Achieving Mass Customization:

A case study of Mass Customization and Supply Chain Management at a modern automotive manufacturer.

Abstract

This paper examines how a modern automotive manufacturer copes with the challenging aspects of Mass Customization (MC) with the use of Supply Chain Management (SCM). The method of Mass Customization, known for its promises, limitations and ultimately for its ability to provide highly customized goods without the drawbacks of small scale craft production, has gained traction over the last decade in Operations Management literature. By identifying in which category of Mass Customization strategies the manufacturer resides, a small part of the spectrum of Mass Customization strategies is populated with a real world observations on Supply Chain Management practices. By combining multiple theories on Supply Chain Management and MC, a theoretical framework is constructed in order to build a base upon which to compare empirical findings with theory. By conducting an interview & observation based single case study at the location of a modern mid sized, automotive manufacturer, the research finds several interesting discrepancies in SCM practices, not predicted by current literature, giving reason for further case based research and possibly a slight revision of theory surrounding SCM within an MC setting.

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Author: Teodor Hällestrand, 22374

Supervisor: John Söderström

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1.0 Introduction

In this introductory chapter, a background to aid in understanding the chosen field of research is provided. Then follows motivation for why the specific research field has been chosen. The chapter is concluded with the purpose of the thesis, the research question, previous research, delimitations, assumptions, definitions and disposition.

1.1 Background

Nearly everything we eat, wear, use and drive is manufactured in some sense. Manufacturing involves a set of processes which when in combination are applied on raw materials, result in a finished good that can go to a consumer or into the manufacturing of another good. The combined size of the global manufacturing industry is vast and dauntingly massive. A report by Mckinsey (Manyika *et al.* 2012), the management consultancy, attributes the manufacturing industry a 16% share of global GDP as of 2010. By Mass Production, manufacturing has made a plethora of goods cheap, reliable and easily accessible. Ford introduced on a large scale the assembly line and Toyota, left lasting impressions in the industry by creating the ideas surrounding the concept of Lean production. As manufacturers seek to improve margins, the next step has become to manufacture goods to specific requirements set by customers. Many different goods for sale are offered in a great variety, from which the customer can choose a specific item that best matches his or her preferences. Not nearly as many goods can be tailored to user specific preferences, without becoming much more expensive.

Nearly all manufacturers work with chain spanning from raw material to finished and delivered good. Ensuring this chain, or supply chain, is difficult even when goods are made completely to a set production plan. When making customer specific goods, which have been customized to a certain extent, a degree of complexity is introduced as there is more uncertainty as to which part will be needed for whatever specification is submitted by the customer ordering tomorrow.

1.2 Mass Customization

Mass Customization (MC) follows as a response to growing customer demand for customized products, and to the need for low cost, high volume production. By producing large volumes at a low cost per unit, the method of MC resembles Mass Production (MP). However, in a MP setting, products are not customized to the whims of individual customers. In MC, products are made specifically to set specifications not dictated by the internal forecasting function within the manufacturing company, but rather the specific product characteristics preferred by the customer.

Important to note about achieving Mass Customization, is that it is fundamentally different from producing a large variety to stock. Duray *et al.* (2000) provide an example in that having lots of different cereal types on a shelf in the supermarket is very different from being able to deliver a custom blend of cereal directly to customer specification.

1.3 Purpose & Relevance

The intricate nature of manufacturing automobiles is fascinating. However, this thesis is not solely centered around the production of vehicles, but around how a modern manufacturer delivers large amount of customized goods (MC) through the use of Supply Chain Management (SCM). Important to note is that the Supply Chain is according to theory not the only area to be considered important when examining Supply Chain Management and its effect on capabilities tied too mass producing customized goods.

According to research articles in the Mass Customization field, the strategy of MC is "costly" when examined through a lens of production and operations management. (Salvador *et al.* 2004) Several issues may arise when choosing to adopt MC, as Åhlström and Westbrook (1999) discovered from a large questionnaire-based study of a large sample of manufacturing firms. Operational problems, increased manufacturing costs and extended delivery times were identified in the firms surveyed These issues carry implications for the profitability and general performance for firms, which adds reason to examine the central question chosen for this thesis.

There is a lack of case studies on modern manufacturers on the subject of Supply Chain Management and it's importance within Mass Customization (Da Silveira *et al.* 2011; Gensheng & Dietz 2011; Chandra & Kamrani, 2004). Da Silveira *et al.* (2011) calls out for empirical validation in the MC research field, as the MC field of literature has become unbalanced, having experienced a shift in the ratio between empirical and theoretical research, towards the latter. Efstathiou & Zhang (2004), in another literature review very clearly call out for case studies of Mass Customization. They mention a need for *"populating the spectrum of Mass Customization manufacturing strategies"* with case studies; a need which this thesis is aimed at satisfying through identifying the MC strategy in use. Efstathiou & Zhang (2004) further state that the theoretical model of a MC manufacturing model exists, but that it will have to be "*reinforced with carefully chosen case studies and their supply chains"*. The decision to pursue an empirical validation of a firm's choice of MC strategy & supply chain management practices, can therefore be considered well supported and correctly made.

By firstly determining which manufacturing strategy that is used for achieving Mass Customization, with the purpose to prove that the requirements of Mass Customization are fulfilled at the specified manufacturer, an analysis can be performed on how said manufacturer manages its supply chain. The analysis and the generalizable conclusions that can be drawn on Supply Chain Management within the field of Mass Customization, constitute a relevant contribution the academic field of operations management.

1.4 Research Question

Based on the background and purpose detailed above, the research questions of this thesis is:

> How is Supply Chain Management used to achieve Mass Customization within the operations of a modern automotive manufacturer and which Mass Customization strategy does this manufacturer employ?

1.5 Previous Research

Here follows a description of the current knowledge base within the chosen field of research. An introduction is made with definitions of Supply Chain and Supply Chain Management, which are followed by a review of the current research on Mass Customization.

1.5.1 Supply Chain & Supply Chain Management

To delve into Supply Chain Management, also known as SCM, one must have a clear definition of what constitutes a *Supply Chain.* One of the most cited works in the field of Supply Chain Management, is the article *Defining Supply Chain Management,* written by John T. Mentzer *et al.* (2001). The Supply Chain is defined in their article as:

"a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer.

This definition, is deemed fitting for use in this thesis due to its popularity, simplicity, understandability and relevance. The definition from Mentzer *et al.* (2001) is also considered relevant due to it being used in the literature on Mass Customization & SCM used in this thesis. The definition is used to give an accurate description of the supply chain present at the company chosen for the case study.

For the term Supply Chain Management, there is a plethora of definitions. Mentzer's *et al,* (2001) article again provides a concoction of the most cited, relevant and fitting definitions, reduced to the following:

"the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole."

1.5.2 Previous Research on Mass Customization

A definition of Mass Customization (MC) can be made as the ability to provide individually designed products and services to every customer through flexible processes at reasonably low costs. The very book that contributed to that broad definition, is also the one that coined the phrase: *Future Perfect* (Davis 1987). Later, the concept was popularized in the book *Mass Customization: the new frontier in business competition* (Pine 1993). MC can be achieved mostly through modularized product design, flexible processes and integration between supply chain members and has been shown to be highly beneficial as a strategy when trying to achieve a competitive edge. This has been shown in multiple industries, including the automotive industry according to a literature review on the subject of MC by Da Silveira *et al.* (2011). The review concluded, based on comparison with their previously published literature review on the same subject (Da Silveira *et al.* 2001), that the research field has evolved significantly over the last decade.

Mass Customization has been observed to take on different shapes and forms across different industries, company sizes and companies with differing intended target customer groups. These shapes and forms can be summarized as Mass Customization approaches. Naturally, over the course of the last few decades, many attempts have been made within this field of research, to conjure with a typology of how firms can approach MC. Gilmore & Pine (1997), in a popular and well cited article in the Harvard Business Review, make an attempt at classifying approaches by examining the change in products and the change in how a company interacts with it's customer. The four "faces" they identify on are the cosmetic, collaborative, adaptive and transparent.
Gilmore & Pine are not alone in having attempted to categorize Mass Customizers; Alford *et al* (2000) focused on looking at where the product becomes varied in the production process. They call this the customer involvement point or decoupling point. Using this focus on decoupling point, Spring & Dalrymple (2000) constructed a spectrum of strategies, containing five approaches by examining a selection of cases from manufacturing firms.
However, the most relevant, cited and empirically validated categorization has been made by Duray *et al.* (2000), where the researchers surveyed 194 manufacturing plants. Their categorization is based on:

1. The point where the customer is present and involved in the production.
2. The kind of modularity used in production.

This categorization will be used to identify the approach taken by the organization studied in this case study and will therefore be more thoroughly covered in the coming chapter on the theoretical frame of reference. The choice of this categorization is based upon a literature review of the existing typologies of Mass Customization approaches, where this particular categorization stood out as prevalent, accessible and relevant.

1.6 Scope

This study will be conducted within the organization of Tesla Motors. The study will be limited to Tesla Motors and it's operations due to the time and resource constraints imposed by the institution at which the thesis is written. With data collected, an attempt will be made to draw generalizable conclusions about the utilization of Supply Chain Management to achieve Mass Customization. The company studied operates out of one main factory, sometimes referred to as the "plant", and the thesis is therefore limited to examining this main plant, the manufacturing that takes place within and the adjoining activities relating to supplying the parts needed for manufacturing.

1.7 Delimitations

This thesis focuses exclusively on the operations within the chosen automotive manufacturer. Within the operations of this particular manufacturer, a further focus has been put on the Supply Chain function, with the addition of some parts of the production with which the Supply Chain function tightly interfaces.

1.8 List of Definitions

List of definitions	
Abbreviation	Meaning
SCM	Supply Chain Management
MC	Mass Customization
TPL	Third Party Logistics
VIN	Vehicle Identification Number
CRM	Customer Relationship Management
MRP	Material Resource Planning
ERP	Enterprise Resource Planning
EDI	Electronic Data Interchange
ROP	Re-order Point
JIT	Just-in-time

Table 1 List of Definitions

2.0 Methodology

This chapter provides a description of and justification for the methodology used in performing research on the topic of this thesis. Among the areas covered are scientific approach, data collection, interview & observation design. The chapter ends with a discussion on reliability.

2.1 Scientific Approach

2.1.1 Single Case, Qualitative Case Study

When studying a current phenomenon in its natural environment, Yin (2014) suggests the use of a case study approach. Yin also suggests that for research questions including *how* or *why,* the case study approach is fitting. One reason for why the case study approach was chosen, is the aim of the thesis which is to uncover the key Supply Chain Management related factors of *how* Mass Customization is achieved. The choice of examining a single case is necessitated by the implications of the empirical access. Large automotive manufacturers, especially the manufacturer studied, are secretive and difficult to gain empirical access to. The researchers employment with the case subject has granted unique access, which gives the single case study support as *"the descriptive information alone will be revelatory"* (Yin 2014)

To research the chosen phenomenon, there are two analytical approaches to choose from. The first approache consists of finding a starting point in the current theories around the phenomenon, with the aim to progress into creating hypotheses around what *should* happen in the case that is studied. This is the *Deductive* approach. The second approach includes introductory collection of empirics, from which theoretical conclusions subsequently are drawn. This is called an *Inductive* approach. (Andersen 1998).

The *Inductive* approach is the approach chosen for use in this thesis. Initially, some empirics were collected through observation as an employee of the company studied. Theory was then identified, which was used to categorize and analyze what was observed during the initial gathering of empirics. The gathering of theory then led to questions coming to mind for the researcher, especially regarding what the company studied was doing differently in comparison to other vehicle manufacturers.

2.1.2 Choice of Case Subject

The specific company chosen for this single subject case study is Tesla Motors (Tesla), an American automotive manufacturer with operations in the Americas, Europe and Asia Pacifica. The choice of studying Tesla is mainly motivated by the researcher's proximity to the company. A second motivating factor is the relatively low age of the company, having been founded in 2003. The low age should have allowed the company to build the organization after Mass Customization began to gain widespread adoption as a management concept. This in turn should allow for the chosen company to have set up processes and functions around the principle of building cars to order, instead of having merely adopted it as a natural progression from Mass Production. The choice was also motivated by the general media's interest in the company as well as by the researchers own interest and employment with the company. The employment allowed for access very difficult to achieve for a non-employees simply due to the currently high workload for the relevant employees within supply chain, which in turn should decrease the probability of them participating in an interview based study conducted by someone outside the organization.

2.2 Data Collection

2.2.1 Primary and Secondary Data

During an intense week in the beginning of April 2015, a majority of the data in the form of interviews and observations was collected during a visit to the home state of Tesla Motors in the United States: California The primary data collected during the visit consists of 10 interviews conducted in-person at the location of the Tesla Motors factory and three separate observations. The four observations not already mentioned, took place inside the factory and the connected office building. Other studies on Mass Customization have shown that conducting a case study at the plant level is preferable, as the plant is the most useful unit for analysis (Spring & Dalrymple 2000; New 2000). This evidence assists in motivating the visit to the factory. The secondary data consists of internal documents, which provide in-depth details of how information flows within the Supply Chain function. These cannot be shown in their original form due to confidentiality, but are used in this thesis after having been heavily modified.

2.2.1.1 Interview Design

The interviews were conducted using a semi-structured format in order for the researcher to be able to continually adjust to the data that was retrieved. The interview subjects were all promised anonymity as recommended by Rowley (2012), which is provided through the used of code words in substitution for full names and positions. These code words can be seen in table 2 and are used in the chapter for empirical findings, in order to denote which interview resulted in the data that is presented. Significant care has also been taken to reduce the likelihood of individual interview subjects being identified by their colleagues or managers. Voss *et al.* (2002) suggest the use of a recording device in the interview process, to help reduce the bias inherent in being an observer. Therefore the researcher of this thesis requested the permission to record each interview. Permission to record was fortunately granted by all interview subjects.

2.2.1.2 Selection of Interview Candidates

Naturally, when selecting interview candidates for a case study, it is to important identify the individuals who can be deemed the most fitting to interview. These are the individuals who are best informed about the data being researched. Also, an ideal introductory contact is someone who can be considered “senior” enough that can “open doors” and who knows who is best to interview to gather the data required. It is also beneficial to have this person support the research, giving guidance where needed (Voss *et al.* 2002). The access gained is partly due to the author’s connection to one of the Vice Presidents (VICEP) within in the company. This allowed for unmatched access and guidance to whom to interview in each specific sub-area of the research question. The process of gaining access began with a request from the researcher via email, prompting the VICEP to assist in finding suitable interview candidates and contact a member of the executive scheduling function to have 10 interviews scheduled in conference rooms in the factory’s adjoining office building.

Interviews		
Title	Code word	Date of interview
Director	DIR 1	13/04/2015
Director	DIR 2	07/04/2015
Director	DIR 3	08/04/2015
Manager	MGR	07/04/2015
Senior Manager	SRMG 1	08/04/2015
Senior Manager	SRMG 2	09/04/2015
Senior Manager	SRMG 3	10/04/2015
Senior Manager	SRMG 4	13/04/2015
Senior Manager	SRMG 5	09/04/2015
Vice President	VICEP	11/04/2015

Table 2 List of Interview Subjects

2.2.1.3 Observations

Here follows an explanation of the observations used to gather data for this thesis. In a part time position within the sales function at Tesla, the author had the chance to observe practices and methods used within the company. The two factory observations occurred on the same day, with the first observation being a personal tour of the factory given by one of the directors interviewed. During that tour, many questions about the production process could be asked in order to prepare for following interviews as well as the second factory tour that was scheduled later that day. The second tour was of a different kind as it mainly served to showcase the factory to current owners of Tesla vehicles and the press. The SC Analytics Team meeting provided insight into the supply chain function. By observing what issues were being discussed in the meeting, data could be gathered for subsequent adaption of the interview questions and theoretical framework. The meeting with the potential IT supplier provided similar insight, although it was focused on the challenges of keeping the IT-systems required to building customized vehicles, fully up to date and to required specifications.

Observations & Meeting Participation			
Type	Total time	Code Word	Date of obs.
Long Term Participatory Obs.	6 Months	OBS1	01/11/2014-01/05/2015
Factory Observation	90 Min	OBS2	08/04/2015
Factory Observation	60 Min	OBS3	08/04/2015
Supply Chain Analytics Meeting	60 Min	MEET1	07/04/2015
Meeting with Potential IT Supplier	30 Min	MEET2	09/04/2015

Table 3 Table of Observations

2.3 Reliability

Voss *et al.* (2002) provide guidance on the subject of reliability. They state that a researcher entering a field might bring previous interest and thus strong biases. The authors also describe how students of a certain subject, such as manufacturing strategy, will have a strong bias toward that area. This bias will affect the nature and quality of the data that is collected. To circumvent this, the researcher of this thesis has picked a field that is not immediately within the focus of the researchers current education. Supply Chain Management and Mass Customization are as concepts not focused upon within the chosen academic specializations of the researcher.

However, as the researcher has been and continues to be under employment by the case subject corporation, the researcher risks becoming an advocate instead of an observer. Unfortunately, this issue is more difficult to circumvent, as access to the company and it's operational processes, might have been made impossible had it not been for the employment itself. Voss *et al.* (2002) give a simple solution, which is to make use of several interviewers. Making use of several researchers was considered in the beginning of the planning phase of this thesis, but was made obsolete as an option due to the practical impossibility, since a non-employee would not have been allowed to enter the studied organization with the same unrestricted access into interviews and observations. This in turn could in hindsight have been solved by having a second researcher taking part of very detailed information in recordings, transcriptions, the questions that were asked and data collected during the interviews, to identify any observer or advocate bias in order to correct for it.

Very important to note, regarding the researcher's employment with the case study subject, is that no financial nor need-to-contribute agreement was made between the researcher and the organization studied. This means that no funding was received to cover any costs related to travel or accommodation. The research project was completely funded by the researcher's private funds. This allows for greater degree accuracy in the recollection of empirical findings and allows the researcher to escape the pressure that might arise from having to deliver managerial implications of use to the management of the organization, a pressure that is described by Bryman & Bell (2014).

3.0 Theoretical Frame of Reference

This chapter exists to provide a theoretical framework upon which the empirical research and analysis can be based. It will provide a description and an explanation of the theories connecting Supply Chain management & Mass Customization.

3.1 Identifying Mass Customization Strategy

Following the discussion of MC approaches from the previous research section of the introductory chapter, a way to categorize MC-approaches has been chosen for use in classifying the approach taken by the organization that is studied in this thesis. As mentioned in the section about previous research, the categorization of approaches chosen for use in this thesis was chosen due to its popularity, modernity and applicability. The two defining aspects of Mass Customization in the categorization by Duray *et al.* (2000) are:

1. The point where the customer is present and involved in the production.
2. The kind of modularity used in production.

For each aspect, there are four different subsequent stages of production, which together represent a very condensed model of the manufacturing timeline: design, fabrication, assembly and use. Duray *et al.* (2000) argue that the point of customer involvement and where it fits in the condensed model of manufacturing, acts as a one of two proxies for the level of Mass Customization, with the second one being the type of modularity used. Duray *et al* (2000) specify four different types of Mass Customizers from these two factors, shown in figure 1. The model shows how a Mass Customizer can be categorized by first examining where a customer becomes involved in the production process, shown on the vertical axis. The observed type of modularization is then used to determine a position on the horizontal axis. For example, an organization exhibiting customer involvement in design and a type of modularity that fits well into the assembly stage of production, will be categorized as an Involver. If the modularity instead occurs in the fabrication stage, the categorical description is changed to Modularizer as a result. Duray *et al.* (2000) also provide a very interesting insight: several companies named for their success in MC-literature, are actually not employing MC at all. Both Pine (1993) and Davis (1987) are called out for providing examples of "Mass Customizers" that are actually just providing made to stock items, although with extensive variety provided. Duray (2000) argues that customer involvement in manufacturing, is key to fulfilling the Customization part of MC.

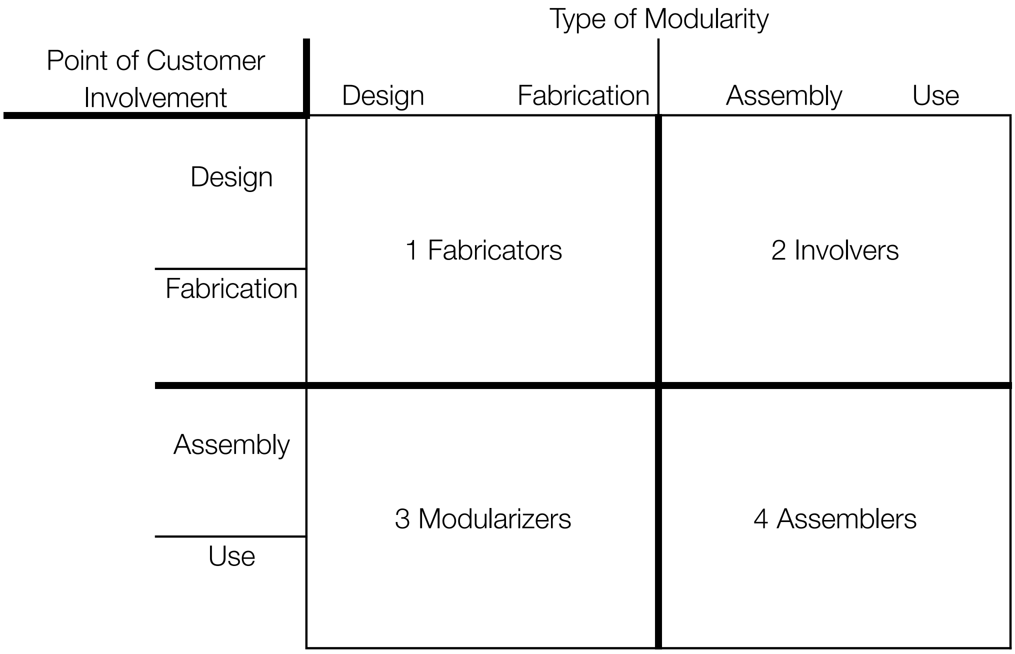

Figure 1 Adapted from Duray et al. (2000)

3.1.1 Customer Involvement

The customer involvement detailed by Duray *et al.* (2000), can be examined and evaluated using the model in figure 2. Customers can be involved in different stages in the creation of the product. Central to the model is the point where the customer is involved. The degree of customization and accompanying modularity type are in the model positioned above and below.

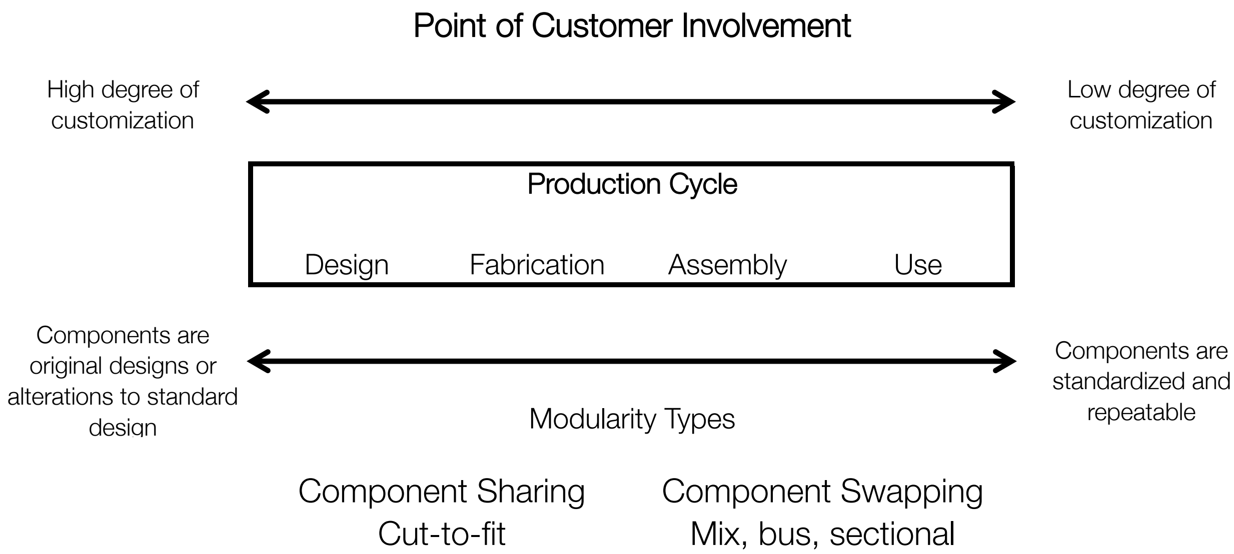

Figure 2 Adapted from Duray *et al.* (2000)

3.1.2 Types of modularity

One of the central questions regarding MC, is how it can be implemented. Duray *et al.* (2000) state that according to Pine (1993), modularity can be used to, in production, break down a customized good into separate mass produced modules that can be combined or modified in order to create a distinct product. Modularity allows for the low cost of mass production, to be combined with the value created from customization. Duray *et al.* (2000) deduce that modularity is a critical component in creating scale and the "mass" in MC. In figure 3, six different types of modularity are described. The model, originally developed by Ulrich & Tung (1991), provides short explanations on the different types of modularity. The explanations have been directly adapted from Duray *et al.* (2000).

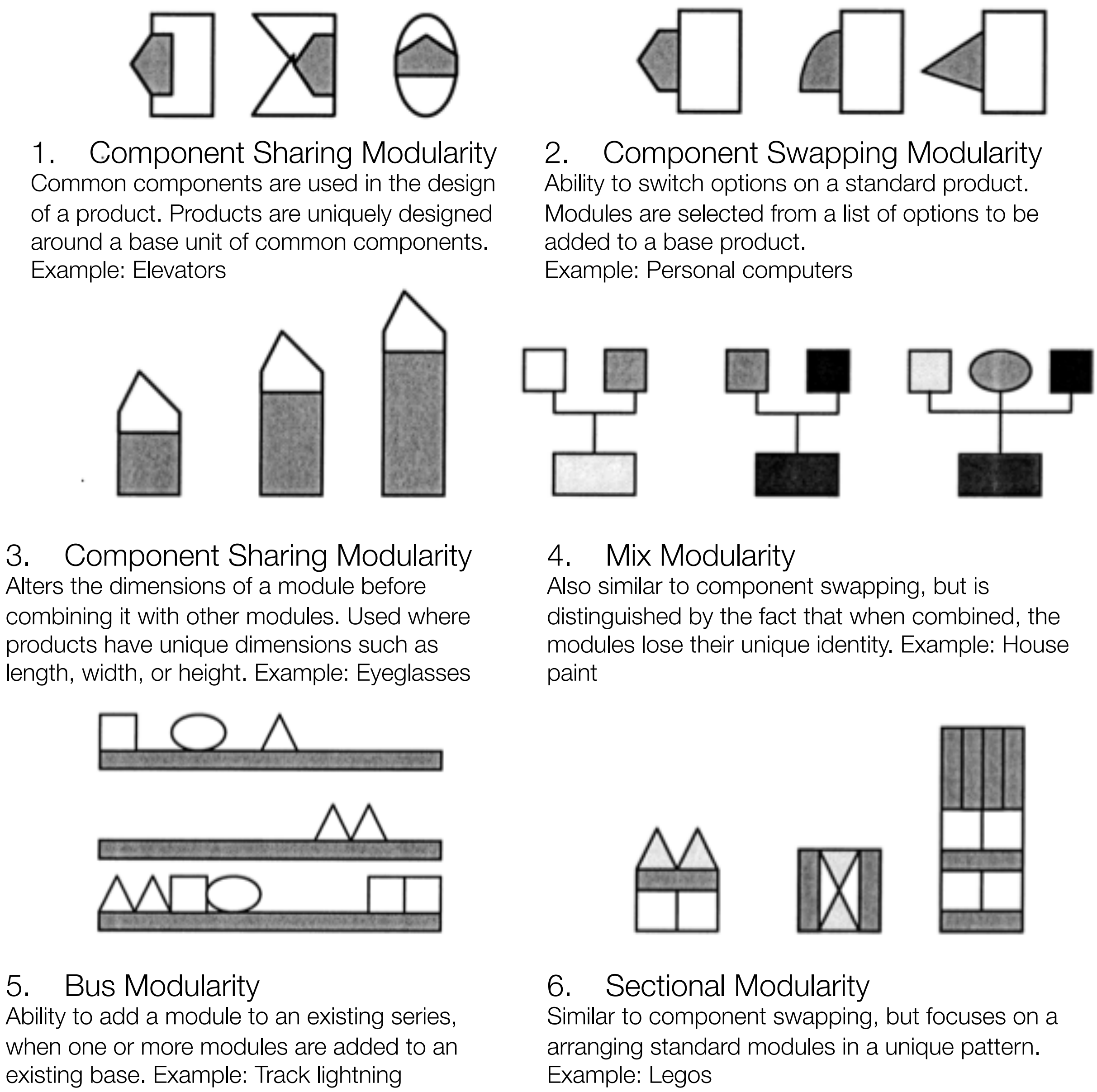

Figure 3 Adapted from Ulrich & Tung (1991) via Duray *et al*. (2000),

3.2 Supply Chain Management & Logistics within Mass Customization

Regarding the specific aspects of Supply Chain Management & Logistics within Mass Customization, Chandra & Grabis (2004) go into detail on five different problem areas. The authors find these five to be the main problems within SCM & Logistics for adopting Mass Customization and they can be seen in figure 4. The areas encased by dashed lines are the ones covered by Chandra & Grabis (2004), and examined by this thesis. In figure 5 a simple restatement of the problem areas is provided for ease of oversight for the reader. For criticism of the framework put forth by Chandra & Grabis (2004), one can question the lack of depth in the descriptions of some of the problem areas and the scarce attention given to their work. An attempt to mitigate these two items of criticism has been made by the inclusion of additional literature within the different problem areas detailed by Chandra & Grabis (2004).

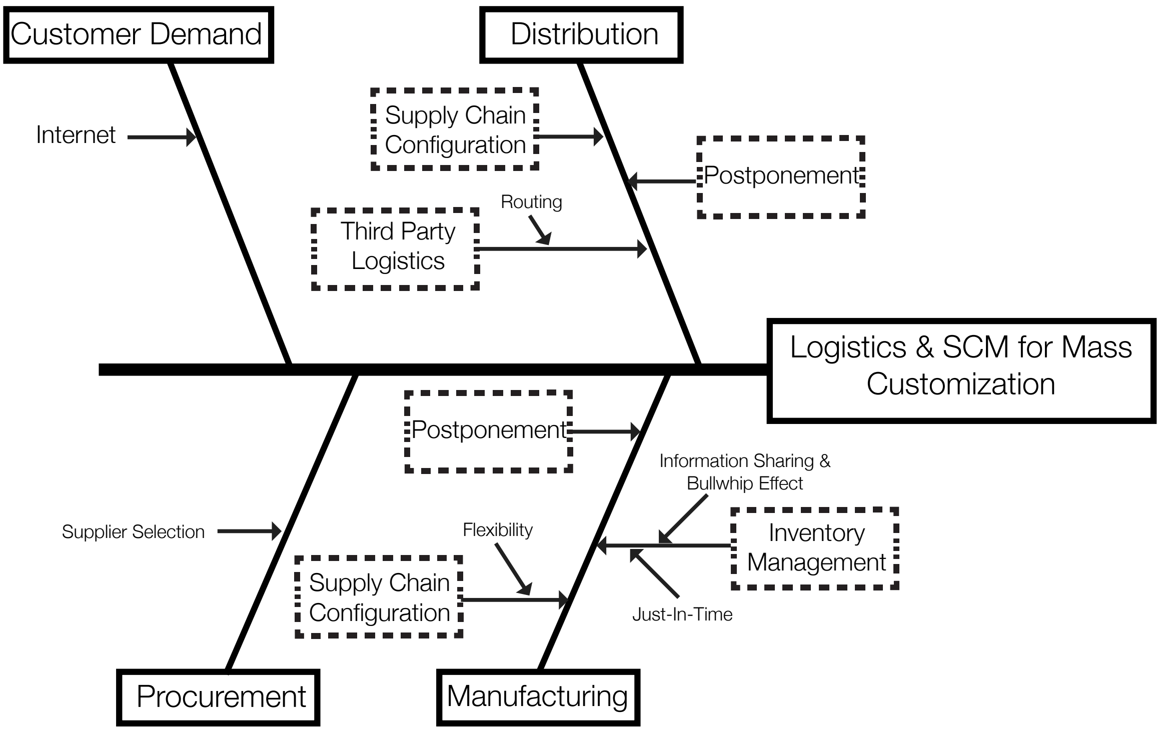

Figure 4 Key Issues in Logistics and Supply Chain Management for Mass Customization, adapted from Chandra & Grabis (2004)

Figure 5 Condensed Key Issues in Logistics and Supply Chain Management for Mass Customization (Chandra & Grabis, 2004)

Below, the five relevant areas will be described individually and more specifically in order to provide a solid foundation upon which to base the collection of empirical evidence and to construct the analysis.

3.2.1 Supply Chain Configuration

Supply chain configuration is defined by the Chandra and Janis (2004) as the processes of deciding on the location of and activities to be performed by suppliers, manufacturing facilities and distribution centers, as well as to construct flows in between these entities. Decisions to be made within this specific area are made with respect to costs of certain aspects of business; fixed investments in facilities, processing, procurement, transportation and capacity constraints. The issue of SC Configuration for Mass Customization has been covered in depth in an article by Salvador *et al* (2004). In their exploratory, multiple case study based research, the authors conclude how the configuration of a supply chain should be made, dependent on the degree of customization offered by the manufacturer. The authors examine six companies, three of which exhibit a *moderate* level of customization, while the other three firms offer a *high* level. The level of customization is decided by the total variations of a product that are available to the customer, which is calculated using the amount of choices within each specifiable category in product configuration. The *moderately* customizing manufacturers provide around one hundred options, while the *high* leveled manufacturers allow for one thousand or more.

The companies are compared on three supply chain configuration related areas: Supply Network, Manufacturing Network and Distribution Network. However, the firms exhibiting a *moderate* level of customization are not letting the customer customize any aspect of the product. These firms make goods, in many variants, but only directly to stock at dealers and agents. This practice goes against Duray's (2000) definition of a Mass Customizer, covered previously, as there is a lack of customer involvement in the production process. The only customer choice in the *moderately* customizing firms, occurs when the customer picks a good from an already existing stock of manufactured items at a dealer or reseller.

Within Supply Chain Configuration, according to Salvador *et al.* (2004), there are three types of networks: the *Distribution Network,* the *Manufacturing Network* and the *Supplier Network* . How a firm acts in relation to the structure of these networks, defines how it configures its supply chain. By examining how Salvador *et al.* (2004), describe how other Mass Customizers configure each of these sub areas of supply chain configuration, an opportunity appears for searching for either affirming or contrasting practices within the empirical findings.

In the *Distribution Network* described by Salvador *et al.* (2004), it is observed that the firms displaying a *high* level of customization all have a shorter network than the firms displaying a *moderate* level. This means that the total number of steps between manufacturer and the customer is smaller. For *highly* customizing manufacturers, goods are observed to go either directly to the customer from the factory, or to a dealer where the customer can pick up the product. For *moderately* customizing manufacturers, the distribution chain more often contains a distributor as an extra step.

The *Manufacturing Network,* defines the physical and geographical layout of the manufacturing operations in the supply chain. It was observed in all firms employing a *high* level of customization, that they used an assembly system in a central plant with component manufacturing outsourced to suppliers or to separate plants. It was also observed that the modularity type employed by each of the highly customizing manufacturers, was different to the type employed by the moderate customizers. The modularity type found in *highly* customizing firms, by Salvador *et al.* (2004), is based on the *Component Swapping* modularity first described by Ulrich & Tung (1991) with the exception of that assembled products coming off the assembly line can differ from each other in every module. Hence, the whole product is based upon modules, compared to the product implied in *Component Swapping,* where the product is built on a standard base with the addition of several modules that can differ between each other.

The *Supply Network* is constructed by the choices made and the restrictions imposed on and by the manufacturer when deciding on where to source parts for production. Salvador *et al.* (2004) observe very different practices between *highly* customizing and *moderately* customizing firms in terms of supply network configuration. M*oderately* customizing firms are shown to have differing power in relationships with suppliers of common body components and swappable components. Suppliers of swappable components are usually smaller than the *moderately* customizing manufacturer and are therefore the weaker part in the relationship. The manufacturer can push the supplier to absorb inventory and to delivery a specifically crafted, insertable module, on demand very late into the assembly process, which in turn increases flexibility and helps to achieve Mass Customization. (Salvador *et al.* 2004)

3.2.2 Postponement

Postponement as a concept can be found in literature as far back as 1950, with further research made from 1966 and forward, (Bucklin, 1966; Van Hoek 2001). Postponement is the practice of postponing the activities which alter and change the fundamental characteristics and functions of a product being produced, to the latest possible point in the supply chain. This definition is found in Chandra & Grabis (2004), who in turn drew inspiration from Bowersox & Morash (1989). Van Hoek (2001) states that *"postponement is and increasingly relevant to realize Mass Customization"*. Chandra & Grabis (2004) agree and call postponement "*one of the dominant strategies to achieve mass customization"*. Chandra & Grabis postulate, with the assistance of Van Hoek (2001), that postponement can occur in both manufacturing and in distribution. In manufacturing, postponement is achieved by postponing activities such as final assembly, labeling and packaging of products. In distribution, it is achieved by producing goods before it is decided to which geographic market they are to be sent.

According to Chandra & Grabis (2004), there is a possibility for postponement overlap between manufacturing and distribution, where the final manufacturing activities are relocated from the manufacturing facility, to the point of distribution. This would be the case if vehicle was built to 90% completion in the manufacturing plant, with the last 10% of assembly or testing to be completed at the delivery center. This overlap is more common with the globalization of supply chains (Chandra & Grabis 2004).

The actual degree of postponement is measured in the "*number of supply chain operations… completed after a customer order is received"* according to Chandra & Grabis (2004). A low number of SC-operations completed after a customer order is received, implies a higher degree of postponement. By examining the manufacturing activities and distribution processes at Tesla and comparing observations with the theories on postponement described herein, an analysis can be made of the role of postponement in enabling MC.

3.2.3 Inventory Management

In the Mass Customization context, where production follows what customers are ordering and not a preset plan of production, the need for items composing customizable elements can be unevenly distributed. This makes the need for inventory management greater. Chandra & Grabis (2004) expand on inventory management (IM) in a MC setting and identify different types of components for use in manufacturing. The first type, core components, do not change between configurations. For example, all vehicles need a filter for the air that flows into the cabin. Another type of component is one that is allowed to be customized, such as an interior décor insert. These two types of components show different characteristics of demand. The core components will see the most invariable demand, as the demand purely follows production volume. The customizable components will see variable demand, as a customer has to order a specific configuration for demand of that component to arise. Of the customizable components, the ones constituting the most bought product variations will likely experience quite steady demand, while components that make up less popular product variations will experience a more variable demand. These different types of components have implications for strategies for inventory management. Chandra & Grabis (2004) suggest differing strategies for each type of component:

- Material Resource Planning (MRP) for components with variable demand that can be forecasted.
- Just-In-Time (JIT) for locally sourced, steadily demanded components
- Re-order Point (ROP) for globally sourced products with steady stochastic demand.

These strategies are suggested to allow for flexibility in delivering the exact variation that the customer orders, and therefore prove to be important tools for achieving MC. By examining IM practices at Tesla, analysis can be made on how IM as a SCM subarea, affects an automotive manufacturer's ability to Mass Customize.

3.2.4 Third Party Logistics

Chandra & Grabis (2004) explain the term Third Party Logistics (TPL) as the usage of extra-organizational providers of logistics services, able to supply their clients with a high degree of flexibility in technology, packaging and delivery speed. By outsourcing logistics, a firm can according to Chandra & Grabis (2004): focus on their core competences, provide flexibility and gain access to established logistics networks. In regards to Mass Customization, TPL can help reduce the financial cost of the manufacturing of high volumes of customized goods. Chandra & Grabis also identify that distribution of finished, customized goods often occur on a "per item basis" which can induce problems in achieving economies of scale in logistics for the manufacturer. By combining the requests of several clients at once, the TPL suppliers can more easily achieve scale and therefore decrease the cost, which in turn make them valuable partners to Mass Customizing manufacturers.

3.2.5 Information Technology

Duray (2004) argues that well functioning IT-systems play a key role in an MC setting, if they can directly link together internal functions such as manufacturing and design as well as external actors such as customers and suppliers. On a similar note, Chandra & Grabis (2004) state that the three primary benefits of using IT from a supply chain management perspective within a Mass Customizing organization are: the simplification of receiving of customer orders, conversion of orders to production information and handling of inventory & transportation information. The first benefit of IT, the simplification of receiving of customer orders can be achieved by allowing the customer to directly input an order to the factory through a website, where the customer can pick from a selection of options that represent underlying modules to be combined in production. The modules implied by the options chosen by the customer, tell of which parts that will be needed in the production. The second benefit consists of systems that allow for conversion of orders to

production information. These systems constitute a link between the system that receives the order, and the internal production system. The third benefit is that IT can help with the handling of information flows regarding inventory and transportation (Chandra & Grabis 2004).
By using Enterprise Resource Planning (ERP) systems, this third benefit can be had. The use of ERP systems is a practice evaluated in depth in a well cited article by Akkermans *et al.* (2003). The authors of the article performed an exploratory study of 23 supply chain executives. They identified several issues within SCM of which some are related to Mass Customization. They identify that flexibility in IT is needed to cope with fluctuations in supply chain needs and that ERP systems allow for an increase in the customization of goods and services. Chandra & Grabis expand on Akkerman *et al.*:s work and explain that adoption of Mass Customization can be facilitated by ERP systems, as they have been shown to prove useful in both communicating with customers as well as in overseeing all information necessary to produce a customized good.

Another of the methods detailed by Chandra & Grabis (2004) is Electronic Data Interchange (EDI). EDI is a standardized way of exchanging data related to the procurement of parts in a manufacturer & supplier relationship. The nature of EDI allows a purchasing organization to partly outsource the restocking of inventory at the location of the purchaser, since information about inventory levels, production and current shipments can flow freely and automatically over the interchange (Lee *et al.* 1999). By contrasting the theories surrounding IT's role in SCM & MC, with empirical findings, analysis can be performed on how IT supports Mass Customizing method of manufacturing.

4.0 Empirical Findings & Data

The following chapter presents the organization chosen for this case study and the empirical findings that are analyzed in the Analysis chapter. The findings are partly categorized using the theories described in the previous chapter. The interviewed managers have all chosen to remain anonymous, hence the use of code words as shorthand for reference purposes, with added numeration to identify separate interview subjects when information from their interviews have been used.

4.1 Tesla Motors

Tesla Motors, headquartered in Palo Alto, California is a maker of premium electric cars. Founded in 2003, the company produced approximately 35 000 cars in 2014 out of their factory in Fremont, located 29 kilometers to the north east of their headquarters. A special side of Tesla Motors is the ownership of all service and sales locations worldwide. No third party is involved in the contact with the customer or in the receiving of orders, which stands in stark contrast with other large automotive manufacturers that may take in orders and perform vehicle maintenance through licensed franchises known as dealerships. As for variety in choice of models, Tesla Motors is currently producing one model, although with 4 sub-variants containing different batteries & motors. The Model S, as it is called, is an electric 5-door premium sedan that comes with different sizes of high voltage batteries used in either a single motor or in dual motor drive unit configuration. The Model S comes either rear wheel driven with the single motor option or four wheel driven with the dual motor option.

4.2 Description of the Production Process

In order to understand how Tesla achieves a process of Mass Customization, one must first understand: how a vehicle configuration, colloquially known as a design, is created online by a customer; how the information of what to build is transferred to the factory and how the vehicle is composed from a collection of components, raw sheet metal and man-hours & robot-hours. The last step to understand consists of how understanding how the customer who started the process, finally receives a vehicle.

The process begins when a customer enters an order through a web-based interface, capable of displaying a visual representation of a combination of chosen options. The customer using the web based tool, called the Design Studio, is presented with a plethora of options as shown in table 4. In combination with regional differences in safety requirements, vehicular body construction and more, these options bring the total amount of possible variations of the vehicle up well above two million (OBS1). Important to note is that the customer can not change the actual design of the car. The dimension and overall looks of the vehicle have already been decided upon by the designers and engineers at Tesla. Allowing the customer to be a part of the design process of the body of the car would imply that the customer would be able to construct a different fundamental body shape, without having to adhere to predetermined dimensions, which would be prohibitively difficult and expensive to put to market, given the safety regulations and the demands for crash testing that exist in nearly every country in the world. Regulations typically demand that every variation of body shape needs to be independently crash tested. (Interview with DIR2)

Options Available for Customization			
Type & no. of options		Type & no. of options	
Colors	8	Autopilot Package	2
Seats	7	Interior Trim Level	2
Roof	2	Suspension	2
Rims	4	Hifi-Package	2
Inner Ceiling	3	Rear Seats	2
Interior Decor	4	Winter Package	2
Battery & Drive Unit	4	Trunk Child Seats	2

Table 4 Options Available for Customization

When the customer is satisfied with his or her order, it is confirmed and entered into the custom built backend software aptly named MyTesla. The order is also imported into Salesforce, which is the Customer Relationship Management (CRM) software used by Tesla. Salesforce establishes a link between the specific Vehicle Identification Number (VIN) that each vehicle produced receives and the actual identity of the customer. From MyTesla the order is imported into the custom built Enterprise Resource Planning (ERP) software called Warp Drive. Warp Drive itself is very interesting and will be covered separately. Warp Drive originates from within the company. It is designed to completely eliminate the need for a conventional ERP system such as those supplied by companies like SAP of Germany or Oracle of the United States.

4.2.1 A Car is Born

The chassis and the body of the car are made of metal. In the fabrication stage, the body panels of the car begin as sheet metal, unrolled from large cylinders of sheet metal in the beginning of the production line. Very large hydraulic presses are used to press the sheet metal into parts that can be welded together later on. These parts are put through quality control before being sent to the body shop. (OBS3) In the body shop, the different parts of the chassis and body are joined together by various forms of welding performed by robots and manual labor. (OBS2)

When all of the body parts have been joined, a Body in White (BIW) has been created. The creation of the BIW was triggered by a specific customer order and it has already become tied to a full list of specific options requested by that very customer. If the customer wishes for 7 seats or dual electric motors for example, then quite significant modifications need to be made to the body of the car in the welding stage. This means that a car body that was welded together with the intention of becoming a single motor car, or to have only five seats, cannot without significant rework be used as the body for a dual motor car or as the body for a car with seven seats (OBS2, interview DIR3). The BIW is then sent towards the paint shop, where it is coated multiple times to minimize metallic oxidation and to increase surface resilience of the metal. Subsequently, the BIW receives one of 8 possible colors that customers can choose from.

When the painting process is completed, the now painted body which is no longer called BIW, is sent towards the General Assembly (GA) line. Between the paint shop and the GA-line, there is an overhead conveyor containing a buffer of painted car bodies. When a car leaves paint, different activities are triggered, both within internal production and within external suppliers. *"The production of seats at our external supplier, is triggered when the car leaves paint"* explained one of the Sr. Managers when (SRMG3) when interviewed, which was corroborated by one of the directors within production (DIR3). In the GA-area, the car receives a full interior, motors and the correct high voltage battery for the configuration. The possible combinations of options provided to the customer in the GA-area alone is immense. Not counting colors and regional differences between vehicles, the GA-area can output approximately 170 000 different variations by combining the different options available online to the customer. Once inside the GA-area, each vehicle goes through three different assembly lines. The trim line, the chassis line and the final line. In the trim line, initial trim pieces and wire harnesses are inserted. Various trim modules have by now already been manufactured "off-line" on lines called feeder lines, which means that they have been prepared on separate manufacturing lines. Their production is triggered by the body leaving the paint shop. These modules are then sequenced into the trim line for insertion. The alternative to this approach would be to build the modules directly on the main trim line. (OBS 2, Interview MGR)

In the chassis line, the battery is inserted, followed by underbody work. On the final line, the vehicle receives the correct software, is thoroughly tested and inspected in order to ensure quality. (Interview SRMG3, OBS 2). Depending on which geographical area the customer is located in, each car is readied for the transport method that has been chosen for that specific region. (Interview DIR1, OBS3)

4.3 Five Key Problems in Logistics & SCM

As detailed in the introductory paragraph of this chapter, the general overview of the production process is followed by empirical findings within the identified SCM specific areas.

4.3.1 Supply Chain Configuration

On the inbound logistics side, where parts and components enter the manufacturing operations, there are approximately 400 different suppliers sending around 700 shipments per week. Naturally, not all suppliers are located within the same geographical region; some are located *"across town"* (SRMG1) with lead times measured in hours. Seating for example, arrive in already assembled sets, ready to be sequenced into a car in general assembly, having been put together at the facilities of a seating supplier. The production of high variability components such as seats are intentionally kept close to the main plant. Some suppliers are located in Asia with lead times of around four weeks. (Interview DIR1, SRMGR 1) Components sourced from Asian suppliers include electronics and other low-variability goods. "*We avoid having high variability off the continent*" said one manager (Interview MGR). Low variety components that are simpler to keep in inventory are sourced from locations further away. The implications of variety in components from a supplier can be mitigated by flexibility, but flexibility is drastically hampered by geographical distance. "*Let's say you have a supplier in Asia: even if they are really quick and responsive, you still have a long lead time sending stuff over the water.*"(MGR)

4.3.2 Postponement

In addition to the description of the production process, the following empirical findings bear relevance from a postponement point of view. When the production control department plans

which cars to schedule for production, there is a consideration made for which region they are shipping to. Cars going to Europe, America or Asia & Pacific are "geo-built" in batches based on final destination in order to ease the scheduling for the logistics function (Interview SRMG1). Previously given in this chapter is a description of how the seats supplier receives a build order to assemble a collection of components into fully finished seats, once the car is done in the paint shop. The same signaling method is used to trigger the in-house production of several items to be installed in general assembly. Modules such as drive units and front & rear bumpers are also triggered to be built when the vehicle leaves paint (Interview MGR & DIR3, OBS2)
A very interesting fact was uncovered when speaking to one of the managers about what he saw as enabling an MC approach: *"we are pretty booked up for about X months forward"* in terms of orders which according to him greatly helps in making each car to customer order. This is due to that the sales volume continuously grows at a pace that equals or exceeds the pace at which the production capacity is able to grow. He expressed concerns about how the MC approach would be affected by less foresight in incoming orders.

4.3.3 Inventory Management

Inventory management (IM) is very important to the flow of production. Without correct IM practices, the production grinds to a halt. One missing part, which is also referred to as a component, in the production makes the whole production come to a complete stop (Interview MGR). Of the 4000 components that constitute a vehicle, approximately 2000 do not differ between vehicle configurations. (Interview SRMG5) These parts that do not change, can be referred to as core components. Before being used in production, most of these components are held in a warehouse inside the factory. Factors that determine when to order additional components, differ between the different categories of components. When due to be used in production, the core components are retrieved from a warehouse inside the factory (OBS2). By monitoring the stock levels in the Manufacturing Execution System (MES), and comparing them to the component requirements of the upcoming months, based on orders that are visible in the ERP, the production control function can decide on how many core components to order each week. Min-max levels in combination with estimated shipping times from suppliers, are used to decide when the orders need to be sent to suppliers.

The remaining 2000 parts that go into each car, depend on what the customer of that car has ordered. Within this group of components, some are more commonly ordered than others. This has an effect on their demand characteristics. However, as noted in the previous section on Postponement, the backlog of orders is of such significant size so that when a customer orders a vehicle, the time it takes for production of that specific vehicle is between four and six weeks. (SRMG4) This time simplifies the task of IM, as the need for forecasting decreases. This is due to sales to grow as fast, or faster than production, as also noted in the Postponement section of the empirical findings. (Interview SRMG5, OBS1)

Some of these parts are ordered based on specific trigger points in the production. As described previously, some components are ordered from suppliers when a car leaves the paint shop. These parts have appearance related characteristics that vary to a great extent. Seats and trim parts such as inner ceilings, which come in a plethora of colors and qualities, arrive pre assembled and spend little to no time waiting to be inserted into a vehicle in the assembly line. These parts are stored on racks between the assembly line and the loading bay where shipments arrive. (Interviews MRG, DIR1) These parts with large variability arrive directly from suppliers that are located nearby. In turn, these suppliers have been given prior notice of between six to nine months for which quantity of parts they should carry in stock. This prior notice is based on forecasting that is performed by the production control function, which in turn is simplified by the backlog of orders. (Interviews SRMG5, SRMG4)

Five out the ten managers interviewed mentioned that the maintaining of high inventory levels of components, is a significant enabler for Tesla to be able to build cars to order.[1] Maintaining high inventory levels allows for absorption of inaccurate forecasts. One manager expressed himself quite clearly when asked what he thought enables the method of making cars to customer specifications: *"We are making it work, but its basically with inventory"* (Interview DIR3).

4.3.4 Third Party Logistics

When shipping finished goods, the logistics team prefers to contract smaller shipping firms, instead of going to larger firms. The motivation for this is the increased flexibility provided by smaller logistics suppliers. (Interview with DIR1) The last leg of the journey to the hands of the customer is often completed by the customer, as she picks up the vehicle which is sent to the Tesla Service Center that is the closest to her residence. These centers act like distribution centers where the customers can pick their car up and receive a guiding introduction. The use of Service Centers as pickup points allows for simplification of the delivery process by letting orders have a predetermined shipping destination the minute the order is placed. This allows the logistics team to greatly simplify shipment planning, as they can estimate a date when a certain vehicle will be delivered, and thereby pass the information on to logistics partners. The majority of all vehicles shipped end up in North America. Worth mentioning is that for vehicles shipped to Europe, a stop is made in Tilburg, the Netherlands, for a second round of final assembly. The European vehicles are fully assembled and tested in California, but are disassembled into three major parts, for shipment across the Atlantic. Based on revenue proportions for the year of 2014, gathered from the latest annual report (Tesla Motors, 2015), North America accounts for approximately 62% of all revenues and can therefore be assumed to absorb a similar percentage of all deliveries made.

[1] Interviews with DIR3, SRMG2, SRMG4, SRMG5, VICEP

4.3.5 Information Technology

Covered earlier in this chapter is the process of how a customer order enters the system. A simple view of the implications of this is that by entering the order online, the customer indirectly submits the order to the factory. Shown in figure 6, is a simplified overview of the path that a customer order takes after having been submitted online.

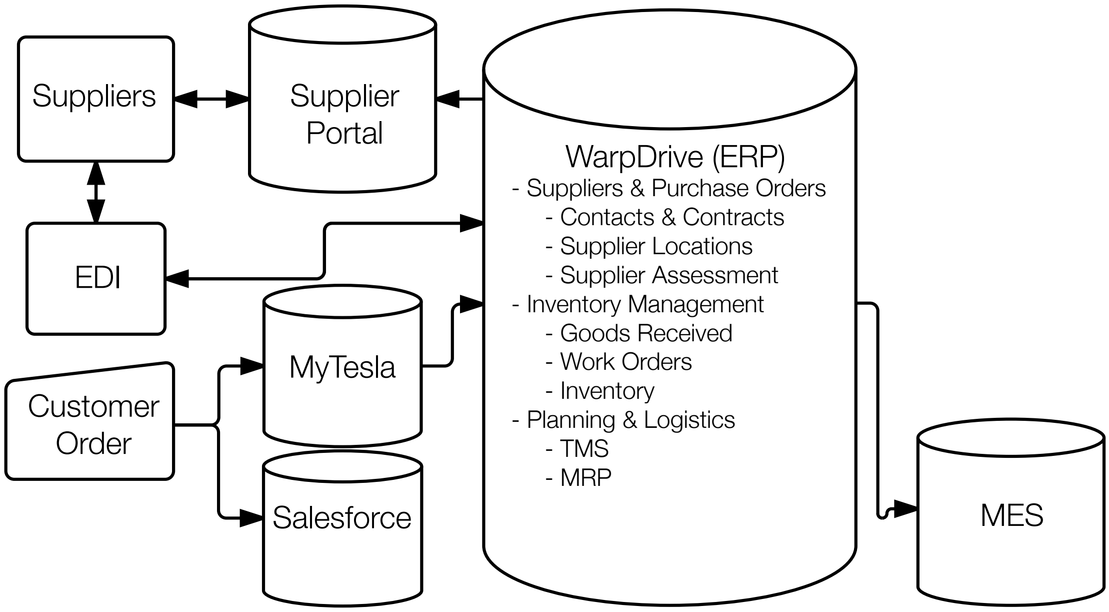

Figure 6 Supply Chain Centric Information Flowchart

Regarding the handling of information flows in inventory and transportation, Tesla uses multiple systems. Within the ERP called Warp Drive, the customer order is broken down into an initial Bill of Materials (BOM), that dictate the specific parts that will go into the car that has been configured in the customer facing online design studio. The BOM is used to make sure that all the parts, both from internal production and from outside suppliers, are available at the time of actual production. (Interview with DIR 3) The BOM itself is used in the Manufacturing Execution System (MES), after having been "exploded". The term BOM explosion was encountered times during research and it refers to how the parts list, also known as bill of materials (BOM), of the car is broken down into smaller elements. For example, a seat is comprised of parts such as cushioning, heating elements, electric motors for adjustment of seating position. Prior to the BOM explosion, the seat would perhaps be listed as "Black Sport Seats", occupying a single line in the BOM, while after the explosion, it would take up 10 or more. Each car contains around 4 000 distinct parts which together make up an exploded BOM. About half of the parts of a car are the same for each vehicle, while the other half is different between vehicles produced. (Interview SRMG5). The exploded BOMs, containing nearly 4 000 individual items, present a challenge as there are nearly 1 000 unique exploded BOMs generated every week, generating close to four million records to be processed each week before being they are fed to material planners and suppliers. (Observation from MEET2).

Several of the interviewees remarked that since the CEO has a developer background, there are several systems being built and maintained by in-house expertise. The ERP system kept coming up as an example as it is constantly upgraded to further improve the co-ordination within supply chain (Interview SRMG1). The Transportation Management System (TMS) that allows for accurate tracking of shipments originating from suppliers, was also cited as an example.

Suppliers receive information about what to produce and deliver through 3 different methods: Electronic Data Interchange (EDI), the Supplier Portal and email. The Supplier Portal, which has been developed in-house, is an online tool for suppliers to exchange information about current shipments & addresses, drawings of parts to be produced and more with Tesla. The Supplier Portal is web-based and provides each supplier to log in to only access the information that is relevant to that specific supplier. More than half of the suppliers use the Supplier Portal, while EDI is used by most of the remainder, with ordering via email taking up a negligible part of information submission. (Interview MGR)

5.0 Analysis

The following chapter aims to analyze the empirical findings generated in this case study. The analytical contributions are discussed thematically based on the theoretical frame of reference, with a beginning in an identification of the employed Mass Customization Strategy, progressing into a breakdown of SCM specific operational aspects affecting the ability to Mass Customize, which are individually analyzed with the purpose of answering the research question.

5.1 Identification of Mass Customization Strategy in Use

5.1.1 Customer Involvement

By comparing what Duray *et al.* (2000) say about point of customer involvement, to the empirical findings, there is evidence of customer involvement in both the fabrication stage and the assembly stage. The customer can influence how the car is welded together, which as a process precedes the General Assembly, by choosing options such as panoramic roof or seven seats. Therefore the first point of involvement occurs in the fabrication stage. In both the paint shop and the assembly area, the customer also has clear influence on the appearance and characteristics of the end product, which is a requirement for a point of involvement, as put forth by Duray *et al.* (2000).

5.1.2 Type of Modularity Used

The manufacturing process and its sequential stages exhibit various characteristics of modularity. From the empirical findings it is clear that when a vehicle enters assembly it encounters several examples of modules. Some of these modules are assembled separately next to the main assembly line and some arrive to the factory pre-assembled by suppliers to be sequenced in to match the car that they were purposely built for by the supplier as a result of the signal received by the supplier as the car exited the paint shop. The most common type of modularity discovered through interviews and observations, closely matches the type called *Component Swapping* which implies that options are selected from a list to later be added to a standard products, which in this case is the painted body of the car. However, seeing as the customer has a way of affecting the fabrication stage,

5.1.3 Partial Conclusion

Identifying that the customer can affect the end shape and functions of the product already in the fabrication stage and that the modularity used most likens *Component Swapping,* one can conclude that Tesla can be categorized as an *Involver.* Most importantly, proof is found that Tesla can be categorized as a Mass Customizer.

5.2 Five Problem Areas

5.2.1 Supply Chain Configuration

The empirical findings on supply chain configuration partially match what is described by Salvador *et al.* (2004). The total amount of variations available to a Tesla customer is over 2,7 million, not counting the regional specificity that adds even more variation.[2] This means Tesla maintains a *high* level of customization, as defined by Salvador *et al.* (2004). As for the distribution network, a short distribution network is utilized for North America, as the outbound logistics team directly sends each car to service centers that act as pickup centers for customers. No third party dealer or distributor is identified in the North American distribution network. The European distribution network however, is altered by the existence of the assembly center in Tilburg. However, it can be assumed that more than 60% of vehicles produced go to the North Americas where the shortened distribution network is currently in place, as evident by the sales revenue allocation per region.

The manufacturing network observed to be in use is also similar to what is described in theory for Mass Customizers. However, the type of modularity detailed in the empirical findings contrast the type of modularity predicted by Salvador *et al.* (2004) for *highly* customizing firms, as Tesla's type merely can be classed as *Component Swapping* according to the typology first defined by Ulrich & Tung (1991) and then revisited by Duray *et al.* (2000). If there was a possibility for each vehicle to be

[2] Calculated with information in table with options available for configuration: 8*7*2*4*3*4*4*2^7=2 752 512

different in all separate modules, then the *Combinatorial* modularity would have been a better categorization. Therefore, the configuration observed, differs slightly from what theory predicts. Each vehicle coming off the assembly line at Tesla contains around 50% of standard parts, as can be seen in the empirical findings.

As for the supply network, an interesting aspect is observed in that Tesla likens more a *moderate* customizer. Providing a *high* level of customization, according to Salvador *et al.* (2004) should be characterized by a different supply network configuration than what Tesla exhibits. This means that Tesla goes against the predictions for how Mass Customization is achieved through the use of Supply Chain Configuration.

5.2.2 Postponement

Even though cars that belong to the same region are built together in geographical batches, the cars have already been assigned to a customer since the beginning of production. There is also no evidence in the empirical findings of that postponement in distribution is used, which theory suggests could be used to achieve MC, especially if the supply chain is globalized (Chandra & Grabis, 2004). Tesla's supply chain demonstrates qualities of being globalized as there are continental, geographical discrepancies of location amongst suppliers.

As can be deduced from information given in the general description of the production process, some activities occur only once a car exits paint. More specifically, these include the building of seats at suppliers and front bumpers and drive units within internal production, which points to postponement being used to achieve MC in the assembly stage.

In the postponement problem area, findings unfortunately become less relevant since the production currently is capacity constrained. Having very high demand eases some of the hardship regarding postponement decisions in the supply chain.

5.2.3 Inventory Management

Analysis on the specific aspect of IM as an enabler of Mass Customization is made based on the general description of the production process and the specific section on empirical findings relating to inventory management provided in the previous chapter. Theory accurately predicts the use of MRP, JIT based policies in IM, as use of these policies can be witnessed in observations and interviews. Also apparent, is that challenges arise due to the unpredictable nature of following customer demand in manufacturing. However, these challenges appear to be mitigated by the backlog, caused by the apparent lack of a steady state in the relationship between sales and production. This allows for components with high variability in demand, to be ordered and forecasted for in a manner similar to components that experience a more predictable and steady demand.

5.2.4 Third Party Logistics

As noted in the empirical findings, Tesla uses smaller logistics providers that can provide flexibility, which in turn makes TPL important to their ability to provide customized goods. This is very interesting, as the behavior cannot be predicted by theories on TPL in MC.

As witnessed in the empirical findings, the planning of shipments is helped by the use of predetermined delivery destinations, also known as Service Centers. If customers instead received delivery to their residences, there is a greater degree of customization required as the flatbed trailer carrying the finished vehicle would have to take a detour to deliver perhaps only a single vehicle to a customer. This would make it difficult to achieve economies of scale for the logistics supplier, which is something that logistics partners prefer (Chandra & Grabis, 2004) which in turn has an impact on the cost of shipping of customized goods. Reducing uncertainty by better planning of outbound shipments and thereby increasing future shipment visibility is highly beneficial to reducing the costs of Mass Customization, as it allows logistics partners to more effectively achieve economies of scale. Interesting to note is that this allows the logistics function to function in a way more closely related to the way in which a non-customizing manufacturer would schedule shipments; in large batches to dealers in every region.

5.2.5 Information Technology

Receiving customer orders is made very streamlined and efficient by the use of a custom built web interface, which is detailed in the description of the general production process. This enables simplified collection of customer orders, which according the theory is beneficial from an MC point of view. The proposition by Duray (2004), that IT is beneficial for MC if it can link together different internal functions as well as customers and suppliers is applicable in Tesla's case as the collection of systems that can be observed in the empirical findings, allow for that linkage.

Tesla has the in-house IT-capability to build and develop their own ERP system (Warp Drive), which allows them greater freedom in adapting to the needs created by their choice to build all vehicles to customer orders. As the ERP is the central hub for all activities that relate to the supply chain, the ERP system can be identified as one of the central aspects of IT within SCM at Tesla. Possessing capability to swiftly adapt the system to a changing set of needs and requirements imposed by Mass Customization, is greatly beneficial. This capability likens that of IT-flexibility, as detailed by Chandra & Grabis (2004), which is proposed to be beneficial for a Mass Customizer from a SCM perspective. As Chandra & Grabis also state, systems that allow for integration and management of inventory and transportation such as inbound & outbound shipments, are beneficial to manufacturers seeking to Mass Customize. By using EDI and the Supplier Portal to handle supplier relationships, and the MES to monitor inventory, Tesla can maintain tight control of the information flows in the supply chain with the help of IT.

6.0 Conclusion & Discussion

This chapter presents the results of the analysis chapter and provides an answer to the research question. A discussion on the results and their reliability follows. Also in this chapter, suggestions on further research are given.

6.1 Conclusion

In this thesis, an attempt has been made to provide an answer for the following research question:

How is Supply Chain Management used to achieve Mass Customization within the operations of a modern automotive manufacturer and which Mass Customization strategy does this manufacturer employ?

Previous research within Mass Customization point to a difficulty in managing a supply chain in a Mass Customization setting. The complexities inherent in meeting granular customer demand, present challenges in various supply chain areas. In the analysis section of this thesis, empirical validation is sought for the existing theories on how organizations should approach Mass Customization from a Supply Chain Management perspective.

Through analysis of empirical findings, it has been discovered that the general effect of SCM on Mass Customization is beneficial, as predicted by theory. Evidence from the case study suggests that Tesla can be categorized as a Mass Customizer as they employ a certain MC manufacturing strategy characterized by semi-early customer involvement in the fabrication stage of manufacturing and component swapping modularity. Within the five problem areas defined by Chandra & Grabis (2004), several interesting results were discovered. Within supply chain configuration, Tesla showed similarities with both *highly* and *moderately* customizing firms from a previous exploratory study. Tesla employs a differing modular strategy in manufacturing, compared to the *highly* customizing firms. By providing over 2.7 million possible configurations to customers, Tesla exhibited far more variety than what theory prescribed for *highly* customizing firms. Other factors contributed to Tesla to be more similar to a *moderately* customizing manufacturer, that according to theory from Duray *et al* (2000), can not be categorized as Mass Customizers. This leads to a questioning of current theory on Supply Chain Configuration in an MC setting. In Postponement, some elements of what theory described could be witnessed. Due to the early customer involvement point, no postponement in distribution was found. Postponement in assembly was found however, which was found to be enabling a cost reduction for highly variable items such as seats and interior trim, allowing for one of Mass Customizations principles; a high grade of customization combined with a fair price. However, the discovery that the sales volume grows at pace that exceeds growth in production capacity, puts a dent in the validity of that conclusion. In Inventory Management, answers from managers showed a high dependence on inventory as the provider of the flexibility needed for MC. The forecasting for purchasing of components was also made simpler by the previously mentioned discrepancy between sales and production capacity growth, which carries negative results for the generalizability of the conclusions within inventory management.

In Third Party Logistics, Tesla was found to favor smaller logistics partners that could provide the flexibility needed for shipping on a "per-item-basis" as theory described that MC distribution could take shape. It was discovered that the logistics function leveraged economies of scale by "geo-building" cars aimed for the same region in the same batch. Also, the placement of wholly owned distribution centers decreased logistics costs otherwise inherent to shipping customized goods, directly allowing for a cheaper cost of MC. Lastly, in IT the enabling of MC through SCM was apparent in the flexibility and competency inherent in Tesla's systems. Building most systems in-house seems to provide greater flexibility as changes can be pushed through faster, in order to cope with changing market and customizing conditions. By effectively linking together the supply chain's constituents through the likes of in-house run ERP, EDI and supplier portal, the IT in Tesla proves to provide increased capability to Mass Customize.

6.1 Discussion

6.1.1 Generalizability

As the overarching purpose of this thesis is to answer a general research proposition, the single case study design becomes an issue. The observed condition consisting of a lack of a steady state in the proportion between growth rates of sales and production capacity, decreases the generalizability and transferability of the conclusions. Also, the issue of the researcher's inexperience in the field is non-trivial. As a first time researcher of SCM & MC, there is a risk of oversight of commonly substitutable words in research articles, affecting the literature search, which in turn can have compromised the relevance of the previous research and theoretical frame of reference. Also, there is a possibility of achieving slightly differing results if other interview subjects were to be chosen, which is due to two factors: by selecting interview candidates based on guidance from a senior employee (VICEP) and interview subject selection decisions taken based on a semi-limited insight into actual areas of responsibility of the interview subjects. Worth noting is that the long term validity of the results are difficult to ascertain, due to the currently growing demand and production capacity observed within the studied organization.

6.1.2 Suggestions for Further Research

The theoretical gap lacking Mass Customization related in-depth case studies still exists. This thesis provides a point of reference for future, although further research is expected to narrow down more carefully on selected issues within the SCM aspect of MC. Multiple case studies of organizations providing more than 1 million of variations to customers are suggested, to truly validate which SCM aspects are the most important to achieve MC. This research would enable other manufacturers to take note on how to more easily transition in to the more modern approach of serving each customer on a semi-personal level.

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