customer, about requirements and needs, is that solid starting base for the product development and implementation.

The manufacturing process at Co.FI.Plast is divided into three main steps; beads production, wire production and plasticization. The particular features of wires come from the single wires that make up the main wire. Plasticization process is principally the same for any diamond wire typology. Beads hold the key point for cutting, and their manufacturing process consequently is considered the most important. A mass customization system will mainly consider the beads. In fact, beads are the cutting instruments; wire is only the mean in which beads are transported to the cutting place. The current manufacturing process schedules the production of beads and the assembling of wires only after customer orders are received, thus mass customization is at this point not employed.

The production process usually consists of the following steps: Data is being collected from the customer, about the type of materials to be cut and the methods of cutting to be employed. Next the mixing of the material forming the beads are evaluated then mixed and the beads are formed. The beads go then through a sintering process, which is an industrial and company secret. Following, there is a molding process and a hole is cut out in the centre of every bead through which the wire will go. All beads are counted and tracked through out the process and then mounted manually onto the wires. Wires are also made manually and are pre-manufactured in

different durability and tolerances and cut into required lengths. Wire and beads are then washed, every wire given a specific code, and finally the plasticization process is performed, which separates each bead from another with a plastic or rubber (for cuts in quarries) cover.

Customization will allow Co.FI.Plast to manage a warehouse where different types of personalized beads, according to the different possible customer requirements, will be stocked.

### ***Mass Customization***

Co.FI.Plast even though being one of the global leaders in the industry in terms of quality and efficiency is still interested in improving the production and wants to do this by implementing personalization and, even more, mass customization of diamond wires. By implementing a flexible production can speed up the specific customer requests that the company is currently facing. Putting into operation a mass customization system would allow the company to organize both supply chain and production better according to customers needs. The customer is the key point for production in a mass customization system and Co.FI.Plast is dedicated to satisfy customer at all times. Therefore, the needs will be identified and individualized using an expert system. The expert system can be identified as an artificially intelligent software system; it will collect and store data from cuts, and correlate them with help of rules and information. By simulating the thought processed of a human expert, the system will be able to correlate parameters – data and functioning, from in a knowledge base stored expertise concerning cutting, in order to answer questions or solve problems related to customers' requirements. The customization outcome from this expert system will concern mainly the development of bead production, since beads are the cutting tools, but also wires will be made customized.

Co.FI.Plast's customer base is divided into two groups, customers are either 'hard stone' cutting or 'unspecified'. This means that Co.FI.Plast can, based on previous sales and forecasts estimate the bigger percentage of their sales over the year, but for the 'unspecified' customers it has to, for every order, go through all the requirements of the customer and set up a process and manufacture from 'scratch', beads and wires for that

specific order. Co.FI.Plast's Mass Customization execution will therefore be directed only at those unspecified customers.

Co.FI.Plast is at the moment in the process of developing a database, which will later be used for the setting up of an expert system, of the different parameters affecting cutting and the type of bead and wire to be used.

Currently it is tested what parameters and factors affect the different cutting performances and how. Both what different types of beads have for an effect on the cutting, depending on how the cutting process is performed and what types of materials, speeds, temperatures, cutting angles and etc. requires special types of beads and wires.

Parameters that are tested, in various cutting conditions and for different types of beads, are:

- Cutting speed
- Cutting angles
- Cutting length
- Dimension, width, of slabs to be cut
- Materials to be cut, all possible different types of stones
- External environmental factors
- Machining parameters, types of machines, various settings

Data is also collected from customers' machines and from their cutting processes. The machines that are sold keep track of cuttings and data is later collected and analyzed by Co.FI.Plast. The different parameters taken into account and analyzed from this collection of data are the same as the parameters tested internally, but also include factors like;

- Country
- External environment
- Economy
  - Of country
  - Of company
- Type of company – end customer or not.

The aim is to have data collected and to gain knowledge about each specific cut for every machine and for each customer, in order to produce the right type of bead, with the right combination of materials, and the most fitting wire, for every single customer.

At this time all data is collected and the work is performed in Excel sheets, using different statistical tools and basic analyses to evaluate correlations among the various bead, machining and cutting parameters. The analyses will be based on knowledge and experimental work. This is currently very much a 'work-in-progress' for the company where the first three months are dedicated to the data collection and setting up of a database, defining the database actors, deciding how to correlate the data, which and how information is needed. The following three months to defining rules for correlation and the analyzing of data. The goal is to later use this database and the logic for the development of an expert system, be able to realize the statistics in an automated way. By providing the expert system with specific inputs, it will produce outputs in the form of specifications for bead compositions, sizes of the beads and wires, together with probabilities and suggestions of life-length depending on the materials to be cut. In other words, the customer will provide Co.FI.Plast with his wants and requirements, e.g. what materials are to be cut, how the stone is to be cut, sizes, shapes, angles etc., the machines to be used and expected performances or the wires. Inserting these variables into the expert system, it will then give out specifications for what beads to manufacture and different probabilities depending on what materials will be cut.

To conclude, not only wire rupture can represent a critical value, other cutting parameters influence the process efficiency as well. By collecting cutting parameters, a better understanding of the various correlations between manufacturing process and cut behavior can be gained, which will act as the starting point for a better optimized and personalized production.

Once the cutting parameters are collected and processed together with customer needs, it will be possible, using the expert system, to produce a particular mixture for each specific customer. The personalized beads can later be manufactured over again and sold to customers with the same requirements and needs, through this customization the factory process flexibility will be improved.

Below can be seen an illustration of the process.

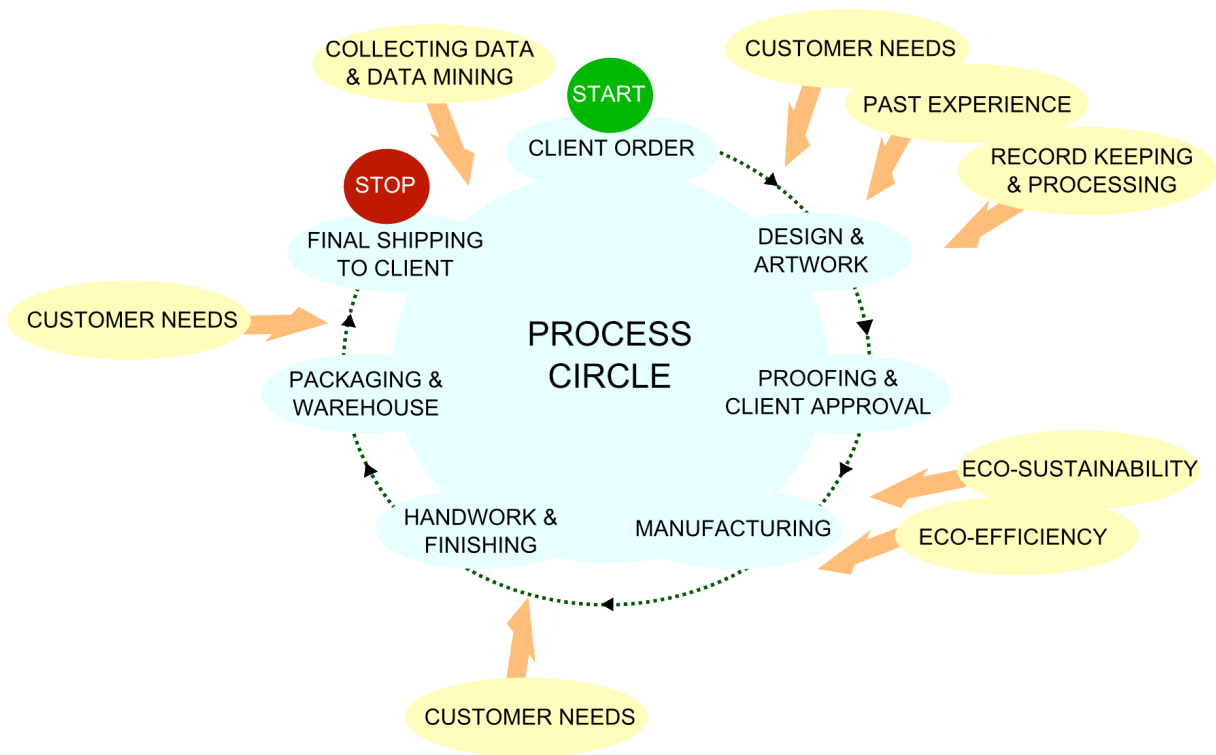
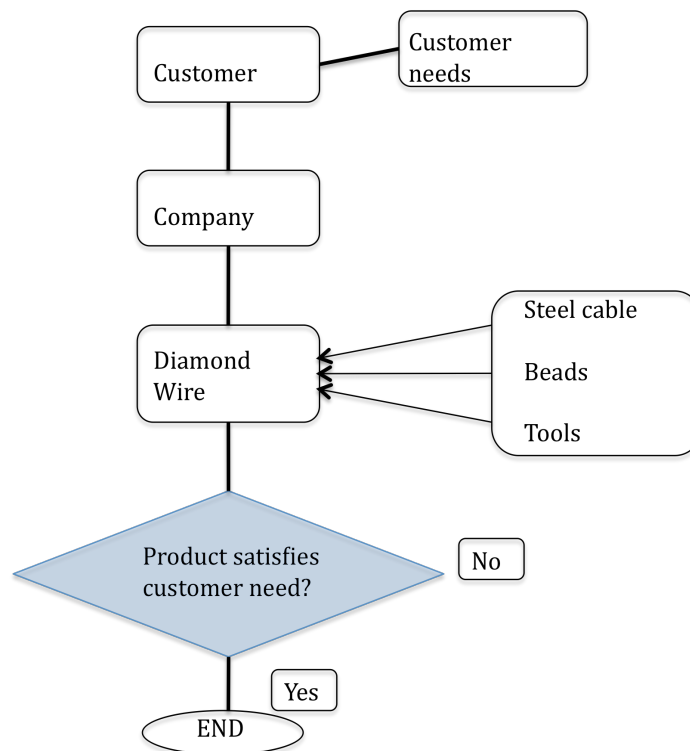


Figure 7 - Production process at Co.FI.Plast



A mass customization system will have to consider these elements to best fit the actual process. The main question for Co.FI.Plast to answer will be, which kind of beads and steel cable to best fit with customer needs?

Furthermore, Co.FI.Plast want to increase the range of possible types of customers and applications, the mass customization and personalization is seen as a starting point for doing it. Utilizing the cutting parameter analysis would also allow the company to point out to its customer what the effects of the different parameters concerning the expected life of the diamond wire.

Co.FI.Plast also sees the future personalized rod-wire scenario as an interesting point of view for application into different domains. There are no specific environments in where diamond wires are used; diamond wires are employed all over the world, though particularly in Brazil, USA, India and Spain, this due to the presence of great mineral repositories in the area. At the moment, applications are mainly used on the ground but it would be possible to think of also undersea applications, besides the chemical, nuclear or underground.

### ***Supply chain***

Once products are ready, shipment are arranged for any specific customer. Transport costs are a great part of expense during the whole product chain process. At the moment Co.FI.Plast manages expedition in order to optimize time and cost, but it is not possible at all times. The company evaluates that in regions, which we have a local office, costs are reduced, because of the possibility to arrange a single big expedition instead that lots of small expedition.

As regarding supplying at the moment any raw material comes from outside and transport cost will be added to manufacturing costs.

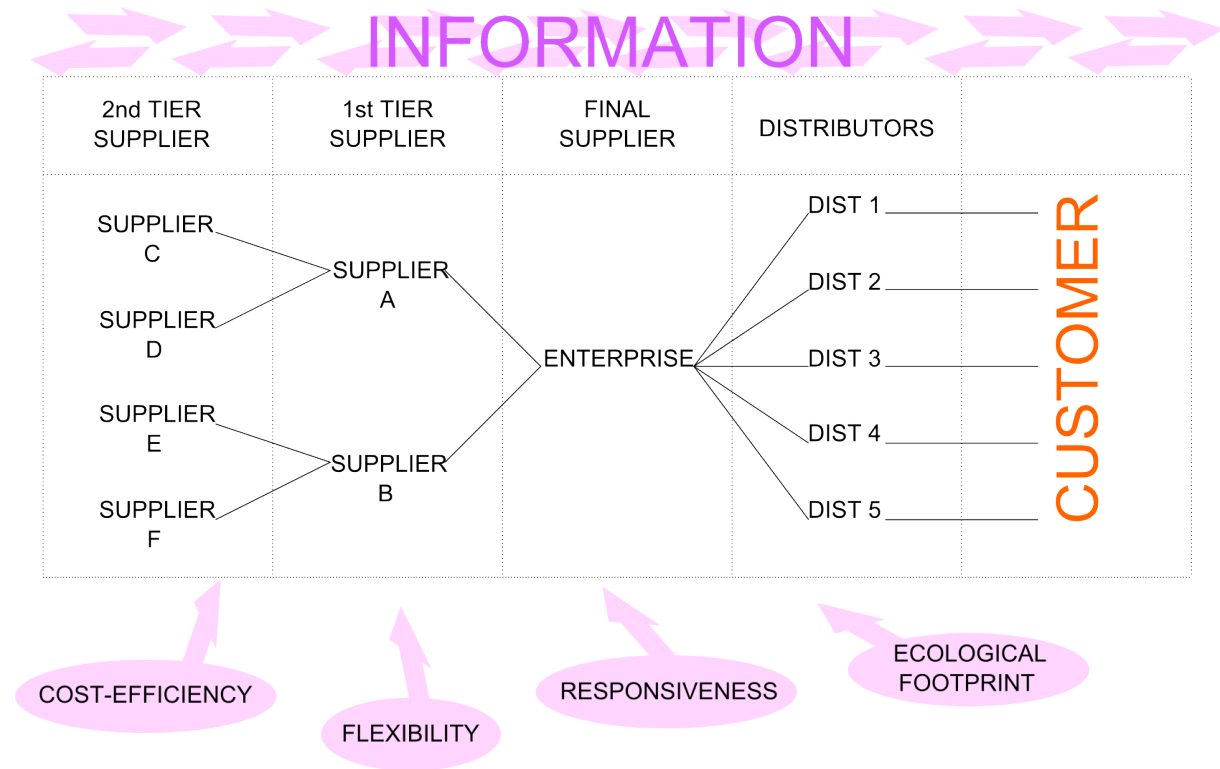


Figure 8 - The flow of goods and information in Co.FI.Plast supply chain, and influencing factors

**Sustainability**

Co.FI.Plast want also to take into consideration ecological aspects. The possibility to utilize green plastic for the plasticization process will be analyzed and currently the company is working on wire diameter reduction in order to reduce the amount of material to be used. Moreover, the company is in process of evaluating the possibility of reclaiming and recycle cutting waste, as to reduce the environmental impact and to re-utilize it, in the place of raw material. Co.FI.Plast believes that, by doing this, the ecological footprint can be reduced two times.

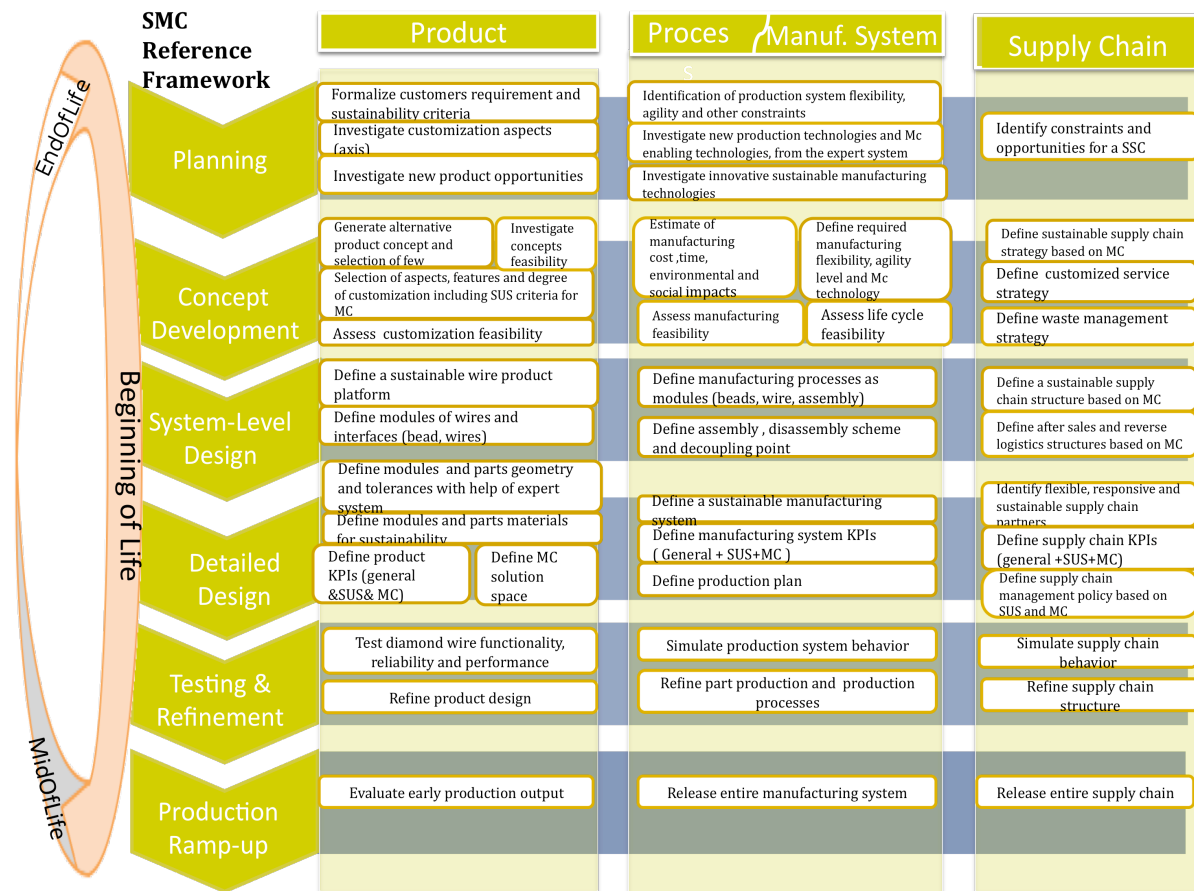
Co.FI.Plast seeks to fulfill the balance between cutting tool performance and the cutting speed to make the product more sustainable. The company is more concerned about producing a product that will be sustainable for the customer, increasing life-length, reducing the energy requirements, possibility to re-use and recycle, than to have a completely sustainable manufacturing process. One action that is being considered regarding the manufacturing process is the installation of control panels on machines for the controlling of power and energy consumption and other operational parameters.

Moreover, Co.FI.Plast wants to also analyze the plasticization process in particular concerning ecological aspects. Saying that, in an eco-compatible and ecological environment also the plastic impact has to be considered.

To sum up, the goal of Co.FI.Plast is reaching a balance between cutting tool performance and cutting speed. By implementing mass customization, recycling and reclaiming activities, opening new local offices, improving local office already existing know-how acquisition, personalization, cutting parameters collection and analysis by expert and a validated system Co.FI.Plast is aiming at reaching that goal.



**Implementing the framework**



**Product**

Collecting cutting parameters, and using an expert and validated system will allow Co.FI.Plast to improve beads customization to organize the manufacturing in a different and more efficient way. The personalized bead mixture coming from the expert system will allow producing specific diamond wire for the wanted particular technologies or requirements directly. Employing the system will reduce the time to client substantially. Further, using an intelligent management system over the cutting process will include the prediction of possible wire breaks, which in turn, can improve the economical margin for the company and reducing costs for customers.

### ***Planning phase:***

All previous customer requirements will be collected using track record of orders and records from machines. Using the expert system, specific requirements, like cutting speed, cutting process, type of material to be cut, type of machines to be used, can be formalized together with sustainability criteria for the customer. The expert system should also be able to give preferences or possible solutions for product development and new product opportunities. Taking into account the market trends, for example how stone is being cut and what materials are more popular, the expert system should be able to, together with human knowledge, suggest new product solutions and how these can be customized. Moreover, the planning phase have to include sustainability criteria in the three levels of sustainability – social, economic, environmental – when developing new solutions. The objective is to see how a product will impact on these levels.

The planning problem will have to be addressed from different points of view:

- Interaction between material and cutting tool (chemical level – transformations and reactions dangerous for human or environment)
- Interactions between material and ambient (physical level and waste management)
- Customer requirements regarding performance of diamond wires. It can be said that the customer co-design, starts already in the planning phase, although not actively from the customer point of view.

### ***Concept development:***

- *Generate alternative product concept and selection of few*
- *Investigate concept feasibility*

Co.FI.Plast will, from the specification given and the output from the expert system, be able to develop different product concepts, regarding dimensions and cutting parameters etc. Once developed, feasibility can be tested, again using the expert system and general knowledge. Thereafter, a few product models, different type of beads, can be chosen for production and further development.

### Master Thesis

- *Selection of aspect, features and degree of customization based on sustainability criteria*
- *Assess customization feasibility*

All suggested aspects and features have later to be evaluated depending on degree of customization and the sustainability criteria, regarding the environmental impact. Product and modules suggested have to undergo evaluation of these criteria to see if they are feasible or not. Feasibility is concerning pre-defined customization levels and sustainability. Co.FI.Plast has to on beforehand decide upon these criteria, what requirements they contain and levels are to be accepted. Which particular material combinations, sintering processes and sizes for beads, also what different types of wires and their performances to accept for production. The chosen features will then be assessed based on the pre-defined criteria for sustainability.

At the moment Co.FI.Plast offers full customization for the customers that require it. This cannot be performed if the company wants to achieve mass customization; in this case a few models and modules have to be chosen to make available for customers.

### ***System level design:***

- *Define a sustainable product platform*

Co.FI.Plast needs to define a platform where products can be produced in a sustainable and mass customization way combined. Regarding the process 'as-is', the company will have to develop the platform in system level to get a general view of how the product modules and components can be set together in subsystems. As a matter of fact, the products produced – the diamond wires – are already divided into subsystems, seeing as the composing parts are; beads, wire and plasticized material. However, the platform has to be designed taking into account sustainability principles. As they are at moment, diamond wires are designed to be disassembled, and are in fact so when the wire needs to be replaced. What more have to be designed is possible remanufacturing of wires, life extension for the same and for beads, types of reusability, and dematerialization of the composing parts. Further, options based on waste management strategy, which is defined in concept development of supply chain, should be designed.

- *Define product modules and interfaces*

The modules of diamond wires are already clearly defined and manufactured in such, as separate parts. What more should be modularized are the compositions of bead materials. To have a set of standard combinations that can be used.

#### ***Detailed design:***

- *Define modules and parts geometry and tolerance*

The different composing parts of the final product – beads, wire, etc. – have to be designed properly, in order to fit with each other in the assembly. The detailed design of the bead must be performed in such a way that the geometry, as well as the tolerance, will fit well on the intended wire, e.g. the hole in the bead must match for the wire and the tolerance of wire and beads needs to be appropriately matching.

- *Define modules and parts material for sustainability*

It's important to define the parts and modules regarding all aspects of sustainability – economic, environmental and social. All the materials composing the bead must be chosen to have minimal environmental impact; when using the materials should be such as to reduce energy, or require less than other materials, they cannot be dangerous to use for the customer's health and should perform their functionality efficiently. This should concern both the final products in their use and the in production or development of the composing and raw materials. Meaning Co.FI.Plast should also control their suppliers to make sure they achieve the required standard.

- *Define product KPI's (general & SUS & MC)*

KPI's have to be defined in order to be capable of measuring the products' performances in terms of criteria for mass customization as well for sustainability. KPI's that would fit well for Co.FI.Plast's products and their performances can be:

For mass customization:

- How many combinations, beads + wire, can be produced, number

### Master Thesis

- How many different types of beads can be produced on the mass customization platform – what number of different types is it worth to produce, number
- How many different types of wires can be produced, number

### For sustainability:

- Life length: how many blocks of stone can one wire cut, depending on length of wire machine type, etc.,  $m^2/wire$
- How many blocks of stone can one bead cut, depending on length of wire, machine type, etc.,  $m^2/bead$
- How many times can beads be remounted on new wire, number
- Performance of diamond wire when cutting, energy consumption/cut

### General:

- Material cost per bead, euro/bead
  - Material cost per wire, euro/wire
  - Material cost rubber, and polymer, euro/kg
  - Time to produce on bead, hours/bead
  - Time to produce one wire, hours/meter of wire
- *Define MC solution space*

Deciding on which parts and modules to produce and which combinations to allow. Defining a fixed number of sets to manufacture and sell. At the moment, Co.FI.Plast offers fully customized products for those customers who require it. But to reach Mass Customization and the benefits from it, only a pre-defined number of product, modules and sets should be offered for production. In this way the products, modules and processes to manufacture them can easier be standardized and made efficient.

### ***Testing and refinement:***

- *Test product functionality, reliability and performance*

Since Co.FI.Plast has the advantage of working together with Wires Engineering S.r.l, all products can be tested directly on site.

- *Refine product design*

If needed, previous activities have will have to be performed again.

***Production ramp-up:***

- *Evaluate early production output*

Co.FI.Plast will have to evaluate the product quality in the beginning of the product's commercial distribution. This can be done on site, like the testing of the product, since all the necessary tools and machines needed are available thanks to the collaboration with Wires Engineering S.r.l.

Process/Manufacturing System

***Planning:***

- *Identification of production system flexibility, agility and other constraints*

When developing the expert system, Co.FI.Plast will then be able to realize how to plan the manufacturing system and the processes. At the moment, all production processes look the same, for all different types of beads, different types of wires and the assembling. The machines used, for sintering and bead production can easily be reset for the various bead types. Wire manufacturing and assembly of the diamond wire is performed manually and is therefore very flexible already. Machine settings can easily be changed depending on outputs of the expert system; they require no long-term production planning. Modules of the products are clearly defined, with this comes also process modules, which are the steps in where product parts are manufactured.

In this phase, also production limits will be indentified, as to remove or reduce them. Production limits at the moment in Co.FI.Plast are; factory floor space, number of machines, machines for the sintering process, which takes time, machines for plasticization of the wire, there are only a few and they require much space for the wire to be looped around them. Moreover, number of skilled workers to manufacture the wires, out of steel cables, number of workers to mount beads on wire and machines to

test the final products for durability and tolerance. A new building is already in production, which means soon more space will be available.

- *Investigate new production technologies and MC enabling technologies*

As for production technologies Co.FI.Plast is one of the leading companies regarding innovation and in fact, some parts of the production are kept as a company secret. Co.FI.Plast has developed these technologies by operating in the specific environment, close to quarries and stone cutting, and through the collaboration with Wires Engineering S.r.l. The technologies are continuously developed. Mass Customization technologies however, will be refined together with the help of the expert system.

- *Investigate innovative sustainable manufacturing technologies*

Co.FI.Plast has, as it is a good balance regarding sustainability in the manufacturing system. The company considers its processes of good a sustainability level and is currently more focused on producing a good sustainable product for the customers, rather than operating under fully sustainable conditions.

If new technologies would be investigated,

- Tools for energy consumption measurement
- Working conditions for employees
- Reduction of energy consumption, machines
- Scrap material handling, and waste management
- Reusing of materials
- Reducing CO<sub>2</sub> and greenhouse gas emissions
- Resource exploitation efficiency

The planning problem will have to be addressed from different points of view:

- Eco sustainability of cutting tool construction process
- Eco sustainability of diamond wire assembly

### ***Concept development:***

- *Estimate of manufacturing cost, time environmental and social impacts*

In order to meet target costs and time values for cost-effective manufacturing, Co.FI.Plust must estimate the costs of the manufacturing processes, this, as well as the environmental and social impacts. By installing control panels on manufacturing machines, energy consumption and etc. can be measured and through this also the occurring costs. Every diamond wire is tracked through the production; consequently costs per product can be estimated. Control panels on machines can also help in the evaluation of materials used, resource consumption, waste amount, and green house emissions of each technology. However, workers' health and security, and other social impacts must also be estimated.

- *Define required manufacturing flexibility, agility level and MC technology*

Deciding on required flexibility and agility level of manufacturing system can only be carried out once the different modules and module mixes to offer for the Mass Customization are decided upon. Currently the machines and technologies used by Co.FI.Plust have no limits regarding customization and adaptation to the various product mixes. What is not flexible is the order, in which the diamond wires are manufactured. This seems, however, not to be a problem for the mass customization system since, even if the wires have very varying parameters for performance, the manufacturing would basically look the same.

- *Asses manufacturing feasibility*

Together with product feasibility, the manufacturing feasibility should be assessed. Since Co.FI.Plust developed its own technology for manufacturing, it can be assumed that the required feasibility is in function.

- *Assess life cycle feasibility*

This activity's output is life cycle feasibility constraints, regarding all from enabling technologies to the waste management strategy in the supply chain. Co.FI.Plust has currently no such strategy, apart from life cycle assessment of the product itself. An assessment of the enabling technologies however, would be the proposed installation of control panels on machines, in order to control processes, and through that, waste



### ***System-level design:***

- *Define manufacturing process as modules*

Co.FI.Plast has already in operation a manufacturing process divided into modules, as where the different parts of the diamond wire are manufactured. The bead manufacturing is also divided into modules, in the different steps where the beads are produced; mixing of materials and shaping, sintering, drilling of hole, cleaning. Even if these modules have little impact on the mass customization system, since the processes are hierarchical in the production of beads. Yet, modularization of other product parts will allow them to be manufactured in parallel, that is beads, wires, plasticization material and rubber can be manufactured at the same time.

- *Define assembly, disassembly scheme and decoupling*

Products can only be assembled in one specific way, which is performed manually. Decoupling points are where beads and wires are produced, before the assembling. Until this point products can be produced, with help of the expert system for forecasting, before the receipt of customer orders. Since the products are made up of only three parts, postponement cannot be performed at any point further down the production line.

### ***Detailed design:***

- *Define as sustainable manufacturing system*

This is where Co.FI.Plast should in detail define all the manufacturing system in a sustainable way. However, apart from installing control panels on the machines, Co.FI.Plast considers itself of having a good balance of sustainability and energy consumption. The company uses as little resources as possible, what is reusable is reused and the rest is recycled to organizations that can recycle, for example metals, and the rest is treated as regular waste. Moreover, being more efficient helps in reducing the cost and hence the prices, and costs for customer, which is seen as the most important factor of sustainability at the moment.

- *Define manufacturing system KPI's (general + SUS+MC)*

In order to measure performances of the manufacturing system, a few KPI's should be set up. The KPI's should measure general performance, as well as sustainable and mass customization, for Co.FI.Plast relevant KPI's can be as follows.

General:

- Time to manufacture bead, hours/bead
- Time to manufacture wire, hours/meter
- Time to assemble beads + wire, hours/meter

For sustainability:

- CO<sub>2</sub> and greenhouse gas emissions, Amounts/meter of wire
- Life length of machine, years
- Energy consumption per machine, J/hour or J/bead/wire

For mass customization:

- Manufacturing cost, euro/meter of diamond wire
- Modules production, number of parts/modules manufactured at the same time
- *Define production plan*

In this step the whole production plan should be defined, regarding all processes and activities, in order to decide upon the quantity that can be manufactured and resource consumption, as well as identifying possible bottlenecks, routing and scheduling of products and parts and anticipation of needs of materials. With help from the expert system, Co.FI.Plast will be able to better prepare for the demand and plan the materials requirement, scheduling of the production, of personnel and other activities. Here, the expert system will be able to help, not only in producing a better product, but also to optimize production and making it more efficient, in order to meet predefined goals.

***Testing and refinement:***

- *Simulate production system behavior*

### Master Thesis

Once the new parameters are set; the production system should be tested. By test-running the system, errors or constraints can be detected and fixed. Once control panels are installed, a simulation of the system should be performed in order to see the performance of the panels.

- *Refine part production and production processes*

If needed after the testing, some changes will have to be performed before running the system any further. Referring to parameters set in previous steps.

### ***Production ramp-up:***

- *Release entire manufacturing system*

Start the sustainable – mass customized production, by integration of all previously defined activities and actions. The system should be able to run alongside the ‘normal’ mass production system and its activities.

### *Supply Chain*

#### ***Planning:***

- *Identify constraints and opportunities for a SSC*

Transport costs hold, as it is, a great part of the expenditures during the production chain process. Co.FI.Plust manages to expedite to optimize time and cost, but not at all times. In regions where the company has local offices, it is evaluated that the costs are lower, since it is made possible to arrange a single big transport instead of multiple smaller lots. Most of supplies of raw material come from local suppliers, and transport cost is added to the manufacturing costs.

Opportunities for Co.FI.Plust are to expand supply chain and opening more local offices in markets has great importance, they would reduce transportation costs in the same time as improving local assistance and presence.

An agile supply chain would be a good starting point for customization, it allows the collection of information from customers and market, to later utilize them to improve

the process, supply chain and methods of working. Co.FI.Plast's supply chain is divided into two main parts: supplier and distributors. If the system is not efficient it is duplicate. Concerning supplying, Co.FI.Plast objective is to acquire know-how to arrange the biggest number of activities within the company. As example is the production and mixing of the mixture for beads, which could be a starting point for managing own certain technologies as a way to improve the product and reduce time in order to reduce costs. Having an efficient supply chain is the base for the creation of a sustainable supply chain model, to be able to respond to mass customization demands in a sustainable way. A virtual organization would be better in optimizing time since there would be a reduction of human delays. Better integration of process and a network-based system is allowing the realization of an agile supply chain.

#### ***Concept development:***

- *Define sustainable supply chain based on MC (faster interaction with suppliers)*

The expert system that is being developed will suggest products to have in stock, depending on customer needs and where they come from, in order to distribute product in a sustainable way, without unnecessary duplications. Most of the suppliers of Co.FI.Plast are local, which means transportation costs, and the resulting environmental impact, are lowered. Moreover, with the expert system and from that the development of a virtual organization, faster interactions - in-time interactions - will be possible providing for a more agile supply chain.

An efficient supply chain is the base for the creation of a sustainable supply chain model in order to respond to mass-customization demands in a sustainable way. A virtual organization is able to optimize time because of the reduction of human delay. A better integration with process and a network-based system allow realizing an agile supply chain. Moreover marketing sensitive is a key point in supply chain customization by listening of customer needs.

- *Define customized service strategy*

The current service offered to customers, apart from the customized diamond wires, is

the replacement of wire at end-of-life, and the delivery of the product. This will still be performed with the S-MC-S operating. When, at end-of-life, the wires have to be replaced Co.FI.Plust offers to pick them up and transport back to the production site where the beads are mounted on a new wire.

- *Define waste management strategy*

Metal waste is sent to companies that take care of metals for recycling. The material can be reused is reused in new products, the rest is trashed. A clear strategy should be defined in a way that includes suppliers and distributors in a most efficient way, including the different possible treatments of waste, recycling, reusing and recovery. For example, if possible, materials that are not used, wastes and remaining pieces that cannot be used, could be sent back to supplier for re-working.

Our but is the evaluation of the possibility of reclaim and recycle cutting waste in order to reduce the environmental impact and to re-utilize it in place of raw material. Once the whole process will be done we will be able to reduce ecological footprint two times.

### ***System-level design:***

- *Define a sustainable supply chain structure based on MC*

This step includes the definition of the topology of the supply chain. From the current supply chain operated by Co.FI.Plust, there will not be many changes in the structure with the implementation of S-MC-S. The expert system will allow for better planning of requirements from suppliers, thus more efficient deliveries, and considering most suppliers are local, it can be assumed the flexibility is rather high. As for distribution, it will be, where there is a big enough market, openings of new local offices as to reduce transportation cost. However, to fulfill S-MC-S criteria, not only costs have to be reduced, but the number of transports, even if here they are most likely to come hand-in-hand.

- *Define after sales and reverse logistics structures based on MC*

This activity is based on the S-MC-S strategy defined in concept development, and aims

at defining how the after sales part of the supply chain will work, specially focusing on reverse logistics. This includes the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. Mass customization will allow for bigger stocks of inventory that have to managed and effectively planned and transported. It is important to take sustainability criteria into consideration when planning for efficient mass customization.

#### ***Detailed design:***

- *Identify flexible, responsive and sustainable supply chain partners*

At present, the supply chain partners, considering suppliers, of Co.FI.Plust are mostly local supplier, which make them more flexible and responsive. Co.FI.Plust wants to keep the supplier local, to minimize the cost of transports and the impact on the environment. Moreover, Co.FI.Plust is located where it is, because the presence of 'supplier' and industries in the area and proximity to partner company. Not only because of proximity to market. Therefore, the focus in this step lies on identifying downstream partners of the supply chain. This is set already by having a network of resellers and local offices. Since local offices and reseller are either run by Co.FI.Plust or very dependent on the company, Co.FI.Plust can impose requirements to be followed.

- *Define supply chain KPI's (general+SUS+MC)*

In order to measure the performance of the supply chain, to help detect problems and opportunities for improvements, KPI's should be defined.

For mass customization:

- Cost of orders, cost/number of orders
- Time for delivery, from supplier and for logistic partner, days
- Transportation cost, euro/order
- Time for production, from order received to final delivery

For sustainability:

- Amounts of wires that are brought back to be disassembled, replaced and beads mounted on new wire
  - Number of transports in one area
  - Number of deliveries of raw materials
- 
- *Define supply chain management policy based on SUS and MC*

Here the policy for managing all activities in sourcing, procurement, conversion and logistic management should be defined. And collaboration and coordination with channel partners – suppliers, intermediaries, third-party service providers, and customers.

Integration of supply and demand management, defining and coordination of functions and tactics for the whole supply chain in a sustainable manner: distribution strategy, distribution network configuration, trade-offs in logistic activities, inventory management.

Co.FI.Plust supply chain policy should be fostering efficiency in a mass customization manner, being flexible and agile enough to provide for fast order- and manufacturing time regarding all possible combinations of diamond wires. In the same time the policy have to take into account the dimensions of sustainability; transports should be minimized, distribution of products have to be planned and trade-offs between inventory management and flexible logistic activities have to carefully be considered. Since the mass customization paradigm will be built on standardization and module production, material orders and production has to be performed in order to grant more efficient utilization and energy consumption in manufacturing. Once the expert system is completed, set up and running, the planning of these activities.

### ***Testing and refinement***

- *Simulate supply chain behavior*

Considering the fact that Co.FI.Plast's intention is to keep most of the supply chain, as it is today, no new modeling or simulation of supply chain behavior will specifically take place. What is important though is the scheduling of all activities to support optimization. With the expert system allowing for better demand forecasting, module production based on required performances, the installation of new local offices for reduction of transports and waste management strategy this can be done in a more efficient way.

- *Refine supply chain structure*

If after scheduling of all activities and testing of the supply chain, some refinement can be done, but following the previous steps one more time.

### ***Production ramp-up***

- *Release entire supply chain*

Once the supply chain is fully planned and scheduled it will be released, e.g. start operating as a whole. Once operational, it is important to control and monitor the performances of the supply chain, to make sure it is performing up to the preset requirements.



## Podium Swiss SA

### The company



Podium Swiss SA is a kitchen furniture manufacturing company, located in the industrial area of Cadenazzo, Ticino, Switzerland. The company is producing fully customized and designed kitchens for private customers, specializing in wood furniture.

Podium Swiss SA (previously Mercolli legno SA) was founded in 1980 and started producing kitchen furniture taking over machinery of the former Therma AG of Schwanden (Glarus, CH). Managers and owners of Podium Swiss are Edy Bernasconi and Adelheid Bernasconi-Seeger, both with over 25 years of experience in the industrial area and design. Edy Bernasconi is CEO and his wife Adelheid is chief of design, marketing and public relations.

Between 1981 and 2009 the company sales from CHF 1.65 million to CHF 6.3 million, with a peak of CHF 7.5 in 2008). A big increase in sales was when the company introduced the registered label "Podium *live...*" in 1989. The salary expenses rose from CHF 1.0 million to CHF 2.5 million in the same time as the number of employees increased from 13 to the current 34. During the years also, the product "Podium *live...*" was developed, with help of investments in new material technologies and production lines, into a product of high quality.

Podium Swiss SA, wants to be the innovation leader in its sector, kitchen wood furniture, and has been investing continuously in new technologies since 2005, when five new manufacturing machines were bought. On the basis of the five machines, the company wants to upgrade and enhance product customization, into mass customization, and Just-in-Time production.

In the local area of Ticino, Podium Swiss works together with 'Vibor cucine e arredamenti SA', which is a company located in the same place and also owned by Bernasconi. Vibor is the regional reseller of the kitchen produced by Podium. In other areas, which are mainly within Switzerland, only occasionally are kitchens sold abroad, the kitchens are sold through other resellers.

The company is located in the industrial area of Cadenazzo, where both the production lays, the offices, which employ 7-8 people, and the showroom where customers can come in and look and feel at fully mounted real size kitchens. Here is also the reseller Vibor located.

### ***Customers and the market***

The kitchen developing process depends on the type of customer to be addressed. Podium has mainly two types of customers, the one interested in 'basic' kitchens, who is more price-sensitive, but still wish to get the high Swiss quality and the more luxurious customer, searching for an exclusive high class kitchen to match with home and life-style.

The first type of customer does not require much customization, since that increases the price. Implementing mass customization would allow Podium to offer deeper customization possibilities for this customer without having that much constraints regarding the rise in price. Following, this would give Podium a big advantage in the part of the market where companies operate with other business models focusing mainly on low prices and low customization.

The second type of customer requires the highest level of customization and service possible, if he is willing to pay, Podium can design and manufacture almost everything the customer wants. In this market Podium Swiss is also very competitive, and can build furniture with the exact dimensions required.

Podium Swiss also has a third type of customer, who is represented by 'objects, meaning orders receive from companies that have to install multiple kitchen in, for example, a new building. This sector requires a lower price for the success rate of the businesses operating in it.

Podium identifies several scenarios for when customers order kitchens. Since a kitchen is different from consumable goods, a decision for buying it can be explained by any of the following reasons:

- The building a new home
- Replacement of actual kitchen
- Vacancy homes/apartments

### Master Thesis

- Apartment buildings renovation/building (usually done by the owner, not by the leaseholder)
- Internal kitchens for employees in companies and public administrations

Because of these reasons, Podium does not recognize much benefit from advertising, since considering customer who does not possess any of the reasons mentioned above, will probably not buy a new kitchen. However, marketing and advertising might help to choose kitchens manufactured by Podium, rather than from one of competitive companies. Podium evaluates its customers because of these reasons to mainly be in the age of at least 25-30 years.

The above only applies when full kitchens are sold, however Podium Swiss also sells single cabinets, wardrobes, bookcases, bookshelves, chairs and tables. Taking this into consideration the customer segment is much wider and advertising, marketing, company and brand image have much bigger impact. Though, competition is much more intense.

As a notice can also be made that Podium Swiss does not sell kitchens to restaurants and hotels. The law in Switzerland does not allow wooden furniture or parts to be placed in such kitchens; usually they have to be built in stainless steel.

On average, Podium Swiss produces approximately 2'000 kitchens per year.

### ***The market***

Podium Swiss usually sells its kitchens through a network of resellers; the distribution of the sales is represented as below:

- 70% in the German-speaking part of Switzerland
- 15% in the French-speaking part of Switzerland
- 15% in Ticino (Italian-speaking region)

When kitchens are sold through resellers, the reseller sends an order of a project of the already customized kitchen. The kitchen is then manufactured and sent back through logistic partners to the reseller or straight to the customer's home or building site.

Regarding Ticino region, the kitchens can be divided into two classes, below CHF 35'000 and above CHF 35'000. Podium Swiss states that 70% of their private clients belong to the lower price section and 30% to the higher one. As concerns the resellers, located in the French- and German-speaking areas of Switzerland, less accurate estimations can be made. This because the price range of parts, other than cabinetry, and of other appliances is not known from the resellers. However, Podium estimates that 80% are below CHF 35'000 and 20% above.

Podium has the desire to calculate, as an interesting indicator, how much the percentage distribution will move, when implementing the S-MC-S framework, as in to increase the percentage of luxury kitchens. Also, even if the markup on the lower class kitchen is lower than on the higher class, Podium recognizes the need to fully utilize the production capacity of the company. At the moment Podium Swiss is lacking a good IT solution for the stock of materials, which make it hard to get an accurate number for the markup. The markup is calculated using only the value of ordered materials, instead of used materials divided by sales. On average the final value is ranging from 25% to 30%.

Competition on the market is rising, because large producers of kitchens push the prices to a global downtrend. Especially in the German-speaking part of Switzerland is competition high, where big producers from Austria and Germany have much influence. Podium Swiss can sustain its market share thanks to good flexibility, both in production and customization of the kitchens.

A main difference, and a source of good competitive advantage, between Podium Swiss SA and most other companies is that, while most competitors order the furniture or cabinets from the main producer, and thus only can get standard sizes, Podium can produce furniture to any size and dimension. Thus, better satisfying the individual needs of customers.

The main competitors of Podium Swiss are:

- Piatti
  - Piatti is a Swiss company formed in 1948 in the location where it still is today. Piatti considers it being a trendsetter in the kitchen sector and is striving to re-invent the kitchen over and over again. There is no

restriction to creativity and innovation; the only goal is to satisfy the customers' kitchen dream. The company has been the market leader since 1980, thanks to the quality of the product and the customization services offered. Piatti employs 300 people and produces 14'000 kitchens per year. The company's production system is characterized by high capacity and short throughput times, allowing customers to benefit from short delivery periods. With 80 sales outlets in Switzerland, Piatti's sales network reaches throughout the whole of Switzerland. Moreover, the company holds a ISO 9001:14001 certification for sustainability and was the first kitchen manufacturer in Switzerland to be awarded one.

- Veriset
  - A Swiss company founded in 1999 offering fully customized kitchen, which the customer can design by itself on the company website. Excellent collaboration with its partners allows Veriset to produce kitchens in a competitive way, guaranteeing quality of the product to the final customer. All thanks to the furniture of the products and the efficiency of the structure that form their industry. The company is also set up with an efficient information system, which makes easier to follow every phase regarding the production from project stadium to distribution. Veriset has a large number of products, to be able to propose products to satisfy all the needs of the customers and their attractions. Veriset is also careful with planning for the future, investing in the newest technologies to assure for the most sophisticated production lines.
- Helbau
  - Medium-high quality
- Häcker
  - A German company founded in 1938. Häcker produces modern fitted kitchens that fulfill the highest claims in terms of quality, functionality, durability and design. The Häcker name is well known in the sector as a guarantee of sound design, reliability, commitment and success. Häcker is

the reliable partner of the specialist trade both today and in the future. Rapidity and flexibility are the maxims in the fields of process organization, delivery deadlines and quality. Hacked seeks partnership with its customers. This begins with communication and is conveyed by a versatile network of relations. Energy efficiency, emission reductions and waste disposal are all very important issues that contribute to the sustainability of the Häcker corporation.

### **Product**

The kitchens produced by Podium Swiss are divided into Kitchen product lines, ranging from the basic e.g. VIVA or VISION to top quality lines like DIAMANTE or PLATINO. In the designing, the names of the lines are carefully set to give a suggestion of the quality, and price, of the kitchen, but also to be comprehensible in various languages. In the Podium catalogue it is well explained what a kitchen production line wants to be/represent. Totally, the company has more than 14 product lines, which are as follow:

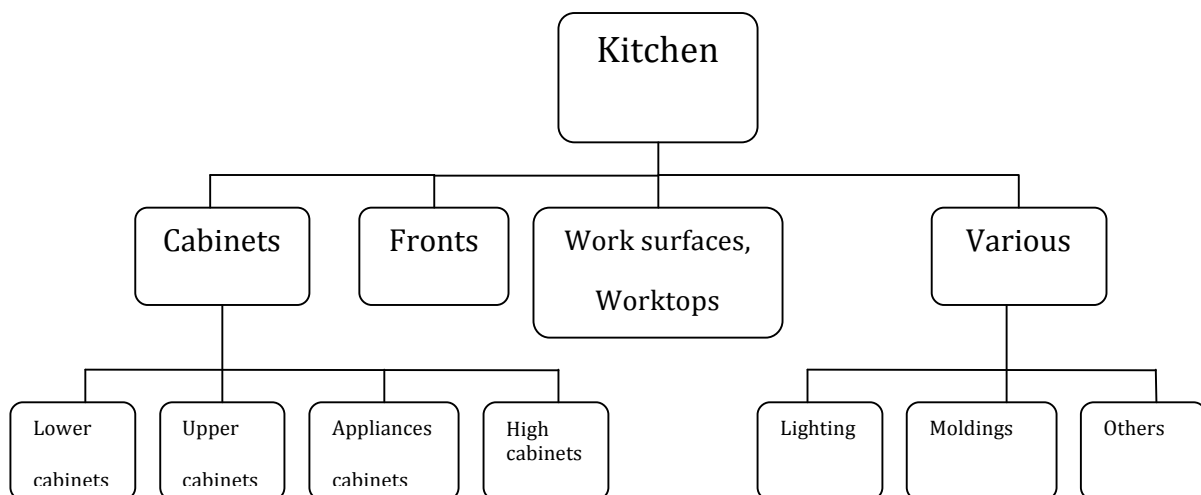
- Gioia
- Tecno-luce
- Vision
- Scala
- Viva
- Piazza
- Piazza-Scala
- Verso
- Parco
- Parco-Tecno
- Parco-Scala
- Parco-Platino
- Platino
- Reflex
- Lotus
- Tiffany
- Chocowood-Platino-Venus
- Bosco
- Tecno
- Diamante
- Viva-Vision-Gioia
- Cubo-Air2-Flex-Sirio-Venere

The company can also produce cupboards, wardrobes, cabinets, bookcases, columns and bookshelves to any dimension on request, and design and produce high-class tables and chairs. All the designs for the kitchens such as, patterns, colors, materials etc., are made by Adelheid Bernasconi-Seeger. She is very artistic focusing on younger peoples likes and fashion, in the same time as bringing in more quality in the design and product, using the styles of today. A kitchen is composed of different pre-built parts (e.g. hinges, cabinetry hardware, lights, ovens, etc) and Bernasconi-Seeger and Podium Swiss are when designing working on bringing all these parts together in a harmonic design, with

inspiration and new ideas taken from many different ways. All of the company's products are later fashioned by master craftsmen with proven experience and good skills. High-quality individual solutions for all types of wood, melamine, glass, metal and other materials based on any design or style desired are worked out.

Normally a 'basic' kitchen is composed by 10 to 15 cabinets, a custom high quality kitchen of 20 to 25 cabinets, but the number vary depending on the size of the kitchens. Some luxury kitchens have as many as 60 drawer or cabinets. The price range varies from CHF 15'000 to CHF 30'000 for the basic kitchens up to over CHF 100'000 for the luxury high-class kitchens.

The following parts, shown below, normally compose a kitchen.



As for the customization of colors for the front panels, Podium Swiss has more than 100 colors available for the customer to choose from. However, should the customer require a different color than the ones offered, it can be arranged. Choosing the colors to make available is considered very important and is guided by trends and the will of providing exclusive materials and colors to apply to the cabinet fronts. A part from a wide range of colors, Podium has also produced some cabinets with more unconventional materials such as leather, synthetic fabric, fur, glass or paintings.

The most popular colors, ranked by percentage of sales, are shown below. The top ten colors represent about 50% of all sales.

### Master Thesis

1.	005	White	13%
2.	063	White HP	5%
3.	120	Mountain Maple	5%
4.	131	White Grey	4%
5.	065	Lightgrey	4%
6.	137	Silver	4%
7.	---	Without front panels	4%
8.	164	Pastel Platinum	3%
9.	168	White	3%
10.	144	Vanille	3%

The “carcase” of the cabinet, which is the part behind the front, is usually always white.

The costs of the product, are divided as follows:

- Materials 30%
- Direct Work 30%
- Office (specifications) 40%

The cost of work (factory and office work, which is to give the factory the specifications of the cabinets to build) accounts to 70% of the cost of the product. This is one of the points in production that Podium wants to optimize. Saving on materials is not possible since the product is to remain kitchens of high quality.

In a near future, Podium Swiss SA, also want to start the production of baths and bathroom furniture.

### ***Production processes***

#### Kitchen design process

Every kitchen is made from a platform, a general layout. When a new idea for a kitchen line is created, many samples are bought to see in reality the quality and appearance of the materials. Some stress and resistance tests are also run on those materials or samples. Podium Swiss builds prototypes, not on a regular basis, but when there are



new functionalities or designs that need to be tested. All prototypes are built in actual real-life sizes, no virtual models are built.

The design process of a customized kitchen starts with one of the company's technical advisers sits down with the customer in some sessions, in order to define every aspect of the kitchen. The aspects to define essentially include the following:

- Choice of production line
- Customization of cabinet faces/fronts (shapes)
- Choice of colors
- Materials (wood, or wood-like)
- Cabinet hardware, the handles (size, color, material)
- Treatment of the surfaces (matt to glossy)
- Working surfaces (stone, glass, inox, or other)
- Type of mechanism in the movement of drawer (basic, airbrake, electrical motion)
- Type of mechanism in the movement of the cabinet faces/face frames (HS lifted, scissors-type, clap, electrical motion)
- Type of mechanism in the movement of cabinet doors (hinges, scissors, others ways)
- Hinges
- Household appliances (integrated into kitchen cabinetry) including ovens, roasters, steamers, dishwashers, coffee machines, refrigerators and more. Choice of the mixer/kitchen faucets (hot and cold water or even carbonated water dispenser or integrated LED light technology)
- Kitchen sinks (shape, materials)
- Lights and cabinet lighting (type, number, placement)
- Spatial disposition of the cabinets
- Wall coverings (usually between the base cabinets and the upper cabinets), many customizations are possible such as materials, thickness, colors, back-lights
- Kitchen hood
- Internal part of the cabinets (customization is possible)
- Glass display cabinets
- Placement of sockets
- Accessories (e.g. soap dispensers)
- Wall cabinets/"upper cabinets" configurations
- Baseboard / skirting / base molding (height (usually 105 mm), color, material)
- Top molding (height, color, material)
- Ventilation grids (different types and sizes)
- Garbage/recycling containers (built-in, size, type)

Once all of the aspects of the kitchen are decided upon, and all dimensions are defined, the manufacturing process can start.

#### Kitchen manufacturing process

The basic structure of the productions is as follow:

- Project of the kitchen is approved by the customer and the production can start
- The wood panels (dimensions usually 2800mmx2050mm, thickness from 16mm to 25mm) are first cut in the desired dimension by a numeric control machine.
- The border of the panel is applied by a numeric control machine, which located after the cutting/saw machine.
- The panel is then drilled with a numeric control machine and the hinges are placed.
- The panels are mounted and the cabinets are moved to the shipping area where it is packed carefully and stocked.
- The logistic partner (Holenstein AG) delivers the kitchen to its final location.

If the customer would want other materials than what Podium Swiss is working with, it has to be ordered and cut into the required dimensions by an external company. This is very time-consuming and in fact Podium is currently considering employing also the cutting of different materials than wood in-house.

A 10m long machine manufactures the borders, using laser or glue. Borders are also made by hand, but are only for special requests and will not be considered for mass customization. This machine has to be programmed for every border, however the settings stay in the memory and can be reused. In reality, all specifications and dimensions have to be entered into the machine before starting the work, which can be very time consuming if there are no data stored of those settings already. Once all settings are entered, the piece will receive a label, which provided information about the making of the borders for machines during the rest of the manufacturing process.

The attaching of hardware is made automatically. Packing is made carefully and the kitchens stored in a random design, in waiting for the delivery, which is made by 9-10 people who also mount the kitchens (in the area of Ticino).

All production is based on orders received, which means there is no stock of merchandise of finished products kept. Only some stock of the 'carcase' is kept, in the most commonly used size.

Inventory is not controlled, only manually and no track record is kept. It has to be checked for every order.

Considering the company was not build from scratch, but is a result of changes and improvements during the 30 years of existence, it has given rise to some inefficiency in the production process. These inefficiencies are due to and located especially in the IT and software used. The company is both making use of old software, like IBM AS/400 and other 'contemporary/new' software, like Access and Excel. Further, there is a lack of a common database to be readable and modifiable by all used the software, which generates some issues. E.g. some operations that could be performed automatically have to be done manually by the office since the software is not interconnected. Moreover, a bit amount of time is spent on completing orders received, since most of the time the orders received from resellers are non-finalized projects. This is one of the activities that consume the most time in a very ineffective way, leading to increased costs.

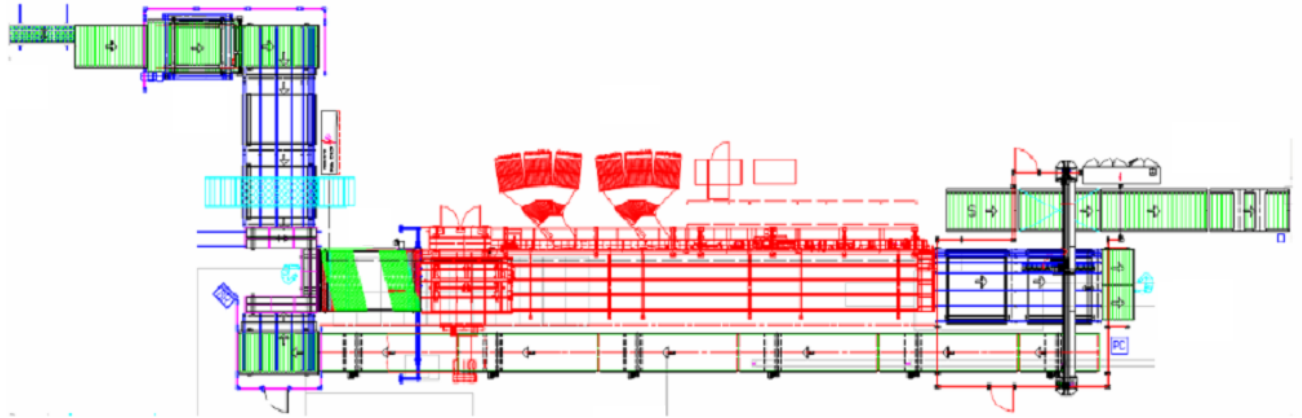
A scheme of the kitchen manufacturing process, representing the whole production of a kitchen can be found in appendix 2.

A manager of production, currently a student, has been hired to study and assess maintenance of the production line. He is working on the forming of a new concept for production and recycling of materials. The program is also including employees, layout ergonomics, energy consumption and etc.

### ***Mass Customization***

A new border machine, a Laser Edge machine, has recently been installed, costing Podium in total (with all other required investments) more that CHF 5 million. By utilizing the machine, Podium hopes to bring more strength to the implementation of mass customization. The machine, which is very complex and utilized a new laser technology, reaches a length of approximately 50 meters.

Below is a representation of the new Laser Edge machine:



This new laser edge machine is capable of producing 72 edges at the same time, all in different colors if needed, while the previous ones had to be prepared every time a new color was to be produced. With this the production can be made faster and more flexible.

Podiums' production machines are mainly from two companies HOMAG AG and IMA AG that are competing brands. This means often 'ad hoc' solutions have to be designed in order to transfer the needed data from one machine to the other. For example, cutting performed by the HOMAG AG machine must print a label on the part, to specify what work needs to be done by the edge machine, IMA AG. Two cameras placed in line before the edge machine can only read this label, and if this is not made correctly, the edge machine will simply reject the piece.

Moreover, the machines used in the company have a very high degree of flexibility, the border machine, can produce 1000 pieces in one day, all in different types and colors. Podium Swiss is also fast with adopting new technologies; in fact they are the only one in the area with the IMA machine, which uses laser technology instead of glue for the borders. The management is also frequently visiting fairs and expos to gather information and knowledge about new machines and technologies. The new generation is a plasma machine, but at the moment the ray of the plasma is too big for Podium to operate with. Visiting expos is currently the only method for the company to gather knowledge about new technologies; no own research is performed within the company. Also, after the hiring of a new CEO, Mr. Bernasconi, it took some time for the company to

get back in line, while the CEO settled in. During this time not much new research was done or new technologies tested.

The process of designing and manufacturing a whole kitchen can be very time intensive, which is one big reason why Podium Swiss wish to implement S-MC-S. It would mean saving of both time and money, resulting in a big advantage against competitors. Podium clearly recognizes that the customization can be made more efficiently. As it is very difficult for customers, who have little or no, experience and knowledge in the field, choosing of all the parameters for the kitchen can take very long time. Podium Swiss wants to help the customer to be able to choose better and faster. However, since many of Podium Swiss' customers are from the luxury kind that wants kitchens which fit their style and needs, even if sometimes the needs are only to look good and match well with the rest of the design in the home. These customers would not use the typical mass customization tools, like online design tools and trial-and-error building of the kitchen. Instead they like to have the personal service offered, to come in to the office and discuss possible designs with an expert over a cup of coffee or a drink. Mass customization cannot be offered to this type of customers in the traditional ways, it can only be offered to customer who are more price-sensitive and/or have the time and will to do the design and choosing of modules themselves.

Also, an important fact to take into consideration is that, what the company calls 'gli speciali' (the specials), sometimes the customer wants some parts or details of the furniture from a different product line than the one chosen. In this way the kitchen takes an 'ad hoc' design and production. Of the 20% percent that are custom cabinets, about half are 'specials'.

For the implementation of mass customization, a new IT system is being studied. An ERP system, Essenzia, is being installed, which should allow the company to control most of the relevant aspects of the production. The system will also include a database connected to all software used to monitor and manage every part of the production process.

#### Customized service for customers

Kitchens are mounted and installed at the customers' homes by Podium Swiss (in the local area of Ticino). Later on, customers are also visited, sometimes also taken to

dinners, to check upon the kitchen and the performances. It is planned to carry out these visits more frequently in the future. The kitchens have five years of warranty in Europe, which is not a problem to reach. However, it is not in the business of Podium Swiss as a producer, but of the resellers (Vibor in Ticino).

### ***Sustainability***

Podium Swiss holds no certificate for ISO standards regarding sustainability. However, the company acts as if it would, because they believe in it. As was said at the visit, "... we do not have any ISO certificate (it is too expensive and there are already too many work-in-progress) and not for marketing purposes, but we act as we do because we believe in it."

All the three pillars of sustainability, economical, ecological and social, are being addressed and evaluated. From the S-MC-S project, Podium expects to, economically; shorten the order processing time, gain a faster production and thus a shorter customer lead-time, ecologically; use less electricity, use less PU glue (substituting it with laser edge) and socially; simplify the work for the employees and make them part of something more special than the company currently are, resulting in better work-satisfaction.

The kitchens are also made possible for recycling, however, only in Ticino where Podium Swiss operates is this brought into action. The kitchens are de-mounted, brought back to the company and separated. The metal is brought back and sold, electric appliances are brought back to appropriate companies, and woods are recycled or reused. To manufacture the wood panels, the surface, a lot of energy is required, old wood parts are used for this energy. In other parts of the country, or abroad, the kitchens are sold through resellers and therefore the control and managing of them at end-of-life is lost.

Other aspects that the company is caring about regarding sustainability are, waste material from the cutting of panels is used to produce pellets, which are then used to heat the building; the ecological quality of materials, including materials used related to the production process, is investigated; Eurolite panels are bought, which are eco-

sustainable, specially for the veneering (covering the fronts with real-wood 'slices'); and on the factory floor a pipeline is installed collecting all sawdust from machines for the employees to have a healthier environment to work in.

Furthermore, also in production and for the end product, the company is trying to stop using glue. Glue is polyurethane that requires much energy to produce. Using a laser requires a lot of electricity in production, but taking into account all factors, the pollution of the glue, transportations, etc., the laser is far less energy consuming and on top of that, produces a better quality wise and healthier, more sustainable product.

However, not all criteria of sustainability are always considered. When designing the kitchens, the designer takes no regard concerning the choice of materials and their sustainability. For example, one material, similar to stone, is made out of petrol. Materials are chosen on the base of customer preferences and the tastes of the designer solely. A program to analyze different materials and depending on how they are used, is however, under development. After this focus will be on buying the right materials, to offer for the S-MC-S system.

### ***Supply chain***

The main constraints in Podium's supply chain, as it is organized today, are that suppliers want big orders. Podium Swiss uses the big, and of best quality, suppliers for the materials this results in having to align to suppliers conditions. Usually that means ordering material lots of a certain size, depending on the type of wood, color, material etc., even if only a few pieces are needed, for one single customer and kitchen. In this context Podium Swiss is a too small company to have any influence or power to decide, put pressure or bargain with its suppliers. Only regarding the hinges that are used, for cabinets and drawers, are the same in all kitchens, and have therefore a good economy of scale. The suppliers utilized by the company are not at all dependent on Podium Swiss. Conversely, Podium Swiss has more power on resellers. But, as mentioned earlier, specifications from resellers are not standardized, which is very time consuming. To be able to better cope with this; Podium wants to introduce new software for the exchange of data about customers.

Another issue is when customers want lacquered front panels, since it is one of the few processes that are outsourced by the company. Usually, companies in Italy make the lacquering, which takes about four to five weeks. Lacquered fronts belong to luxury kitchens and these customers specially do not like to wait. If then something would happen to the panel while being mounted in the kitchen, it would take another four weeks to replace it. Seeing as this is quite a big problem, Podium is considering enhancing their painting department in order to be able to do the lacquering in-house. More than the timesaving, this would also result in lower costs, and more flexibility. The project of a new production area for lacquered fronts is currently being studied.

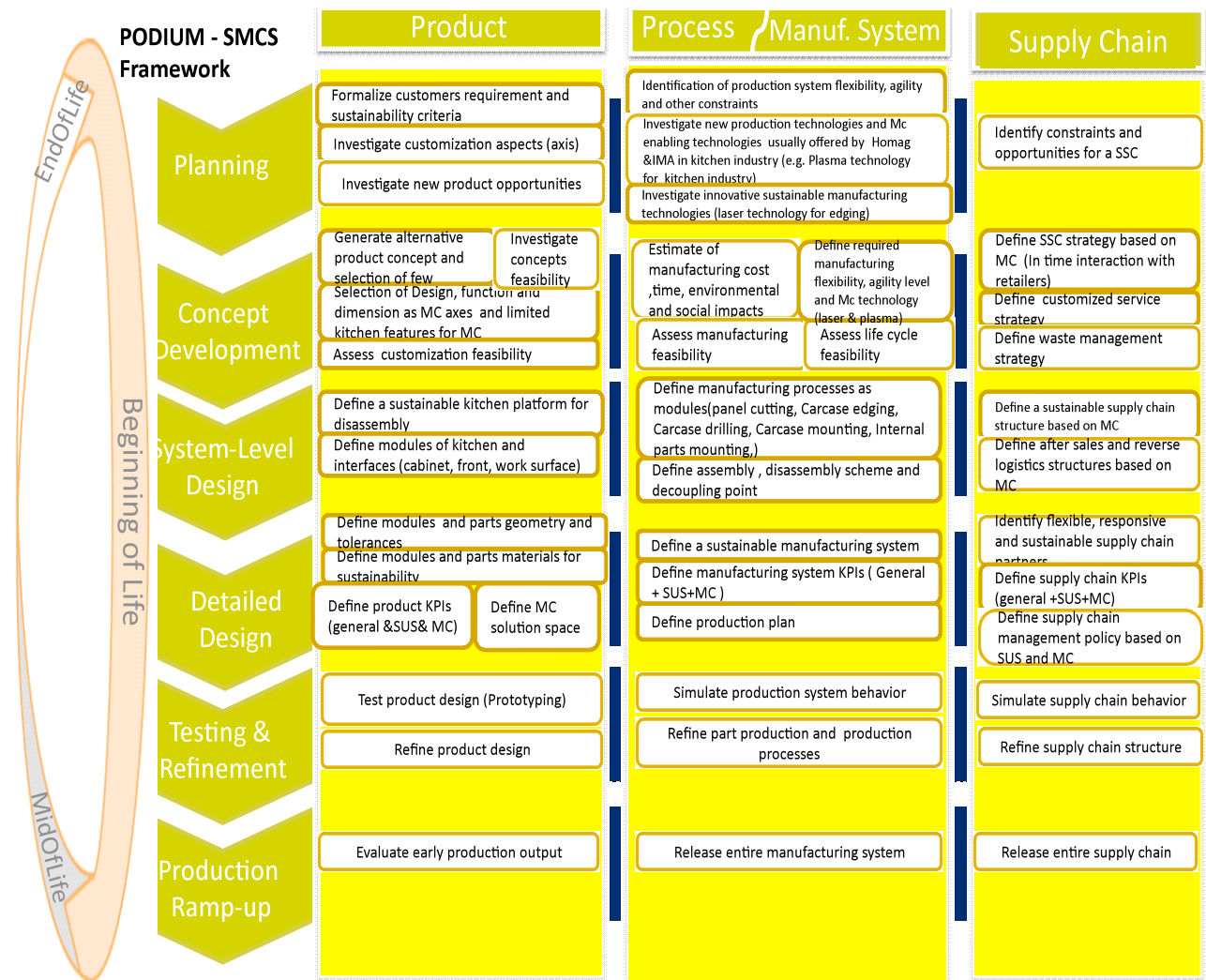
Conclusively, Podium Swiss considers their supply chain not yet ready for S-MC-S, since the current supply chain is not flexible enough, deliveries are not fast and small sized orders are extra charged.

Summarizing, with the implementation of S-MC-S Podium Swiss is hoping also to be able to address price dependant market and low-low price, by saving on some resources in the customization and definition of the kitchens. More customers that are interested in low prices could be captured with the basic kitchen. Low cost for increased customization would mean better customer satisfaction through better fulfillment of individual needs thus improving the competitive advantage. New machines and technologies can produce better quality products. Power savings and better utilization of only the materials needed, no waste-materials and installment of trashcan compartments, would mean a smaller ecological print. As well as reduction of customer lead-time with a more flexible, agile, supply chain.



**Implementing the framework**

Podium Swiss has at it is, a clear view of how the future processes are to be. Not all aspects are represented in the framework, in the same time as the framework also contains aspects not considered by the company. The framework has been modified to better fit for Podium Swiss processes, and the design and manufacturing of kitchens. Nonetheless, the steps and activities of the framework for the company to implement should be explained in detail.



As a way to reach mass customization, a database must be set up. For this database, parameters and specifications for all kitchens should be collected. Data should also be

regarding times and when to produce, for the optimization of cutting, by cutting more kitchen panels at the same time.

Product

#### ***Planning phase:***

Basic kitchens will be used for the mass customization system, predefined dimensions will be offered to the customers to choose from. The customer will be able to choose different sets and, for example, door handles to match, not entirely new designs. Conversely, designs will be made in what Podium Swiss call 'reverse' co-design, meaning the company will be designing from customers' likes, taking customer preferences into designs that will work functionally. Functionality is very important, some measures can be set will design but have to be tested for functionality. The company will have to help the customers in making the kitchens functional, to fit for each specific customer.

For this also an information system should be developed which can recognize and tell what designs (modules) function together and which ones do not. Podium is currently working on installing an ERP system; the mass customization feature should be integrated into this.

- *Formalize customers requirements and sustainability criteria*

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The kitchens are also made possible for recycling, however, only in Ticino where Podium Swiss operates is this brought into action. The kitchens are de-mounted, brought back to the company and separated. The metal is brought back and sold, electric appliances are brought back to appropriate companies, and woods are recycled or reused. To manufacture the wood panels, the surface, a lot of energy is required, old wood parts are used for this energy. In other parts of the country, or abroad, the

kitchens are sold through resellers and therefore the control and managing of them at end-of-life is lost.

In this step also the customer requirements, regarding functionality, design and sustainability, will be formalized.

- *Investigate customization aspects (axis)*

The three different axes for Podium to customize a kitchen around are Design, Function and Dimension. Design is the different options for color, shapes of cabinet faces and fronts, treatments of surface (matt or glossy) and the work surface (stone, glass, etc). Function is the different types of usage options for the customer like, electric drawers and doors, type of mechanism for cabinets; sliding doors, clap, scissor-type, HS lifted, etc. and how many and what kitchen appliances to be integrated into the kitchen. Dimension relates to different sizes and fits of cabinets and furniture. Other features of the kitchen that can be customized are kitchen faucet, lighting, sink, wall covering and hood. Also kitchen appliances such as oven, dishwasher, coffee machine, etc., however, it depends on the suppliers of these products.

In this step the axes are identified and investigated, to later be defined in the *concept development* phase.

- *Investigate new product opportunities*

New product opportunities for Podium, as mentioned earlier, are bathrooms and bathroom furniture. More than just investigating the possibilities for production of these, it has to be considered how the product would work for mass customization, as well as how sustainability criteria aligns with these products, how it can be integrated into Podium Swiss' already working system.

### ***Concept development:***

- *Generate alternative product concept and selection of few*

Product concept that are to be selected here must be generated taken into account also production and supply chain constraints. To achieve sustainable mass customization, kitchens that require less time to manufacture and whose including parts do not require

any special treatment that would mean outsourcing to other partners, should be chosen. Alternative product concepts may include also the products investigated in previous activities, bathrooms and bathroom furniture. However, Podium Swiss is a kitchen-wood furniture company, and products other than wood furniture are at this point not feasible to manufacture.

- *Investigate concept feasibility*

The different product lines of kitchen have, obviously, varying production times. Below is an example of production times for standard customization.

<b>VIVA</b>	<b>GIOIA-HG</b>	<b>TECNO / PARCO</b>	<b>DIAMANTE</b>
<b>VISION</b>	<b>GIOIA-POLISH</b>	<b>PARCO-S/ CHOCOWOOD</b>	<b>SCINTILLA</b>
<b>FORMA / GIOIA</b>		<b>PIAZZA / VERSO / BOSCO</b>	
		<b>SCALA-(K-SYS)</b>	
		<b>PLATINO / LOTUS</b>	
<b>4 weeks</b>	<b>5 weeks</b>	<b>7 weeks</b>	<b>9 weeks</b>
<b>20 working days</b>	<b>25 working days</b>	<b>35 working days</b>	<b>45 working days</b>
<i>Standard (no special pieces)</i>	<i>Standard (no special pieces)</i>	<i>Standard (no special pieces)</i>	<i>Standard (no special pieces)</i>

The first two columns of product lines are faster to produce for the reason that some of the including panels are held in stock. For the reason that the lines VIVA and VISON are the most sold. To be more flexible, which is required for mass customization, stock for the offered product lines should be kept. This would mean a reduction in time also for the product lines with longer production time.

With the current technology employed by Podium Swiss, including the new border machine, concept feasibility is not a problem. All machines are capable of producing furniture of all dimensions and sizes. Furthermore, new technologies are frequently researched for.

- *Selection of Design, function and dimension as MC axes and limited kitchen features for MC*

In this step a few of the possible customization features regarding the axes for customization, should be chosen for the mass customization system. At the moment there are, almost, endless possibilities for customization of the different designs, functions and dimensions. Only a few can be chosen for the implementation of an efficient mass customization paradigm. Considering that Podium wants to address, with the S-MC-S system, more price-sensitive customers, features for the more basic kitchens should be chosen; materials, appliances, sizes, etc. that require no special treatment and that can be quickly ordered (if not already kept in stock) and delivered.

- *Assess customization feasibility*

Customization possibilities are, as it is, basically endless. Podium Swiss' technologies allow all customizations apart from special features, which in any case will not be included in the S-MC-S system.

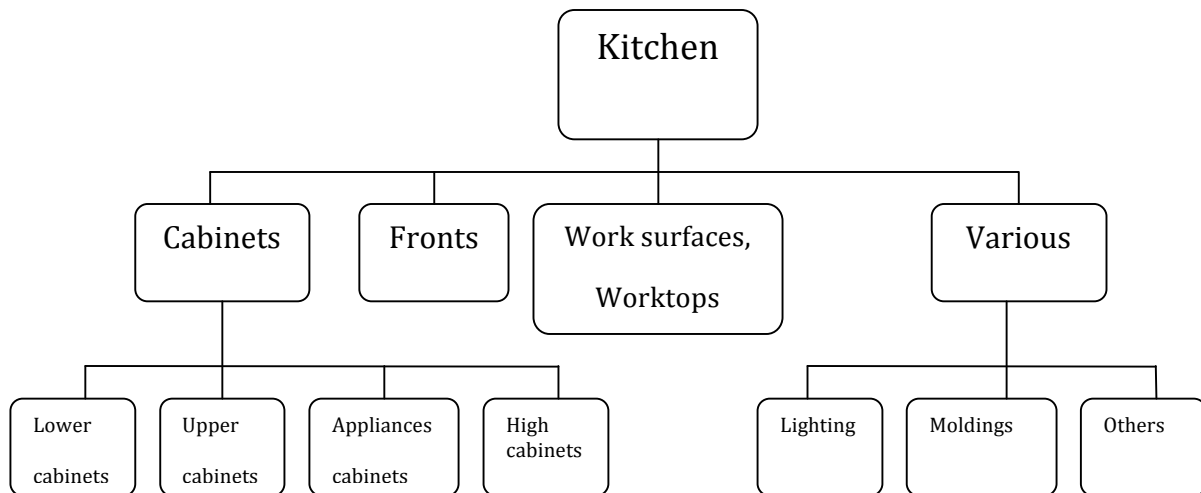
#### ***System level design:***

- *Define a sustainable kitchen platform for disassembly*

All product lines offered by Podium Swiss are based on a platform. When deciding on parts and modules to be included, it has to be made sure that it is possible to disassembly. Podium offers to demount kitchens after end-of-life, however only in the area of Ticino. Kitchen parts and module has to therefore be designed to make disassembly easy for either customer or reseller. This means that, at end-of-life, the kitchens have to be possible to demount and separated into parts that can be reused, recycled or remanufactured. Using as little extra material as possible when mounting and designing the kitchens in clear modules is a way to do this.

- *Define product modules of kitchen and interfaces (cabinet, front work surface)*

A basic kitchen consists of the following modules:



The possible variations for each module to offer has to be decided, only a limited number of possibilities can be made available for mass customization. The modules have also to be designed in such way that they can fit in various combinations with other modules, when building the whole kitchen. It has to clearly be defined with possible combinations can be made for the customer.

#### ***Detailed design:***

- *Define modules and parts geometry and tolerance*

Geometry and tolerance have to be defined in such way that the different combinations of modules are feasible. At the moment, only real-life, actual size prototypes are built, which is not possible for all modules. However, using standardized measures this can be avoided. An option is to install a program where virtual models can be built and tested. This would nevertheless, require tolerance and geometry testing or the single modules, as to insert the data into the program.

- *Define modules and parts material for sustainability*

As mentioned earlier, when creating kitchens, the designer is not always considering the sustainability of materials used. However, production tries to choose materials such way to fulfill sustainability criteria, to have as little impact on environment possible. For the S-MC-S paradigm materials and parts have to be chosen carefully, taken into account all levels of sustainability, environmental, economical and social.

### Master Thesis

- *Define product KPI's (general SUS & MC)*

KPI's have to be defined in such way as to make possible for measurement of product performances regarding criteria for mass customization as well as for sustainability.

Possible KPI's for Podium are:

For mass customization:

- How many different combinations of kitchens can be manufactured, number
- In how many different designs, measurements, dimensions, can each module be produced, number
- How many appliances to offer, and in how many combinations they can fit, number

For sustainability:

- Expected life lengths for full kitchen, years
- Expected life-length for the composing modules, years
- Ecological print of materials chosen

General:

- Cost of material for cabinets, euro/meter
- Cost of material for fronts, euro/meter
- Cost of material for work surfaces, euro/meter
- Cost of colors, euro/liter

- *Define MC solution space*

Deciding on which parts and modules to produce and what combinations to allow. Defining a fixed number of kitchen 'sets' to manufacture and sell. Currently, Podium offers any possible configurations and designs of kitchens, as long as the customer is willing to pay. For a mass customization solution space, only a predefined number of product combinations can be offered, to make sure of efficient production.

### ***Testing and refinement:***

- *Test product design (prototyping)*

At this time, prototypes are only made in full size, and only when new designs need to be tested. In order to test the defined modules and combination of modules and parts, a virtual prototyping program should be installed. As if only to test durability, tolerance and sustainability of the full kitchens, which can possibly be performed with programs, like AutoCAD or even Excel with the right formulas.

- *Refine product design*

If needed, the product and module designs will have to be refined after testing. Following the previous steps.

#### ***Production ramp-up:***

- *Evaluate early production output*

Podium Swill will have to evaluate the product quality in the beginning of the product's commercial distribution. This can be done when building prototypes for testing on site, but should also include the evaluation of customer satisfaction regarding modules and combinations available for the building of a full kitchen. Total costs have also be evaluated, and related to markup on materials and price of kitchens.

Process/Manufacturing System

#### ***Planning:***

- *Identification of production system flexibility, agility and other constraints*

This is one of the very important steps in implementing as sustainable mass customization system. Production capacity and capability has to be flexible and easy to change depending on the different required modules' dimensions. Production technologies at Podium Swiss are constantly researched, developed and considered. A new border machine has recently been bought, which is very flexible compared to the old one, since it can produce multiple borders, all in different colors at the same time. However, since the company employs machines from different, competing, manufacturers the transfer of pieces from one machine to another is not always that smooth, there is not much flexibility. Pieces from one machine have to be set and produced in a specific way (setting of labels) for the next machine to even accept the piece. This is a big constraint for the production system regarding flexibility and agility.



Moreover, the production process follows one line, and for most actions there is only one machine to perform them. This means less flexibility since products cannot be produced in parallel.

- *Investigate new production technologies and MC enabling technologies usually offered by Homag & IMA in kitchen industry (e.g. plasma technology)*

The new investigated technology, the plasma machine, would mean faster and better production, but at the moment the rays are too long to be operational. For better utilizing the technologies offered for a more efficient mass customization system, Podium should consider purchasing machines of only one manufacturer, to easier integrate them in the production line.

- *Investigate innovative sustainable manufacturing technologies (laser technology for edging)*

At the same time as investigating the feasibility of integrating new technologies into the system, e.g. the plasma machine, sustainability aspects should be taken into account. At the moment, Podium Swiss is in the process of switching all previously glued products (borders) to be worked by laser technology. As mentioned earlier, using laser means consuming more electricity, but taking into account all factors with glue (production, deliveries, usage by final customer) laser technology proves to be much more sustainable. Also, the current technologies should be considered and their sustainable performance should be measured, e.g. energy consumption, CO<sub>2</sub> emissions, etc.

#### **Concept development:**

- *Estimate of manufacturing cost, time environmental and social impacts*

More than investigating new technologies, there has to be a system for measurement of the existing technologies' performances. Costs should be calculated, energy consumption measured, CO<sub>2</sub> and fossil fuel emissions measured, workers health, working conditions and attitudes surveyed or controlled among others. Moreover, waste management has to be defined, scrap material handling, reusability of materials and resource exploitation has to be made efficient.

- *Define required manufacturing flexibility, agility level and MC technology (laser & plasma)*

For the modules and parts decided upon to produce, the flexibility, agility level and technology has to be properly defined. Some parts or modules should be made possible to manufacture in parallel, meaning probably there should be made investments in new technology. However, the machines and technologies currently used by Podium Swiss are capable of producing all possible configurations of the kitchens. Only big issue is the agility and time consumption of certain activities.

- *Asses manufacturing feasibility*

At the same time as product feasibility is investigated, so should manufacturing feasibility, regarding technologies, be. This would include the possibility of manufacturing different modules in parallel, and assessing if all different types of modules can actually be produce. The latter will most likely be no problem considering Podium Swiss can already produce almost anything that is requested by customer.

- *Assess life cycle feasibility*

This activity's output is life cycle feasibility constraints, regarding all from enabling technologies to the waste management strategy in the supply chain. For Podium this life cycle assessment means also the life cycle of the machines. Currently, Podium makes more effort in assessing and finding the right technologies for better quality production, than assessing the activities of waste management and reusability, producing a high quality product is considered more important.

### ***System-level design:***

- Define manufacturing process as modules (panel cutting, Carcase edging, Carcase drilling, Carcase mounting, internal parts mounting)

The production process has to be defined into modules. At this moment all customization, e.g. all new projects, start with cutting the panels, each in new dimension for every kitchen and follows a line of production until final assembly. The three different modules that can clearly be made out are; carcase edging, fronts edging, and

special units. In the mass customization system will be no special units. Instead, the manufacturing process can be divided into the following units:

- Panel cutting
  - Carcase edging
  - Fronts edging
  - Carcase mounting
  - Assembly
  - Packing for shipment
- *Define assembly, disassembly scheme and decoupling point*

Disassembly is performed, apart from the area of Ticino, by the reseller (or customer) and is considered not to be Podium Swiss' as a manufacturer business. Postponement, with all standardized modules can be done with the decoupling point in assembly of/putting together the kitchen for shipment. Particularly if customer demand can be forecasted, modules and parts can be manufactured on beforehand and stored in wait for orders.

#### ***Detailed design:***

- *Define as sustainable manufacturing system*

In this point, the whole manufacturing system should be defined in detail in a sustainable way, including all three levels of sustainability, from start to finish. Using an integrated information system would allow the reduction of time from order to start of production, thus lowering time to customer and costs. Utilizing the waste from panel cutting, and all cutting of wood, for the making of pellet that is later used to heat the building. Controlling the energy consumption of the machines, trying to use better technologies and having the pipeline collecting sawdust and thus creating a better environment for workers are all parts of a sustainable manufacturing system.

- *Define manufacturing system KPI's (general + SUS+MC)*

### Master Thesis

Currently, workers make their own KPI's, regarding the production, but no record is truly kept for long. Considering the usage of an ERP system, parameters can easily be inserted and a track record can be kept. However, first the KPI's have to be defined.

For mass customization:

- Cutting time, panels/hour
- Border production, meters/hour
- Av. time to start production from that orders are received, hour
- Time to assemble/pack kitchen for delivery, hours
- Modules production, number of modules/parts manufactured at the same time
- Manufacturing cost, euro/kitchen module
- Drilling time, hours/carcase
- Internal parts mounting, hours/carcase
- Edging time, hours/front, hours/carcase

For sustainability:

- Percentage of waste that can be reused, amount used/amount waste
- Energy consumption of machine, J/hour or J/carcase (front) produced
- CO<sub>2</sub> and greenhouse gas emission, amounts/kitchen produced
- Life length of machines, years

- *Define production plan*

The whole production plan is defined here, from start to finish. All activities and processes should be included, in order to decide upon the quantity to be manufactured, the resource required as well as identifying possible bottlenecks, routing and scheduling of parts and materials and anticipate the need of materials. At the moment, bottlenecks are the defining of customer orders and finalizing kitchen projects, since there is not standardized way in which orders are sent from resellers to Podium Swiss. With the installment of an integrated information system, this can be overcome. Moreover, there is only one cutting machine working, for all kitchen wood materials, which possibly can

become a bottleneck if a large amount of material has to be cut urgently. However, if pieces are constantly pre-cut, into standardized measurements the bottleneck can be removed.

#### ***Testing and refinement:***

- *Simulate production system behavior*

Once all parts and modules for the mass customization systems are set, and parameters for sustainability; the production system should be run and tested. In this way Podium Swiss can estimate the time for production, detect errors or constraints and correct what is needed.

- *Refine part production and production processes*

After test running the production systems, the planning can be refined and the parts of the system that are not performing as expected can be fixed. Some of the previous steps will have to be performed again.

#### ***Production ramp-up:***

- *Release entire manufacturing system*

Starting the sustainable – mass customized production, by integrating all previously defined activities and actions. Since the S-MC-S system is mainly implemented for better efficiency in production, and to address to new customers, the system should be able to run alongside the ‘normal’, currently employed, fully customized system and its activities.

### Supply Chain

#### ***Planning:***

- *Identify constraints and opportunities for a SSC*

When planning the supply chain, Podium Swiss wants to consider every partner under the aspects for compatibility, flexibility, delivery time, reliability, minimum order size and cost-efficiency. Yet, Podium has not much influence in fostering a change in the

direction of the S-MC-S paradigm, since most of the suppliers employed are big global companies and can easily impose their conditions. In the planning phase, these constraints have to be identified, such as order lot size minimum, in order to find opportunities to work around those issues.

One issue is with the logistic partner, Hostenstein AG that delivers to resellers or construction sites. Podium has noticed that the partner makes no difference in the treatment of the transport whether it is a luxury (80'000 CHF) or a standard (25'000 CHF) kitchen. This can be a problem, since if parts are damaged they have to be replaced and parts for luxury kitchens can take weeks to replace.

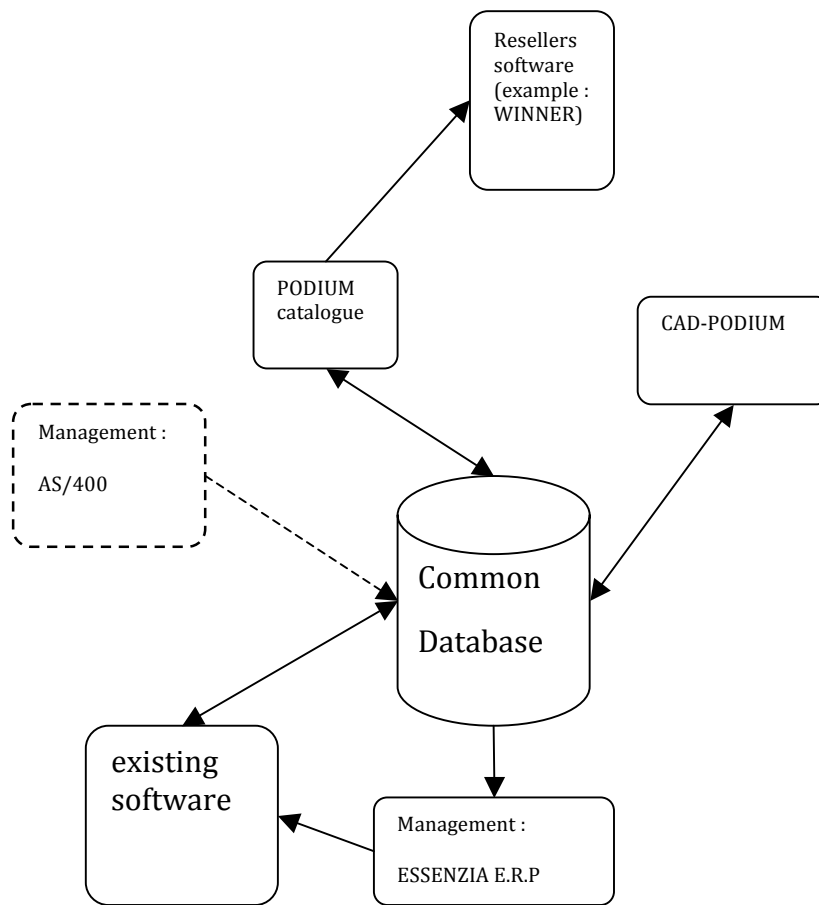
Another issue is with the partner for worktops, Staron. Staron sells boards only in sizes of 3000mm x 700mm, the boards are very expensive and it is not possible for Podium to order the exact size needed, since Staron do not cut the parts. Consequently there is a big waste of money, when boards of smaller sizes than the ordered ones are required. The same thing happens with the glue that is used to attach the board, which is expensive as well, and can only be used within a few days after opening.

### ***Concept development:***

- *Define sustainable supply chain based on MC (in time interaction with retailers)*

Considering that Podium's suppliers are big and powerful, the negotiation possibilities of Podium are quite low. What Podium can influence, however, are the resellers and retailers. By providing the resellers with software, the supply change strategy can be changed and let resellers be in an in time interaction with Podium, thus informing about any new customers requirements as soon as they happen.

Podium Swiss is planning to install and integrate the IT system as shown in the figure below. The Essenzia will replace the AS/400 from IBM currently employed, and with the new system Podium expects a better and faster management of the company resources. Planning of the production will also be possible to make over longer periods, a faster response time for orders and better control of stocks will also be achievable.



Furthermore, the supply chains strategy should be defined considering all aspects of sustainability, social and environmental impacts as well as economical, in the same time as it is based on mass customization strategy. The defined supply chain has to be made competitive but in the same time taking into account the mass customization technologies, sustainability criteria, product concept, degree of customization and previously defined points regarding product and manufacturing system.

- *Define customized service strategy*

The service offered by Podium Swiss at this moment is fully customized to every customer's needs; customers are paying a lot for the kitchens and are offered all the service they need to be fully satisfied. In a mass customized system this will not be possible to the same extent. Therefore service strategy has to be defined, both regarding customers and resellers. Podium will keep a high level of customer service, with helping in designing the kitchen, only for the difference that it will be based on modules. Most of customer have little or no experience in kitchen design and building and must therefore

be helped. Moreover, packaging, delivery, warranty, check-ups and disassembly at end of life will continue to be offered, as well as replacement of damaged parts.

- *Define waste management strategy*

Currently, Podium Swiss employs no particular waste management strategy, only focusing on minimizing the waste by reusing the most material possible. For example, waste product from cutting wood is transformed into pellets and reused to heat the building. A clear strategy should therefore be defined, including the different possible treatments of waste, recycling, reusing and recovery. More than the recovery of material from cutting, the possibility of recycling or reusing pieces from cut for the standardized modules production should be considered. Materials that cannot be recovered or in any way reused should be separated and sent to the proper channels to be taken care of in the most sustainable way. Also from kitchens disassembled at end of life, a strategy should be set for the possible remanufacturing of materials and parts.

#### ***System-level design:***

- *Define a sustainable supply chain structure based on MC*

The topology of the supply chain will in this step be defined. As for how the supply chain structure currently looks for Podium, there will not be many changes. For the procurement of the high quality products and materials that define Podium Swiss, the best suppliers have to be used. As for resellers, when installing the new information system and software for customer orders, maybe more direct sales to final customers can be made. However, the current network of resellers and retailers are important for the spread of Podium Swiss' products over the country and abroad. The following commercial partners are currently used; all of which are big companies that can impose their conditions on Podium Swiss.

#### *Household appliance:*

- AEG, BAUKNECHT, BOSCH, ELECTROLUX, GAGGENAU, MIELE, SIMENS

#### *Cabinetry hardware:*

- BLUM, BUCHER, GRASS, OPO OESCHGER, PEKA

#### *Coffee and coffee machines:*



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- CHICCO D'ORO

*Panels/boards, materials, panel edges:*

- EGGER, HERZOG ELMIGER, REHAU ZH

*Kitchen hoods, sinks, worktops:*

- FRANKE, GALVOLUX, KRONOSYSTEM

*Water treatment, kitchen faucets:*

- HWT, KWC

*Lighting:*

- KMD

*Logistic partner, shipments:*

- HOLENSTEIN

Resellers were not named.

- *Define after sales and reverse logistics structures based on MC*

After sales logistics are only applicable if parts of the kitchens need to be replaced, in that case the furniture is brought back to Podium by its logistic partner Holenstein. Reverse logistics if for Podium Swiss only taken into concern in the area of Ticino. In areas outside of this region, reverse logistics are considered being the business of the reseller. In Ticino, the kitchens are demounted and brought back to Podium by the logistic partner, where the parts that can be remanufacture, reused or recycled are done so, kitchen appliances are sent back to the company of origin and the waste is sent to the proper companies to be taken care of. More than just making sure that materials and products are treated in a sustainable way, the reverse logistics have to consider the aspects of mass customization and provide a cost efficient flow of goods. More specifically, when sending back materials for remanufacturing or recycling, it has to be considered whether it is in the whole worth it.

***Detailed design:***

- *Identify flexible, responsive and sustainable supply chain partners*

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At present, the supply chain partners, considering suppliers, of Podium Swiss are not particularly flexible or responsive, only in some occasions and then with an additional fee for the order. This is because big companies such as the suppliers mentioned before, are not dependant on the orders from Podiums Swiss. However, the company can carefully chose between the companies, concerning aspects such as sustainability and flexibility, when ordering materials. On resellers and the logistic partner, Podium can impose more conditions. Also, searching for better options if needed. The aim is to construct a supply chain that is a source of competitive advantage and make cost reductions possible.

- *Define supply chain KPI's (general+SUS+MC)*

In order to measure the performance of the supply chain, to help detect problems and opportunities for improvements, KPI's should be defined.

For mass customization:

- Cost of (small) orders, additional fee/number of orders
- Time for delivery, from supplier and for logistic partner, days
- Transportation cost, euro/order
- Time for production, from order received to final delivery

For sustainability:

- Amounts of kitchens that are disassembled and remanufactured/reused, of total amount
  - Number of transports in one area
- *Define supply chain management policy based on SUS and MC*

Here the policy for managing all activities in sourcing, procurement, conversion and logistic management should be defined. And collaboration and coordination with channel partners – suppliers, intermediaries, third-party service providers, and customers.

Integration of supply and demand management, defining and coordination of functions and tactics for the whole supply chain in a sustainable manner: distribution strategy,

distribution network configuration, trade-offs in logistic activities, inventory management.

Podium Swiss supply chain policy should be fostering efficiency in a mass customization manner, being flexible and agile enough to provide for fast order- and manufacturing time regarding all possible module combinations and designs of kitchens. In the same time the policy have to take into account the dimensions of sustainability; transports should be minimized, distribution of products have to be planned and trade-offs between inventory management and flexible logistic activities have to carefully be considered. Since the mass customization paradigm will be built on standardization and module production, material orders and production has to be performed in order to grant better economies of scale, as well as more efficient utilization and energy consumption in manufacturing.

### ***Testing and refinement***

- *Simulate supply chain behavior*

Considering the fact that Podium Swiss intention is to keep most of the supply chain as it is today, no new modeling or simulation of supply chain behavior will specifically take place. What is important though is the scheduling of all activities to support optimization. With demand forecasting, module production, integrated information system with resellers and waste management strategy this can be done in a more efficient way.

- *Refine supply chain structure*

If after scheduling of all activities and testing of the supply chain, some refinement can be done, but following the previous steps one more time.

### ***Production ramp-up***

- *Release entire supply chain*

Once the supply chain is fully planned and scheduled it will be released, e.g. start operating as a whole. Once operational, it is important to control and monitor the

performances of the supply chain, to make sure it is performing up to the preset requirements.

## 5 Comparison

### *Product*

#### **Companies**

For the implementation of S-MC-S, the biggest issue for Co.FI.Plast lies in the planning phase of the product. The development of an expert system requires preceding careful investigation of all possible factors, and their interrelations, influencing on performance of the final product.

For Podium Swiss, regarding the product, the main issue lies in deciding upon which kitchen lines, and in how many different variations the modules of kitchens, will be offered for S-MC-S. Since offering all configurations and designs the customers can ask for, is not in fact employing mass customization.

Moreover, with the development of the product both companies are focused on producing a product that will be sustainable for the customer. For Podium Swiss the objective is to design and produce a product that will be user-friendly, healthy for the user and motivate to user to take care of the environment and sustainability issues (e.g. glue that does not evaporate hazardous substances when kitchens are used and the installment of separated trash containers). For Co.FI.Past the focus lies on developing a sustainable product for the customer, in the sense of lasting long and being of better quality, thus saving on costs for the customer.

#### **Framework**

Regarding the product development phases of the framework all phases, apart from alternative or new product opportunities and customization feasibility, are relevant for both the companies. None of the companies are particularly focused, at this point, on investigating new product opportunities (apart from the wish of in the future also manufacturing bathroom furniture by Podium Swiss). In this starting point of the S-MC-S, both companies focus lie in designing the currently produced product for application.

## ***Process/Manufacturing System***

### **Companies**

The two companies processes and manufacturing systems are very different, in terms of customization. For Co.FI.Plast the biggest customization is right in the beginning of the process – the different material mixtures and sizes for the beads, following the first step, the rest of the manufacturing process is basically the same for all customizations. Only number of beads and wire length varies. On the other hand, the production process of Podium Swiss customizes, or adds on the different customer requirements, step by step to the final product. This means that, with the implementation of S-MC-S, more changes and planning will have to be made throughout the progress of the manufacturing, e.g. the steps in the framework to follow will have more changing effect on the current process. The kitchens have many different modules and design axes, resulting in implementation of S-MC-S, regarding manufacturing process, being more complex than for the diamond wire production of Co.FI.Plast.

Regarding the estimation of environmental and social impacts, it can be said the neither of the companies put much focus into this issue. As mentioned before, both Co.FI.Plast, even if to a larger extent, and Podium Swiss are making more effort in producing a product that have less environmental and social impact when in use, rather than designing manufacturing system to be sustainable. This meaning not that the companies are indifferent to whether the production processes are sustainable or not, but that this particular phase in the framework is not where most effort is put into.

### **Framework**

For Co.FI.Plast, the later steps of the production process will stay basically the same, regarding customization, and many of the phases in the framework are not as relevant as other steps. By not putting that much focus on phases that are less relevant for the company, the framework can easily be adapted for the manufacturing system. However, the information system used (or to-be used, in the case of Co.FI.Plast) should be integrated into the implementing process. Especially meaningful KPI's are difficult to set and measure without an information system fully integrated and spanning over the whole production system, integrating the whole company. Moreover, the identification phase of system flexibility, agility and other constraints will vary much depending on the changes that are needed for the implementation of S-MC-S. In cases where the

manufacturing system its processes for production do not need much modification, or if products will be produced more or less in the standard production, these issues will not need much analyzing as it can be assumed they will not change. Also simulations of the entire production system behavior will vary depending on purpose, type of process and company. If the changes that are needed to address are small, it can be in some cases not necessary to perform extensive simulations.

### ***Supply Chain***

#### **Companies**

Both companies employ at this moment supply chains that are not yet ready for mass customization, or that are considering all sustainability criteria. However, in order to fully implement the S-MC-S paradigm, and for the companies to operate more efficiently, more importance should be given to the planning and defining of the entire supply chain. Both companies are also relatively small and have therefore little influence on suppliers; on the other hand more requests or conditions can be imposed on reseller and distributors.

#### **Framework**

Regarding the supply chain dimension of the framework, it can be concluded that it fits for both companies. However, a consideration should be taken to the fact that it is difficult for a company, particularly a small company, to influence and change the behavior of all its supply chain partners. Moreover, KPI's are not easy to set, and control, for a single company, as well as simulation the entire supply chain before release.

## 6 Conclusions

Regarding the companies it can be concluded that; for Co.FI.Plast the biggest issue is the development and installment of the expert system. Once it is in operation, other steps for implementing S-MC-S, following the reference framework can be performed. Steps that are at this point not entirely clear, for example number of variations of the different modules to offer, and measuring sustainability of manufacturing system, can be defined once the expert system is up and running, and integrated into all parts of the company, manufacturing and supply chain. For Podium Swiss, the biggest issue is the alignment to suppliers' conditions and the little influence the company has on its biggest suppliers. Since Podium Swiss uses well-known and often global companies for the supply of wood, colors, kitchen appliances, and etc., it has little influence on the suppliers behavior, sustainability concern and supply chains. Therefore, fully implementing the S-MC-S paradigm, with the required level of sustainability, flexibility in manufacturing and delivery and all other parts necessary for efficient mass customization, can be difficult for such, in the context, small company as Podium Swiss.

Regarding the framework, phases to define and set up KPI's are a bit vague. The definitions, types and purposes of the KPI's, as well as the monitoring, can vary largely across companies and industries. Perhaps standardized KPI's should be developed and/or guidelines for their implementation and measuring. Also, an information system implementation phase and integration into all parts of the company should be added. Even if information systems vary much across companies and their needs, a phase concerning its integration into all departments could be useful.

Overall, the framework can easily be modified and can be considered applicable for all type of companies. This conclusion may be taken without enough ground, considering only two case studies have been presented. However, the two cases are widely different, regarding industry, customers, competitors and markets, and seeing as the frameworks easily applies to both types, enough reason to draw a conclusion like the one just mentioned should exist.



## Bibliography

- advice, T. G. (2006, october). *The Global and Ethical investment advice*. Retrieved from The Global and Ethical investment advice: <http://www.gaeia.co.uk>
- Arena, M., Duque Ciceri, N., Terzi, S., Bengo, I., Azzone, G., & Garetti, M. (2009). A state-of-the-art of industrial sustainability: definitions, tools and metrics. *Int. J. Product Lifecycle Managemetn* , 4 (1/2/3), 207-251.
- Australian Government, D. o. (2004, june 2). *Australian Government*. Retrieved from Australian Govenment, Department of the Environment and Heritage: <http://www.deh.gov.au/industry/corporate/eecp/index>
- Baroulaki, E., & Veshagh, A. (2007). Eco-Innovation: Product Design and Innovation for the Environment. In S. D. Takata, & Y. D. Umeda, *Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses* (pp. 17-25). London: Springer-Verlag London Limited 2007.
- Berger, C., & Piller, F. T. (2003, august/september). CUSTOMERS AS CO-DESIGNERS. *IEE MANUFACTURING ENGINEER* .
- Boer, C. R., & Dulio, S. (2007). *Mass Customization and Footwear: Myth, Salvation or Reality*. EUROshoE Project.
- Conference, E.-e. (2004, July 13). *Eco-efficiency conference*. Retrieved from Eco-efficiency conference: <http://www.eco-efficiency-conf.org/content/home.definitions.shtml>
- Da Silveira, G., Borenstein, D., & Fogliatto, F. S. (2001). Mass Customization: literature review and research directions. *Int. J. Production Economics* , 72, 1-13.
- Da Silveira, G., Borenstein, D., & Fogliatto, F. S. (2000). Mass Customizatoin: Literature review and research directions. *Int. J. Production Economies* , 1-13.
- DTIE), U. N. (2004, june 2). *United Nation Environmental Programme*. Retrieved from United Nation Environmental Programme, Division of Technology, Industry, and Economics: <http://www.uneptie.org/>
- Duray, R. (2000). Mass customization origins: mass or custom manufacturing? *International Journal of Operations and Production Management* , 22 (3), 314-28.
- European Commission. (2001). *Sustainable Production, Challanges & Objectives for EU Research Policy*. European Commission, Community research. Competitive and sustainable growth.
- European Environmental Agency, E. (2004, June 7). *EEA European Environmental Agency*. Retrieved from EEA European Environmental Agency - Glossary: [http://glossary.eea.eu.int/EEA\\_Glossary](http://glossary.eea.eu.int/EEA_Glossary)
- Feitzinger, E., & Lee, H. (1997). Mass customization at Hewlett- Packard: The power of postponement. *Harvard Business Review* , 75 (1), 116-121.

Fiksel, J. (2009). *Design for Environment A Guide to Sustainable Product Development*. New York: The McGraw-Hill Companies, Inc.

FoF.NMP.2010-2. *S-MC-S Sustainable Mass Customization – Mass Customization for Sustainability*. Lugano: Seventh Framework Programme.

Gilmore, J., & Pine, J. (1997). The four faces of mass customization. *Harvard Business Review*, 75 (1), 91-101.

Glavic, P., & Lukman, R. (2007). Review of sustainability terms and their definitions. *Journal of Cleaner Production*, 15, 1875-1885.

Haglund, M., & Helander, J. (1999). Development of value networks } an empirical study of networking in Swedish manufacturing industries,. *Proceedings of the International Conference on Engineering and Technology Management*, 350-358.

Hart, C. (1995). Mass Customization: Conceptual underpinnings, opportunities and limits. *International Journal of Service Industry Management*, 6 (2), 36-45.

Hirsch, B., Thoben, K.-D., & Hoheisel, J. (1998). Requirements upon human competencies in globally distributed manufacturing . *Computers in Industry*, 36 (1-2), 49-54.

initiative, G. r. (2006, october 9). *Global reporting initiative*. Retrieved from Global reporting initiative: [www.globalreporting.org](http://www.globalreporting.org)

Kanchanasevee, P., Biswas, G., Kawamura, K., & Tamura, S. (1999). Contract-net based scheduling for holonic manufacturing systems. *Proceedings of the SPIE - The International Society for Optical Engineering*, 108-115.

King, W. (1998). IT-enhanced productivity and profitability. *Information Systems Management*, 15 (3), 70-72.

Kotha, S. (1996). From mass production to mass customization: The case of the National Industry Bicycle Company of Japan. *European Management Journal*, 14 (5), 442-450.

Kotha, S. (1995). Mass customization: Implementing the emerging paradigm for competitive advantage. *Strategic Management Journal*, 16, 21-42.

Kratochvíl, M., & Carson, C. (2005). *Growing Modular - Mass Customization of Complex Products, Services and Software*. Heidelberg, Germany: Springer.

Lampel, J., & H, M. (1996). Customizing customization. *Sloan Management Review*, 38, 21-30.

Lau, R. (1995). Mass customization: The next industrial revolution. *Industrial Management*, 37 (5), 18-19.

Moser, K., & Piller, F. t. (2006). The international mass customisation case collection: an opportunity for learning from previous experiences . *Int. J. Mass Customisation*, 1 (4), 103-109.

Organization for Economic Co-Operation and Development . (2001). *Environmental Outlook*.

- Pfeiffer, F., & Rennings, K. (2001). *Employment impacts of cleaner production - Evidence from a German Study using Case Studies and Surveys*. Germany: Business strategy and the environment.
- Piller, F. T. (2005). Mass Customization: Reflections on the State of the Concept . *The International Journal of Flexible Manufacturing Systems* , 16, 313–334.
- Piller, F. T., & Tseng, M. M. (2010). Mass Customization Thinking: Moving from Pilot Stage to an Established Business Strategy. In F. T. Piller, & M. M. Tseng, *HANDBOOK OF RESEARCH IN MASS CUSTOMIZATION AND PERSONALIZATION*. Aachen, Germany: World Scientific .
- Piller, F. T., Moeslein, K., & Stotko, C. M. (2004). Does mass customization pay? An economic approach to evaluate customer integration. *Production Planning & Control* , 14 (4), 435-444.
- Piller, F. T., Schubert, P., Koch, M., & Möslein, K. (2005). Overcoming Mass Confusion: Collaborative Customer Co-Design in Online Communities. *Journal of Computer-Mediated Communication* , 10.
- Piller, F. T., Schubert, P., Koch, M., & Möslein, K. (2005). Overcoming Mass Confusion: Collaborative Customer Co-Design in Online Communities. *Journal of Computer-Mediated Communication* , 10.
- Pine, J., Victor, B., & Boyton, A. (1993). Making mass customization work. *Harvard Business Review* , 71 (5), 108-111.
- Recchioni, M., Mandorli, F., Germani, M., Faraldi, P., & Polverini, D. (2007). *Life-Cycle Assessment simplification for modular products*. Università Politecnica delle Marche; Indesit Company, Mechanical Engineering Department. Ancona, Ital: CIRP Conference on Life Cycle Engineering.
- remanugact, h. (2005, November 2). *remanufacturing*. Retrieved from remanufacturing: <http://www.ciwmb.ca.gov/WPIE/remanugact>
- Robert, K., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, J., Kuehr, R., et al. (2002). Strategic sustainable development and selection, design and synergies of applied tools. *Journal of Cleaner Production* , 10 (3), 197-214.
- Salvador, F., de Holan, P. M., & Piller, F. T. (2009, April). Cracking the Code of Mass Customization. *MIT Sloan Management Review* .
- SAP Info. (2004, September 1). The Personal Touch: Mass Customization. *The SAP Magazine* , 120, pp. 12-16.
- Seliger, G., Kim, H.-J., Kernbaum, S., & Zettl, M. (2008). Approaches to sustainable manufacturing. *Int. J. Sustainable Manufacturing* , 1 (1/2), 58-77.
- Spira, J. (1998). Mass Customization through training at Lutron Electronics. *Computers in Industry* , 30 (3), 216-229.
- Tischner, U., & Charter, M. (2001). *Sustainable Product Design, Sustainable Solutions: Developing Products and Services for the Future*. London, UK: Greenleaf Publishings.

Master Thesis

Tseng, M., & Jiao, J. (2001). *Mass Customization, in: Handbook of Industrial Engineering, Technology and Operation Management* (Vol. 3rd ed.). New York: Wiley.

US Environmental Protection Agency, E. (2004, june 1). *US Environmental Protection Agency (EPA)*. Retrieved from US Environmental Protection Agency (EPA): <http://www.epa.gov>

Wenick, I., Herman, R., Govind, S., & JH, A. (1998). Materialization and dematerialization: measures and trends. *Daedalus* , 171-198.

Westbrook, R., & Williamson, P. (1993). Mass Customization: Japan's new frontier. *European Management Journal* , 11 (1), 38-45.

World Business Council for Sustainable Development. (2000). *Eco-efficiency - creating more with less impact*.

## Appendix 1 – List of bead types

<b>Sintered, diamond-edged for cutting marble and medium and/or low hardness stone</b>			
<i>Diameter</i>	<i>Bead</i>	<i>Material</i>	<i>Sintering</i>
11mm	<b>Marble Sardinia TD</b>	All types of marble	1.20mm layers
10mm	<b>Marble Sardinia TD</b>	Dolomitic marble	1.20mm layers
	<b>Marble Sardinia TS</b>	Dolomitic marble	1.20mm layers
	<b>Marble Gold</b>	Calcitic marble	1.20mm layers
	<b>Marble Yothy</b>	Green marble	1.20mm layers
	<b>Marble Bronzo</b>	Calcitic and/or Travertine	

<b>Sintered, diamond-edged for cutting granite and hard and/or abrasive rock</b>			
<i>Diameter</i>	<i>Bead</i>	<i>Material</i>	<i>Sintering layers</i>
11mm	<b>Standard</b>	All types of granite	1.20mm
	<b>Plus Norway</b>	Low hardness/large cuts/ Low power machines	1.45mm
	<b>Super Plus</b>	Universal for granite	1.70mm
	<b>Super Plus CF</b>	For extremely powerful machines/ low seams	1.70mm
	<b>Mega Plus</b>	Universal for granite	2.20mm
	<b>Mega Plus CF</b>	For extremely powerful machines / low bearings	2.20mm
10mm	<b>Standard</b>	Universal for granite	1.20mm
	<b>Plus</b>	Latest generation for granite	1.70mm
9mm	<b>9 Plus</b>	Granite	1.60mm
8mm	<b>Standard</b>	All types of granite	0.95mm
	<b>Plus 2001</b>	Very hard materials	1.20mm
	<b>Plus Standard</b>	Universal for granite	1.20mm

7mm	Beads for multiwire machines and for spitting slabs, all types of granite	0.85mm
6mm	Multiwire machines and splitting slabs, all types granite	0.85mm

<b>Sintered, diamond-edged for cutting concrete</b>			
<i>Diameter</i>	<i>Bead</i>	<i>Material</i>	<i>Sintering layers</i>
11mm	<b>Concrete</b>		1.25mm
	<b>Super Plust</b>		1.70mm

<b>Electroplated, diamond-edged beads for cutting marble and medium and/or low hardness stone</b>				
<i>Diameter</i>	<i>Bead</i>	<i>Type</i>	<i>Band</i>	<i>Lenght</i>
10mm	<b>Electroplated Bead</b>	EDSM CR10E	4.5mm	8.8mm
	<b>Standard Electroplated</b>	EDSM 10 T3	5.5mm	9.8mm
10.7mm	<b>Super Electroplated</b>	ED XC10XT	6mm	10mm
For small sized cuts, lower than 50m <sup>2</sup> , for squaring, bead with diamond-edged band centered on the pin				
10.3mm	<b>Super Electroplated</b>	<b>ED XM10XT</b>	7mm	11mm
For large cuts greater than 50m <sup>2</sup> , bead with diamond-edged band not centered on the pin				
10.3mm	<b>Super Electroplated for Squaring in quarry</b>	ED XM10600	7MM	11mm
8mm	<b>Electroplated Bead</b>	EDSM 08		
6mm	<b>Electroplated Bead</b>	EDSM 06		
10.3mm	<b>Super Electroplated for Concrete</b>	ED XC10	7mm	11mm

*These are dry cutting. Co.FI.Plast has recently introduced the electroplated beads for the dry cutting in quarries. Technologically patented, their geometry has been designed to reach an average speed of 10 sqmt/h. The bead can be used on all material on the MOHS scale from 1 to 4 (limestone, dolomite, sandstones, etc.).*

**Appendix 2 – Kitchen manufacturing scheme**

