Mass Customization:
An analysis of planning and control issues and solutions in operations, when a market demands increasing flexibility

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ABSTRACT

Due to the progression of the Internet in the recent decades, and the advances in production techniques, the practice of mass customization has become a hot topic. This evolution of things has forced companies into offering customized products at a large scale production, with low costs, short lead-times, high quality and a high degree of flexibility. This paper takes a look at mass customization with the central question of: How can a production company optimize its operations capabilities, in a market where the market demand is shifting towards mass customization?

First, the levels of customization are discussed, revealing four levels of customization in the production process. Out of these four levels of customization, two of them are identified as being mass customization, namely assembly-to-order and make-to-order production. Further the paper identifies the operations capabilities, and discusses these in the context of mass customization, identifying flexibility, speed and cost as the most important to excel in.

Then the enablers of mass customization are discussed in relation to the operations capabilities identified, as well as the levels of mass customization defined. For the enablers, the philosophies of Lean and Agility are discussed as well as the combination of Leagility. Further discussed is the use of modularity in the assembly-to-order and make-to-order production showing great ties with both Leagility and postponement. The last enabler discussed is digitalization, which plays a large role in making the option available to the customers.

Finally the planning and materials flow control mechanisms are discussed in relation to the levels of mass customization, the operations capabilities. The mechanisms discussed in the paper are MRP, Kanban, CONWIP, m-CONWIP and POLCA. The paper finds that the most suitable mechanism for doing customization in a mass customization context is the m-CONWIP and the POLCA, whereas the Kanban and CONWIP can be used in the upstream stages of modular production. Further, the MRP should only be used as a higher level planning mechanism.
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CHAPTER 1 – INTRODUCTION

Back in the early 20th century, Henry Ford could sell his cars by letting costumers choose “…any color they wanted, as long as it was black.” (McMurray, 2004). This was to allow as little variation in the production line as possible, and costumers allowed it at the time. This was due to the market being young, and the order-winning factors, were at a very low level. However, about ten years later, one color was not enough for the costumers, and they began buying cars from other companies, like Buick and Chrysler, which offered a wider variety options, i.e. a higher degree of customization.

As time progresses, and the market matures, these order-winning factors will erode, as competing companies will eventually adopt the same winning factors (Slack & Lewis, 2011). The costumers will then expect these factors in the specific product and thus it has been turned into an order-qualifying factor. Companies are thus forced to offer costumers more and more options in their products as competitors start to offer more and more of the same options.

This continuous evolution of order qualifying- and winning factors, has in some markets led to companies having to offer customized products in order to keep up with the trends and survive in the current business environment. But what defines customization? According to a literature review by (Duray, Ward, Milligan, & Berry, 2000), customization is not only having a hundred different options available for the costumer at the store. This only provides the costumer a choice between a variety of products, leaving them with no influence on the products. On the contrary customized product is defined as a product, where the customers are involved in the process of specifying the product, and designing it to meet their own needs.

However not all customization is the same. (Duray et al., 2000) show, through their literature review, that the degree or type of customization depends on the point in the production cycle where the initial customer involvement is. They define four points in the production cycle, where each of the points is an expression of the degree of customization: Design, fabrication, assembly and use. The first three are quite easily recognized as commonly know, engineer-to-order (ETO), make-to-order (MTO) and
assembly-to-order (ATO). The ‘use’ dimension, which is normally known as make-to-stock (MTS), and is normally considered as standard, mass-produced products, is in this case defined as products which can be modified by the costumer, at the usage stage, to provide customization, and should thus also be regarded as a customized product.

One of the never approaches to customization is the mass customization. This is a strategy, which have received an increasing amount of attention in the last two decades, not only from industries and companies, but also from researchers looking deeper and deeper into the subject. The mass customization strategy is focused on producing personalized goods or services, at near mass-produced costs, through modularized designs, flexibility and a company-costumer interaction at some point in the production cycle (Kaplan & Haenlein, 2006), (Fogliatto, da Silveira, & Borenstein, 2012).

Customization has been highly enabled by the progression of the Internet (Schulz, 2007). The Internet has enabled customers to get in touch with the companies more easily, and thereby breaking down the contact barrier (Juergen, 2011). It has also decreased the cost of sharing data between costumers and companies to zero, and has thus made it affordable for the costumer to customize the products they buy. Furthermore the fact that the technologies used on the Internet that have made it possible for costumers to design their products online, has been a major driver of mass customization.

This trend of mass customization has come at a convenient time, as the ‘generation Y’, often defined as people born around the 1980’s, are now in their 20’s and are drawn to products that, define and broadcast their personalities (Palmer, 2008). E.g. mass customization has made it possible for all groups of costumers to afford customized products, in contrast to earlier where only the people with money could afford it, especially now that costumers are realizing that it is available to them.

The trend has grown so much that, according to a study by Forrester Research, that about “Seventy percent of product strategists currently offer customized products” (Juergen, 2011). An example of an industry that applies the mass customization as standard is, the Sports shoe industry, with major manufacturers such as Nike (Schulz, 2007), Rebook (Palmer, 2008), and Adidas (Schulz, 2007). Where the first two examples offer costumers the opportunity to customize the shoes with regards to
designing it from a selection of colors etc. Adidas allows its customers to choose from a wide selection of lasts as well, so the shoe will have a perfect fit on your foot. Other industries such as the automobile industry, with major players such as Ford (McMurray, 2004), allows customers to add different components to the car at the factory stage. Also the computing industry, is engaging in mass customization, where Dell (Juergen, 2011) lets consumers customize the speed, capacity etc., of their products when buying a computer.

1.1 Problem Statement

As many companies, in the industries where customization increasingly is becoming a qualifying factor, are forces into mass customization, it is important for them to realign their operations strategies. This realignment of operations is in many ways not an easy task, however it is perhaps the most important part of the company, to succeed when a restructuring of strategies like this, takes place. Therefore this paper will focus on the operations aspect of companies in the setting of moving towards a higher degree of customization, in their product line. The specific research question will be as follows:

“How can a production company optimize its operations capabilities, in a market where the market demand is shifting towards mass customization?”

To answer this question I have come up with a series of sub questions stated below.

1. What are the characteristics of the different levels of mass customization?

2. Which operations capabilities are important for a company doing mass customization?

3. What enablers are required to implement mass customization successfully into the operational part of a company

4. What is the most suitable tool for production in mass customization?
1.2 Organization of the paper

The first section is comprised of chapters one and two. Chapter one, of this paper, contains the introduction to the subject of mass customization, how the markets have evolved into it, and the implications that it has for the manufacturers, as well as which direction the paper will take. The second chapter is concerned with the methodology of the paper. The second section is the main section of the literature study, and is comprised of chapters three to six, which all addresses the sub questions to the problem statement set out in the introduction of this paper. Chapter three focuses on defining mass customization and identify on which levels it can take place, and to what extent. The fourth chapter discusses the different operations capabilities in the context of mass customization, trying to identify the factors, which would be most important for manufacturers in mass customization on a general basis. Chapter five then discusses the enablers of mass customization, i.e. factors or methods that needs to be present, for the implementation of mass customization to be successful. Chapter six looks at some of the different kinds of planning and materials flow control systems that are commonly used in the manufacturing industry. The chapter will take a look at the components of the systems and see how they would work in a mass customization environment. The third and last section is the results and conclusion part, containing chapter seven. It will try and summarize the findings of section two, and give an overview of how companies moving into the mass customization industry should adjust to be able to survive. At the end of the chapter it will come up with an answer to the problem statement set out in the introduction.

1.3 Delimitation

In optimizing the operations capabilities in a mass customization context, as well as in most other contexts, it requires the alignment of the whole supply chain, from suppliers, to the operations of the company and on to the customer. However this paper will mainly focus on the operational aspects of entering a mass customization market. Even though there are many approaches a company can take to manage its operations, this paper will try and focus on the more central issues and components of mass customization, which is considered to be the most relevant for this paper. The paper will
have a focus on goods manufacturers, and will thus not discuss mass customization in services.

Even though companies are often perceived to use a specific strategy or method, many of these often utilize an altered version of these. This paper will take a look at the strategies from a theoretical point of view and disregard any inconsistencies there might occur with strategies in companies.

1.4 Definitions

Production process
This paper will use the term ‘production process’ throughout. It is defined as the process between, when the order is released, and the first work starts on the product, up until the point in the process when the final product is finished and ready to be shipped, or picked up by the costumer.

Workstation
In this paper the terms ‘workstation’ and ‘cell’ will be used synonymously, to mean a physically separated entity of the production line, or shop floor layout, with its own specialized part in the production process.

CHAPTER 2 – METHODOLOGY

This paper has been performed by the use of a literature study. The literature study has been based on scientific articles, as well as a few relevant books. The primary way of finding the articles used in this study has been through the search database “Business source complete”. Also databases such as “Science Direct” and “Emerald” have been utilized for the purpose. To find books on the subject, the Aarhus University library has been the main source, as well as they have been helpful in finding some of the scientific articles.

The initial search for articles was done by using search terms such as “mass customization”. These results was narrowed down by studying the abstracts of the articles in terms of the applicability of the information in the context of this paper.
Studying these papers lead to an expansion of the search to include search terms like, “operations capabilities”, “planning and control”, “enablers of mass customization”, and “customization modes”. A further study of the research papers, lead to search terms such as “modularity”, “postponement”, “Kanban”, etc.

Most articles used are from generally accepted academic and scientific journals, such as the “International Journal of Production Economics” and the “Harvard Business Review”. The books used are by widely accepted authors within their fields, and has been cited often throughout the articles studied in the process of this paper.

CHAPTER 3 – MODES OF CUSTOMIZATION

There are a couple of different views on what exactly the term mass customization covers, and to what extend it can be called ‘customization’, ‘mass customization’ or ‘mass production’. Further, the degree of customization, or the different Mass customization levels, has been discussed in the literature as well. To find out what characterizes mass customization, as well as the different modes, or levels, the following sub-question, from the introduction, is going to be considered.

*What are the characteristics of the different levels of mass customization?*

It is generally accepted that the degree of customization varies in accordance with the time of interaction with the customer, in the production cycle (Duray et al., 2000). Although authors have different expression for this point of interaction with the customer, it seems that the traditional understanding of this is coined by the term of the Costumer Order Decoupling point (CODP). The CODP is defined as the place in the production and assembly of a product, where the costumers’ enquirers are introduced into the operations (Wang, Lin, & Liu, 2010). The more upstream the CODP is, the more order driven the products become, and thus has a higher degree of customization. Similarly, the more downstream it is, the more forecast driven, and thus standardized, the products become. There are typically four positions, of the CODP, defined, i.e. engineer-to-order (ETO), make-to-order (MTO), assemble-to-order (ATO), and make-to-stock (MTS). Figure 1 illustrates the interaction between the point of customer
interaction and the degree of customization. Furthermore, it illustration of the different levels of the CODP in relation to the point of customer interaction.

(Lampel & Mintzberg, 1996) characterizes four types of interaction modes which fit into the this terminology. These are: pure customization, tailored customization, customized standardization, and pure standardization. The pure customization can be characterized as ETO as the customers’ wishes are considered at the design stage of the production, and thus the product is designed and engineered into a highly customized product. The tailored customization corresponds to the degree of customization of an MTO product, where the customer interacts with the company at the fabrication stage of the production. These products can be adapted or tailored from an existing design to fit the customers’ needs. The customized standardization is an ATO strategy, where the customer is given the choice of a set number of components that can incorporate into the end product. In this connection (Lampel & Mintzberg, 1996) mentions the production of automobiles, where the customer can chose between a number of colors, interior materials, etc. Finally the pure standardization is pure MTS production where the products is designed and produced in very low variety. The customer does not

![Figure 1 – point of customer interaction vs. the degree of customization](image)
interact with the company until the time of purchase of the final product, thus the company makes no distinction between the customers. (Lampel & Mintzberg, 1996) also presents a fifth category called segmented standardization. This category has the same CODP as pure standardization, however it is defined as giving the customer some extra choice when buying the product. The difference between this category and pure standardization is that segmented standardization allows the customer to make small modifications to parts of the product design.

In the case of (Da Silveira, Borenstein, & Fogliatto, 2001) they identify eight different levels of mass customization are identified. The four main levels are: ‘design’, ‘fabrication’, ‘assembly’ and ‘standardization’, whereas the four additional levels are: ‘additional custom work’, ‘additional services’, ‘package and distribution’, and ‘usage’. The first level, design, is the stage where the customer enters the production cycle before manufacturing has begun, making it an ETO strategy. The fabrication strategy is custom tailored products, produced from a predefined design, thus making it a MTO production. The assembly strategy is mainly focused on configuring modular components into many different kinds of products, in accordance with the customer orders, and is as such considered an ATO strategy. They use the standardization strategy as a referral to (Lampel & Mintzberg, 1996) ‘pure standardization’ strategy, and is thus an MTS strategy.

The three levels, ‘additional custom work’, ‘additional services’, and ‘usage’, all have the customization at, or after, the point of sale, making them all MTS, in the matter of this framework. The ‘package and distribution’ level customizes at the packaging level, by for example, differentiating the packaging for different regions and customers, however the products are still MTS products and this will therefore be considered as such in this framework. As these last four levels are considered as MTS, and thereby has a production equal to the standardization level, they will go under the standardization label, and will thus not be considered further in this paper.

Furthermore (Duray et al., 2000) presents the ideas of (Mintzberg, 1988). He views customization divided into three categories, which are pure, tailored and standardized. The pure strategy contains products, which has been designed and produced to the customer specifications, i.e. the CODP has been at the design phase making it ETO. The
tailored strategy considers the customer at the fabrication stage, working from working from a basic design to create a product that is customized. The standardized strategy is the equivalent to the ATO strategy, where the customer can choose from a predetermined set of options to customize a predesigned and fabricated product.

(Gilmore & Pine II, 1997) identifies four approaches to customization being ‘collaborative’, ‘transparent’, ‘adaptive’ and ‘cosmetic’. These approaches are distributed on two dimensions, 1. Customization in the product itself, and 2. Customization on the representation of the product, e.g. the packaging. Collaborative customization lets customers engage in the design process of the production cycle, and decide how the product should fit. The example given by (Gilmore & Pine II, 1997), describes a shoe store who custom makes the shoe to fit the exact size of the customers foot. The collaborative customization is thus considered an ETO strategy in this context. The adaptive customization strategy, allows customers to modify, or adapt, their products after the point-of-purchase, and the production of each item is thus similar, making it an MTS product. In cosmetic customization, the company differentiates the product on e.g. its packaging and how it is displayed in the store. This strategy is thus not relevant for the purpose of this paper, as the product is a standard product in terms of the production. Finally the transparent customization strategy has its focus on the customization of products without the customer realizing it, using market knowledge to achieve this. One could say that it is kind of an ETO as the product is tailored through analyzing what the customer wants, however the actual CODP is at the point-of-purchase, making it an MTS strategy. For the purpose of this paper it will thus be disregarded, as it does not fit into the framework of the CODP.

(Pine II, 1993) presents five types of mass customization, and doing so identifies four levels of CODP’s. He proposes the use of ‘Quick Response’ through optimization of the whole value chain in the company. This would allow for faster production of the products customers want, when they want them. (Pine II, 1993) uses this as his top level of customization, having customers define what they want at the engineering stage, making it an ETO strategy. As Quick Response optimizes the whole supply chain it could be used for most other CODP’s, however it would give the highest advantage, when implying a time-based-competition (TBC) strategy, to allow for fast delivery of completely customized products. The second type of customization, which is proposed,
is ‘modularity’. Modularity allows for pre-production of a standard set of components, which can then be combined to create a customized product. Modularity is further discussed in chapter five. The modularity strategy is positioned at the MTO as well as at the ATO, depending on the type and degree of modularity used. The third type of customization is called ‘point-of-delivery’. This type of customization lets the customer pick a standard product and then make minor customization to it within a couple of hours from ordering it. This type of products could be cloth, e.g. stock suits that are then tailored to fit the customer, or t-shirts that can be customized by adding a vast variety of heat-applied prints directly at the shop. The point-of-delivery strategy is at a point between ATO and MTS, as the products produced are standard stock items, however there is some minor customization at the delivery point. The strategy of ‘customizable products’ provided the customer with a standard produced product, which does not contain any kind of customization throughout the production cycle. In stead it can be customized by the customer at the use stage, e.g. office chairs which can be adjusted into many different positions and angles by the customer after the purchase. The fact that every product sold, is identical and standardized makes it an MTS strategy. The last type of customization presented by (Pine II, 1993), is the ‘customization through service’ strategy. Here the company sells standard product and provides any tailoring or customization as a service, after the purchase of the product. An example of this could be computer systems, that are bought as standard products, and is then put together as a service for the customer. This strategy has a CODP at the MTS however no customization is made to the product in the production, but through a service, so this strategy will be disregarded in this paper.

Finally (Duray et al., 2000) uses the points of customer involvement which are ‘design’, ‘fabrication’, ‘assembly’ and ‘use’. These point reffers to the point at which the customer is introduced in the production process. The three highest levels of customization, design, fabrication and assembly, has the same characteristics as those of (Da Silveira et al., 2001) by the same names. The lowest level of customization does differ by name, however the meaning of the two is the same. By using, ‘use’ as the label for the level that characterises MTS, (Duray et al., 2000) tries to stay in the same same terminology as the other levels, and labels it after where the costumer enters the customization process, and that is at the use of the product.
These levels of customization is summericed in figure 2, providing a good overwiev over the literatures definition on the levels of customer integration in the production process. It is clear to see that many of the authors stay in the grid of the CODP framwork. Although there are some coherence in the way of characterizing different levels of mass customization, there are some authors that has another view. Although they have been sought implemented into the framework of the CODP in figure 2, (Gilmore & Pine II, 1997; Pine II, 1993) has somewhat different approaches. These articles fokus more on defining types of customization than on the different levels of customer involvement, which is in the CODP framework.

(Pine II, 1993) uses four key links in the organisations value chain, to define the kind of mass production. These four key links are: development, production, marketing, and delivery. Then the different kinds of mass customization is characterised by which combination of the links of the value chain, the customization happends in. However it does not appear to be any way to identify mass customization by using the framework, but it merely appears that the value chain is a means of illustrating which areas are effected by predetermined methods.

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*Figure 2 – levels of customer decoupling points in mass customization*
Unlike (Pine II, 1993) the framework of (Gilmore & Pine II, 1997) defines four approaches to customization by means of defining two dimension. One dimension distinguishes between approaches which makes changes to the actual product, and those which leaves the products unchanged as part of the customization. The second dimension distinguishes between products which makes changes on the representation, e.g. packaging, as part of the customization of the product. This framework, lacks the variety of the CODP, however it does bring up an interesting view of customization being possible not only through product features, but also through its representation.

Although (Duray et al., 2000) uses the point of customer involvement to characterize the CODP, and thereby also the degree of customization, he also proposes four different groupings of mass customization. They use four categories of modularity, i.e. ‘design’, ‘fabrication’, ‘assembly’ and ‘use’, as well as the four points of customer involvement to create a matrix, illustrated in appendix 1. He defines the types of modularity as, when the modules are designed to be altered or modified, it is categorized in the design and fabrication stages, whereas when a module are meant to be added or interchanged, they are categorized as ‘assembly’ and use ‘stages’. From this matrix they derive the four groupings of mass customization, i.e. ‘fabricator’, ‘involvors’, ‘modularizers’ and ‘assemblers’.

The fabricators involve the customer early in the production cycle, as well as using modules which they can modify to produce the customized product as the customer wants (Duray et al., 2000). This strategy reassembles the traditional strategy of ETO, with its highly customizable products. The group of involvers, involve the customer in the process at the ‘design’ or ‘fabrication’ stage, however they do not make any customization until the ‘assembly’ or ‘use’ stages. This early involvement could give the customer an increased sense of customization or ownership, although they do not receive additional customization than that of the assemblers. Furthermore the involvers could take advantage of the early customer involvement, and late modularity, to gain a higher degree of economies of scale, than that of the fabricators. The modularizers have the point of customer involvement at the ‘assembly’ and ‘use’ stages, whereas the type of modularity is of the kind of ‘design’ and ‘fabrication’. This requires the company to incorporate a modular approach in the early stages of production, so the products can be customized to the customers order later in the production cycle. The last group is the
assemblers. This group incorporates the customer in the production cycle at a late stage i.e. ‘assembly’ or ‘use’, and the type of modularity used is ‘assembly’ and ‘use’ as well. By using modular components that is assembled into customized products, the company provides customization to the customer on a ATO basis. According to (Duray et al., 2000) this group is the one group that reassembles mass production the most. However, as the choice of components, that the customer can choose from, is very large, the customer perceives this kind of products as custom made. This reassemblence with mass production gives the companies the advantage of being able to utilize the concept of economies of scale, better than the other types of companies.

This framework by (Duray et al., 2000) proposes not only a framework to identify different kinds of mass customization, but also a framework to identify companies whom does not possess the capabilities of mass customization. This is due to the arguments put forward by (Duray et al., 2000), that only manufacturers possessing both customer involvement as well as some degree of modularity are mass customizers. Without the involvement of the customer in the production process, a product cannot be characterised as customized and thus falls out of the mass customization framework. Further if the production process does include the customer, but does not contain any form of modularity, the product is thus a traditionally customized product, and thus falls out of the framework of mass customization. The fact that modularity is a prerequisite to performing mass customization, is supported by e.g. (Pine II, 1993), who states that true mass customization requires modularity.

Although there are arguments that mass customization takes place in all the four categories of the CODP, it should be noted that this framework of (Duray et al., 2000) does seem to eliminate both the MTS and ETO from being mass customization strategies. The MTS approach does not contain any custumer involvement in the whole spand of the design and production thus it lies outside the scope of mass customization. Although some argue (Gilmore & Pine II, 1997; Lampel & Mintzberg, 1996), that MTS products can by customized for the masses by giving the customer the opportunity of adjusting the products, they do not satisfy the framework by (Duray et al., 2000). The ETO strategy does not make use of modularization, due to the strategy of completely customizing the product from the design stage. This makes it more of a traditional customization approach, and it is then left out of the framework. This leaves two levels
of mass customization, which both satisfy the criteria of modularity, and customer interaction.

CHAPTER 4 – OPERATIONS CAPABILITIES

When talking about operations capabilities in this paper, it will be referring to the aspects of: Quality, speed, dependability, flexibility, and cost, and how the manufacturing company masters these in terms of their products. The operations capabilities are known under many different terms, e.g. (Slack & Lewis, 2011) calls them ‘market requirements’ and (Ferdows & De Meyer, 1990) calls them ‘manufacturing capabilities’. Quality is the aspect of being able to produce a product at a given standard, with regards to different attributes like design, how durable it is, and how easily it is broken. The speed, or time, aspect evaluates how fast the company is to provide or produce the product, and is variable in many places other than the production facilities, e.g. handling of an incoming order before it reaches production. Dependability is sometimes confused with speed, as it is the ability to deliver on time, however dependability is the ability to deliver on time. Cost is the ability to produce the product at a low expense, and in return yield a higher profit on the sales price.

To try and divide the operations capabilities into groups of their importance to the mass customizing company, each capability will be sought put into the framework of the order winning and qualifying factors. The order-qualifying factors are the aspects that needs to be at a specific level for the customer to even consider the product (Slack & Lewis, 2011). These aspects may not be of a kind that has a competitive edge compared to competitors, but must be maintained to achieve sales. The order-winning factors are the aspects that help persuade the customer into buying the product.

To find out how the operations capabilities link to the theory of mass customization, we will use the first of the sub questions, stated in the introduction:

*Which operations capabilities are important for a company doing mass customization?*
4.1 Flexibility

For the flexibility aspect, it shows how well the company copes with change in demand, production etc., so when looking at customization, and in this case mass customization, the aspect of flexibility is of the essence. When talking about different stages or modes of customization it is actually the change in the aspect of flexibility that is discussed, and the interaction of the two should thus be a logical consequence. As it is linked to the different modes of customization, including the CODP, it is not necessary to look at flexibility in the same context as the other operations capabilities. Instead the flexibility term should be used as a variable to measure the other factors against.

In the context of mass customization, flexibility can either be an order winning or qualifying factor, depending on what it is measured against, i.e. what kind of product the customer is looking for. For example, if the customer is looking for a product that can be both standardized as well as customized, then the flexibility could make for an order-winning factor. This could for example be illustrated by buying a computer, where Dell could have the advantage by offering flexibility compared to other computer manufacturers. However if the customer were looking for a customized product, then flexibility would only be an order-qualifying factor.

4.2 Cost

Many authors identify low cost as one of the most important aspects of mass customization. Authors such as (Da Silveira et al., 2001) and (Piller & Kumar, 2006), implies the importance of the cost perspective by including it in their definition of mass customization. They do this by mentioning that mass customization has the low costs, which is normally associated, only with mass production. One of their definitions is stating that mass customization is a system, which is capable of delivering “…a wide range of products and services that meet specific needs of individual customers (often defined by a series of options), at a cost near that of mass-produced items.” (Da Silveira et al., 2001).
Some authors, like (Rudberg & Wikner, 2004), point out that there has been a tradeoff present for many years, between flexibility and productivity, i.e. cost, in all kinds of production. However, new manufacturing environments have enabled mass customization to, somewhat, work around these tradeoffs. Companies employing mass customization methods, still have to identify where the optimal balance, between the two factors, is in order to gain the full potential. The authors argue that the balance point between the two factors determine the positioning of the CODP. The further upstream the CODP is, the more flexibility would be the main strategic capability, whereas if it is moved downstream in the production process, there will be more emphasis on the productivity, and thus making costs as low as possible. Sources such as (Pine II, Victor, & Boynton, 1993) however, argues that the traditional beliefs of cost vs. flexibility belongs in the past. Beforehand the assumption was that the two factors, cost and flexibility, required each of their own organizational structure, and so they could not be combined and the companies face a tradeoff between the two. The authors argue that the old assumption that the two different factors cannot be combined, has now been broken with the development of mass customization. Figure 3 illustrates how the traditional beliefs and the more modern mass customization methods differentiate on the tradeoff of cost and flexibility. It clearly illustrates how the mass customization has changed the game, and allowed for much lower costs than the traditional customization approaches.

![Figure 3. Customer Order Decoupling Point in the Flexibility / Cost tradeoff](image-url)
With the amount of research acknowledging the importance of cost in mass customization, it can thus be inferred that cost could be an order-winning factor. This meaning that customers can be won over by the lower costs, and possibly lower prices on the products, as well as the company will yield higher profits and have an easier time surviving.

4.3 Speed

A group of authors going in another direction is, (Trentin, Perin, & Forza, 2011), and (McCutcheon & Raturi, 1994), who focus mainly on the concept if time being an important performance capability in the operations of producing a customized product. Included in this measure of the time is the production time, including set-up time, queue time, move time and actual production time, as well as waiting times external to the production, like delivery of, and receiving of orders. The reason for them to focus on the time performance is to address the trend of the so-called customization- responsiveness squeeze, where customers are demanding both customized or specialized products along with short delivery lead-times. This trend forces manufacturers to have an order lead-time, of less time than it takes to actually manufacture the product. Furthermore, (Trentin et al., 2011) mentions that the lead-times of the products are, effected by the position of the CODP, i.e. a tradeoff between lead-times and flexibility. Figure 4 illustrates this tradeoff between lead-time and flexibility, and furthermore shows how mass customization has been able to cut down the lead-time of customized products.

(Pine II, 1993) supports the notion of time being of the essence in mass customization. His view on time is that the main focus should be directly on the ‘process throughput efficiency’, in contrast to the traditional mass production where focus is on the operational efficiency. The total process efficiency includes both the time that the product is in productive stages, as well as unproductive stages, like queuing, sitting in inventory, moving from one place to another, reworking defects, etc. By focusing on the process efficiency, and thus speed, it is possible to get the side effects of this and have lower costs, a better response time, and becoming better at coping with the flexibility. Furthermore (Pine II, 1993) describes mass customization as producing affordable, high quality, customized products, correlating with the definition of many authors. Also
(Riezebos, 2010) agrees that most customization companies should have a strong focus on throughput times, to be able to stay in the market.

The speed aspect could well be an order-winning aspect when comparing to traditional customization, where lead-times are often longer than, when using mass customization practices. Although, in some situations, lead-time could be a qualifying factor, if for example the product has a smaller degree of customization, and thus might compete with readely available mass-produced products.

### 4.4 Quality

When looking through the literature, it is obvious to see that quality, as such, is not considered an important operations capability; in the sense that authors do not consider it a variable in the equation between mass customization and mass production. It has thus not been discussed to the extent of the other capabilities, making it difficult to discuss in this section. That said, many authors, like (Pine II, 1993), implies, in their writings on, and definitions of mass customization, that quality should be of the same, or higher, quality than mass-produced goods. This is illustrated in figure 5 where the quality of mass customization is shown as having close to similar level of quality as

![Figure 4. Customer Order Decoupling Point in the Flexibility / lead-time tradeoff](image-url)
compared to the traditional production. It could well mean that quality could be the most important operations capability to master in mass customization, however it might not be suitable to use it as a factor in this context, as the difference in quality between mass customization and mass production should be zero.

That the quality needs to have the same or higher quality than mass-produced products, as implied by the authors writing about mass customization, makes it, a qualifying factor. This is thus even true for mass-produced products competing with mass customized products, as well as within the segment of mass customized products.

4.5 Dependability

The aspect of dependability on mass customized products, has not been covered in the literature, and can thus not be commented thoroughly on. The absence of this aspect in the literature does not necessarily mean that it is not important, however it could mean that it is not seen as an obstacle in the operations aspect of mass customization. This would show that the production methods used in mass customization, does not have any significant difference on the dependability aspect, compare to normal mass production, and thus is not mentioned. As dependability has not been mentioned much in the literature, it makes it hard to classify, however it can be assumed that it is a qualifying

![Figure 5. Customer Order Decoupling Point in the Flexibility / quality tradeoff](image)
factor, as the dependability of stock products can be assumed to be highly dependable. Thus products competing with stock products thus have a hard time competing with the dependability, and thus making it a qualifying factor for the mass customizers.

CHAPTER 5 – ENABLERS OF MASS CUSTOMIZATION

As defined by (Da Silveira et al., 2001), the enablers of mass customization are “…the methodologies and technologies that support the development of the organization-based factors.” (Da Silveira et al., 2001). There are four of these organization-based factors:

1. The value chain must be ready, as mass customization requires its supply chains willingness and readiness to be able to acquire raw materials efficiently.

2. The technology must be available, as it depends on the powers of technology to be able to communicate and produce goods, at the rate cost and quality that is required.

3. Products should be customizable, meaning it should be possible to assemble individual units into different products.

4. Knowledge must be shared, as the company should be able to pick up on new customer trends and demands, and be able to translate them into new products.

These factors cover the whole of mass customization, however, in this paper the main focus is on the operational aspects of the company, and so there might be areas that the discussion of the enablers will not cover, due to irrelevance to the subject. To take a closer look at the enablers, the following question has been identified.

Which enablers are required to implement mass customization successfully into the operational part of a company?

The enablers selected to make the basis of this section are Lean, Agility and the combination of the two. Furthermore the concepts of platforms, modularity, and postponement will be discussed as part of the enablers.
5.1 Lean

The principles of Lean, or leanness, was first introduced by the Japanese car manufacturer, Toyota, and this is how the term ‘muda’ makes its way unto the Lean terminology (Womack & Jones, 1996). Muda means ‘waste’ in Japanese, and waste is what Lean is all about: it seeks to eliminate all waste created in all aspects of a production. Waste is, in this context, defined as any activity, which uses resources, but does not produce any value, such as: mistakes on orders or products that does not meet costumers needs, steps in production which is not actually needed, pileups of inventories due to low costumer willingness to buy, movement of goods or persons without any reason, and workers in a downstream production unit waiting for products from an upstream unit because it has not delivered on time. Lean relies on a set of principles to achieve the desired effect of eliminating waste. These principles are: to specify what and who defines the value of the product, to identify the value stream of each product, to make all of the steps, from taking the order to delivering the product, flow, to let the costumers pull the products, and lastly to make all of the previous steps perfect.

Identifying value

When defining the value of a product in Lean, it is very important to look at what the costumer values in the specific product, as according to (Womack & Jones, 1996) many companies never realize what their costumers want. They use an example of a company making wire guides, often found in office building etc., where the wires are kept inside the guides and allows for outlets to plug into. The company thought that what their costumers wanted was to have a rugged, cheap product with a high degree of safety. However after performing a survey they found out that what costumer also wanted was to have a product, which had a nicer design. And by designing the look of the wire guides they created new value, or in other words they eliminated the waste of the product not fitting their costumers needs.

Analyzing the value stream

The value stream is all the activities taking place along the journey of a product, from the raw materials are handled for the first time, to the final product is received by the costumer (Womack & Jones, 1996). By analyzing the value stream it should be possible
to identify which activities are actually adding value to the product, and more importantly which activities that are non-value adding. These activities could be materials waiting in storage, for several weeks, before they are actually needed, and is therefore adding no value, making it by definition, waste. When this principle is perfected, the value stream will only consist of value adding activities, as seen from the costumers perspective, and nothing will ever have to sit around in a warehouse. Rather parts and materials would arrive, just as they are needed, i.e. taken out of the delivery truck and directly into production. This is also the principle of the flow management system; invented in the 1950’s, known as ‘Just-In-Time’.

To generate flow
The idea of Just-In-Time goes on in the flow principle of Lean. To achieve flow the production line in a company must be broken up and realigned so that each product family has a separate smaller production line (Womack & Jones, 1996). This will give fewer changes in production and fewer setups, resulting in more production times in the different parts of the production line, and fewer breakups in production yielding more flow. Further, the flow principle adjusts recourses in the different workstations in the production lines, such that the throughput time for each station is equal, getting the same pace throughout the production line, allowing the products to flow continuously.

The Lean pull
The principle of pull in a Lean production, works by not letting an upstream cell start production before it has received a signal from the downstream cell, directly following it (Womack & Jones, 1996). This principle of pull, in the production, is guided and controlled by the Kanban system, and if perfected this pull effect leads to zero WIP inventory.

5.2 Agility
To be an agile company, or to have Agility, a company must possess a set of characteristics: To be able to respond quickly as well as efficiently to changes, both expected and unexpected, while at the same time meeting customers requirements, which is mostly varied, in terms of price, quality, quantity and delivery (Bottani, 2010). The term ‘Agility’ has received allot of attention from scholars since its introduction in
1991 by researcher at the Iacocca institute, however researchers are still struggling to find a commonly accepted definition of the term (Narasimhan, Swink, & Kim, 2006). For example, (Naylor, Naim, & Berry, 1999) defines Agility as the ability to use knowledge and virtual corporation to exploit opportunities in an unpredictable market, whereas (Narasimhan et al., 2006) defines it as the ability to make changes in the operations as a response to the changes in the market, or as a response to unique customer requests. (Brown & Bessant, 2003) supports the definition by (Narasimhan et al., 2006), but adds that Agility also proactively prepares for the future market opportunities. Further, (Barutçu, 2007) defines Agility as a technology that a company can use to achieve more flexibility and higher responsiveness. Although researchers cannot seem to agree on a common definition of the term they do seem to agree on the overall understanding of the matter, i.e. Agility increases the capability of responding to high variety in demand, and uses this capability to exploit the opportunities in the market.

Like Lean, a decrease in non-value adding activities is amongst the benefits of agile manufacturing (Bottani, 2010). Further benefits derived from agile manufacturing are, lower operations costs, and an increase in the companies competitiveness. The main drivers of the integration of an agile strategy, into an enterprise, come from customers’ demands, the market place and the competition, as well as technology and Social factors.

This discussion of drivers fits very well into the terminology of mass customization, where, as written in the introduction of this paper, the customers’ demands are increasing, the competition is getting fierce, the technology is driving the progress faster and faster, as well as the social factors in the society has a major impact on the development, recalling the discussion on the generation Y. Some authors, such as (Vinodh, Sundararaj, Devadasan, Kuttalingam, & Rajanayagam, 2010), highlights this connection between Agility and mas customization. They notice that only a few researchers working on Agility have touched upon the term of mass customization, whereas many researchers who study mass customization have been able to connect the two terms in their research. This last group of researchers has in many cases been broadening their definitions of mass customization to incorporate some of the attributes of Agility into them. Furthermore it is mentioned that these authors have seen agile
manufacturing as extension of mass customization. (Vinodh et al., 2010) notice through their literature study that, whereas Agility is based on responding fast to customer demands, mass customization does not put too much emphasis on the matter of quick response. A study of the definitions has lead to the conclusion that the outcome of agile manufacturing is mass customization, i.e. using agile manufacturing to obtain mass customization.

Another line of thought, on the topic of the connection between mass customization and Agility proposed by (Brown & Bessant, 2003), which argue that in order to gain competitive advantage, concepts from mass customization must be used as part of the companies agile strategy. They do this by arguing that the two terminologies are not mutually exclusive, but mass customization should be seen as an example of agile performance, so in this line of arguments companies can use mass customization to obtain Agility. They argue that to function properly and be successful, Agility is dependent on a set of other underlying operations management abilities, such as Just-In-Time (JIT) and Total Quality Management (TQM). Another link between agile manufacturing and mass customization is proposed by (Wang, 2009), who sees mass customization as a trend, and proposes that an Agility based manufacturing system should be used to cope with this trend.

5.3 Leagility (Naylor et al., 1999)

When looking at the link between Agility and leanness there are very divided opinions. On one side some authors argue that Lean is a prerequisite for Agility, and is such suitable for customization (Narasimhan et al., 2006), while others argue that increasing levels of leanness is only suitable when moving towards MTS where products are more standardized and schedules are level (Naylor et al., 1999). Further (Naylor et al., 1999) came up with a framework for incorporating leanness and Agility into the same company, even though they argue that Lean is mostly suitable for standard production.

To support their argument of leanness being a prerequisite for Agility, (Narasimhan et al., 2006) argues that previous research has been made which conclude that manufacturing plants move along an evolutionary path, where they evolve from one group to the other, and in this case moving from Lean to Agility. I.e. in order to move
towards Agility a company must possess the characteristics of leanness, reduction of waste and cost efficiency. Also (Brown & Bessant, 2003) supports this view, as they suggests that Agility relies on a set of fundamental Lean elements and thus makes Lean a precursor for Agility. (Pine II, 1993) supports the arguments that Lean is part of achieving both higher flexibility and responsiveness, and thus the ability to provide an increased amount of customization, without the increase of costs. This is due to the developments that have been made within this area of management, such as reductions in setup and changeover times, lowering costs and write-offs on unsold goods.

The arguments of (Naylor et al., 1999) saying that Lean is only suitable for MTS production falls into the same category as their own definition of Lean: “Leanness means developing a value stream to eliminate all waste, including time, and to ensure a level schedule.” (Naylor et al., 1999). This definition of Leanness tells us that, even though the elimination of waste can be valuable in agile manufacturing, as well as mass customization, it still strives to set an even schedule, making no room for variable demand and flexibility. They argue that, even though the theories of Lean and Agility are quite similar on many characteristics, the aim of achieving smooth demand is too diverse from the objectives of Agility, thus the two theories cannot be combined. However they do still manage to demonstrate how Lean and Agility can be combined in the same supply chain in a company.

The framework provided by (Naylor et al., 1999), shows how the position of the CODP should indicate where and to what extend both Lean and Agility should be used. Upstream from the decoupling point production can be standardized and demand can be smoothened, and by keeping buffer inventory, of semi finished modules, at the decoupling point, demand downstream is allowed to fluctuate. This system allows for Lean to be implemented upstream while Agility can be used downstream. (Naylor et al., 1999) uses the example, of the case study by (Feitzinger & Lee, 1997), of the company HP whom produces printers sold in many countries around the world. These printers need different specifications for each country, and in the past they had problems with stock outs for one country and other countries would have excess products. They fixed this by moving the customization of the standard printers, before they got the national specifications, out to the distribution centers. This means that they moved the
customization process down the supply chain, allowing for fluctuations in the demand of the nationalized printers, while sticking to the forecast for the standardized printers.

Also (Yao & Carlson, 2003) supports this concept that Lean and Agility can work together. They argue that Lean production works together with agile manufacturing to keep the units moving smoothly. However, they do it by realigning a Lean system by using flexible equipment and skilled workers to be able to produce orders of reduced batches, and thereby minimizing WIP and throughput times of the customized products. They show the example of a company producing upholstered furniture, on a MTO basis. To reduce the variety of products they have selected a range of “standard” designs and fabrics, which customers usually choose amongst, while they are still able to produce special custom orders if needed. Because the furniture is large and takes up allot of space, the company does not have the possibility to have an inventory of semi-produced goods like the printer company. They thus need to have any given order flowing through the system, to take up as little inventory space as possible. Using the “standard” components in the Lean system of flexible equipment and skilled workers they are able to make fast changeover between batches, and keep the flow going.

5.4 Modularity

The Leagility concept of (Naylor et al., 1999) can be characterized as production done by producing standardized modules, which is then turned into customized products. This is an attribute, which is shared with what is known as modularity, and these can thus be derived as the same, or very similar concepts. For mass customization to be efficient during manufacturing and thus affordable, it must utilize modularity, as it would otherwise not to be able to get even close to those of mass production (Duray et al., 2000; Pine II, 1993). As stated it works by producing standard modules on a Lean type mass production line, whereas the modules, after this point, is customized to the customers’ orders.

As modularity uses mass production in part of its line of production, it allows for a much simpler, and thus cheaper production of customized goods, making it suitable for mass customization, although some authors claim that it does not carry the fundamental characteristics of mass customization, of products being produced completely
individually made (Da Silveira et al., 2001), whereas others claim that modularity is a requirement for mass customization.

According to (Pine II, 1993) and (Duray et al., 2000), there are six different modularity strategies, which are called: component-sharing-, component-swapping-, cut-to-fit-, mix-, bus-, and sectional modularity. These strategies can be used individually on products or they can be mixed together. The strategy of component-sharing modularity uses the same component for different products, and by doing this allowing for economies of scope. This can be done by, for example, making a core module that can be used across all of the companies’ individual products. The component-swapping modularity shares the same characteristics of the component-sharing strategy where the customized product is built by pairing component with a standardized module. The cut-to-fit modularity, contains many of the same characteristics as the previous two, however at least one of the components are variable, usually in length or size, so that it can be cut to fit the customers order. The mix modularity is suitable for products that needs a recipe to produce (Pine II, 1993). A mix modularity product could, for example, be paint, which mixed together from different colors, and as the amount of each color can be varied to create custom colors it is a mix modularity product. Also products like chemicals, drinks etc., can be adjusted on each their components to allow for a specialized product. A product that is a bus modularity product is a standard structure, which can facilitate different kinds of components. The term ‘bus’ comes from computers, where the bus is the central pathway for all the components of the computer to communicate, thus it is possible to plug a wide variety of components into the bus, depending on what is needed. The final modularity type, sectional modularity, is the one, of the six types, which provides the highest degree of customization. This type of modularity allows the product to be customized in any way by combining a range of different components in many different ways, as long as they are connected to each other by use of standard interfaces. A great example of this type of modularity is LEGO, which allows for any combination of components, as long as they are fit together using the interlocking system.

The HP case (Feitzinger & Lee, 1997) demonstrates the use of a mix between both bus- and component-sharing modularity very well. The case describes the use of a power supply for the printers, which would work with both the American voltage supply as
well as the European. This made it possible for the company to install the power supply in the printer without knowing where the printer needed to go. This shows how HP made use of component-sharing modularity, as they used a single component for printers that needed different specifications, as well as they would be able to use the same power supply in other products as well. The bus modularity comes into play, as when the printer is shipped to the local distribution center, the printer is then repacked with the specific power cord that would work in that region. These power cords are designed so that any of the world’s different power plug standards will fit into the power supply in the printer, making it possible to use the same component with all the external components.

When looking at modularity in terms of the mass customization framework, by (Duray et al., 2000), then the different kinds of modularity is divided into either upstream modularity or downstream modularity. The types of modularity used to produce products with an upstream CODP, i.e. ETO or MTO, are the ‘component sharing’ and the cut-to-fit approaches. This is due to the nature of the types of modules, as the components, in the case of an upstream decoupling point, are either original designs or alterations to standard design. The ‘component sharing’ modularity, allows for a unique design to be made around a standard component, and the cut-to-fit modularity takes a standard design and alters it to fit the needs of the customer. When the CODP is downstream, i.e. ATO or MTS, the modularity used are ‘component swapping’, mix, bus, and sectional modularity. These modularity types have in common that they use components, which are standardized and repeatable. They allow the customer to choose from a selection of components in order to customize the product, however they do not allow for any altering of the components. Although (Duray et al., 2000) proposes this division of the components on the upstream and downstream CODPs, their own framework for the different approaches to mass customization, determines that each of the groupings of the modularity types can be distributed both upstream and downstream, depending on the strategy.

5.5 Postponement

Another enabler of mass customization, is the concept of postponement, and it is pointed out by (van Hoek, 2001) that it is consistently mentioned in the literature as one
of the main features of mass customization. Postponement is a concept where some of the supply chain activities are retained until the customer order is received and can then be produced to customers’ preferences. In his article, (van Hoek, 2001) illustrates how the degree of application of postponement correlates to the position of the postponement in the supply chain. It shows that when the postponement is at the fabrication stage of the supply chain, there is a high degree of application of postponement, whereas the opposite is true when the position of the postponement is downstream, e.g. at the assembly or distribution level. When interpreting the position of the postponement as the CODP, it is clear to see that this approach is in line with the frameworks presented so far. So a high degree of postponement corresponds to the ETO or MTO, resulting in a high degree of customization. Figure 6 illustrates how degree of postponement corresponds with the degree of customization of the product, as well as showing how the CODP fits inside this framework of offering customization.

(Zinn & Bowersox, 1988) discusses two types of postponement, namely time postponement and form postponement. Time postponement is delaying the delivery of the product until after the customer order arrives. This means that they can only differentiate the delivery, making all the time postponed products MTS products. The form postponement further consists of four different types of postponement: labeling, packaging, assembly, and manufacturing. These form postponements are concepts of delaying the product differentiation until later in the supply chain, after the customer order has been received. For the assembly and manufacturing postponements, it is the processes of putting together or manufacturing, respectively, which is postponed. For

![Figure 6 - postponement vs. CODP vs. Customization](image)
the labeling and packaging postponements, it is not as such the specifications of the products that are being delayed, but the merely alterations to the external representation of a MTS product.

5.6 Digitalization

Although it is not widely discussed in the literature it is important to note that the evolution of the information technology has had a tremendous influence on the application of mass customization through the last decades. (Bardakci & Whitelock, 2003), states that the integration of computer based information systems with the production systems, are the key element when distinguishing mass customization from traditional customization.

(Vinodh et al., 2010) discusses the importance of the use of digitalization in the Agile Customization Program (ACP). As discussed earlier there are parallels tying mass customization and agility together. The digitalization of the ordering has lead to a faster response of the customers’ dynamic requirements.

The progression of the Internet has enabled customers to gain easier access to the companies and the options they provide (Juergen, 2011). This has decreased the cost of sharing data, making it highly affordable for companies to corporate with customers on the products. Further the technology used on the Internet has made it possible for customers to visualize the products on the screen in accordance with the choices they make.

Examples of companies making use of the Internets possibilities are Nike Inc. and Apple Inc. (apple.com, 2012; nike.com, 2012). Apple is selling computers, which they let customers customize in terms of the performance of the computer. The customer chooses a base model, where the customer can choose to make it faster, bigger hard drive etc. This allows them to receive a vast amount of customized orders without having to even talk to the customer. Nike allows customers to make their own shoe, by selecting the basic design of it. Then they can change colors, graphics etc. to get a completely personalized shoe. This allows the customer to see how the finished shoe looks like, as it is displayed on the screen in the design the customer has chosen. And as
in the Apple case, they can receive a large amount of information without having to talk
to the customer.

CHAPTER 6 – PLANNING AND MATERIALS FLOW CONTROL

Any type of manufacturing needs some sort of tool or system to excel. There are many
of these systems present in the literature today. As with most variety, many of the
options have different attributes, i.e. areas of focus, prerequisites etc., and it can thus be
fundamental for the company to find the right set of tools and systems for their kind of
production, to succeed. Often this type of system is referred to as the planning and
materials flow control (PMFC) mechanism. To take a look at the different aspects of
PMFC systems, and to see the systems in the aspect of mass customization, the
following sub-question introduced in the introduction, is going to be considered.

What is the most suitable tool for production in mass customization?

The planning and materials flow control mechanism is a process or procedure that is
designed to control both material and production flow in a production system
(Fernandes & Carmo-Silva, 2006). A PMFC has the main functions of controlling,
when an order is released into the production, and to manage the flow of materials
throughout the production process. The order release function, determines what order
and when it is released into the production cycle, and when this happens the product is
then what we know as work in progress (WIP). The decisions on these questions are
then made on a set of rules, e.g. how urgent the order is. The materials flow control, is a
mechanism that manages the flow of WIP in the production process. It takes decisions
for moving materials between workstations, and it activates them when the material is
available.

There are mainly two kinds of PMFC mechanisms, namely input and output (Fernandes
& Carmo-Silva, 2006), which is also known as push and pull systems (Suri, 1998). The
input, or push, mechanisms releases orders into the production system, based on a
predefined production schedule. For example, Material requirements planning (MRP),
uses the estimated lead-time of a product to calculate which date work must begin for
that order. The output, or push, mechanisms release orders based on the consumption of
the current inventory, as well as it considering the current workload in the system. An example of an output mechanism is the Kanban system, where the production of a part can start, only when a downstream workstation consumes a part, from the upstream workstation buffer inventory (Suri, 1998).

6.1 MRP (Materials Requirements Planning)

Materials Requirements planning (MRP) is a computer based, push system, that uses predetermined lead-times, to calculate the flow of materials through the production process (Sagbansua & Alabay, 2010). MRP uses the forecasted demand for the finished product, to create a master schedule, which works backwards from the agreed delivery date, and calculates the demand for materials and components in all of the lower levels of the production process. The systems uses pre-defined lead-times, for production and ordering, to determine a plan for when each part of the production should start, and when they must have the components finished for the next step in the process. When thinking in the lines of MRP, it is important to know the difference between, products with dependent demand, and products with in-dependent demand. The MRP system only deals with planning of the dependent demand, thus the delivery dates for the products with independent demand must be put into the system.

Products with independent demand is in this case the final product, which does not have any other than that of the costumer, i.e. it is not a part or component of a product within the production process (Sagbansua & Alabay, 2010). Products with dependent demand are thus products that are needed in a downstream process, making it dependent to produce or assemble the part or product, as well as the demand of the upstream product is dependent of the demand for the finished product.

The process in the MRP system is divided into periods varying from one day to a quarter of a year or longer (Vollmann, Berry, & Whybark, 1997).

The information needed to be put into the MRP system is, a bill of materials, a main schedule for the final product, and an inventory records file (Sagbansua & Alabay, 2010), (Vollmann et al., 1997). The bill of materials, in MRP, is a list of all the components going into the final product; also showing which materials goes into what pre-assembled parts. The main schedule contains information on when and how much
of the final product is needed. Finally the inventory records contains data on what inventory is at hand and what is ordered. Then it can be planned what is required for each planning period.

As the system calculates when assembly needs to be completed at each level of production, to be ready for the next step, there is no need for safety stock of the dependent demand products (Sagbansua & Alabay, 2010). This minimizes WIP and thus the costs associated with this.

To produce the predicted schedule for demand for the system, there is an amount of guess work involved (Schonberger, 1983). As demand is not always predictable, especially not for mass customization products, companies will have to guess the demand, in each period for each variation of their products. Wrongful predictions will lead to either access inventory, or longer lead-times for the final product.

According to (Suri, 1998) and (Sagbansua & Alabay, 2010) a further limitation of the MRP system is that it does not take into consideration, if there are manufacturing capacity available, i.e. if the next cell in the production is available for the produced parts. This will create a buildup of inventory before that workstation, creating unnecessary WIP, when capacity, could have been used to produce parts for a workstation with available capacity, making the system ineffective.

When looking at a push system like MRP, it has some drawbacks compared to the pull systems (Spearman, Woodruff, & Hopp, 1990). The MRP system does not consider the variation in the effectiveness of the system, leading to either a clogged up production chain, or excess capacity. This problem is addressed by the pull systems, where the timing of the order releases into the system is controlled by the cards (e.g. Kanban cards, POLCA cards etc.) and thus is controlled by the current throughput time.

Even though MRP has evolved over time, into systems such as MRPII and ERP, it has still not managed to tackle the characteristics of the customization industry, which differs significantly from the more repetitive production strategies (Stevenson, Hendry, & Kingsman, 2005). However the use of MRP is also found as a component in some of the more flexible production systems. For example the POLCA system uses a higher
level MRP for planning and coordination of the ordering of materials from suppliers, and to coordinate the delivery of materials for the internal work centers (Suri, 1998).

6.2 CONWIP (Constant Work In Process)

The Constant Work in Process (CONWIP) system, is a card based pull system (Germs & Riezebos, 2010). Before the order is sent into the production process, it is collected in an order pool, which holds all the orders available for production. The system then relies on a card to be available before an order can be released into the production process. Throughout the whole production line, where the product follows the specific route, which is called the control loop, as it should be imagined as a control barrier, surrounding the whole of the routing for the specific product. This system insures that the WIP is limited to the amount of cards circulating the shop floor. However the system cannot control the flow between the work centers, as the cards only control the total amount of orders that are currently being processed throughout the production line.

The cards in the CONWIP system can be electronic signals, as well as it can be physical cards like the ones in the Kanban system (Spearman et al., 1990). The cards in the CONWIP system follows an order from when it enters the production line until it is finished. When the cards reaches the end of the line they are returned to the beginning of the line, where they will be available for the next order to enter the system.

The CONWIP system employs a backlog system, containing all the orders, which have not yet been dispatched into the production system (Spearman et al., 1990). The backlog keeps track of all the orders waiting to get into the system. It is usually generated from a master production schedule, and it gives the opportunity to reorder the orders into a sequence, which could minimize the amount of changeovers during production. Throughout the production cycle there is a strict rule of treating the orders in the order they entered the system, although when rework occur it receives immediate attention.

In (Germs & Riezebos, 2010), there are two versions of the CONWIP system discussed. The first one is, the CONWIP with just one control loop covering the whole production layout, not distinguishing between what kind of product is in the system, its routing, and if a certain route is free or busy. This system does not consider the possibility that one routing could have available capacity, and running idle, while another routing would
have a buildup of WIP in front of a workstation that could have had a breakdown. If all the cards are in use, in this situation, order that are stuck in front of that work center, would be using a card, which could otherwise have been used, for an order going through the first routing, with available capacity. The second version of the system that they present is, the CONWIP with multiple control loops (m-CONWIP). In this version, the specific routings would have its own control loop, allowing the system to control the amount of work going through each routing. That somewhat makes up for the flaw of the single control loop of the CONWIP. It would give the system the skill to spread out the work, such that orders could be released to routing 1, even though routing 2 would be using all its available capacity.

The COWIP system does offer a better solution for the MTO production, than Kanban does (Stevenson et al., 2005). But still, the control of the job releases, job entries, and customer enquiries is not suitable for this type of production. (Spearman et al., 1990) points out how the CONWIP system is highly related to the Kanban system, especially with respect to the fact that standard sized containers should be used in the production to minimize variety. This makes it unsuitable for customization production, as it does not allow for much variety in the products going through the system. However what sets it apart from the Kanban system is the fact that the backlog system in CONWIP allows the production planners to arrange and sequence the order, in which the orders enter the production system. In systems with more than one product in a production line, it allows for a more coordinated sequence of orders, lowering costs in connection with changeovers. Another advantage of CONWIP compared to Kanban, is that the control loop system makes WIP pile up at the bottleneck instead of, at each of the workstations upstream from the bottleneck, as it is the case of Kanban. According to (Spearman et al., 1990) this makes for a higher utilization of the process at bottleneck and improves the throughput time. Although it does not change the problem with production containing customization, it does give CONWIP some advantage when looking at the production of components for modularization.

6.3 Kanban

For planning and materials control, Lean was designed to, and most often do, use the Kanban system. This system was developed by the Japanese car manufacturer Toyota in
the 1980’s (Stevenson et al., 2005), (Schonberger, 1983). It is a card based pull system, which objective is to cut inventory, as well as minimizing flow times. When preparing to use Kanban, the production process must be divided into cells, or work-centers, which does their specific part in the production process, so that when work is done in the first cell, it is moved to the second cell for further processing and so on, until the product is finished. In this system, every type of component would have its own container, which has been designed to hold a very specific amount of components.

The number of containers is a carefully made managerial decision, as it determines how large a buffer there is in front of each cell (Stevenson et al., 2005), (Schonberger, 1983). Too many containers mean more inventories, and too few containers, meaning high risk of production stopping if just one cell falls behind. In the original Japanese concept, manager would deliberately remove a container from the buffer inventory, or remove a worker from the workstation, in order to see where there might be a problem in that specific workstation. When there are no available production cards available at a workstation, the workers are encouraged to work on seek for productivity improvement within their workstation, e.g. by finding solutions to shorten down times and increase quality of the work, etc.

For every container there are two cards that hold information on the specific component, amount in the container etc. (Stevenson et al., 2005), (Schonberger, 1983). One of the cards is the production card, which is linked to the cell that produced the part, whereas the other card, the conveyance card, is linked to the cell, which is currently using the part for further processing. When a container has been emptied in the downstream cell, the production card is sent back to the upstream cell, giving the sign that production on a new batch can start, due to available capacity in the downstream cell. So as a cell uses parts from its buffer inventory, it pulls a new set of parts from the upstream cell.

For the Kanban system to function optimally, it should be part of a Just In Time (JIT) system (Stevenson et al., 2005), (Schonberger, 1983). It needs a continuous flow of parts or large orders, i.e. stable demand, as well as it demands few setups, and a limited number of parts. These parts running through the Kanban system must be used every day, as it needs the intermediate buffers inventories to function at its best, and thus it
would mean allot of inventory if it did not get used on a daily basis. However, even though Kanban requires the JIT system to function optimally in its original form, it can be used as a signaling system in corporation with a more sophisticated approach, usable in more MTO and ATO situations.

As the Kanban system is a system designed for continuous flow in conjunction with Lean, it is not, as such, a PMFC that would be suitable for mass customization (Stevenson et al., 2005). However it could serve in that context, in an altered version, where it mainly would function, as a signaling system, and another system would manage the other jobs that the Kanban would then leave behind. Furthermore the systems demand a limited number of parts and few setups, which usually does not fit in a MTO and ATO strategy, as these often require many different parts, assembled or produced in many different combinations, adding many setups.

Many authors agree that the Kanban system does not allow for the production of high variety and low volume, which is required for MTO production (Riezebos, 2010; Stevenson et al., 2005; Suri, 1998). However if the Kanban system is used in combination with a planning tool, to control the aspects of job release, job entry and customer enquiry stages (Stevenson et al., 2005). In a pure MTS situations the Kanban system allows for very fast throughput times, giving the manufacturer the ability of reacting very fast to changes in demand of their products.

As Kanban can only accommodate a very limited variety of products it is thus not suitable for customization (Stevenson et al., 2005). It can however be incorporated into a mass customization production cycle, as in the Leagility example, the Kanban system can accommodate the production of the components and modules produced upstream from the decoupling point (Naylor et al., 1999). In that way it will still have the key prerequisites, e.g. a steady demand, flow, etc., that is needed for the Kanban system to function optimally.

As the Kanban system is purely pull controlled, it does not react until a customer demands, or pulls, a product from the last cell in the production cycle, and then that cell pulls another component from the next upstream cell, and so on (Suri, 1998). This system means that the product the customer pulls is already manufactured, and customization is as such not possible. (Suri, 1998) argues that the Kanban system is
however able to produce products which involve minor customization from a main product or products which should be assembled from components already in production. This supports the discussion of Lean being able to being a part of the production of customized products in a modularity concept.

6.4 POLCA (Paired Overlapping Loops of Cards with Authorization)

The Paired-cell Overlapping Loops of Cards with Authorization (POLCA), was first developed as a materials control system to fit into the Quick Response Manufacturing (QRM) strategy (Suri, 1998). The QRM strategy is based on Time-Based Competition (TBC) which has the objective of minimizing delivery lead-times to gain a competitive advantage over competitors (Suri, 1998). QRM is build on the basis of consumers having higher demands to the products they consume, in aspects like product development and customization, and thus it strives to help manufacturing companies to respond faster to this kind of demand. In other words, QRM has been designed to be implemented in companies competing in the Make-to-Order markets, giving it an edge, at first sight, compared to other strategies. POLCA aims to eliminate the “Response Time Spiral” (Suri, 1998), which is often occurring in traditional pull and push systems. This means that it, according to (Suri, 1998) is very effective for companies producing custom products, that is made in very small quantities, or even unique products. Furthermore POLCA seeks to bring down the WIP inventory, that most other systems demand to function, making it cheaper to run, as well as making it possible to have great product variety, as there is no need to have intermediate stock for the products.

When implementing POLCA, the production process must be rearranged so that the different steps of the process are arranged into cells (Suri, 1998). This must be done not only along the production line, but also within the different areas, so that e.g. the assembly part of the process is divided into cells that have different kinds of specialties. Each of these cells should be divided from the other cells into physically separate units, each containing the machines that are needed to do their part of the production.

When a costumer order comes into the system, it calculates the lead-time of that particular product, looking at the route it must take through the system, i.e. which cells it will have to go through and how long their individual lead-time is (Suri, 1998). An
authorization time is then given to the specific order, determining when the order may start to be processed. Furthermore, each cell has a number of “POLCA cards” for each of the cells coming right after it in the process. Production in a given cell can only begin if the materials needed, a POLCA card is available, and if the authorization time has passed. The POLCA card between cell 1 and 2 is attached to the order when it starts production in cell 1. When the process in cell 1 is done, the order is then moved to cell 2, which again only can start production if they have a card available between cell 2 and 3. It should be noted that the card between cell 1 and 2 stays on the order throughout the production of cell 2, so that it then both carries cards from the first link and the second link. The advantage of having the first card on the order throughout the production in cell 2 is that cell 1 then only produces orders that, cell 2 has available capacity for, in stead of piling up orders.

An advantage of the POLCA system is that it only starts to produce when a downstream cell, in the near future, will have the required available capacity to process that work. (Suri, 1998). The resources are thus better used somewhere else, e.g. for products for an order to another cell. For the same reasons, the system also results in less buildup of WIP, i.e. buffer inventory, as production only starts if the downstream cell is having available capacity to produce. This is in contrast to an ordinary pull systems, which has allot of buffer WIP. Furthermore the system is more flexible compared to, e.g. the Kanban system, as the cells, in that case, are highly coupled, and thus makes for less flexibility, which is much needed in the setting of a high variety in demand.

As the cells in the POLCA system, is required to have each their specific machines to complete their production process, there might be a need to have more of the same type of machine. As there might be 3-4 cells on the assembly stage, some of these cells might need a particular machine as part of the assembly process. If the machine is only used in some cases, but this factor is not what the cells are divided by, each cell must have a machine, even though there might not be enough products to even support one machine fully in the first place.

The POLCA system is both a push and a pull system, thus it does not have the same problem, of customers pulling from the last cell, as the Kanban system does (Suri, 1998). The fact that POLCA uses a higher level control system for release control and a
card system to control the workload and flow in and between the cells, makes it much more suitable for customized products. This makes the system suitable for even high degrees of customization as well as for lower degrees of customization, or companies that just have a large variety of products.

The study of (Germs & Riezebos, 2010) notes that, in an MTO environment, the POLCA system has a positive impact on the total throughput times, compared to system without workload control, e.g. CONWIP. However the POLCA system fail in detecting and signaling problems in the workload, making for an increased possibility of orders backing up on the production floor. Further, the study also shows that the m-CONWIP performs better on the total throughput time, than the POLCA, and shows the best results of the study. (Germs & Riezebos, 2010) notes that the results varies greatly with the implementation of the systems.

6.6 Shop configurations

As described by (Stevenson et al., 2005) there are four different kinds of shop configurations, namely Pure Flow Shop, General Flow Shop, General Job Shop and Pure Flow Shop. The main difference between the cases of the two extremes, i.e. Pure Flow Shop and Pure Job Shop, is the direction of the flow of goods. In a Pure Flow Shop, the products can only travel in one direction through a strict sequence of work centers, whereas the Pure Job shop allows for the production of the product to begin, and end, at any given workstation, allowing for a high degree of customization. In-between is the General Flow Shop, which, although work still travels in only one direction, allows products to go through a subset of work centers, to undergo minor customization. The last one is the General Job Shop employs a dominant direction of flow, however the orders can move in multiple directions within the production, giving it more flexible routing options, compared to the General Flow Shop, allowing it to provide a higher degree of customized products.

The case of shop configuration does support what has been discussed, that the more the system support a Job Shop configuration and flexible routing, e.g. POLCA, the higher is the allowed degree of customization, whereas when it resembles a Flow Shop configuration, e.g. Kanban, the degree of customization decreases. This can thus lead to
the notion that a mass customization PMFC system could gain from implementing a shop configuration, depending on the degree of customization, which seeks towards a more Job Shop oriented configuration.

The Kanban system would be characterized as a Pure Flow Shop due to its very strict nature, where everything needs to flow at the same pace, in order for the system to work, allowing no room for any sidesteps for any order. The CONWIP system would also be characterized as a Pure Flow system as it shares many of the characteristics of the Kanban system. Further the mechanism that the orders have to follow the order in which they enter the control loop, does not allow the order to visit any subset of workstations, without delaying the whole production. The m-CONWIP can be classified as more of a General Flow Shop, as it does allow for a higher variety of routings, with the multiple control loops, allowing for a higher variety in the products. The POLCA system can be characterized as a General Job Shop, as it allows for individual routings of orders, giving a higher level of customization as well. However it does have a fixed starting and ending point in the routing, and can thus not be characterized as a Pure Job Shop. The MRP can allow for a Pure Job Shop configuration, as the routing of the order is scheduled in a computer system. As it takes into account the lead-times of all orders in the system, it makes sure that the capacity is ready when needed, at any of the work stations in the production floor. And this can allow for a high degree of customization.

6.5 Comparing planning and materials flow controls

Figure 7 summarizes the key features of the PMFC systems discussed in this chapter. It gives an overview of how the different mechanisms differ in relation to one another. It can be seen that, although Kanban and CONWIP are quite similar when looking at how the systems function when the order has been released into the production, they do differ in the way that order are released. The release system used by CONWIP is somewhat similar to that of the Kanban, where the rate of ingoing order equals that of the outgoing orders. But whereas Kanban just pulls all the way up through the chain, the CONWIP sends an authorization card to the backlog, which then pushes the order into the system, making it a pull/push mix. The backlog also works as a forecast module, as it allows managers to rearranged backlogged orders in order to minimize setups. The
difference in the amount of control loops allows the CONWIP to be a little more flexible, however it may result in poor workload control.

The m-CONWIP system differs in the way that it has a different structure in the control loops. This allows for a higher variation in the production as it provides a separate routing for each of the product lines. It allows the orders to move somewhat more independently of each other, moving it towards the general flow shop classification. The POLCA system has a General Job Shop configuration, allowing each product to travel to any workstation, although production still has a dominant flow direction. In contrast to the CONWIP and m-CONWIP, POLCA does not distinguish between kinds of products in the matter of the control loops, but it has a loop between each pair of work cells, required in the production process, making allowing it to have a high level of workload control. POLCA relies on a higher-level MRP system to administer the release authorization and the materials control however the flow in the production system is mainly demand driven, where order are pulled to the downstream work cell when it has free capacity.

The MRP system differs highly from the other PMFC systems, as it is a pure push system. This, however, allows it to coordinate the production routing in any way possible, as it can administer the lead-times etc. to coordinate a schedule that suits all current orders. This also means that it can be characterized as a Pure Job Shop, as it can start production at any work station and finish it at any work station, not taking any flow direction into consideration. MRP does not utilize cards as signals, but have the computer generated master schedule of when orders should be moved to the next work cell. This master schedule is completely forecasted and does, in some cases, not consider current production speeds and lead-time, after the order has been released.

<table>
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<th>MRP</th>
<th>Kanban</th>
<th>CONWIP</th>
<th>m-CONWIP</th>
<th>POLCA</th>
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<tbody>
<tr>
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<td>Forecast driven</td>
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<tr>
<td>Shop Configuration</td>
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<td>Pure Flow Shop</td>
<td>Pure Flow Shop</td>
<td>General Flow Shop</td>
<td>General Job Shop</td>
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<tr>
<td>Between-cell signalling</td>
<td>Computer based</td>
<td>‘Card’ based</td>
<td>‘Card’ based</td>
<td>‘Card’ based</td>
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<tr>
<td>signal configuration</td>
<td>Master schedule</td>
<td>One loop per cell</td>
<td>One loop</td>
<td>One loop per routing</td>
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Figure 7 – Overview of Planning and Materials Flow Control systems
CHAPTER 7 – RESULTS & CONCLUSION

The central question in this paper, as it has been set out in the introduction is: How can a production company optimize its operations capabilities, in a market where the market demand is shifting towards mass customization? To answer this question, a series of sub-questions were set up, with the purpose of leading the discussion of the components of mass customization.

The first part of this paper was focus on answering the sub question: “What are the characteristics of the different levels of mass customization?” Four overall levels of customization where identified and discussed, namely the customer order decoupling point levels of make-to-stock, assembly-to-order, make-to-order, and engineer-to-order. These four levels where supported by a range of authors, having the indications of the same basic levels covered by different concepts and names. However as a couple of authors argue, that mass customization needs to have both customer interaction as well modularity in the production, it can thus be said that only the two middle levels, i.e. ATO and MTO, can be characterized as mass customization.

The second part of the paper looked at the different performance objectives, and discussed their importance to a mass customizing company, in terms of order-winners and qualifiers. The five objectives discussed were: flexibility, quality, cost, speed, and dependability. The flexibility was found as the key characteristic of mass customization, and was thus found as an order-winning factor in the competition against standard products. However, as some companies are forced into mass customization due to the competitors, it may just be a qualifying factor if many customizers are already in the market place. The aspect of cost is present in many definitions of mass customization underlining its importance to succeed in the field. The tradeoff between flexibility and cost is discussed and some authors argue that although it has been present earlier, the trend has shifted and it is now diminishing, due to the shift towards mass customization methods. In the end it was concluded that cost could be an order-wining factor, due to the hard competition on prices in this kind or market.

The paper then looked at the objective of lead-time. It touches upon the phenomenon of the customization-responsiveness squeeze. It falls right in the lines of mass customization, where customers want more customization but with the same standards
of the mass-produced products, in this case fast delivery. The lead-time component was found to be an order-winning factor, due to the large interest in the matter and the pressure to deliver faster and faster. Quality did not receive much attention in the literature, however it was frequently included in the definitions of mass customization. These definitions infer that quality should be of the same quality as the mass-produced products. This lead to the conclusion that quality is an order-qualifier for mass customization and not much advantage could be gained from exceeding in this area. The dependability aspect was not mentioned at all in the literature, thus it is not a focus for the mass customization industry, at least not on the scale of the other areas. It was thus concluded that it, at the most is a qualifying factor. Recall the sub question set out in the introduction: “Which operations capabilities are important for a company doing mass customization?” To summarize an answer to this question the most important capabilities for the mass customizing company is the cost, speed and the flexibility aspects. Dependability and quality are thus secondary and not as important factors.

The enablers of mass customization was discussed in accordance with the sub question: “Which enablers are required to implement mass customization successfully into the operational part of a company?” As mentioned in an earlier part of the paper, modularity needs to be present for mass customization to be achievable. The six different types of modularity are discussed, namely component-sharing-, component-swapping-, cut-to-fit-, mix-, bus-, and sectional modularity. It was discussed that they can be split into two different categories depending on the point of the CODP. If the company uses an ATO strategy, they would most often use the component-swapping-, mix-, bus-, and sectional modularity, whereas an MTO strategy would make use of the component sharing and cut-to-fit modularity. The modularity allows for a much cheaper, and faster customization than traditional customization methods and is thus a huge advantage when looking at the performance capabilities. Further the notion of postponement is brought up, and supports the framework of the CODP and modularity due to its idea of postponing different activities until after the customer order has been received.

Further the concepts of Lean and Agility are discussed as enablers of mass customization. Lean has a set of component that allows the company to effectively eliminate the waste that might be present in a company, and thus lower its costs. It does
this through a series of steps that turns the company into a streamlined production being able to produce products very fast. However the Lean approach is mostly argued to be suitable for production of standard products. Agility is all about being quick at responding to customers’ requirement. It is discussed how authors disagree on how Agility and mass customization is connected. Some see Agility as an extension of mass customization, whereas others view it the other way around, as mass customization being the outcome of Agility. The term Leagility combines the two philosophies of Lean and Agility. It uses Lean as a tool for producing the components upstream from the CODP and Agility as the tool for the downstream customization process. This is the same kind of framework that is used around modularity, and the two support and complement each other very well.

The last enabler of mass customization that is discussed is the use of digitalization and computers to ease the order taking, and to bring all the information into the production stage.

The last sub question defined in the introduction was “What is the most suitable tool for production in mass customization?” This question lead to the discussion of five types of planning and materials flow control systems. These were MRP, Kanban, CONWIP, m-CONWIP, and POLCA. Further the concept of shop configuration was touched upon, adding to support the conclusions on each of the PMFCs.

MRP as a flow mechanism was discussed to be a good system for traditional pure customization, where speed was not an important factor. Even though it provides the great amount of flexibility, it would however not work for mass customization, as it is not effective enough to keep down the cost and lead-times. It can however be used as a planning system for other, more suitable, systems at a higher level.

The Kanban system does not accommodate any customization as it only handles a very limited amount variety. It can however be used as the part of the production lineup producing module components. As described in Leagility the production is split up into production of standard components and customized products. In this way Lean can provide the necessary minimal costs it takes to compete in a mass customization market. CONWIP has some of the same characteristics of the Kanban system. Although some authors points out that CONWIP is a better choice for MTO production, there is a
consensus that it is not particularly suitable for it. Further it lacks the kind of workload control that the Kanban to a higher degree possesses

The m-CONWIP somewhat makes up for the flaws of the one control loop of the CONWIP, and thus allows for a higher variety of products, however it does not allow for the product variety that is characterized by mass customization. The last system is called POLCA, and it utilizes a higher flexibility in the production routings than the m-CONWIP, and does thus allow for a higher level of flexibility. It also uses an altered version of the card-based system of the Kanban, making it quite responsive and cost effective. This makes it a suitable system for both ATO and MTO environments, as is the case of mass customization. A study has shown that the m-CONWIP achieved better results, than POLCA, in an MTO environment, and it should thus not be disregarded for mass customization.

From these discussions of the different components of mass customization the paper has come to a conclusion that a company trying to enter a market of mass customized products, should employ an assembly-to-order or make-to-order strategy. These strategies both offer the flexibility that ensures the customization as well as they make use of modularity, which makes the customization both cheaper and faster. Modularity should be used optimally in the setting chosen by the strategy. Furthermore the use of digitalization can come in handy, and can, in many situations, give an extra advantage.

The planning and materials flow control that should be used in connection with an assembly-to-order or make-to-order strategy, could be very varied. As the Leagility framework proposes, the mechanism used upstream from the decoupling point, to produce module components, should be Kanban, or a system similar to it, like CONWIP. For production downstream from the decoupling point, a system like POLCA should be used, as well as m-CONWIP has proven to be a good fit as well. An MRP system should only be used as a higher level planning system in connection with another materials flow system, as it is not suited for mass customization by itself.
7.2 Research significance

The paper addresses the issue of operations in mass customization as a whole, and tries to cover the split between the papers currently available, which have discussed only specific parts of the field. In particular it helps to understand how modularity, links with Leagility and postponement and shows how similar they effectively are. It also gives an overview of the operations capabilities, and points out the importance of the ones that really matter in mass customization. Furthermore it underlines how important modularity is to a production of this type. It addresses how a company should structure its operations, when looking to start production of mass customized products, to either keep up with the competition or to gain an advantage over competitors.


## APPENDICES

### Appendix 1

*Matrix grouping of mass customization configurations (Duray et al., 2000)*

<table>
<thead>
<tr>
<th>Point of Customer Involvement</th>
<th>Type of modularity</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Design</td>
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<td>Fabrication</td>
</tr>
<tr>
<td>Fabrication</td>
<td>Assembly</td>
</tr>
<tr>
<td>Assembly</td>
<td>Use</td>
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<td>Assembly</td>
<td>3 Modulizers</td>
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<tr>
<td>Use</td>
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</tbody>
</table>